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Wartime vascular injuries in the pediatric population of Iraq and Afghanistan: 2002–2011 ☆

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ABSTRACT

Background: Contemporary war-related studies focus primarily on adults with few reporting the injuries sustained in local pediatric populations. The objective of this study is to characterize pediatric vascular trauma at US military hospitals in wartime Iraq and Afghanistan.
Methods: Review of the Department of Defense Trauma Registry (DoDTR) (2002–2011) identified patients (1–17 years old) treated at US military hospitals in Iraq and Afghanistan using ICD-9 and procedure codes for vascular injury.
Results: US military hospitals treated 4402 pediatric patients between 2002 and 2011. One hundred fifty-five patients (3.5%) had a vascular injury. Mean age, gender, and injury severity score (ISS) were 11.1 ± 4.1 years, 79% male, and 34 ± 13.5, respectively. Vascular injuries were primarily from penetrating mechanisms (95.6%; 58.0% blast injury) to the extremity (65.9%), torso (25.4%), and neck (8.6%). Injuries were ligated (31%), reconstructed (63%), or observed (2%). Limb salvage rate was 95%. Mortality rate was 9%.
Conclusions: This study is the first to report vascular trauma in a pediatric population at wartime. Vascular injuries involve a high percentage of extremity and torso wounding. Torso vascular injury in children is four times lethal relative to other injury patterns, and therefore should be considered in operational planning both in the military and civilian setting regarding pediatric vascular injuries.

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Wartime vascular injury among adult combatants is well described, with an incidence of 12% most often involving extremity vessels [1]. As the counter insurgency wars in Iraq and Afghanistan have been largely conducted in the vicinity of civilian populations, pediatric casualties have been sustained [2,3]. However, the incidence of vascular injury during wartime in a pediatric population has not been previously reported.

In a peacetime environment, vascular injuries constitute 0.3% of pediatric trauma admissions; although rare, they are associated with significant morbidity and mortality [4,5]. In contrast to the management of adult vascular injuries, there is little established evidence for the management of pediatric vascular injury. Lessons learned from military conflicts have proven vital in advancing adult treatment modalities for vascular trauma, allowing great progress for the adult population [6]. It is unclear whether these advances have extended to pediatric vascular trauma.

The aim of this study is to characterize pediatric vascular trauma, including injury patterns, management strategies, and outcomes at US military hospitals during the wars in Iraq and Afghanistan. These insights will provide the platform for more accurate and operational planning both in the military and civilian setting regarding pediatric vascular injuries.

1. Methods

This is a retrospective analysis of pediatric patients sustaining vascular injury identified from the Department of Defense Trauma Registry (DoDTR). Institutional review board approval was obtained from the US Army Medical Research and Materiel Command. The DoDTR prospectively captures data of all patients treated at a DoD medical facility including demographics, injuries, treatments, and outcomes data. The DoDTR is primarily used as a performance improvement tool to audit trends in care and the implementation of clinical practice guidelines through the Joint Trauma System [7].

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The DoDTR was queried using ICD-9 codes to identify all pediatric admissions (aged <18 years) to military Role III hospitals (equivalent to civilian Level 1 trauma centers) in Iraq and Afghanistan between 2002 and 2011 [8]. Demographic information, mechanism of injury, identity of injured vessels, treatment modalities, injury severity scores, outcomes and follow-up were retrieved. To improve data granularity, a chart review of all identified patients was performed, enabling the identification of the specific anatomical vascular injury(ies) sustained. Those with incomplete, missing charts, or those found to have a non-vascular injury were excluded.

Vascular injuries were divided into anatomical regions, followed by a major or minor sub-division. *Cervical* vascular injuries were delineated as *major* or *minor* subgroups. *Major* injuries are of the carotid, jugular, and vertebral vessels, others are *minor* (jugular vein, thyroid vein). *Torso* vascular injuries were of the chest, abdomen, and pelvis. *Major* torso vascular injuries are from the aorta and primary branches. *Major* extremity vascular injuries were arterial or venous at or above the brachial for the upper extremity and at or above the popliteal for the lower extremity. *Minor* extremity vascular injuries were arterial or venous distal to the brachial or popliteal in the upper and lower extremities respectively.

1.1. Statistical analysis

Nonnormally distributed variables were reported as a median and interquartile range (IQR) and categorical data were reported as a percentage. Demographic parameters and injury pattern were compared between survivors and nonsurvivors. Data were compared using a Mann–Whitney rank sum test for continuous and chi-squared or Fisher's exact (if $n < 5$) tests for categorical data. Unadjusted risk ratios (RRs) and 95% confidence intervals (95% CI) for mortality were graphically presented per anatomical region of injury. Cause of death data was presented with the major focus of injury as the primary cause of death, with the contribution of the vascular injury noted. Statistical significance was defined as $p < 0.05$.

2. Results

2.1. Study cohort

During our query, there were 54,663 total entries in the JTTR from March 2002 to April 2011. Of these, 4402 patients were age <18 years; 213 had a reported vascular injury. Following detailed chart review, the final study cohort consisted of 155 pediatric patients (3.5%) who sustained at least one vascular injury. There were 122 males and 33 females with a median (IQR) age of 12 (7) years. The age distributions were age 2–5 ($n = 22$), age 6–9 ($n = 27$), age 10–13 ($n = 48$), and age 14–17 ($n = 58$). Table 1 presents the demographic characteristics of this cohort, comparing survivors with nonsurvivors. Overall, there were 14 deaths (9%), with no significant difference between gender and age. The median (IQR) ISS for the cohort was 14 (11), with survivors sustaining a significantly lower injury burden than nonsurvivors [13 (10) vs. 25 (17); $p < 0.001$]. The predominant mechanism of injury was blast related (58.0%) followed by gunshot wounds (GSW) (37.4%), with falls and miscellaneous mechanisms making up a minority (1.9% and 2.6% respectively). There was no significant difference in mechanism between survivors and nonsurvivors. Survivors had a longer mean hospital stay (days) than nonsurvivors [6 (8) vs. 0.5 (3); $p = 0.001$].

Table 1
Demographics and mechanism of injury.

	Overall ($n = 155$)	Alive ($n = 141$)	Dead ($n = 14$)	p
Demographics				
Male, n (%)	122	111 (78.7%)	11 (78.6%)	0.608
Age (y), median (IQR)	12 (7)	12 (6)	9 (8)	0.232
ISS, median (IQR)	33.6 (13.5)	13 (10)	25 (17)	<0.001
Mechanism of injury				
Blast, n (%)	90 (58.0%)	82 (58.2%)	8 (57.1%)	0.578
GSW, n (%)	58 (37.4%)	52 (36.9%)	6 (42.9%)	0.432
Fall, n (%)	3 (1.9%)	3 (2.1%)	0 (0%)	0.751
Misc, n (%)	4 (2.6%)	4 (2.8%)	0 (0%)	0.682
Follow-up				
Inpatient days, median (IQR)	10 (2)	6 (8)	0.5 (3)	< 0.001

2.2. Overall injury pattern

Table 2 presents the injury patterns by body regions with "major" and "minor" subgroups in relation to mortality. The bulk of wounding was the lower extremities (37.8%) followed by upper extremity wounding (28.1%). Torso injuries (chest, abdomen, pelvis) resulted in 25.4% of injuries followed by 8.6% caused by head and neck injuries. Comparison of injury patterns relative to mortality demonstrates that wounding of the torso especially in "major" subgroups conferred a higher burden of death. Of those who died, 71.4% were a result of torso vascular injuries.

Fig. 1 presents the RR for mortality for each body region, relative to other vascular injuries. Torso vascular injury was significantly the most lethal, with a RR (95% CI) of 4.14 (1.47–11.68; $p = 0.006$).

2.3. Head and neck surgical intervention and outcome

A total of 15 patients sustained a vascular injury to a head or neck vessel; 14 survived. In the survivors, 50% underwent vascular reconstruction and 50% underwent ligation. In those reconstructed, six had carotid artery injures and one had an internal jugular vein injury, which was primarily repaired. Three of the six patients with carotid injuries underwent primary repair, two had vein patch repair (one with saphenous vein graft and one with internal jugular vein graft), one was repaired using a reversed saphenous vein interposition graft, and one with PTFE. No complications related to interventions were noted in these patients throughout their hospital stay. Six of the 14 patients were managed with ligations (3 external carotid arteries, 1 internal carotid artery, 1 temporal artery, and 1 vertebral artery), with no resultant complications. One patient was managed expectantly (internal carotid injury) as the patients had sustained 80% burns which was deemed unsurvivable.

2.4. Torso surgical intervention and outcome

A total of 39 patients sustained torso vascular injuries. There were 34 "major" and 13 "minor" torso injuries, with 6 and 3 deaths

Table 2
Injury patterns.

	Alive ($n^a = 141$)	Dead ($n^a = 14$)	p
Head and neck, $n = 16$ (8.6%)			
Major	13 (7.8%)	1 (6.3%)	0.632
Minor	2 (1.2%)	0 (0%)	0.838
Torso, $n = 47$ (25.4%)			
Major	28 (16.6%)	6 (37.5%)	0.056
Minor	10 (5.9%)	3 (18.8%)	0.097
Upper extremity, $n = 52$ (28.1%)			
Major	26 (15.4%)	1 (6.3%)	0.466
Minor	20 (11.8%)	2 (12.5%)	0.623
Unknown	3 (1.8%)	0 (0%)	1.000
Lower extremity, $n = 70$ (37.8%)			
Major	56 (33.1%)	3 (18.8%)	0.251
Minor	9 (5.3%)	0 (0%)	1.000
Unknown	2 (1.2%)	0 (0%)	1.000

[a] The number of patients is less than number of injuries because of patient incurring more than one injury.

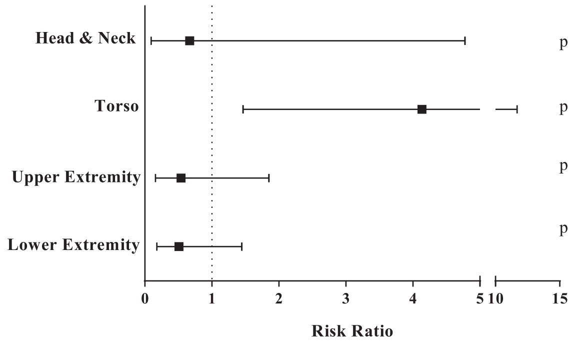

Fig. 1. Risk ratio of mortality for the four anatomical regions of vascular injury.

respectively. A total of 20 laparotomies and 5 thoracotomies were performed for hemorrhage control. Those who underwent a laparotomy all had torso-related injuries. There were eight deaths in the laparotomy group; six of eight patients died of exsanguination secondary to uncontrolled hemorrhage while in the operating room from either aortic, IVC, or iliac injuries, one died from a concurrent traumatic brain injury, and one died from postoperative mesenteric ischemia and necrosis of small bowel and right colon after primary repair of an aortic and IVC laceration. There were no deaths in those who underwent thoracotomy; vessels primarily injured were the pulmonary and innominate vessels, and the thoracic aorta at the ligamentum arteriosum. The pulmonary and innominate vessels were repaired primarily; the aortic transection at the ligamentum arteriosum was repaired with a prosthetic tube graft. In those three nonsurvivor patients who sustained "minor" torso vascular injuries, one patient required ligation of combined hepatic artery and vein injuries, but subsequently died of coagulopathy. The other two patients each had injuries to unspecified thoracic vessels and died from uncontrolled hemorrhage; although unspecified, it is worth noting that these vessels were likely of the "major" classification as these patients appeared to have succumbed quickly to their injuries. Those individuals who did not require laparotomy or thoracotomy for torso vascular injuries were those who had isolated pelvic vessel injuries of the iliacs; these were managed with primary repair ($n = 4$), ligation ($n = 4$), or reverse saphenous vein interposition grafts ($n = 2$).

2.5. Extremity surgical intervention and outcome

Forty-five patients sustained upper extremity vascular injuries (25 with "major" and 20 with "minor"), and 59 patients sustained lower extremity vascular injuries (49 with "major" and 8 with "minor"). The total upper and lower extremity injuries were 52 and 70 respectively as some patients had multiple extremity injuries. Extremity vascular injury treatment modalities included observation, ligation, reconstruction [primary repair, patch angioplasty, reverse saphenous grafts (RSV), nonreverse saphenous grafts (NRSV), or prosthetic grafts], and amputation (primary and secondary). The majority of patients who survived underwent either ligation (42.9%) or reconstruction (56.1%) of their vascular injury. There were four patients who underwent primary amputations because of an unsalvageable limb or prolonged ischemia with no distal pulses; all of these patients survived. Five patients required secondary amputations following failed revascularization. One of the five patients underwent revascularization (unspecified) which resulted in nonviable tissue leading to amputation. The remaining four patients had thrombosis of their RSV grafts (time elapsed from graft placement to thrombosis not indicated in the chart); one of these patients underwent four revisions of the same graft prior to amputation. Similar to those who underwent primary amputations, patients who required secondary amputations also survived to discharge.

Damage control adjuncts were also utilized in this population including fasciotomies, intravascular shunt insertion, and tourniquet placement. Of the 70 lower extremity injuries, there were 15 fasciotomies performed, 12 shunts placed, and 6 tourniquets applied. No adverse outcomes were noted with fasciotomies performed or shunts placed. Of the six tourniquets that were applied, three were applied in the field and three were applied in the emergency department (ED). Those patients whose tourniquets were placed in the field all survived. Two of the patients with field applied tourniquets however subsequently required a primary amputation for a nonsalvageable limb and the other a secondary amputation for a failed RSV graft. Two of the three children whose tourniquets were place in the ED survived amputation free. The one death from this group was in a patient with concomitant brain injury. There were three deaths in those who had lower extremity vascular injuries. Two of three patients had popliteal artery and vein injuries, one was repaired primarily and the other with RSV graft; these two patients however also sustained traumatic brain injuries, which were the ultimate cause of death. One of three patients sustained a femoral artery injury following GSW which was repaired with an RSV graft. This patient decompensated postoperatively, was found to have retroperitoneal bleeding, and subsequently died in the operating room.

In those patients who suffered upper extremity injuries, there were a total of two deaths; these deaths however were not directly a result of the upper extremity vascular injuries themselves but from other injuries. One death was in a patient who had sustained an axillary artery injury that was repaired primarily who subsequently coded, underwent an exploratory laparotomy, and died from uncontrollable hemorrhage. The other death involved a "minor" upper extremity injury that was incurred with a nonsurvivable torso vascular injury (Tables 3 and 4).

3. Discussion

This study is the first to characterize the epidemiology of current wartime pediatric vascular injury. Vascular injury rate (3.5%) in this cohort is significantly higher than the 0.6% quoted in civilian literature [4]. Furthermore, our results identify extremity vascular injury as the most common wounding pattern but torso injury as the primary source of mortality in these patients.

The current study extends the current body of military literature on pediatric injury. Creamer et al. [9] described the epidemiology of 2000 pediatric admissions to US military combat hospitals.

Table 3
Treatment modalities.

	Alive	Dead
Head and neck, $n = 15$	14	1
Observation	1 (7.1%)	1 (100%)
Ligation	6 (42.9%)	0 (0%)
Reconstruction	7 (50%)	0 (0%)
Torso, $n = 25$	17	8
Thoracotomy	5 (29.4%)	0 (0%)
Laparotomy	12 (70.6%)	8 (100%)
Extremity, $n = 104$	98	6
Observation	1 (1.0%)	1 (16.7%)
Ligation	42 (42.9%)	2 (33.3%)
Reconstruction	55 (56.1%)	3 (50%)
Primary amputation[a]	4 (4.1%)	0 (0%)
Secondary amputation[b]	5 (5.1%)	0 (0%)
Extremity adjuncts, $n = 33$	32	1
Fasciotomy	15 (46.9%)	0 (0%)
Shunts	12 (37.5%)	0 (0%)
Tourniquet	5 (15.6%)	1 (100%)

[a] Amputation without attempted reconstruction.
[b] Amputation following attempted reconstruction.

Table 4
Cause of death.

Patient	Cause of death	Mechanism	Vascular injury	Vascular injury contribute to death?
1	Torso hemorrhage	GSW	IVC and aortic laceration	Yes
2	Torso hemorrhage	GSW	Unspecified pelvic vessels	Yes
3	Torso hemorrhage	Blast	R. hepatic artery, portal vein branches, R. hepatic vein	Yes
4	Torso hemorrhage	GSW	IVC and aortic Injury	Yes
5	Torso hemorrhage	GSW	Unspecified thoracic vessels	Yes
6	Torso hemorrhage	Blast	Unspecified thoracic vessels	Yes
7	Torso hemorrhage	GSW	IVC laceration	Yes
8	Torso hemorrhage	Blast	R. axillary artery	No
9	80% burns	Blast	Internal carotid	No
10	Traumatic brain injury	Blast	R. popliteal artery	No
11	Traumatic brain injury	Blast	L. popliteal artery and vein	No
12	Torso hemorrhage	GSW	L. femoral artery	No
13	Traumatic brain injury	Blast	Aortic laceration	No
14	Torso hemorrhage	Blast	L. external iliac vein	No

Penetrating injuries accounted for >50 % of admissions, with extremity injuries as the leading injury pattern (38.3%) followed by torso (23.6%). In their cohort, mortality was 6.9%, the majority secondary to head injuries, torso wounding and burns.

A subsequent study of 1132 pediatric by Matos et al. [10] demonstrated that children <8 years of age had an independently associated increased risk for in-hospital mortality (18%). Head and neck injuries were the leading causes of death. Interestingly, deaths in those >8 years old were predominantly from torso wounding (53%) with 21% resulting from hemorrhage. In a separate analysis, Edwards et al. [11] focused on blast injury in children in Iraq and Afghanistan (2002–2010) and found no increased risk of in-hospital mortality associated with children <8 years old; the mortality rate was similar to earlier studies at 7.8% with injury to the head and burns as the leading causes of death.

Recently, Borgman et al. [12] evaluated pediatric trauma during 10 years of military operations in Iraq and Afghanistan (2001–2011). Their study summarized and corroborated findings of previous studies that evaluated subsets of the pediatric population in those 10 years. Children represented 5.8% of all admissions with 79% resulting from blast and penetrating injuries. Mortality from trauma-related injuries was 8.5%, predominantly from head/neck injuries, with children <8 years old having a higher burden of mortality.

Each of these military studies presents a different aspect of pediatric trauma while illustrating a common theme that blast and penetrating mechanisms are the primary means of injury, with head and neck trauma carrying a high burden of mortality. While these studies all corroborate previous findings, none describe any specific injury pattern beyond body region injury associated with increased mortality.

Notable findings from this study are that although extremity vascular injuries made up a majority of the injury patterns, 10 of the 14 deaths were from torso vascular injuries that resulted in exsanguination. These findings bear semblance to an earlier study by Meagher et al. [13] that looked at a 20-year (1957–1977) retrospective evaluation of vascular trauma in the civilian pediatric population. Their study found that torso injury accounted for 59% of the injury patterns and were responsible for the 13% mortality in that population. A subsequent study by Cox et al. [14], which collected retrospective data on truncal vascular injuries between 1986 and 1996, found a >50% mortality rate.

Our study shows that the percentage of torso vascular injury in this cohort (24.1%) is double that of the adult population described by White et al. [1] (12%). This disparity is likely caused by the protection that body armor has afforded the adult population; it gives insight into the type of injury pattern likely to cause death in the pediatric population. Clearly, pediatric torso vascular injuries carry a high burden of mortality not only in a wartime setting but also in the civilian population.

Children will continue to be casualties of war and pose a challenge to military hospitals. As previously mentioned, vascular injuries in children are uncommon and as such there are no set management guidelines. In our study, techniques of traditional adult vascular repair were extended to children with vascular injuries, with resultant successful short-term outcomes. While observation, ligation, and primary repair continue to be the predominant form of intervention in the pediatric population with vascular trauma, it is compelling to observe that aggressive management strategies were employed in this population (31%) which is almost twice the rate in the pediatric civilian setting [5,15]. Moreover, adjuncts such as shunts and tourniquets, not routinely use on children, are reported in this study population with no acute complications. In fact, a recent study by Kragh et al. [16] described 88 pediatric patients admitted to US combat hospitals with tourniquets, whose survival rates were similar to the adult population (93%).

The limb salvage rate for our cohort was 95%, consistent with reports from civilian pediatric trauma literature. Despite promising pediatric limb salvage rates in both military and civilian studies, the question continues to be whether aggressive revascularization will lead to future limb function and/or length discrepancies [17]. Fig. 2 is a photograph of a fragmentation wound through the right superficial femoral artery which was revascularized using contralateral RGSV interposition graft with interrupted GORE-TEX® sutures. This example provides insight in situations where often decisions regarding operative management of pediatric vascular injuries are met with consideration of vessel size and future growth potential.

Vascular bypasses are uncommon in the pediatric population. Few studies report on this revascularization modality in children, and even fewer report on long-term outcomes. A study by Harris et al. [18] in 2003 examined the outcomes of 19 pediatric patients requiring vascular bypass reconstruction secondary to trauma. Nine of the 19 patients were available for late follow-up (mean of 35 months to follow-up). Seventy-eight percent were reported as resuming normal activities. Unfortunately, 22% had persistent difficulties with use of the affected limb; however, these patients had concurrent major orthopedic, soft tissue, and nerve injuries. A key finding in these patients was that there were no limb length discrepancies or aneurysmal degeneration identified via clinical exam or duplex on the saphenous vein bypass grafts up to 2 years postsurgery.

Limitations of our study include those inherent of retrospective studies. Only patients receiving care at a level III facility US Military Hospital are entered into JTTR and therefore may not capture all pediatric casualties. Children who died of wounds at level I or II facilities were not included. Also, the search mechanism based on ICD-9 codes will not capture patients coded incorrectly, leading to exclusion of vascular injuries. These limitations result in an underrepresentation of vascular injury in the pediatric population. Additionally, despite access to patient charts, not all charts contained complete information regarding the injury, i.e. some patients were noted to just have “torso vascular injury” or “abdominal vascular injury” without further detail. These patients were classified as having “unspecified vessels” injury in our study. Those who died as a result were presumed to have had a devastating vascular injury leading to

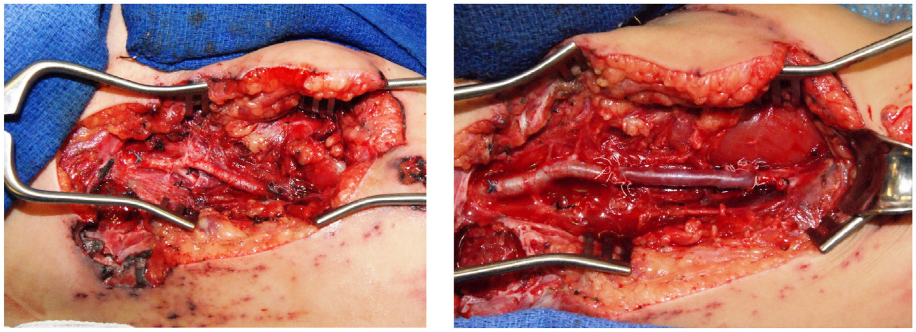

Fig. 2. Superficial femoral artery gunshot injury in a 4-year-old (left). This was repaired by an interposition graft of reversed saphenous vein (right). The anastamoses were fashioned with interrupted 7-0 gortex suture.

death. Another limitation worth noting is the lack of long-term follow-up after revascularization procedures, which limits the assessment of long-term outcomes. Although data in this study have shown that successful revascularization has led to good short-term results there are questions regarding whether this patient population is at increased risk for vascular compromise, late graft failure, and limb loss as they reach adulthood.

4. Conclusion

This study is the first to report on wartime vascular trauma in the pediatric population of Iraq and Afghanistan. Vascular injury in children involves high injury severity with high percentages of extremity and torso wounding. Torso vascular injury in children carries a high burden of mortality, four times lethal relative to other injury patterns, and therefore should be considered in operational planning both in the military and civilian settings regarding pediatric vascular injuries. Revascularization procedures have shown short-term success in this population, and although long-term outcomes remain uncertain, this treatment modality should not be discounted in a child with major vascular injury.

The opinions or assertions contained herein are the private views of the author and are not to be construed as official or as reflecting the views of the Department of the Air Force, Department of the Army or the Department of Defense, or the United States Government.

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