Pediatric Vascular Injuries: Acute Management and Early Outcomes

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Background: Although uncommon in children, traumatic vascular injuries have the potential for lifelong disability. We reviewed these injuries, their acute management, and early outcomes at a Level I trauma center.

Methods: Retrospective review of patients identified through trauma registry was query of all noniatrogenic vascular injuries in a pediatric population during a 13-year period. Demographics, injury type and management, concomitant injuries, and inpatient outcomes were analyzed.

Results: From 1995 to 2008, 8,247 children with traumatic injuries were admitted. Of which 116 (1.4%) sustained 138 significant vascular injuries; 111 arterial and 27 venous. Mean age was 12.7 years ± 4.1 years. Penetrating mechanism was more frequent (57.8%; 67 of 116) than blunt (42.2%; 49 of 116). The overall mean injury severity score was 17.3, of which 12.3 ± 11.7 was for penetrating trauma and 24.1 ± 19.3 for blunt trauma. Thirteen of the 36 patients with torso injuries and one with carotid/jugular injury died. The surviving 102 patients sustained 118 vascular injuries (102 arterial and 16 venous). Of this group, 15 (14.6%) had multiple vascular injuries. There were 23 (22.5%) with torso injuries, 72 (70.6%) with extremity injuries, and 7 (6.9%) with cerebrovascular injuries. Primary repair was the most common arterial repair technique for survivors (25.5%, 26 of 102) and was used more frequently in penetrating trauma (35.0%, 21 of 60) than blunt trauma (12.0%, 5 of 42). Limb salvage was 97.4% (113 of 116).

Conclusions: Pediatric vascular trauma is uncommon. Penetrating mechanism is more common than blunt. Injuries to the torso carry a high mortality. Limb salvage is almost universal.

Key Words: Pediatric trauma, Noniatrogenic vascular injury, Vascular repair.

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Trauma is a major cause of morbidity and mortality across all subsets of the population and is the leading killer of those aged 2 years to 18 years. Vascular injury has been well studied in the adult population with a significant amount of data from the management military casualties translated to civilian practice.[1–4] Regarding the pediatric population, however, most reports of vascular injury describe iatrogenic etiologies from misadventures of arterial or central venous catheterization.[5] Only a few series exist describing the occurrence, injury patterns, initial management, and outcomes associated with noniatrogenic vascular injuries. Vascular injuries in children may differ from adults in that significant injuries are more difficult to detect because they are asymptomatic, are associated with spasm, or have other more severe life-threatening injuries that take priority in the resuscitation process.[1,5,6] Management strategies are less clear, because these injuries are less frequently encountered. In addition, the more pronounced vascular spasm that occurs in children and the reduced vessel size compared with adults may present technical difficulties during diagnosis and treatment.[7,8]

The purpose of this study was to assess the acute management strategies, acute outcomes, and the morbidity and mortality associated with vascular injuries from penetrating and blunt trauma to the torso, head/neck, or extremities, and to determine the incidence of traumatic vascular injuries in the pediatric population.

PATIENTS AND METHODS

Study Design

This study is a retrospective review and was approved by the institutional review board at the University of Texas Health Science Center at San Antonio. The study population included all patients, 17 years old or younger, who were admitted to the University Hospital Trauma Service between February 1995 and June 2008. Subjects were identified through a query of the University Hospital Trauma Registry for pediatric patients admitted to the trauma service with an International Classification of Diseases—9th Revision code for a traumatic vascular injury (900.0–904.9). Vascular injuries to the torso, upper extremity, lower extremity, and cerebrovascular circulation were included. Torso vessel injuries were defined as injuries to any major vascular structures within the thorax, abdomen, or pelvis. Cerebrovascular vessel injuries were defined as injuries to the jugular vein or carotid artery. Major vascular injury in the extremities was considered to be proximal to the wrist for the upper extremity and proximal to the ankle for the lower extremity. Subjects were excluded if their primary injury treatment occurred at another institution or if the etiology of their vascular injury was an iatrogenic mechanism, such as catheter placement. We recorded demographic information, mechanism of injury, identity of injured vessels, concomitant injuries, initial diagnostic

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modalities, treatment used, and acute outcomes. Injury severity scores (ISSs) were obtained for each patient from the trauma registry.

Data Analysis

Subjects and injuries were grouped according to body region: cerebrovascular, torso, upper extremity, and lower extremity. An intrathoracic common carotid injury was grouped with the cerebrovascular group because of its association with complications such as stroke. A child with a subclavian artery injury was included in the torso group.

Binary outcomes were summarized with counts and percentages, and continuously distributed outcomes with the mean ± 1 SD. Age groups were contrasted on continuously distributed outcomes with a t test and on binary outcomes with Pearson's χ^2 test or Fisher's exact test. The strength of associations was measured with the odds ratio (OR) and its 95% confidence interval (CI). All statistical testings were two sided with a significance level of 5%, and SAS Version 9.2 for Windows (SAS Institute, Cary, NC) was used throughout.

RESULTS

Injury Description

During the study period, 8,247 pediatric trauma patients were admitted to University Hospital. A total of 116 patients (1.4%) sustained 138 vascular injuries, 111 arterial and 27 venous. Of the 116 patients, there were 14 deaths (12%). The distribution of all injuries sustained by the study population is listed in Table 1. Of the 138 injuries overall, there were 118 injuries in survivors (102 arterial and 16 venous) and 20 injuries in nonsurvivors (9 arterial and 11 venous). There were more penetrating injuries than blunt injuries (57.8%, 67 of 116, and 42.2%, 49 of 116, respectively). The overall mean ISS was 17.3 ± 16.4; this was lesser (12.3 ± 11.7) in those with penetrating injuries than those with blunt injuries (24.1 ± 19.3; $p < 0.001$). Mortality was not different between blunt and penetrating mechanism groups. The demographic information of the surviving and nonsurviving patients is detailed in Tables 2 and 3, respectively.

TABLE 1. Injuries by Location in All Patients (Survivors and Nonsurvivors)

Vessel	Arterial Injuries	Vessel	Venous Injuries
Head/neck	8		2
Common carotid artery	4	Internal jugular vein	2
Internal carotid artery	4		
Torso	30		16
Aorta	12	Vena cava	12
Iliac artery	5	Hepatic vein	2
Renal artery	3	Iliac vein	1
Innominate artery	2	Superior mesenteric vein	1
Epigastric artery	1		
Hepatic artery	1		
Hypogastric artery	1		
Ileal mesenteric artery	1		
Internal mammary artery	1		
Superior mesenteric artery	1		
Splenic artery	1		
Subclavian artery	1		
Lower extremity	28		8
Femoral artery	10	Popliteal vein	5
Posterior tibial artery	8	Femoral vein	3
Popliteal artery	7		
Anterior tibial artery	2		
Peroneal artery	1		
Upper extremity	45		1
Brachial artery	16	Brachial vein	1
Ulnar artery	16		
Radial artery	12		
Axillary artery	1		
Total	111		27

Upper Extremity

By injury location, the highest percentage of patients (36.8%; 43 of 116) had injuries to the upper extremity. We found a total of 46 vascular injuries in this group (45 arterial and 1 venous) and this accounted for 33.3% (46 of 138) of all vascular trauma identified in this study. The most frequently injured arteries in the upper extremity were the ulnar and brachial arteries (35.6%; 16 of 45 for each) followed by the radial artery (26.7%, 12 of 45). No deaths occurred in this subset of patients.

Torso

The next largest patient group included those with torso injuries (30.8%, 36 of 116), accounting for 33.3% (46 of 138) of all vascular injuries in the study population (30 arterial and 16 venous). More blunt injuries (52.8%; 19 of 36) than penetrating (47.2%; 17 of 36) were identified in this group. Injury to the torso was more associated with death than all other regions combined (survivors: 23 of 102 [22.5%]; nonsurvivors: 13 of 14 [93%]; $p < 0.0001$; OR, 44.65; 95% CI, 5.54–359.67). Thirteen of the 36 patients (36.1%) with torso injuries died, 12 of them were presented in extremis and died within 24 hours of admission. The specific vessels injured in the nonsurvivors are detailed in Table 4. In these 13 patients, there were 7 deaths associated with blunt injury and 6 with penetrating injury. The two most commonly injured vascular structures were the aorta (26.1%, 12 of 46) and the vena cava (26.1%, 12 of 46); half of the patients (6 of 12) with aortic injuries and 66.7% (8 of 12) of patients with vena cava injuries died.

Lower Extremity

Twenty-nine patients sustained lower extremity injuries (25.0%; 29 of 116). There were a total of 36 vessels injured (26.1%; 36 of 138), 28 arterial and 8 venous. Arteries below the knee (anterior tibial, posterior tibial, and peroneal) were the most commonly injured vessels (30.6%; 11 of 36), followed by the femoral artery (27.8%; 10 of 36) and the popliteal artery (19.4%; 7 of 36). The popliteal vein was the most commonly injured vein (62.5%; 5 of 8). No deaths occurred in this group.

TABLE 2. Demographic Information for Survivors

	All Survivors	Head/Neck	Torso	Upper Extremity	Lower Extremity
Total patients	102	7	23	43	29
Male	72	7	13	33	19
Female	30	0	10	11	10
Age (yr)*	12.6 ± 4.1	10.4 ± 5.3	14.1 ± 3.2	12.6 ± 4.4	12.1 ± 3.7
ISS*	13.6 ± 12.0	17.4 ± 8.8	25.5 ± 14.5	7.3 ± 5.5	12.5 ± 10.3
Blunt mechanism	42	3	12	12	15
Penetrating mechanism	60	4	11	31	14
Complications		1 stroke		1 amputation	2 amputations, 1 graft thrombosis, and 1 wound infection

* Values listed are expressed as mean ± SD.

TABLE 3. Demographic Information for Nonsurvivors

	All Nonsurvivors	Head/Neck	Torso
Total patients	14	1	13
Male	10	0	10
Female	4	1	3
Age (yrs)*	13.1 ± 4.5	10	13.3 ± 4.6
ISS*	43.9 ± 19.9	24	45.4 ± 19.8
Blunt mechanism	7	0	7
Penetrating mechanism	7	1	6

* Values listed are expressed as mean ± SD.

TABLE 4. Injuries by Location in Nonsurvivors

Vessel	Arterial Injuries	Vessel	Venous Injuries
Head/neck	1		1
Internal carotid artery	1	Internal jugular vein	1
Torso	8		10
Aorta	6	Vena cava	8
Iliac artery	1	Hepatic vein	2
Innominate artery	1		
Total	9		11

Cerebrovascular

Cerebrovascular injuries made up the smallest group (6.9%; 8 of 116) with patients sustaining a total of 10 vascular injuries (8 arterial and 2 venous). There was one death in this group in a patient who sustained concomitant internal carotid artery and internal jugular vein injuries from a dog attack. This patient presented in extremis and died within 1 hour of admission to the hospital.

Arterial Injury Management

The techniques used to manage arterial injuries in the surviving 102 patients are detailed in Table 5. Preoperative or diagnostic angiograms were performed in 14.7% (15 of 102) of the 102 arterial injuries; most of these were in patients older than 10 years (86.7%, 13 of 15). No angiographic complications were found. Expectant management was undertaken in 10.8% (11 of 102) of patients with arterial injuries. Management without vascular repair is summarized in Table 6.

TABLE 5. Management of Arterial Injuries in Survivors

Arterial Injury Management	Head/ Neck	Torso	Upper Extremity	Lower Extremity	Total
Primary repair	2	3	13	8	26
Ligation	0	6	17	2	25
Venous interposition graft	1	0	11	8	20
Angioembolization	0	5	0	0	5
Bypass	0	0	1	3	4
Synthetic interposition graft	0	3	0	0	3
Vein patch	1	0	0	3	4
Synthetic patch	0	1	0	0	1
Stent	0	1	0	0	1
Primary amputation	0	0	0	1	1
No vascular repair	3	3	3	3	12
Totals	7	22	45	28	102

Venous Injury Management

Venous injuries were infrequent and compromised only 13.6% (16 of 118) of the total injuries in survivors, but when occurred they were significantly associated with death ($p < 0.001$; OR, 7.25; 95% CI, 2.79–21.75). The management of these injuries is summarized in Table 7.

Complications

Fasciotomy was performed in 13 cases, 10 of which occurred in the lower extremities. The majority 61.5% (8 of 13) were performed for diagnosed compartment syndrome and 38.5% (5 of 13) were performed prophylactically. There was one fasciotomy site infection that occurred in a patient with a lower extremity vascular injury. Thrombosis of a reversed saphenous vein graft bypass occurred in a patient with a superficial femoral artery injury. This was managed by a repeat bypass with vein graft. Three patients underwent amputation: two were delayed and one was performed in the acute setting. Overall limb salvage was 97.4% (113 of 116). One stroke was noted, associated with a carotid injury that was discovered days after admission in a patient with a severe traumatic brain injury.

TABLE 6. Summary of Patients Who Did Not Undergo Vascular Repair

Patient	Vessel(s) Injured	Management
1	Internal carotid artery	Delayed diagnosis
2	Internal carotid artery	Diagnostic angiogram
3	Internal carotid artery	Diagnostic angiogram
4	Renal artery	Observation, expectant management
5	Hypogastric artery, renal artery, iliac artery, hepatic artery	Angioembolization of right hepatic artery and internal iliac artery. Diagnostic angiogram of hypogastric artery and renal artery without embolization
6	Ulnar artery	Preoperative diagnostic angiogram, exploration of right ulnar artery with right forearm fasciotomy
7	Ulnar artery, brachial artery	Brachial artery repaired with RSV graft, intact radial artery provided sufficient blood flow to the hand
8	Brachial artery	Release of entrapped right brachial artery from fracture site
9	Posterior tibial artery	Preoperative diagnostic angiogram, right intramedullary femoral nail, right lower extremity fasciotomy
10	Femoral artery	Observation, expectant management
11	Posterior and anterior tibial artery	Popliteal to posterior tibial artery bypass provided sufficient blood flow to the foot and distal lower extremity

RSV, reverse saphenous vein.

TABLE 7. Management of Venous Injuries in Survivors

Venous Injury Management	Head/ Neck	Torso	Upper Extremity	Lower Extremity	Total
Primary repair	1 (100%)	5 (83.3%)	0	5 (62.5%)	11 (68.8%)
Ligation	0	1 (16.7%)	1 (100%)	2 (25%)	4 (25%)
Primary amputation	0	0	0	1 (12.5%)	1 (6.2%)
Total	1	6	1	8	16

Children Aged 10 Years or Younger

There were 21 children aged 10 years or younger. The patterns observed in this patient population were the same as in the older cohort including injury severity, mechanism, rate of use of angiography, rate of primary repair, and amputation. A complete description of management of the youngest quintile of patients is presented in Table 8.

DISCUSSION

Noniatrogenic vascular injury in children is infrequently encountered, but often presents both diagnostic and treatment challenges related to the small caliber of the vessels, the greater effect of arterial spasm and consideration for further growth.[7,9] This study examined our outcomes managing children with traumatic vascular injuries. We found that our incidence (1.4%) and distribution of injuries is consistent with that reported in previous studies.[5,10,11]

TABLE 8. Management of Arterial Injuries by Patient Age (in Survivors)

	Children Aged 10 Yr or Younger	Children Older Than 10 Yr	*p*
Number of patients	21	74	
Number of arterial injuries	21	81	
ISS	11.8 ± 9.6	13.8 ± 12.4	0.51*
Mechanism			
Blunt	10	31	0.64†
Penetrating	11	43	
Angiogram (by number performed)	3	25	0.28†
Preoperative (diagnostic)	2	13	
Therapeutic/embolization	1	3	
Intraoperative	0	9	
Repair (by arterial injury)			
Primary repair	10	16	0.07‡
Ligation	5	20	1.00‡
Venous interposition graft	2	18	0.36‡
Bypass	0	4	
Angioembolization	1	4	
Expectant management	No matched data	No matched data	
No repair	2	10	1.00‡
Other	1	8	
Fasciotomy	2	12	
Amputation	2	1	

* *T* test on log-transformed data.
† Pearson's χ^2 test.
‡ Fisher's exact test.

The management of arterial injuries differed between patients depending on mechanism. Primary repair was performed more than twice as often in patients with penetrating than with blunt trauma, and vessel ligation showed a similar pattern. These findings are consistent with other reports of noniatrogenic pediatric vascular trauma in the literature.[5,10] The differences in management may be attributed to how the mechanism of injury affects the vessel involved. Penetrating trauma is more likely to create a clean, focal injury that may make it more likely amenable to primary repair. Blunt mechanisms create more shear and traction-type injuries with injury to a greater length of the vessel making it unsuitable for primary repair. When primary repair is not feasible, the choice of conduit for reconstruction is of particular importance. Autologous grafts such as reversed saphenous vein are preferred and have demonstrated the best results.[12] Synthetic conduits, such as polytetrafluoroethylene, can also be successfully used; but they are more prone to infection and small diameter grafts have high thrombosis rates with poor long-term patency.[13,14] Because of the consideration for growth, anastomoses should be sewn with interrupted sutures.[13] The smaller caliber of vessels offers less room for error, so great care should be paid to ensure meticulous technique.

In our series, 11 patients underwent expectant or nonoperative management of their vascular injuries. Expectant management was twice as common in blunt versus penetrating injuries and the majority of patients were older than 10

years. There were no formal criteria used to decide to pursue expectant management. Thus, the natural history of the injury, whether vascular insufficiency would be expected to develop, and degree, if any, of physiologic derangement were the determining factors. For extremity injuries, vascular repair was not performed as long as there was sufficient distal blood flow to hand or foot. For example, the brachial artery was repaired only in a patient with ulnar and brachial artery injuries. The ulnar artery was ligated, because the patient had adequate distal perfusion through the intact radial artery. Rather than distal perfusion, hemodynamic stability was more often the determining factor for expectant management in torso injuries. Patients with active extravasation on angiogram and with other injuries necessitating laparotomy were operatively managed. Expectant management of cervical vascular injuries was pursued only in patients with intimal flaps who did not have strong contraindications for anticoagulation or antiplatelet therapy. This is not usually the case because of the high association with brain injury, but two patients in this series were treated with anticoagulation and serial neurologic examinations for management of carotid intimal flaps. Neither patient had a subsequent stroke or bleeding complication. Myers et al.[15] reported similar management of pediatric patients with injuries that were not treated with formal vascular repair. Overall, they reported similar management principles that we used in our institution, with the exception of the use of thrombectomy, which we did not perform.

At our institution, all pediatric vascular injuries were managed initially by trauma/general surgeons, and the majority of vascular repairs and extremity angiograms were performed by trauma/general surgeons. Exceptions that prompted vascular surgeon involvement include complex abdominal vascular injuries and injuries requiring bypass or other management below the level of the knee. The cardiothoracic surgery service was usually involved in the management of vascular injuries in the chest. There is no specific institutional protocol for involvement of surgical subspecialists, and overall management decisions were made by the on-call trauma attending surgeons. Although additional service involvement was attending surgeon specific, the practice patterns did not diverge greatly among the trauma attending surgeons who managed the patients in this study, so we do not think that subspecialty involvement or lack there of contributed significantly to outcome variation in this study. Pediatric surgeons were not involved in the management of any of the vascular injuries described in this study.

Angiography was performed in 19% (22 of 116) patients in this study with the majority of patients being 10 years or older. Several studies have reported high complication rates associated with angiograms in small children (younger than 5 years), including arterial thrombosis. In fact, the most common cause of vascular injury in children is due to arterial or venous access procedures.[5,7,9,10] Angiography was performed in three patients younger than 11 years, each of whom had torso or cervical vascular injuries and inconclusive computed tomography (CT) angiograms. There were no complications associated with the use of angiography in our series. Although CT angiography is a useful adjunct in this population and is described as the diagnostic tool of choice in patients without hard signs, it can be limited by the timing of the contrast bolus, which must be hand injected rather than the power injected, and may be of even less utility in very young children due to the size of their vessels.[16] Further reports are necessary to ascertain the utility of CT angiogram in very young children.

There are very few reports that detail management of very young children, that is, 10 years or younger. In our series, there were 21 survivors aged 10 years or younger who had a total of 21 arterial injuries (Table 8). The ISS and rate of blunt or penetrating mechanism were similar between both groups, and in both groups operative indications were consistent with other reports.[13,17] There were proportionally fewer angiograms performed in younger children although possibly, due to small numbers of patients, this was not a statistical difference.

Torso injuries were responsible for all deaths in this series except for the one child who sustained a dog bite to the neck. Thirteen of the 14 deaths occurred within 24 hours of their presentation to the emergency department. More than half of the patients with aortic or vena cava injuries died. Although torso vascular injuries carried the highest mortality rate in this study, the majority of patients with torso injuries survived and had a good outcome. These findings are consistent with previously published reports, which also found that mortality associated with torso vascular injuries was low unless the patient was presented in extremis.[10]

The high rate of limb salvage found in this study is consistent with that reported in the previous studies.[5,9,15] In our series, amputation was performed in one patient in the acute setting and twice in a delayed fashion. Acute amputation was performed for a mangled extremity acquired after ejection from a motor vehicle. Factors contributing to the delayed amputations included delayed presentation, extensive injury, and failed revascularization of the extremity.

In conclusion, noniatrogenic pediatric traumatic vascular injuries are rare. When they do occur, they occur most often in an extremity and are the result of penetrating trauma. Torso vascular injuries carry a higher mortality rate than vascular injuries in other anatomic regions. Similar to all vascular injuries, early identification and treatment maximizes the opportunity for limb salvage and decreases subsequent complications. Most pediatric patients with vascular trauma have a good functional outcome, and the limb salvage rate is high.

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