Management of Vascular Injury in Counter Insurgency Area: A Single-center Study

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Abstract

Background: Vascular trauma can threaten both limb as well as life of the patient. Combat-related vascular injuries are different from civilian vascular injuries in terms of epidemiology, mechanism, pathophysiology, and outcome. Combat or military trauma is generally penetrating trauma (high energy weapons). Difficult evacuation and transportation from the battle field complicates the vascular injury and its outcome.

Materials and Methods: This is a single-center, prospective, observational study conducted at a service hospital in Jammu and Kashmir. Twenty-five patients with mean age 25.76 years (18–43 years) who underwent vascular intervention for trauma from December 2013 to November 2016 were included. Data pertaining to vascular injury regarding to site of injury, associated injuries, type of vascular repair, outcome, and complications were recorded and analyzed. Results: Five hundred and eighty trauma patients were admitted during the study period with 4.3% of the patients having vascular injury. All the patients were males and most of them were in the second or third decade of life. The mean time interval between the trauma and arrival to the hospital was 7 h. Lower extremity was the most common site of trauma (52%) of the patients followed by upper extremity. In 56% of the patients, vessels were repaired with reverse saphenous vein graft harvested from the uninjured limb. Two patients (8%) had secondary amputation and one patient (4%) died due to sepsis. Conclusion: Expeditious evacuation, quick transfer, early diagnosis and management including advanced endovascular care are essential for the limb salvage and survival of the serving soldiers.

Keywords: Penetrating injuries, secondary amputation, vascular trauma

Introduction

Vascular trauma can result from penetrating, blunt, or iatrogenic injuries. Combat-related vascular injuries are different from civilian vascular injuries in terms of epidemiology, mechanism, pathophysiology, and outcome. Combat or military trauma is generally penetrating trauma (high energy weapons). Providing first aid and evacuation of patients from the combat zone is also a significant matter of concern which leads to delay in definitive treatment.

The incidence of military vascular trauma varies from 0.2% to 4% of injured patients, the majority being young males. Peripheral vascular injuries constitute 80% of all cases of vascular trauma. Torso protective gears worn by soldiers protect from high-energy trauma during military conflicts. Lower extremities are more commonly involved as these are relatively less protected. Majority of the injuries occurs with high-velocity weapons (70% to 80%), followed by stab injuries (10%–15%) and blunt trauma (5%–10%).[1–7] In the blunt trauma, local compression or rapid decelerations cause tissue injury. In penetrating trauma, the injury is produced by crushing or by separation of tissues along the path of the penetrating object. Cavitation is a phenomenon that occurs as tissue recoils from the point of impact by a moving object away from that object. Cavitation can also lead to vascular injury even without being in contact with projectiles or bone fragments.[8] Due to difficult evacuation and transport to the health-care facility, the outcome in the wounded patients with vascular injury becomes complicated. On this background, management of vascular injury in the counter insurgency area was studied.

Materials and Methods

This is a single-center, prospective observational study conducted at a service hospital in Jammu and Kashmir which
included the patients who had vascular injury from December 2013 to November 2016. Patients with unsalvageable extremities requiring primary amputation were excluded from the study. All the patients underwent thorough clinical examination for vascular injury to facilitate early diagnosis and prompt treatment. Injury pattern, mechanism of vascular injury, site and type of vessel injured, and any associated trauma were recorded and documented.

Primary survey and resuscitation were carried out as per Advanced Trauma Life Support protocol by well-trained trauma team (Surgeons, anesthesiologist and radiologist, nurses, and paramedical staff). Duplex scan was performed as a part of routine clinical examination. In patients having equivocal diagnosis with soft signs of vascular injury, computed tomography (CT) scan was performed. Patient were immediately shifted to operation room in case there were hard signs of vascular injury at presentation or vascular injury was confirmed on CT scan.

Meanwhile, all the patients received intravenous fluid resuscitation, analgesics, antibiotics, and tetanus prophylaxis. Blood group crossmatching was performed. Tourniquets applied were removed after securing hemostasis. Fracture or dislocation if any was reduced and only external fixation was done before definitive vascular repair wherever required. Use of temporary shunt is not a routine protocol in our hospital. Shunt was used in one patient whose transfer to the base hospital took 24 h. Intravenous heparin was administered depending on the associated injuries. In cases where systemic heparinization could not be administered, heparinized saline was used liberally to flush and irrigate the vessels. Definite arterial repair was performed in the form of interposition graft (using saphenous vein graft/prosthetic graft) or ligation of the artery (isolated tibial, radial, or ulnar artery). Associated injury to vein was repaired in the form of interposition graft with saphenous vein, lateral venorrhaphy, or ligation of vein. Nerve injuries (median nerve) were repaired in only 2 cases along with arterial injury. Diagnosis of compartment syndrome was made on the basis of clinical examination. The threshold for fasciotomy was kept very low. Fasciotomy was performed with the slightest suspicion of compartment syndrome in all patients with lower extremity arterial trauma (52%).

Postoperatively, all the patients received intravenous broad-spectrum antibiotics and aspirin, and in patients with lower extremity arterial injury (52%), prophylactic anticoagulation using low molecular weight heparin was administered to prevent deep vein thrombosis. All the patients were monitored during the postoperative period for impending ischemia, hemorrhage, sepsis, and other possible complications including the need for amputation.

Routine postoperative clinical examination involved the use of continuous wave Doppler for the noninvasive assessment of distal limb perfusion. Duplex scan or angiographic assessment was performed in doubtful patency of limb vessels. Ankle brachial index was not used as a part of routine clinical examination and surveillance. All patients were followed up weekly for a month after discharge from the hospital, and thereafter, 6 monthly follow-up was done.

**Results**

Five hundred and eighty trauma patients were admitted over a period of 3 years. Twenty-five patients (4.3%) had vascular injury. All the patients were males with age range of 18–42 years as shown in Table 1. Of 25 patients, 19 (76%) patients had hard signs and 6 (24%) patients had soft signs of vascular trauma.

The mean time interval between the trauma and arrival to the hospital was 7 h. CT angiography was performed in 28% of the patients. Overall, gunshot injury was the most common...
mechanism of injury in 56% of the patients, and rest of the mechanisms of trauma is shown in Table 2.

Lower extremity was the most common site of trauma including 13 patients (52%) followed by upper extremity. Distribution of the arterial injury pattern is shown in Table 3. Femoral artery was injured in 24% of the patients followed by brachial (five patients, 20%) and popliteal vessels (four patients, 16%). Aorta and inferior vena cava (IVC) were involved in two cases who had reached alive to the hospital and underwent intervention. Junctional arterial trauma was noted in 12% of the cases.

Vascular injuries generally result from high energy trauma, and these injuries were commonly associated with orthopedic injuries in the form of fracture in 64% of the patients [Table 4]. Definite arterial repair was performed in the form of interposition graft (using saphenous vein graft/prosthetic graft) or ligation of the artery (isolated tibial, radial, or ulnar artery) [Table 5]. In 56% of the patients, reverse saphenous vein graft was harvested from the uninjured limb. Prosthetic graft was used in two cases. One patient with common iliac artery injury and other with common femoral artery injury were repaired using prosthetic graft. Arm veins were not utilized for interposition graft or bypass. Four patients underwent combined arterial and venous reconstruction which included patients with aorta, common iliac artery, and vein injury; femoral artery and vein injury; subclavian artery and vein injury; and brachial artery and vein injury.

All the complications were recorded in the form of rethrombosis, wound infection, and secondary hemorrhage and have been described in Table 6. One patient had reintervention with revision of anastomosis.

Primary end point was assessed in the form of perioperative mortality (30-day mortality) and secondary end point was assessed in the form of secondary amputation.

Perioperative mortality in the present study is 4%. One patient with aorta and common iliac vessel injury had died perioperatively on account of persistent metabolic acidosis.

In the present study, two patients had secondary amputation attributed to delayed presentation and compartment syndrome.

**DISCUSSION**

Combat-related injuries to major vessels present unique technical challenges and result in hemorrhage that is responsible for 80% of potentially preventable deaths on the battlefield. The front lines of a battleground are chaotic, located in harsh environments, and vary widely, depending on the goal and scope of military operations. Since the Vietnam War, there has been considerable modernization in the form of advanced tourniquet system (specialized operation force tactical tourniquet and combat application tourniquet system) and hemostats (Hemcon and Quikclot) at the battlefield.

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**Table 1: Age distribution of vascular trauma patients**

| Age groups (years) | Number of patients (n=25) (%) |
|--------------------|-------------------------------|
| 15-20              | 5 (20)                        |
| 20-25              | 8 (32)                        |
| 25-30              | 4 (16)                        |
| 30-35              | 3 (12)                        |
| 35-40              | 3 (12)                        |
| 40-45              | 1 (4)                         |

**Table 2: Distribution of mode of injury among vascular injury patients**

| Mechanism of injury | Number of patients (n=25) (%) |
|--------------------|-------------------------------|
| Gunshot injuries   | 14 (56)                       |
| Splinter injuries  | 8 (32)                        |
| Road traffic injuries | 2 (8)                      |
| Fall from height   | 1 (4)                         |

**Table 3: Distribution of vascular injuries**

| Anatomical distribution | Vessel involved | Number of patients (n=25) (%) |
|-------------------------|-----------------|-------------------------------|
| Lower limbs vessels     | Femoral artery/ vein | 6 (24)                       |
|                        | Popliteal artery  | 4 (16)                       |
|                        | Anterior/ posterior tibial artery | 3 (12)                   |
| Upper limbs            | Brachial artery   | 5 (20)                       |
|                        | Radial/ulnar artery | 2 (8)                       |
| Abdominal vessels      | Aorta            | 1 (4)                        |
|                        | Inferior vena cava | 1 (4)                        |
|                        | Common iliac artery | 2 (8)                       |
| Neck vessel            | Subclavian artery | 1 (4)                        |

**Table 4: Associated injuries**

| Associated injuries | Number of patients (n=25) (%) |
|--------------------|-------------------------------|
| Fracture of long bone | 15 (60)                      |
| Dislocation of joint | 2 (8)                         |
| Abdominal injury    | 3 (12)                        |
| Chest injury        | 2 (8)                         |
| Head injury         | 2 (8)                         |

**Table 5: Surgical intervention**

| Surgical procedure                          | Number of patients (n=25) (%) |
|---------------------------------------------|-------------------------------|
| Reverse saphenous interposition vein grafting | 14 (56)                      |
| ePTFE prosthetic interposition graft        | 2 (8)                         |
| Primary end-to-end repair                   | 3 (12)                        |
| Lateral venorraphy                          | 2 (8)                         |
| Ligation                                    | 4 (16)                        |
| ePTFE: Expanded polytetrafluoroethylene     |                              |
environment, which has translated into a measurable survival advantage.\textsuperscript{[10,11]}

In the Vietnam War, vascular injuries accounted for 2\%–3\% of battle-related injuries.\textsuperscript{[9]} Whereas during global war on terror and operation Iraqi freedom, it was 4\%–6\%.\textsuperscript{[12-17]} In the present study, 25 patients of vascular injuries were transported alive to the hospital. It accounts for 3.8\% of total causalities reaching hospital alive.

Not surprisingly, majority of troops sustaining vascular injuries are male (95\%) and young (mean age, 23 years).\textsuperscript{[13,18-20]} In the present study, all the patients sustaining vascular injuries were males of 2\textsuperscript{nd} to 3\textsuperscript{rd} decade.

Penetrating injury (explosive devices and gunshot wounds) is the most common mechanism of vascular injury in all the wartimes.\textsuperscript{[1,12-14,21]} In the present study, 56\% of the patients had gunshot injury. Lower extremity vascular injuries occur at approximately two times that of upper extremity, reflecting the relative length of axial vessels and the exposed position of lower extremity away from the protection of the torso.\textsuperscript{[12-17]} In lower extremity, the superficial femoral artery is most commonly injured (33\%–37\%), followed by the popliteal and tibial arteries (25\% each). Woodward showed that nearly 50\% of lower extremity vascular injuries had a combined arterial and venous component.\textsuperscript{[15]} Nearly, all vascular injuries have associated orthopedic injuries, and 20\% have partial thickness burns.\textsuperscript{[18]} In the present study, 52\% of the patients had lower extremity arterial trauma and SFA was the most commonly injured vessel. There were two patients who reached to hospital alive with aortic and IVC injuries. About 64\% of the patients had associated fracture.

Patients with hard or obvious signs of vascular injury are taken to the operating room for exploration, and there is often no time to perform a more detailed diagnostic evaluation. Therefore, the diagnostic evaluation pertains mostly to patients with soft signs of vascular injury or penetrating wounds or fragments proximal to a major axial vessel. Most useful modalities in diagnosing vascular injuries are continuous wave Doppler, contrast-enhanced CT angiography, and standard angiography. Continuous wave Doppler in this setting is quick and useful to confirm perfusion to an extremity on initial presentation. In the present study, the mean time interval between the trauma and arrival to the hospital where vascular injury could be repaired was 7 h. The possible explanation for this delay is the mountainous terrains limiting the quick evacuation and transportation. Twenty-eight percent of the patients had soft signs of vascular trauma that underwent CT angiography.

Optimal management requires proper planning and recognition of the essential priorities to prevent immediate hemorrhagic death. Prehospital tourniquets should be inspected and may be left in place during the primary and secondary surveys. Damage-control resuscitation, a strategy of liberal blood product administration, minimal crystalloid use, and selective use of recombinant factor VIIa should begin early in the emergency room and continue intraoperatively.\textsuperscript{[22]}

In patients with overt signs of arterial injury, immediate surgery is preferred instead of further diagnostic testing. Preoperative antibiotics are instituted before making the skin incision. The entire injured extremity should be prepared and draped. An uninjured extremity should be included in the operative field in the event an autogenous vein graft is required. In most cases, harvesting vein from the injured limb should be avoided owing to associated venous injuries and a potential worsening of postoperative swelling.

Proximal and distal arterial control is obtained before exposure of the injury. A careful evaluation of the extent of arterial injury, as well as venous and nervous tissue damage, should be carried out after macroscopic wound debridement and irrigation.

Fogarty catheters should be passed gently, both proximal and distal to the arterial injury, to remove any intraluminal thrombus. Both proximal and distal arterial lumens are flushed with heparinized saline solution. Systemic heparinization prevents thrombosis or thrombus propagation when systemic anticoagulation is not contraindicated.\textsuperscript{[23,24]}

Temporary intraluminal shunting is essential as a limb salvage modality in patients with severe limb ischemia and revascularisation appears to be delayed owing to fracture fixation, complex soft tissue injury, or associated life-threatening injuries.\textsuperscript{[25-27]}

There were two highly challenging cases in the study. First case was a patient with aortic injury due to gunshot wound, in which damage control strategy was adopted. There was extensive bleeding from the aorta and iliac vessel injury. Primary repair of aorta was performed. The patient received 18 units of blood transfusion. Despite the best possible intensive care, the patient could not be salvaged.

Second, a patient presented with multiple gunshot injury in abdomen. Damage control resuscitation was performed and the patient was taken for immediate laparotomy. Along with IVC injury, the patient had injury to left kidney and left colon. IVC was primarily repaired along with nephrectomy, hemicolectomy, and colostomy. The patient received 19 units of blood transfusion and had critical care support. After 3 months, laparoscopic closure of stoma was performed and the patient was discharged.

| Complication          | Number of patients (n=25) (%) |
|-----------------------|------------------------------|
| Revision              | 1 (4)                        |
| Infarction            | 1 (4)                        |
| Secondary hemorrhage  | 1 (4)                        |
| Amputation            | 2 (8)                        |
| Death                 | 1 (4)                        |

Table 6: Complications
DeBakey and Simeone illustrated that only 81 arterial repairs were done out of 2471 arterial injuries during World War II.\(^1\) And, all but three injuries were repaired by lateral suture. Amputation followed vessel ligation was nearly half of the extremity vascular injuries during this era. In 1952, during the Korean War, Frank Spencer from The United States Marine Corps started arterial repair using cadaveric femoral artery as an interposition graft conduit.\(^2\) This resulted in reduction of amputation rate among 269 repairs – from 49% in World War II to 13%.

The later development of prosthetic graft material – expanded polytetrafluoroethylene (ePTFE) – made possible the routine use of prosthetic conduits as a substitute. Surgical experience suggests that ePTFE is more resistant to infection than other prosthetic grafts and has acceptable patency rates when used in the above-knee position.\(^20\) In the present study, reverse saphenous vein graft (harvested from the contralateral uninjured limb) was used for bypass or short segment interposition graft in 56% of the patients. Prosthetic graft was used in 8% of the cases.

During reperfusion, toxic oxygen-derived free radicals are generated producing cell injury and death. This manifests as muscle edema and necrosis leading to compartmental hypertension.

In fact, a retrospective review of 150 patients with lower extremity arterial injuries documented that the incidence of limb loss was significantly higher in patients who developed compartment syndrome (41% vs. 7%) or did not receive perioperative anticoagulation (15% vs. 3%).\(^10\) For all these reasons, the surgeon must be aware of the deleterious effects of reperfusion injury, and systemic mannitol or heparin infusion should be considered before an ischemic limb is reperfused. The clinical manifestation of reperfusion injury – compartmental hypertension – must be sought assiduously and treated aggressively.\(^11\) In the present study, therapeutic or prophylactic fasciotomy was performed in 13 patients (52%) with vascular trauma. Despite all, two patients (8%) had delayed secondary amputation.

**Conclusion**

Military vascular trauma usually involves the extremities and is often a part of an injury complex in patients with exsanguinating hemorrhage presenting to a field hospital. Expedient evacuation, quick transfer, early diagnosis and management including advanced endovascular care are essential for the limb salvage and survival of the serving soldiers. Optimum management includes proper planning and recognition of associated life-threatening visceral organ injury with major vessel injury.

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**Conflicts of interest**

There are no conflicts of interest.
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