Demographics, Treatment, and Early Outcomes in Penetrating Vascular Combat Trauma

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Objectives: To describe arterial and venous injuries and their management and short-term outcomes in a wartime hospital.

Design: Retrospective review of patients with vascular injuries. Mechanism, location, method of repair, and outcomes were analyzed with descriptive and inferential statistics.

Setting: The 31st Combat Support Hospital, Operation Iraqi Freedom.


Main Outcome Measures: Limb salvage and mortality rates.

Results: The overall limb salvage rate was 80%, while all-cause mortality was 6%. Most vascular injuries were sustained by blast and fragmentation mechanisms. Not surprisingly, most vascular injuries were in lower extremity vessels (57% arterial, 50% venous), with a high predominance of superficial femoral vessel injuries. Vascular injuries to the upper extremities were associated with a higher limb salvage rate (95%) than injuries to the lower extremities (71%). Variable follow-up data for 63 (41%) patients revealed that 32 underwent further procedures outside the combat theater, 12 of which were delayed amputations. Of all arterial injuries, 36% were primarily repaired, 34% were repaired with a vein interposition graft, 29% were ligated, and 2% were repaired with a prosthetic graft. A majority of venous injuries (56%) were ligated.

Conclusions: There is an acceptable early patency and limb salvage rate in combat vascular repairs. A majority of penetrating vascular injuries occur in the lower extremities. Overall, penetrating vascular trauma is often a survivable injury.

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Alexis Carrel’s original descriptions of techniques for vascular anastomosis were first published in 1902; however, practical applications of this knowledge lagged far behind. Even 40 years later in World War II, the primary treatment of arterial injuries was ligation. Several years later, in Hughes’s report on arterial injuries in the Korean War, repair was attempted on 269 of 304 major vessel injuries, with a consequent 13% amputation rate. Amputation rates were similar in the Vietnam War; 13.5% of major arterial repairs documented by Rich, Baugh, and Hughes required amputation.

As noted in 1970, the wealth of progress made in techniques for arterial injury repair were derived from prior military experience. However, until the current conflict in Iraq, Vietnam was the last war in which there were a substantial number of vascular injuries. Despite improvements in armor technology, wounding patterns still reflect those seen in Korea and Vietnam. Furthermore, patients diagnosed with vascular injuries are undergoing vascular repairs in hospitals throughout the battle area and, in the majority of operations, are undergoing the same surgical procedures used more than 50 years ago. Primary and secondary patency rates and complications from battlefield vascular repairs have yet to be evaluated for this conflict.

The large number of casualties in Operation Iraqi Freedom provides a significant opportunity to review the outcomes of modern vascular repairs performed on the battlefield today. We reviewed available data to describe the patterns of injuries, types of repairs employed, and data regarding short-term outcome, including the need for further procedures to maintain limb viability or the need for amputation.

Methods

Patients with vascular injuries treated at our level I trauma facility were retrospectively identified from a database. Patients included members of the United States Armed Forces, coalition forces, contractors, and Iraqi civilians and military personnel. Demographic data and in-
jury patterns (type, location, mechanism, and associated injuries) were recorded. The type of vascular repair and associated clinical factors, including vital signs, presenting laboratory test values, and resuscitation requirements were documented. Vascular injuries associated with mangled extremities amputated in the field or on arrival at our facility were excluded from the analysis.

The mechanism of injury was categorized as gunshot wound, improvised explosive device (IED), mortar, rocket propelled grenade (RPG), grenade, or other. Vascular injury was characterized by type (arterial or venous) and location (upper extremity, lower extremity, thoracic, abdominal, or head and neck). Vascular repairs were classified into 5 methods of treatment: ligation, primary repair (including patch angioplasty and/or venoplasty), interposition grafting with autologous vein, interposition grafting with prosthetic graft, and open vessel exploration with embolectomy and/or thrombectomy. Follow-up data was obtained using a military-wide inpatient database system. Descriptive statistics were used to characterize the data set to include the incidence of various injury mechanisms and types, the repairs used, and the rate of limb salvage. Statistical analysis was performed to determine whether factors such as injury type, location, and repair were associated with limb salvage or mortality. Comparisons between continuous variables were made with the t-test; a P value < .05 was considered significant. The χ² test was used to compare ordinal variables, again identifying a P value < .05 as significant.

RESULTS

From January to December 2004, 3443 patients were treated at the 31st Combat Support Hospital in Baghdad, Iraq. Of these, 153 traumatically injured patients with 218 vascular injuries were identified and comprised our patient cohort. Most of our patients were young (mean age, 23 years), male (n=150, 98%), and combatants (n=103, 67%). Their median Injury Severity Score was 13.

The most common mechanisms of injury were combined blast and fragmentation injuries, usually from IEDs (42%) or RPGs and mortars (18%). Twenty-eight (18%) patients suffered gunshot wounds and the remaining 5 (3%) received their vascular injuries from a variety of mechanisms, including stabbing, motor vehicle accidents, and helicopter accidents.

Physiologically, 40 (26%) patients presented to the emergency department hypotensive (systolic blood pressure < 90 mm Hg), 67 (44%) had a heart rate higher than 120, and 29 (19%) were hypothermic (< 95°F). A total of 120 (78%) patients were acidotic (pH < 7.2) and 121 (79%) had a base deficit greater than 6. The length and time of transport and the method of evacuation (air or ground) were not available. On average, each patient received 2.7 units of fresh frozen plasma and 4 units of packed red blood cells and lost an estimated 600 mL of blood during treatment at our facility. All-cause mortality was 6%. While most coalition troops were evacuated within 2 to 3 days after stabilization, the exact length of stay for each patient was not available for analysis.

More than half of all arterial and venous injuries were sustained in the lower extremities. The next most common site of injury was the upper extremities; only a few patients who survived evacuation to our facility had sustained thoracic or abdominal vascular injuries. The overall distribution of injuries is listed in Figure 1. When analyzed by named vessels of the lower extremity, the superficial femoral vessels were the most commonly injured arterial and venous structures in the legs. The remainder of injuries are listed in Figure 2.

As previously mentioned, there were 4 primary methods of addressing vascular injuries: ligation, primary repair, open vessel exploration with thrombectomy and/or embolectomy, and either autogenous or prosthetic interposition graft. A total of 56% of venous injuries were treated with ligation while 36% were primarily repaired. Alternatively, the treatments for arterial injuries were more evenly distributed, with venous interposition grafting (34%) or ligation (29%) being the preferred methods. The distribution of treatments is listed in Figure 3.

Patients with thoracic and abdominal vascular injuries who were alive on presentation had a mortality rate of 11%. In contrast to extremity injuries, 50% of thoracic injuries were caused by gunshot wounds and 50% were caused by IEDs and mortars. In patients with potentially survivable penetrating thoracic injuries, 6 of the 8 injuries were to the innominate, subclavian, or axillary vessels. The remaining 2 patients sustained injuries to the thoracic duct and to a vertebral artery, respec-
tively. Both patients who died in this cohort sustained transections of both the axillary artery and vein that resulted in exsanguination.

Of those with abdominal vascular injuries, 7 patients had injuries to the iliac vessels and 2 to the inferior vena cava. Both in the latter group died while on the operating table. In the patients with iliac vessel injuries, venous injuries were ligated and all arterial injuries were repaired with patch angioplasty.

Of the 11 head and neck vessel injuries, the external carotid artery or internal jugular vein was ligated in 7 patients, most often for bleeding in the face or neck that could not otherwise be controlled. One patient underwent repair of an internal carotid artery with a prosthetic graft. However, 6 hours later the patient had thrombosis with evidence of neurologic deficit. A salvage operation in this patient was unsuccessful.

For extremity injuries, the overall limb salvage rate was 90%, with isolated arterial injury leading to an 81% chance of salvage over variable follow-up. There were no amputations due to isolated venous injuries. Overall, the chance of limb salvage was greater for upper extremity (95%) than lower extremity (71%) vascular injuries. Neither the location of injury, whether combined or isolated arterial or venous injury, nor Injury Severity Score or abbreviated injury severity score were found to be statistically significant predictors of limb amputation (P > .05).

Follow-up data of American patients surviving evacuation from the war theater were available for 63 patients for an average duration of 13 months (range, 1-27 months). Excluding patients with traumatic amputations in theater, 32 underwent further procedures, with 12 comprising amputations during the follow-up period. Of these, 4 patients underwent an above-knee amputation after the following repairs: superficial femoral arterial injury treated with venous interposition graft; superficial femoral artery and superficial femoral vein injuries treated with superficial femoral vein ligation and superficial femoral artery thrombectomy; and superficial femoral artery and superficial femoral vein injuries treated with superficial femoral vein ligation and superficial femoral artery and venous interposition graft. One patient's sentinel injury and treatment were unknown. Three patients received below-knee amputations after failed revascularization procedures with venous interposition graft of injured tibiopereoneal arterial injuries. Two patients underwent Symes amputations, one after ligation of a tibial artery, and the other after primary repair of an injured below-knee popliteal artery and ligation of an associated popliteal vein. One patient underwent a transmetatarsal amputation after initial above-knee popliteal artery repair with venous interposition graft and concomitant patch venoplasty of the injured popliteal vein. Of the patients undergoing limb amputation, all of the injuries were caused by blast and fragmentation mechanisms.

**COMMENT**

From Makins’ observations of vascular injuries in World War I to Hughes’ first attempt at vascular repair in the Korean War, advancements in vascular surgery have occurred during times of armed warfare. The use of temporary vascular shunts, endovascular repair of traumatic vascular injuries, and care in austere environments have been described in other articles. Most vascular injuries currently being sustained in Iraq are secondary to a combination of blast and fragmentation injuries caused by IEDs, mortars, or RPGs. Currently, the most devastating injuries are caused by IEDs, which can vary significantly in composition and sophistication. While the tissue destruction and vascular trauma sustained from high-kinetic energy weapons is difficult to recreate in a civilian trauma setting, the lessons learned from wartime management of these injuries are applicable to the civilian trauma setting. In one of the largest series of vascular trauma injury from the current war in Iraq, we present the nature and distribution of injuries, the surgical treatments of penetrating vascular injuries, and the early outcome data for initial management and early follow-up of our patients.

Peripheral vascular injuries were predominant in our series, with 90% of arterial and 67% of venous injuries sustained to either the upper or lower extremities. More than 50% of all vascular injuries occurred in the lower extremities, where the superficial femoral vessels were most commonly injured. In our experience, thoracic or abdominal vascular injuries were infrequently encountered and were associated with a 20% mortality rate. Most likely, the relatively low numbers of thoracoabdominal injuries requiring vascular repair were due to a combination of improved personal body armor (discussed later) and the immediate lethality of these injuries.

The primary treatment methods of venous injuries were ligation and primary repair, with 56% of venous injuries ligated without immediate adverse sequela. Not surprisingly, while isolated venous injuries were rare, none resulted in amputation of an extremity. Even venous injuries associated with arterial injuries were not found to be predictive of those limbs that subsequently underwent amputation. Our findings are consistent with previous literature reporting vascular trauma treatment algorithms. Quan et al2 identified patients with venous injuries sustained in the conflicts in Iraq and Afghanistan who were evacuated through Walter Reed Medical...
Center. In their series, 34.5% of venous injuries were repaired, comparable with 32.9% in Vietnam. With most venous injuries occurring concurrently with an arterial injury or being self-limited, the decision to acutely intervene in an isolated venous injury is usually due to the associated trauma burden or damage to a central venous structure. For instance, manifestation of hemodynamic instability is most often the result of damage to the venous structures in the thorax, vena cava, or iliac veins that would require repair if feasible. For the majority of venous injuries, ligation can be performed without affecting the overall limb salvage rate.

Although personal experience with prosthetic materials for combat injuries was limited, this was intentional, owing to anecdotal reports of subsequent graft infection and poor outcome. According to reports later in the evacuation process, placement of prosthetic material frequently led to thrombosis and pseudoaneurysm formation, often requiring explantation and revision surgery. On presentation, wounds were universally heavily contaminated with enteric contents, clothing, dirt, or other debris. While the true rate of limb loss and other morbidity due to prosthesis is unknown, based on preliminary data, we do not advocate implantation of prostheses for vascular injuries in such settings.

Improved personal protection technology and mandatory use of body armor has allowed soldiers to survive otherwise lethal torso injuries. This probably accounts for the disproportionately higher frequency of extremity injuries, because body armor does not provide protection below the pelvis nor distal to the axilla. In fact, the higher limb amputation rate compared with that of the Vietnam conflict may be a consequence of more soldiers surviving the sentinel attack and subsequent evacuation, thus permitting operative repair of their vascular injuries. Although the overall amputation rate is higher, there are more lives being saved. In addition to body armor, improvements in evacuation capabilities have allowed rapid transport of injured patients to tertiary level facilities. With air superiority in theater, helicopter medical evacuation can transport patients to a medical facility within minutes. From there, transport back to the United States is facilitated by the Air Force critical care transport teams within days. If medically stable for evacuation, patients injured in Iraq can be seen at a hospital in the United States within days of the time of injury.

As reported by other military physicians, the liberal use of vascular shunts as a temporizing damage control method has played an invaluable part in the treatment of these injuries. In our experience, the use of vascular shunts was helpful in 2 overlapping but occasionally distinct circumstances. The first was in damage control scenarios in which the vascular repair was deferred in light of the overall trauma burden. Patients often presented with multiple injuries. Thus, temporizing surgical measures were performed, followed immediately by further resuscitation and rewarming, leaving definitive repair for a later time. Second, shunts were placed for patients initially taken to a forward surgical team for control of life- or limb-threatening injuries. A forward surgical team is a mobile team with limited surgical capabilities whose primary mission is initial stabilization followed by immediate transport to a higher level of care. With limited capabilities and rapid medical transport readily available, surgeons in a forward surgical team who encountered major vessel injury employed a vascular shunt and then transported the patient to our combat support hospital. In this manner, vascular shunts were an integral part of our armamentarium.

The successful initial management of trauma injuries in patients with suspected vascular injury involves several tenets well depicted by our data. Venous injuries can frequently be ligated without threat to the limb, and attention should not be diverted to perform a venous repair in the critically ill patient. All injuries should be considered heavily contaminated; primary closure should be used sparingly (if at all), and prosthetic grafts should be avoided. Improved personal protection devices continue to make extremity injury more common than truncal injury, but vulnerabilities to the axilla and pelvis remain. Finally, damage control surgery, including the use of temporary shunts as indicated, is a key technique that has improved survival rates of severely injured patients. Adequate debridement of all necrotic tissues, including vessels, is important, but it is followed by further resuscitation and stabilization of the physiologically tenuous patient prior to definitive repair.

Our limitations revolve around the inherent nature of obtaining scientific data in a busy combat hospital. Besides the lack of a standard data entry apparatus connected to the war theater, rapid evacuation of coalition troops to multiple hospitals in the continental United States led to inconsistent and incomplete follow-up data. Of the patients with follow-up data, information regarding the reason for amputation was limited. The vascular repair was presumably intact, but the associated soft tissue, nerve, and orthopedic injury may have led to amputation for functional reasons. It is not known, however, whether thrombosis of the vascular repair led to the amputation. As this data was not collected in a prospective manner, aspects such as the incidence of fasciotomies were not available for analysis. To our recollection, fasciotomies were performed liberally on all patients with major vascular injuries to the extremities, but the end results, including the limb salvage or graft patency rates, are unknown. In an attempt to better standardize data-gathering procedures and other trauma protocols, a research position has been established in the combat theater. The end results of this administrative position should provide a rich data set to permit further progress based on collective experience. The Department of Defense has now employed a newer, more accurate, computerized patient tracking system that allows for access to patient records throughout the different echelons of care. This latest system also integrates multiple patient databases and eliminates different systems for each branch of service. This system will hopefully allow for more accurate patient follow-up and, more importantly, better patient care.

CONCLUSIONS

The lessons applicable to vascular trauma in our current conflict can be illustrated from our series. Over-
all, vascular trauma and the repair of these injuries have an acceptable mortality rate. Vascular repair does not completely prevent amputations, but it may prevent a level of amputation, translating to a more functional limb. We feel that every reasonable attempt should be made to preserve a limb, even if it may turn out to be dysfunctional. Once the patient has recovered from the immediate life-threatening injuries, they can actively participate and decide the outcome for the limb. This participatory role in his or her recovery may benefit the patient psychologically. Another important lesson from this war is the benefit of vascular shunting as a component of damage control surgery. This technique allows temporizing stabilization to a vascular injury until the physiologic effect of the trauma improves.

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REFERENCES