

Military Junctional Trauma

NRM Tai¹, EJ Dickson²

¹Consultant Surgeon, Royal London Hospital Trauma Service, Barts and the London NHS Trust, London; ²Consultant Surgeon, West Scotland Pancreato-biliary Unit, Glasgow Royal Infirmary, Glasgow.

Introduction

Junctional zone trauma, by definition, is an injury occurring at the junction of anatomically distinct zones. These regions are traversed by major vascular structures, and are therefore frequently accessed surgically in the trauma patient for haemorrhage control. Whilst the principles of vascular control still apply in the context of this wounding pattern, these injuries are challenging because proximal and distal control are achieved in *anatomically distinct* regions.

In a paper documenting injuries amongst US Army Rangers during the “Black Hawk Down” incident in Mogadishu, Somalia, Mabry et al noted “...the management of choice for severe extremity hemorrhage is an effective tourniquet followed by surgical repair or ligation of the injured vessels” [1]. Since then, tourniquet use has been promulgated extensively such that it is now the cornerstone of the pre-hospital response to haemorrhagic extremity injury [2]. Mabry also raised the question: “...But what about those injuries not amenable to a tourniquet, such as those to the lower abdomen, groin, axilla and proximal extremities?” Application of direct tamponading manual pressure to these wounds is ineffective (due to skeletal protection, adverse vessel anatomy or depth) and, even if possible, is impractical to maintain consistently in a non-benign tactical situation. In response to this, intense efforts have been made to develop and deploy a raft of novel haemostatic products designed to bridge this gap and increase the likelihood of survival to surgical intervention. Moreover, if such pre-hospital interventions succeed in delivering a live casualty to the surgical team, these wounds are often of the most taxing nature to be faced by deployed military surgeons, being time-critical, anatomically challenging, and starkly intolerant of sub-optimal technique.

The purpose of this paper is to outline the management of such “junctional” injuries - from a Role 2/2E/3 perspective – in order to provide a guide to surgical specialists deploying to operational areas.

Characteristics of military junctional wounds

The hallmarks of military junctional wounds are summarised in Table 1. They may be defined as damage to tissues spanning the root of an extremity and adjacent torso i.e shoulder, thoracic outlet, pelvis and lower abdomen, caused by transfer of energies from the passage of missile, energised fragment, or blast. These injuries are testing because they may frequently be associated with profound haemorrhage and physiological disturbance, and because they transgress the conventional precincts of surgical specialism. The

arteries and veins at risk include the subclavian and axillary vessels in the upper junctional zone, and the external iliac, common femoral, profunda femoris and proximal superficial femoral vessels in the lower extremity zones. Thoracic inlet, or Zone 1 neck injuries, may involve the aortic arch vessels (innominate, left common carotid and left subclavian arteries) and the major veins traversing this region (brachiocephalic and jugular veins). Upper extremity junctional injuries may be associated with haemothorax, pneumothorax, air leak, and trauma to the nerves of the brachial plexus. Lower extremity junctional injuries may occur with damage to viscera such as bladder, rectum, small and large bowel, and gross soiling of the peritoneum. In either zone, the bones and joints of the relevant bony girdles may be disrupted.

Junctional wounds may be classified according to the zone of vascular control. Type 1 injuries are those in which the wound encroaches on a junctional zone and it is not possible to place a tourniquet high enough to gain vascular control, but surgical control can be gained without the requirement to enter an adjacent body cavity. Type 2 injuries are those in which the peritoneal or thoracic cavities must be entered via a laparotomy or thoractomy/sternotomy in order to gain control.

Characteristic	Implication
A tourniquet can not be placed above the wound.	Proximal control requires surgical incision extending across joint flexure or into an adjacent torso cavity
The limb may be at risk due to vascular/ associated injury	Limb salvage must be balanced against life preservation
Neighbouring body cavity structures may be damaged from the same wound trajectory	There is the potential for hidden blood loss as haemothorax or haemoperitoneum. Any vascular repair may be at risk of faeculent contamination

Table 1. The hallmarks of junctional trauma

Incidence of Junctional Trauma

Vascular injury is seen infrequently by the military surgical specialist; junctional vascular injury even less so. Of the largest contemporary series, Clouse and colleagues reported on 347 vascular injuries amongst 6801 battle injured patients treated at

Corresponding Author: Lt Col Nigel Tai MS FRCS(Gen Surg) RAMC, Trauma Clinical Academic Unit, Royal London Hospital, Whitechapel Rd, Whitechapel London E1 1BB
Email: nigel.tai@bartsandthelondon.nhs.uk

Balad Air Force Theatre Hospital over a 24 month period ending in 2006 [3]. The subclavian-axillary axis accounted for 3.7% of all arterial injuries, whilst the external iliac artery, common femoral and profunda femoris vessels accounted for 1, 3 and 4% respectively. Sohn et al, who were based in a Baghdad combat support hospital, treated a population of 153 patients with 218 vascular injuries (many of whom were evacuated to Balad) and reported 6 patients with vascular injury to the subclavian-axillary vessels [4]. The common femoral and profunda femoris vessels accounted for 19 and 15 vascular injuries respectively. Fox et al examined the records of 107 patients with combat vascular injuries treated at Walter Reed Army Medical Centre in Washington, DC from 2001 to 2004 [5]. The junctional artery subset included two axillary, three Profunda Femoris Artery (PFA) and one Common Femoral Artery (CFA) injuries, with venous trauma consisting of one subclavian vein, six femoral and two iliac vein injuries. In Holcomb et al's review of US Special Forces deaths in Afghanistan and Iraq, non-tournequetable haemorrhage was felt to be a contributory factor in the deaths of two soldiers in a series of 12 potentially survivable mortalities [6]. A similar paper by Kelly and colleagues examining injury severity and cause of death during the early and latter phases of these conflicts revealed an analogous pattern, with a fifth of potentially salvageable but ultimately fatal wounds occurring in the junctional areas. Interestingly, this proportion did not change over time, despite the increased range of topical clotting adjuncts available in 2006 (latter study period) compared to 2004 (early study period) [7].

Generic Management

It may be helpful to consider the "Four R's" when faced with the complex decision-making and surgical challenges inherent in managing these injuries appropriately. Firstly, **Recognise** the junctional nature of the injury by rapidly synthesising the immediately available data. Secondly, **Resuscitate** according to the <C>ABC algorithm, but pay particular attention the placement of vascular access catheters with specific regard to potential vascular injury between this access point and the central circulation, and use temporising manoeuvres to gain rapid control. Thirdly, in an era of increasingly organ-specific elective surgery, **Request** appropriate subspecialty help early for assistance with access and / or repair of injured structures. Fourthly, **Remember** the injured *non-vascular* structures – whilst junctional zones are accessed initially for haemorrhage control, there is potential for injury to other structures which must identified after vascular control.

Diagnosis and assessment

The principle and immediate goals of assessing the military patient with a junctional injury follow the standard <C>ABC paradigm of <Catastrophic haemorrhage control>, airway, breathing, circulation. As part of the assessment the attending surgeon should:

- Decide if there is a junctional vascular injury.
- Establish if the vascular injury is the cause of significant patient compromise in terms of haemorrhage or ischaemia.
- Decide if the adjacent cavity has been wounded by the same missile.
- Prioritise the management of these injuries within the overall injury burden of the casualty.
- Determine the optimum strategy for treatment of the casualty (damage control versus definitive, immediate versus deferred treatment [8,9], and the surgical incision necessary to gain proximal control (Table 2).
- Plan how to achieve proximal control.

Question	Subsidiary questions
Is there a vascular injury?	<p>What is the patient history and mechanism of injury?</p> <p>What are the physical findings?</p> <ul style="list-style-type: none"> • Hard signs, soft signs • ABPI, handheld Doppler <p>Are there any associated markers of vascular injury?</p> <p>What special investigations are available?</p> <ul style="list-style-type: none"> • Angiography (on-table) • CT angiography
Is there significant compromise of patient or limb ?	<p>What is the extent of haemorrhage, and is it on-going?</p> <ul style="list-style-type: none"> • Physiology of patient • Blood pressure, pulse, respiratory rate, mentation, urine output • Base Excess, Lactate • Physical evidence of bleeding • Dressings, drains, distended abdomen <p>What is the extent of ischaemia, and is it getting worse?</p> <ul style="list-style-type: none"> • Physical examination (6Ps) • Duration • Tissue affected.
Has the adjacent cavity been breached ?	<p>Are there clinical signs of haemo/pneumo-thorax ?</p> <p>Are there exit/entry wounds consistent with a cavity-breaching trajectory ?</p> <p>What is the result of the chest X-Ray or FAST ?</p>
How urgently does this vascular injury require treatment?	<p>What is the injury burden?</p> <p>Are there other over-riding life-threatening injuries?</p> <p>Is the haemorrhage incompressible or compressible?</p> <p>Is there significant compromise?</p>
What is the best management strategy?	<p>DCS vs Definitive?</p> <ul style="list-style-type: none"> • What is the patient's physiology? • What is the injury burden? • Will the patient survive the repair? <p>Immediate vs deferred treatment ?</p> <ul style="list-style-type: none"> • Is the limb threatened (likely to become unviable without repair) ? • Does patient instability preclude any attempt to address revascularisation ?

Table 2. Key Questions in assessing major junctional vascular trauma

Clinical features and initial investigation

The management of these patients is dichotomised according to the patients haemodynamic stability. This should be determined as early as possible by scrutinising all possible information sources, including the 9-LINER, in-transit casualty reports, updates from the attendant pre-hospital staff [physician, CMT/paramedic] and visual assessment of the patient upon entrance to the R2/3 facility.

The haemodynamically stable patient

Wound Inspection

Standard <C>ABC resuscitation protocols are followed in the Emergency Department (ED). The dressings can be taken down and wound inspected in the ED by the surgeon with a view to immediate redressing if haemorrhage is encountered. The wound is assessed for its size shape and depth. Do not disturb *in-situ* Quikclot®, Hemcon® or haemostatic adjuncts unless the wound is actively haemorrhaging. Any extraneous pressure dressings should be removed if they are not applying effective compression and be replaced by directed pressure.

Assessment of limb

In the absence of obvious external haemorrhage, the diagnosis of vascular injury can be difficult, especially in the shocked polytrauma patient. An ischaemic limb traditionally presents with the 6Ps (paralysis, paraesthesia, pallor, pain, poikilothermia, pulselessness) but the utility of these signs will be nullified by an *in-situ* tourniquet. Clinical signs of extremity vascular injury are classified as ‘hard’ or ‘soft’ (Table 3). The absence of hard signs is considered to equate to evidence of no vascular trauma; the presence of hard signs raises the likelihood of vascular trauma but is not pathognomonic. Soft signs are merely indicative and their presence or absence is not confirmatory - further investigation is required. Musculoskeletal and joint integrity may be difficult to establish in the swollen junctional area especially in the awake patient. Full assessment under anaesthesia, guided by appropriate plain radiography is likely to be of more utility.

Hard Signs	Soft Signs
Pulseless cold pale limb	History of active bleeding
Expanding haematoma	Penetrating injury close to major vessel
Palpable thrill or audible bruit	Non-expanding haematoma
Active bleeding	Neurological deficit

Table 3. Clinical features of vascular injury

Assessment of adjacent cavity

Signs of haemothorax must be sought and signs of haemoperitoneum must be confirmed. Evidence of entry and exit wounds on the limb/thorax/abdomen must be confirmed in order to delineate wounding trajectory.

Adjuncts to physical examination

A hand-held Doppler probe is an easily portable, cheap and accurate tool in the diagnosis of extremity vascular trauma. The

gold standard is to measure the ankle-brachial pressure index (ABPI). Although this requires the careful placement of a pressure cuff around an injured, painful limb, and an accurate assessment of Doppler signal may be difficult in the noisy and hectic circumstances of a trauma resuscitation, the finding of a normal ABPI is almost never associated with significant vascular injury (Box 1). If there are positive clinical findings and findings from handheld Doppler assessment have indicated the likelihood of vascular injury, further vascular investigations should only be ordered if there is doubt about which segment of vessel is injured, such as fragmentation injuries or multiple fractures along the axial course of a vessel, or to investigate other associated injuries such as the potential breach of a cavity from multiple fragmentation wounds.

Technique:

- Apply manual sphygmomanometer cuff around lower calf
- Locate posterior tibial (PT) vessel (halfway between prominence of medial malleolus and tip of heel. If PT not found, document and use dorsalis pedis (DP) instead (midpoint of dorsal surface of ankle, halfway between malleoli).
- Place tip of probe against vessel position, angling probe 60° incident to flow
- Confirm Doppler signal
- Inflate cuff until signal lost
- Release cuff and observe pressure upon which signal regained
- Repeat for other limb
- Repeat for both arms

Ankle Brachial Pressure Index (ABPI):

Systolic pressure (leg)
Systolic pressure (ipsilateral arm)

Markers of vascular injury:

ABPI < 0.9
Pressure differential between lower extremities of > 20mmHg

Box 1 The use of Handheld Doppler in lower extremity trauma

Bi-planar radiographs of injured extremities are helpful in assessing the mangled extremity, although they may be deferred if the urgency of the situation warrants immediate vascular control or revascularization – image intensification in theatre often suffices to allow temporizing skeletal fixation.

A chest x-ray allows confirmation of associated pneumothorax or haemothorax whilst abdominal and pelvic radiographs allows tracking of metallic fragments and calculation of trajectory aided by the siting of radio opaque wound markers prior to plain radiography. Focused abdominal sonography for trauma (FAST) is useful in blunt trauma (and to a lesser degree in penetrating trauma) in helping to triage the body cavities but will not delineate the retroperitoneal structures. The contemporary investigation of choice is contrast-enhanced multidetector CT (MDCT) angiography, which has largely replaced the historical gold standard of contrast angiography. This is particularly useful in patients exposed to a blast mechanism of injury where multiple fragmentation injuries and cavity violations are likely. “Multislice” or “Multidetector” CT scanners, using a two-dimensional array of detector elements acquiring multiple slices simultaneously, greatly increases the speed of image acquisition. High resolution CT angiography (CTA) can reliably delineate the large and medium sized vessels within the thorax, extremity or neck with sufficient

sensitivity to permit accurate delineation of injury track, to rule out vessel wall breach, active haemorrhage or occlusion or thrombosis. Reconstructions in any plane can be reconstructed from MDCT and these have further improved the detection of haemorrhage, although the time taken to process these images may limit their diagnostic utility. Subtle intimal flaps may, however be missed. Furthermore, the CTA, whilst defining vascular injury well, is less good at detecting solid organ parenchymal injury. Consequently, CT image acquisition is often performed during the portal venous phase of contrast enhancement to give the best compromise between arterial and solid organ diagnostic information. Despite the speed of image acquisition, transport to and from the CT scanner can often take longer than anticipated. It is a frequently stated but nonetheless valid truism that unstable patients should not be placed in the CT scanner, particularly when the purpose of the scan is to triage the body cavities for haemorrhage. All patients requiring CT should be accompanied by the full trauma team and associated resuscitation equipment; decompensation should be anticipated and the scan halted with diversion to the operating theatre if this happens.

Formal antegrade contrast angiography is rarely of utility in patients with junctional trauma. The wound is, by definition, at a limb root and opportunity to access the proximal vasculature from simple upstream puncture limited. Remote vascular catheterization, guidewire advancement and selection of a proximal arterial segment is not currently practical in a deployed environment and probably not necessary if CT imaging is available. Duplex doppler ultrasound is very sensitive (98%) and specific in the diagnosis of vascular injury in the hands of accredited personnel but has limited utility in the diagnosis of acute vascular trauma principal. Duplex services are not currently deployed at R3 level. The pitfalls in the diagnosis of extremity vascular trauma are given in Table 4.

Pitfall	Comment
The assumption of no vascular injury as there are "pulses present"	Pulses often present below level of injury if good collaterals present
The assumption of no vascular injury as there is a "good Doppler signal"	The phasicity of handheld Doppler is a poor marker of proximal vascular injury due to collateralisation
Taking down dressings or release of tourniquet in the ED despite patient instability or a history of profuse bleeding	This risks re-bleeding in uncontrolled circumstances and delays definitive surgical haemorrhage control
An assumption that lack of distal blood flow is due to "vessel spasm" rather than injury	"Vessel Spasm" is a diagnosis of exclusion
Failure to institute neuro-vascular observations in patients being managed conservatively	Failure to appreciate evolutionary nature of vascular injury (dissection → flap → occlusion → thrombosis)

Table 4. Pitfalls in diagnosis of extremity vascular injury

The Haemodynamically Unstable Patient

These patients require minimal investigation. Until proven otherwise, the cause of the instability is the junctional wound, where the haemorrhage is either revealed or concealed into the adjacent body cavity. Firstly apply direct pressure over the bleeding wound (Box 2). In thoracic outlet trauma, if pressure is ineffective then consider the use of a Foley catheter for tamponade. The catheter is inserted down deep, narrow tracks, the balloon inflated with saline and a haemostat used to occlude the drainage channel. This may reduce external egress of blood – but may not reduce internal haemorrhage if the track communicates with an adjacent body cavity. This technique has been most often been described in penetrating injuries to the root of the neck [11] but can be effective elsewhere (Figure 1). Following insertion, inflation and traction, a second balloon may need to be inserted above the first to stop the bleeding.



Figure 1. Foley catheter (circled) used to tamponade femoral vessel bleeding

Obtaining proper control of compressible haemorrhage in the resuscitation suite, particularly with brisk bleeding, requires a coordinated sequence of manoeuvres (Box 2). The temptation to utilize haemostats in the ED environment and in the absence of proper lighting, suction and trained assistance should be avoided as this risks further iatrogenic vessel damage. In the unstable patient there must be a swift physical examination concurrent with minimal plain radiography of adjacent torso, or if there is significant active bleeding, radiography should be omitted. This is followed by rapid transport to the operating theatre, definitive airway control and large bore venous access, accompanied by mobilization of a massive transfusion protocol. Institution of damage control resuscitation procedures do not compromise the patency of subsequent vascular repairs [12]. If the handover from pre-hospital medical staff suggests exsanguinating haemorrhage then consideration should be given to by-passing the ED completely in favour of direct transfer to theatre ("Right Turn Resus").

- Ensure personal protective equipment is adequate
- Reassure patient and explain what needs to be done, as it is being done
- Rapidly remove any ineffective dressings
- Application of robust wound compression by the surgeon
 - o Force vector oriented to compress wound against the underlying axial skeleton
 - o Small wounds can be managed with a single gauze swab and digital pressure
 - o Larger cavities can be managed with internal gauze

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- packing (Kurlex) and palmar pressure
- o This is always painful to the patient – give IV opiate analgesia concurrently with any wound manipulation
- o Frequent surgical paraesthesia (if done correctly) – replace with assistant’s hand, oriented correctly, as necessary
- o Avoid application of haemostats to visible vessels
- o Transfer to theatre as soon as possible
- In theatre: surgeon replaces digital compression of wound with “sponge stick” held by assistant who is “prepped in” to operative field
- Proximal and distal vascular control obtained prior to release of “sponge-stick” control

Box 2. Immediate management of junctional injury in the haemodynamically unstable patient

Pre-surgical planning

The pre-operative surgical checklist prior to vascular repair is a generic one regardless of the vessel involved.

Position

The patient is positioned in a cruciform position on an x-ray compatible table and the injured limb/body part plus adjacent junctional area and cavity are prepared as is the uninjured groin and thigh for vein harvesting if possible.

Equipment and personnel

Primarily this is the Vascular set, including appropriate prosthetic grafts if required and the thoracotomy set or laparotomy set as indicated to enter the relevant body cavity if required. In addition there needs to be a range of sizes of Fogarty catheters and heparinised saline. The procedures are best performed using magnification loupes. In addition to the vascular surgeon, both orthopaedic and plastic surgeons should be available.

Philosophy

Successful surgery requires concurrent activity and surgical attack of multiple injury complexes whilst almost continuously updating the anaesthesia and scrub staff as to changes in course and anticipated events. The importance of calm and effective communication between anaesthetist and surgeon can not be overstated. It is vital for the anaesthetist to be regularly updated by the surgeon as to the current scheme of attack, the status of vascular control, and on-going blood losses. If the patient’s condition demands then surgical dissection should stop whilst direct occlusive pressure is maintained and the anaesthetist “catches-up” by administering blood products as required, prior to continuing with the procedure.

Principles of surgery

These involve 2 key decisions. The first is how to achieve proximal control of the likely injured vessel and whether this is from within the adjacent cavity or without? Laparotomy will allow control of the iliac vessels after dissection of the overlying peritoneal tissues and may require medial visceral rotation to expose common iliac arteries above haematoma. In the chest access is via median sternotomy to achieve control of the arch vessels (Figure 2). Control outwith the adjacent cavity can be achieved by an inverse hockey stick groin incision with extension superior to the anterior superior iliac spine allowing extraperitoneal access to the external iliac vessels or for the upper limb supra/infraclavicular incision and

control of axillary-subclavian axis. Whichever incision is used, it must allow for axial extension, to obtain proximal and distal control of the injured vessel with vessel slings, prior to exploration of the haematoma and confirmation of the nature of vessel injury [14].

Systemic heparin is not given due to the risk of bleeding in a patient who is often coagulopathic and has multiple other injuries. If Quikclot® has been used, the wound should be visually inspected for inactivated Quikclot® granules, which are best removed using forceps or dry gauze. Activated Quikclot® can be removed using a Volkman’s spoon, or mopped away using saline gauze, combined with copious irrigation, to reveal the damaged vessel. Chitosan dressings can be peeled off the wound *in-toto*. Thereafter, the vessel is debrided back to healthy margins; the vessel segment may be damaged secondary to the exothermic reaction if Quikclot® has been deployed and debridement may be extensive.

The vessel is carefully swept both proximally and distally with a Fogarty catheter - a size 4 serves most above elbow or knee injuries. Inflow/backflow is confirmed sequentially prior to flushing the downstream and upstream segments with heparinised saline (500iu of heparin per 500mls of saline). The second key decision is to either repair the injury definitively or to resort to a damage control manoeuvre; this requires clear communication between surgeon and anaesthetist as to the current and likely physiological state of the patient

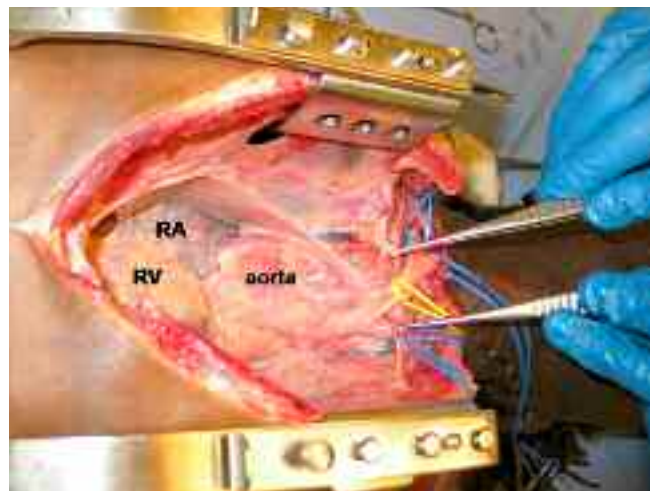


Figure 2. Median sternotomy to achieve access and control if the aortic arch vessels. The head is to the right of the image.

Shunting

Whilst commercial products such as the Javid, Brenner or Sundt shunts are purpose designed for this purpose, appropriately sized and sterile intravenous tubing, nasogastric tubes or feeding tubes are just as effective. The shunt is held in place with clamps or ligatures, umbilical tape or Ramel tourniquets. A check of inflow and backflow, and a Fogarty catheter sweep and flush with heparinised saline must be accomplished prior to shunt deployment (Box 3). Whilst the shunt is *in-situ*, saphenous vein can be harvested, the graft fashioned, the anastomoses constructed, any venous injury repaired and fractures stabilized. Patients with shunts *in-situ* must have their distal perfusion monitored closely e.g. by frequent clinical examination or continuous Doppler flow measurement proximally and distally to the shunt. Shunt patency has been associated with limb salvage in vessels above the knee and elbow, but not in distal vessels. Shunts are equally applicable in venous trauma and particularly advisable in combined venous/arterial injury. Distal, downstream injury should be ruled out before embarking upon revascularisation, using on-table angiography if necessary.

Technique
<ul style="list-style-type: none"> Ligation of juxta-injury tributaries/collaterals to prevent backbleeding Choose tube of appropriate diameter, cut to length and apply clip to mid portion Insert proximal end first into upstream artery slung with 'O' silk and tighten/snug Bleed through by releasing clamp Reapply clamp and insert distal end into downstream artery slung with 'O' silk and tighten Remove clamp and perfuse limb after forewarning the anaesthetist
Pitfalls
<ul style="list-style-type: none"> Too much shunt outside vessel (looping) – shunt displacement if loop “caught” Too much shunt length inside vessel – shunt ostia opposed against vessel side wall with occlusion Damage to vessel luminal surface during shunt placement due to rough handling Failure to control branches back bleeding in to damaged vessel segment between silk snugs

Box 3. Technical tips for the use of vascular shunts.

Ligation

Ligation of bleeding vessels without attempting to reconstruct them is a valid damage control manoeuvre in certain circumstances; the axillary or subclavian arteries can be ligated with little chance of limb loss due to collateralisation.

Amputation

Primary amputation is a legitimate damage control option for vascular injury when the limb is frankly unsalvageable or when the patient would not withstand an attempt at salvage in a potentially salvageable limb. The latter circumstance is heralded by the phenomena of ongoing haemodynamic instability, traumatic coagulopathy, acidosis, and hypothermia. The decision to amputate should be made by two consultants, preferably from different specialties but the decision should not be deferred *in-extremis*. Common techniques for definitive repair, and their indications, are listed in Table 5. Monofilament, double ended prolene is the default suture for vascular repair: 4-0 for iliac/subclavian, 5-0 for femoral/axillary arteries.

The restoration of perfusion to an extremity should be forewarned to the anaesthetist in order to allow mitigation of the effects of wash-through of ischaemic tissues. Following repair, the vessel and anastomosis must be covered by viable soft tissue to prevent break down, exsanguination or fistulation - exposed femoral vessels can be covered by dividing sartorius at its iliac insertion and rotating it across to cover the repair; omentum can be mobilised and interposed between bowel and vessels after intra-abdominal repairs. Fasciotomies should be performed as a routine manoeuvre given these injury patterns and performed prior to any arterial repair if ischaemia is of a prolonged duration. If an adjacent cavity has been opened due to missile track breaching pleura or peritoneum, contamination needs to be controlled once haemostasis is achieved, with rapid isolation of perforated viscera; there should be no attempt to restore anatomical congruity, and deferral of definitive cavity closure to second stage relook procedures.

Technique	Comments
Primary closure	<ul style="list-style-type: none"> Most appropriate with simple transverse lacerations with minimal tissue loss Continuous or interrupted sutures Sutures passed from out to in on upstream edge of laceration, inner surface to vessel exterior on downstream edge. Risks compromising luminal diameter and vessel thrombosis if axial laceration closed primarily
Vein-patch angioplasty	<ul style="list-style-type: none"> Useful for complex vessel wall defects where vessel has not been transected Excess tissue loss (>50% circumference) best served with resection/anastomosis Requires harvesting of vein patch (long saphenous vein, external jugular) Continuous sutures, completing furthest side of patch first Common pitfall is narrowing of vessel at apices of patch Avoid by “clock-facing” sutures at patch apices
Resection and primary anastomosis	<ul style="list-style-type: none"> For cleanly transected vessels with minimal loss of vessel length after debridement Requires mobilisation of vessel ends and apposition without excess tension Avoid sacrificing side branches during mobilisation Anastomose by triangulation/stay suture placement Continuous sutures, completing “back wall” first Spatulation of vessel ends reduces risk of luminal narrowing at suture line
Interposition grafting	<ul style="list-style-type: none"> Used when a primary repair will cause tension on the vessel. Autologous vein grafts: <ul style="list-style-type: none"> Long saphenous vein or external jugular vein are readily usable. Remember to reverse the vein graft. Internal jugular vein can be harvested from the neck assuming the contralateral side is patent “Panel” grafts of composite vein can be constructed to create large diameter conduits if required (but are time consuming) Prosthetic grafts <ul style="list-style-type: none"> quick to utilise; variety of calibres suited to large vessel repair Should be used in military trauma only as short term damage control option due to higher risk of infective complications
Extra-anatomical bypass	<ul style="list-style-type: none"> Infrequently indicated Used for injuries with gross soft tissue loss, contamination or loss of axial vascular length Must be routed away from zone of injury though viable tissue bed to minimise infective complications

Table 5. Techniques for vascular repair

Specific Junctional Vascular Injuries

Upper limb

In the exsanguinating patient there should be no hesitation in defaulting to clamshell thoracotomy if the injury pattern does not clearly direct the operator to one specific pleural cavity. This incision affords sufficient exposure to the great vessels and the arch of the aorta but requires good traction on the upper rib cage. Median sternotomy gives good exposure to the heart and the great vessels and can be extended across either clavicular area or into the neck to allow for exposure of the vessels of the thoracic outlet. Injury to the subclavian and/or axillary vessels is often associated with damage to elements of the brachial plexus. Vascular repair takes precedence over neurological repair, which may be safely deferred in the critically ill patient.

Subclavian vessels

Subclavian artery haemorrhage can result in both profound external and internal (pleural cavity) haemorrhage. Right sided injuries are amenable to control via median sternotomy; dissection to the left subclavian takes longer as the vessel originates from the posterior aspect of the aortic arch [12]. High (3rd space) left anterolateral thoracotomy is an alternative approach to the vessel, located behind parietal pleura of the upper, medial apex of the left pleural cavity. Limb loss after ligation is rare due to collaterals, although claudication and steal syndrome may result if ligation is proximal to the take-off of the vertebral artery.

Injuries to the distal subclavian artery may be controlled with supraclavicular and infraclavicular counter incisions, dissecting the second part of the subclavian and axillary artery respectively. The supraclavicular approach involves division of the clavicular head of the sternocleidomastoid to reveal the internal jugular vein which is retracted medially and the scalene fat pad which is swept laterally, to expose the anterior scalene muscle. The overlying phrenic nerve is protected and the muscle divided to reveal the second part of the artery. The clavicle can be divided to facilitate better exposure, but excision is unnecessary.

Axillary vessels

The axillary vessels can be accessed via an infraclavicular incision made from beneath the mid-clavicle to the deltopectoral groove; Pectoralis major is split in the line of its fibres and the pectoralis minor divided to expose the clavipectoral fascia which is incised to reveal the neurovascular bundle.

Lower limb

Iliac vessels

Penetrating iliac artery injury is controlled initially with digital pressure whilst proximal control is gained at the level of the aortic bifurcation via a right medial visceral rotation. Clamps can be then “walked” on to the vessel adjacent to the injury prior to repair. If necessary, the common iliac artery may be ligated and a femoro-femoral crossover performed to maintain distal limb viability. When ligation alone is undertaken an amputation rate of 50% can be expected. There are usually no consequences to ligation of an internal iliac artery due to pelvic cross-flow.

Division of the overlying common iliac artery may be required to allow access to the injured common iliac vein (with follow-on repair of artery and interposition of omentum between artery and vein). Ligation of iliac veins is accompanied by major limb swelling and should be mitigated by limb elevation and a default to fasciotomy in the shocked patient. Alternatively the extra-

peritoneal approach to the external iliac artery may be utilised (Figure 3), extending the axial vertical incision laterally toward the anterior superior iliac spine – the inverted hockey stick approach.

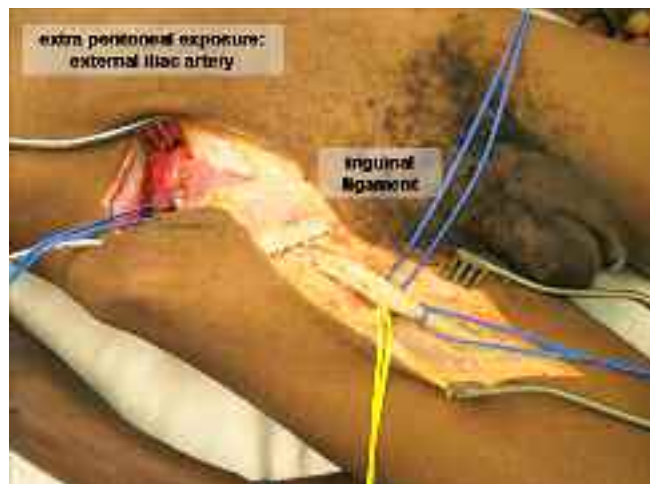


Figure 3. Extension of a vertical groin incision to gain extraperitoneal control of the external iliac vessels

Femoral Vessels

These are exposed via a mid-inguinal vertical incision halfway between anterior superior iliac spine and pubic symphysis. The inguinal ligament may be divided to gain control proximal to haematoma. Simple injuries should be repaired with vein patch or suture repair; complex injuries involving a long length of vessel should be repaired with interposition grafting. Repair of the profunda femoris artery takes precedence over superficial femoral artery in combined arterial injuries to SFA and PFA. Fasciotomies should be performed prior to either repair of the injured section or exclusion and vascular by-pass.

Conclusion

Even for the specialist vascular surgeon, the management of battlefield vascular trauma can be challenging. These difficulties are compounded in junctional trauma. The key determinants of success remain early haemorrhage control and early default to damage control techniques where appropriate. CTA is an exciting diagnostic development but personal physical examination and attendance to the prime surgical directives of vascular control prior to vessel exposure – with rapid access of proximal vasculature in the adjacent cavity if required – are the foundations for good outcome. When faced with severe extremity injury the non-specialist must always secure the patient's physiology before attempting limb salvage.

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