Warfare Vascular Injuries

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Abstract

Vascular injuries as a part of combat injuries have been recorded since times immemorial. Responsible for death due to exsanguination, the management of vascular injuries was ligation or amputation till the landmark Vietnam experience. The present day management has evolved with advances in modern technology and may start at the battlefield with the application of a tourniquet with the definitive treatment continuing beyond the combat operation theatres. A basic understanding of both blunt and penetrating vascular injuries will help minimize mortality and morbidity.

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Introduction

“Bloody vascular trauma - it's either bleeding too much or it's not bleeding enough”.

Anonymous

Unrecognized and uncontrolled haemorrhage is often fatal while untreated ischemia can lead to limb loss. Historically majority of those “Killed in Action” are likely to have had fatal vascular trauma. DeBakey and Simeone calculated the amputation rate from vascular injuries in World War II as greater than 40%. Following rapid evacuation and primary vascular repair in the Korean War and the Vietnam War, it dropped to approximately 15% [1]. This figure has now been reported to be 6-8% in various series from Iraq and Afghanistan [2-4]. Therefore preparation of all surgeons for deployment to a wartime situation must include basic knowledge and skills in vascular reconstruction techniques [5,6].

Clinical Features

Bleeding following vascular injury may be obvious, with visible arterial haemorrhage, or it may be concealed. Haemorrhage tends to be more severe in partially transected vessels, as complete transection results in retraction and vasoconstriction of the vessel, limiting or even arresting arterial haemorrhage. Contusion to a vessel in blunt trauma may be associated with formation of intimal flap and thrombosis.

Clinical examination and re-examination remain the mainstays for identifying and treating these wounds. Conventionally there are hard signs and soft signs of vascular injury. Hard signs, which warrant immediate

intervention include: (i) external arterial bleeding, (ii) rapidly expanding haematoma, (iii) palpable thrill, audible bruit, (iv) signs of acute limb ischaemia-pain, pallor, pulselessness, paresthesia, paralysis and poikilothermia. In presence of hard signs, unnecessary interventions and investigations should be avoided to minimize the delay to definitive care. Soft signs of vascular injury warrant urgent evaluation in the form of colour doppler/angiography. These include: (i) history of arterial bleed at the scene, (ii) proximity of penetrating wound or blunt trauma to major artery, (iii) small non pulsatile haematoma, (iv) neurological deficit, (v) ABPI<0.9 (vi) abnormal wave-velocity waveform on doppler. Temperature change, color change and delayed capillary refill may be obvious on examination besides feeble or absent pulses.

Investigations

Radiographs are valuable for assessing the presence of bone fractures. Bed side hand held Doppler is more sensitive than manual palpation. Colour Doppler is the investigative modality of choice and can detect intimal tears, thrombosis, false aneurysms and arteriovenous fistulae [7]. However, an arteriogram in stable patients and operative exploration in unstable or bleeding patients remains the accepted standards of care at higher levels of care. Diagnostic adjuncts include the use of pulse oximetry. Multidetector CT angiography is a reliable alternative to angiography for vascular trauma in those cases evacuated to the tertiary care setting [8].

Management of Vascular Injuries of Limb

There are two phases in the resuscitation of patients

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with vascular injuries - before and after haemorrhage control. Large bore venous access at two sites is necessary. Prior to haemorrhage control, minimal fluids should be administered as raising the blood pressure will increase haemorrhage and dislodge any clot that has already formed. Once haemorrhage control is achieved, there should be aggressive volume resuscitation to restore circulating blood volume. Warmed fluids - crystalloids, blood or clotting factors, as necessary, are administered to correct acidosis, hypothermia and coagulopathy, and to restore perfusion rapidly to various organ systems. The use of tourniquets should be limited to patients at risk for exsanguination in the pre-hospital and field environments. If left on for prolonged periods a tourniquet markedly increases the incidence of amputation of an injured extremity. Thus, a tourniquet may save life but may also result in loss of an extremity. The US forces have a wide range of tourniquets issued to the troops such as CAT- Combat application tourniquet, SOFTT- Special operation forces tactical tourniquet, and EMT- emergency medical tourniquet. In operations in Iraq and Afghanistan the use of tourniquets has been shown to be useful [4].

Any dislocations of the elbow and knee, or fracture angulations are promptly reduced to prevent further injury to neurovascular structures. Orthopaedic fixation is by internal or better by external fixation. In high-energy wounds it is important to debride dead muscle or tissue with meticulous skill [9].

Vascular repair is always begun by first taking proximal and distal control, and only then exploring the site of the injury/haematoma. Temporary vascular control can be achieved by simply applying direct compression or pressure to the vessel proximal to the injury (e.g., femoral pressure in a lower extremity wound) or by use of pneumatic tourniquet. Blind clamping in the depths of a wound is dangerous, likely to fail, and likely to injure other structures. Vascular repair requires use of small vascular clamps or slings passed twice around the vessel. If vascular clamps are used they should be applied with the minimum force necessary to obstruct flow without causing vessel wall damage. Heparinisation is done 5 minutes before clamping. The options for vessel repair include (i) Lateral arteriorrhaphy, (ii) Patch angioplasty, (iii) Resection with end-to-end anastomosis, (iv) Resection with interposition graft, (v) Bypass graft, (vi) Extra anatomic bypass and (vii) Ligation. A balloon catheter is always passed into the artery distal to repair and then proximally. Postoperative care should consider LMWH in the perioperative period followed by anti-platelet drugs for three months.

The principle of damage control surgery can be applied to vascular injuries by ligation and shunting. The external

carotid, subclavian, axillary, internal iliac arteries can be ligated with few consequences. Ligation of the internal carotid artery carries a 10-20% risk of developing a stroke. Ligation of the external iliac, common femoral or superficial femoral arteries is associated with a significant risk of developing critical limb ischaemia. One of the three crural vessels and one of the forearm vessels may also be ligated in young healthy males.

Warm ischaemia of striated muscles for 4-6 hrs will manifest as compartment syndrome, which must be recognized and treated. A wide four-compartment fasciotomy can be a life and limb saving procedure. The old saying 'If you think about doing a fasciotomy, you should do one' probably still holds true. It is best performed at the time of initial surgery. A standard 2 incision fasciotomy is done to relieve all the 4 compartments in the leg.

As far as venous injuries are concerned, almost all veins including the infra-renal inferior vena cava can be ligated where necessary. Venous injuries need repair only in special situations. Popliteal vein is usually repaired rather than ligated. Ligation of femoral or iliac veins is generally well tolerated but the patient is advised elastic wraps and leg elevation for 7-10 days and then use of stockings for three months. In case of complex venous repairs for major vessels, long term patency of grafts is poor unless accompanied by a distal AV fistula.

Complications of vascular repair include bleeding, infection and thrombosis of the graft and may require re-intervention to prevent limb loss.

Recent advances include use of endovascular techniques where feasible for treatment of vascular injuries. Its availability though will be restricted to select centres at higher level of care [10]. Temporary intraluminal shunts are being advocated at Field Hospital level as a standard of care to temporarily restore flow, so that vascular repair can be done at a higher echelon level III /IV where better outcome may result [11,12]. While specific vascular shunts are available, they can be rapidly constructed out of sterile intravenous tubing and secured in place so that they do not become dislodged during transfer.

Neck Vascular Injuries

Penetrating vascular neck trauma is seen in 5-13% of injured. Zone 1 injuries are usually exposed via an oblique supraclavicular incision. Resection of the middle portion of the clavicle may be required for adequate visualization of the subclavian artery. Zone 2 injuries are exposed through a standard neck dissection incision. Repair of one internal jugular vein should be considered if ligation of both veins is necessary. The external carotid artery may be safely ligated. Techniques for repair of

the common and internal carotid arteries include lateral arteriorrhaphy, end-to-end anastomosis, and grafting. Shunting remains an option to transfer the patient to a higher echelon of care where revascularization can be done. Ligation is considered in desperate circumstances only when attempts to repair the artery have failed. Zone 3 vascular injuries are difficult to access surgically and may require mandibular subluxation or mandibulotomy for exposure. Angiography with embolization may be more successful in controlling arterial disruption at the skull base than surgical exploration and repair.

Surgical exploration was considered mandatory for all wounds, which violate the platysma, however selective management instead of mandatory neck exploration is being advocated in higher centers after CT scanning.

Thoracic Vascular Injuries

The incidence is about 5-13% and many are "killed in action" of such wounds. Management begins with ABC's. Thoracotomy is indicated at the Field hospital (Level II), for suspected vascular injuries on evacuation of 1500ml blood or bleed more than 250ml per hour in the chest tube. The prevalence of great vessel injury ranges from 0.3 to 10% of the survivors who reach the hospital. Emergency sternotomy with supraclavicular extension is the best approach. A trapdoor anterior thoracotomy may be done in desperate cases. A posterolateral thoracotomy is indicated for descending aorta injuries.

The application of CT scan as a primary diagnostic tool has reduced the indication for angiography unless endovascular graft placement facilities are available usually in higher centres and there are case reports of such applications even in the combat settings in Level III facility.

Abdominal Vascular Injuries

Exsanguinating haemorrhage due to injuries to major abdominal vessels is the most important cause of early death. Intra-abdominal vascular injuries pose challenges of exposure during laparotomy and a high probability of association with other major injuries in the abdomen, particularly to the small bowel.

All stable patients should be evaluated with FAST USG examination to exclude haemoperitoneum. Most will require a triple-contrast CT scanning (e.g., oral, intravenous, rectal) to exclude peritoneal penetration. GSWs to the abdomen require laparotomy/ celiotomy for evaluation and treatment. Selective non-operative management of abdominal gunshot wounds (GSWs) in stable patients acceptable in civilian setting is not appropriate in combat scenario. Hemodynamically

unstable patients should be transported immediately to the operating theatre.

Treatment

Midline laparotomy is done to quickly evacuate blood and clots and perform four-quadrant packing. After initial stabilization, the packing is removed systematically and injuries evaluated. Injuries to major abdominal vessels can be grouped into the following five regions:

- (a) *Midline Supramesocolic Haemorrhage* or hematoma (superior to the transverse mesocolon) may be due to an injury to the suprarenal aorta, celiac axis, proximal superior mesenteric artery, or proximal renal artery. Proximal aortic control is achieved by compression at the hiatus, and direct access to the vessels is obtained through retroperitoneal mobilization and medial rotation of all left-sided abdominal viscera (Mattox maneuver) or an extensive Kocher maneuver on the right side. An injured celiac axis may be safely ligated in critical situations. Access to the superior mesenteric artery and vein may require transection of the pancreas. Primary repair of this major vessel is usually the first choice; however, ligation, particularly of the venous structures, may be a better option, however beyond midcolic repair is necessary to prevent gut ischaemia. If mesenteric vein is ligated, significant venous congestion can compromise viability of the bowel, a laparostomy is advisable.
- (b) *Midline Inframesocolic Haemorrhage* or hematoma may be due to infrarenal aortic or IVC injury. Exposure is obtained by incising the posterior peritoneum in the midline after visceration of the small bowel and cephalic retraction of the transverse mesocolon, or by dividing the white line of Toldt adjacent to the caecum and extended cephalad through the hepatic flexure followed by medial rotation of the right colon and small bowel (Cattel-Braasch maneuver). An aortic clamp can then be applied just below the left renal vein, distal clamp near the aortic bifurcation and the injury repaired primarily. Access to IVC can be obtained by mobilizing the right colon and duodenum. Anterior injuries are repaired in transverse fashion, posterior injuries repaired from inside the IVC after proximal and distal control of the vessel. Side clamps like a Satinsky clamp can be used with ease and large IVC defects may be repaired by using a patch from the peritoneum. In patients with multiple injuries and exsanguinating hemorrhage, the infrarenal IVC can be ligated.

- (c) *Lateral Perirenal Haematoma* or hemorrhage may be due to injury to the renal vessels or kidneys. Exploration after blunt trauma is not necessary in patients with a negative result on abdominal CT scan. Penetrating injuries necessitate exploration. Only 30-40% of kidneys with arterial injuries can be salvaged. Before performing a nephrectomy, viability of the contralateral kidney must be assessed.
- (d) *Lateral Pelvic Haematoma* or haemorrhage may be due to injury to the iliac artery, iliac vein, or both. Vascular control is obtained at the aortic bifurcation proximally and close to the inguinal ligament distally. If an injury to the right common iliac vein is present, it may require a division of the overlying right common iliac artery. For best visualization of the internal iliac artery, the common and external iliac arteries are elevated on vascular tapes. Injuries to the common or external iliac arteries are repaired. Injuries to the iliac veins are treated with lateral venorrhaphy or ligation.
- (e) *Hepatoduodenal Ligament Haematoma* may be due to injury to the portal vein, hepatic artery, or both. Vascular control is obtained by clamping the porta hepatis with vascular clamps proximal and distal to the injury (double Pringle maneuver). Portal vein ligation may be required to expeditiously manage portal vein injuries if the patient is exsanguinating, although primary repair may be attempted. Hepatic artery injuries are generally managed by ligation. If portal vein inflow is compromised, the liver should be assessed for ischemia, and restoration of hepatic arterial inflow or resectional debridement of the ischemic section should be undertaken or staged.

Postoperatively these patients may require aggressive management to correct acidosis, active rewarming, and massive blood transfusion (>10 U of blood within 24 hours). Leaving the abdomen open to prevent Abdominal Compartment Syndrome is never a sign of weakness and may be required as part of damage control surgery. Various methods of this temporary closure can be applied; the Uro-bag is the easiest option. A planned reoperation 24-48 hours after the initial procedure is done to complete a damage control sequence.

Conclusion

Management of combat-related major vascular injuries is a challenge to all surgeons and a vascular specialist will not always be available in a wartime setting or in a

field hospital; therefore, every surgeon deployed to a war setting must be able to cope with these life and limb-threatening injuries. The role of endovascular management will remain restricted to select wartime vascular injuries evacuated to higher centres.

Conflicts of Interest

None identified

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