Chapter 16
Thoracic Vascular Injuries: Operative Management in "Enemy" Territory

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Deployment Experience:

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BLUF Box (Bottom Line Up Front)

1. All penetrating thoracic wounds should be assumed to have hit the heart or a big blood vessel until proven otherwise.
2. If you have hard signs of a vascular injury, then the place you need to be is the operating room, not the CT scanner.
3. The battle is won by choosing the correct incision and knowing where to get proximal control. The rest is easy.
4. Don't go diving into hematomas until you are prepared and your anesthesia team is ready for massive blood loss.
5. Ligate and divide the innominate vein to access the proximal great vessels.
6. Know what you can safely ligate. Almost all veins and the subclavian arteries can be safely ligated with little sequelae – exceptions in the chest are the IVC and SVC.
7. Open vascular surgery techniques are still required in combat and disaster surgery.
8. Ensure you have adequate suture and vascular grafts BEFORE you need them.
9. If you have endovascular capability, use it! It can provide easy vascular control for your operative repair or help you avoid a difficult and bloody operation altogether.

Whenever you encounter massive bleeding, the first thing to remember is that it is not your blood

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Introduction

One of the features that distinguish a great surgeon from a good surgeon is the ability to remain calm under pressure, strongly direct a team of providers and stay focused on the mission at hand. Thoracic vascular injuries can make for good theater and subsequent tall tales when there is a successful outcome, but nowhere is it more critical to be in the "great surgeon" mindset than with the management of these unforgiving injuries. "Control" is the operative term. Despite the divergence of Vascular and General Surgery in the civilian sector, every combat Trauma Surgeon needs to have the basic vascular surgery knowledge and skillset to manage these injuries. Consultation with a Vascular Surgeon or transfer may not be an option.

Rule number one. When preparing to open a chest, whether in the emergency department or operating room, check your own pulse first. Slow your respirations and heart rate and get to work. Your movements must be methodical and controlled. There can be no gross or uncontrolled maneuvers and you must keep other excitable assistants or "ham-handed" surgeons out of the way. Speak directly and with confidence to your team members. You will get one shot at saving this life. Move the gawkers out of the way and finish the operation. You are not a hero just because you can open a chest. It's what you do AFTER you open the chest that counts.

Wounding Patterns and Physiology on the Modern Battlefield

Military surgeons are routinely trained in non-military environments and as such, may be unprepared for life on the battlefield. Howard Champion in 2003 described six unique considerations with regard to acute resuscitation in a combat setting: (1) the high energy and lethality of wounding agents; (2) multiple causes of wounding; (3) preponderance of penetrating injury; (4) persistence of threat in tactical settings; (5) austere, resource-constrained environment; and (6) delayed access to definitive care.

The majority (~75%) of survivable chest wounds on the battlefield can be managed with simple tube thoracostomy. Greater than 90% of vascular injuries can be diagnosed based on the history and physical exam findings alone. Hard signs suggesting a vascular injury include: pulsatile bleeding, expanding hematoma, palpable thrill, audible bruit, and evidence of ischemia as indicated by pulselessness, pain, pallor, paresthesia, and paralysis in an affected upper or lower extremity, or stroke when dealing with injury to the great vessels. Soft signs of vascular injury include a history of moderate hemorrhage at the scene of injury, injury in proximity to a named vessel, decreased but present pulse, non-expanding hematoma, and associated peripheral neurologic deficit. Hard signs do not require a lot of workup – in general they belong in the operating room ASAP!

Classic wounding patterns that should cause one to suspect major thoracic vascular trauma include the presence of hemorrhagic shock, jugular venous distension suggesting SVC syndrome or cardiac tamponade, an expanding hematoma at the base of the neck or a discrepancy in pulse exam between each upper extremity or between the upper and lower extremities. The trajectory of the penetrating wound should also lend clues to the nature of the injury. Bullets can take somewhat unpredictable courses or ricochet off of bony structures, but they can't defy the laws of physics. For single projectile wounds knowing the entrance and exit site greatly assists you in focusing your evaluation on the area at risk. For stable patients with no obvious indication for surgery, CT scan with IV contrast is an excellent tool for evaluating critical structures and also for reconstructing the trajectory of the missile or the location of multiple fragments. It is particularly useful for proven or suspected trans-mediastinal wounds.

Pre-operative Management

A classic primary survey should commence immediately in the Emergency Department (ED) simultaneously with attempts at resuscitation. In the presence of suspected massive thoracic vascular injury, venous access should be established if possible in the lower extremities or at least in the upper extremity that seems least likely to be involved with the injury.

If the casualty needs to be transferred to a higher echelon of care; for example from a Forward Surgical Team to a Combat Support Hospital, chest tubes should be placed prior to rotary wing transfer. These patients are essentially inaccessible during transport in a modern evacuation helicopter and placement of a chest tube en route can be extremely difficult. If there is concern for exsanguination from chest tube placement, the thoracotomy should have already been initiated and your decision to transfer was incorrect. The patient described won't survive transport and needs your expertise now.

If the patient rapidly decompensates in the ED with suspected thoracic vascular injury or if you witness cardio-vascular collapse, a resuscitative antero-lateral thoracotomy through the fourth or fifth interspace is required. Upon entering the chest, the location of the injury should be identified. Inspect the heart. If the pericardium is tense, you need to incise the pericardium sharply and longitudinally anterior to the phrenic nerve. Deliver the heart out of the pericardium and begin compressions against the sternum with the palm of your hand if needed. Be gentle!

If there is a lot of blood in the left chest and the patient's heart appears empty, incise the parietal pleura over the aorta to be able to get a clamp fully across the aorta to the spine, and clamp with an atraumatic clamp. Remember that you are now on a clock so mark the time in your head. You have just less than 30 min to release that clamp and the more time that passes by, the more risk this patient has of dying from uncontrolled coagulopathy, liver failure, or reperfusion injury. If you get the patient back – continue your resuscitation but get the patient to a place where you can conduct a formal operation.

Patient Preparation

We have found the orientation of the operating room in a Forward Surgical Team to be best with OR beds oriented in a head to head fashion. This allows a central station for anesthesia providers who can then care for and administer blood products to each patient simultaneously. This decreases the movement around the OR beds by multiple personnel thus potentially lowering the risk of contamination of sterile fields (Fig. 16.1).

Patients with suspected thoracic vascular injuries should be prepared for operation with standard surgical approaches in mind and with additional preparations allowing for access of more proximal vascular control. In addition, preparation should be made for recovery of an adequate vein for a reconstructive conduit from an uninvolved extremity. Hence, patients with suspected thoracic vascular injuries should have the entire chest and neck prepped into the field to allow for rapid performance of median sternotomy or thoracotomy, as well as preparation of one or both of the lower extremities to allow for recovery of the greater saphenous vein for conduit. In the chest, the first goal is to stop the bleeding and then perform a definitive repair. If suture won't fix the problem, a large prosthetic graft or bovine pericardial patch will. It is rare to use saphenous vein for reconstruction in the chest with the exception of

Fig. 16.1 Two-bed set up in a Forward Surgical Team operating room. Note that the beds are arranged head to head, which minimizes crowding with two teams working at once, and allows a single anesthesia provider access to the head and face of both patients

elective aorto-coronary bypass. We prefer to stock 18×9 mm collagen-coated knitted and bifurcated Dacron grafts. The tubes are long enough to repair any aortic injury and the limbs come in handy and are a perfect size for any great vessel reconstruction that is required. When you arrive at your facility, immediately inspect your current stock and supply level of vascular grafts. The time to discover what you have available (if anything) is not in the middle of one of these cases.

What Incision Do I Make?

This is one of those classic oral board type questions that actually has immense importance in these scenarios. The choice of incision for thoracic vascular trauma has been covered elsewhere in this book but will be briefly covered here as well. Simply put, in an unstable patient with suspicion for an injury to the heart or great vessels, a left anterior thoracotomy affords the most rapid approach at gaining access to the left heart, left subclavian and descending thoracic aorta. This incision can be easily and quickly extended into a clamshell to gain access to the right heart and SVC, IVC, and azygous vein. Remember to ligate the right and left internal mammary vascular pedicles when coming across the sternum. If time permits and the injury pattern is consistent, a median sternotomy affords full access to the heart, ascending aorta and great vessels (see Table 16.1).

Principles of Repair for Specific Injuries

In general, incisions of election should be made as a preference over incisions of opportunity. This is not always possible as the wound may provide adequate exposure for definitive control of the vascular injury. Proximal control is a basic tenant of vascular surgery. For those surgeons not accustomed to conducting a vascular surgical procedure, remote proximal control offers the best opportunity for success in the

Table 16.1 Ideal incisions for various thoracic vascular injuries

Injured vascular structure	Exposure
Unknown	Left anterolateral thoracotomy +/− clamshell
Ascending aorta	Median sternotomy
Transverse aortic arch	Median sternotomy
Innominate artery	Median sternotomy
Right subclavian artery	Median sternotomy or right supraclavicular if distal
Proximal left common carotid artery	Median sternotomy
Left subclavian artery	Left anterolateral thoracotomy or left supraclavicular if distal
Descending thoracic aorta	Left posterolateral thoracotomy
Superior vena cava	Median sternotomy
Suprahepatic inferior vena cava	Right thoracoabdominal with splitting of diaphragm

combat casualty. Don't hesitate to extend incisions across costal margins or widen the exposure to get control. Similarly, don't ever let something like the clavicle stand between you and adequate exposure of the subclavian vessels or carotid/vertebral take-off points. Resection of a portion of the clavicle can be done rapidly and provides excellent exposure of the subclavian artery and vein to obtain control and perform repair or bypass.

Upon exposure, the first goal is to get control of the bleeding. This often requires just simple digital control. Unfortunately, on the battlefield, holes in arteries can be bigger than one's digit so this is not always possible. If the injury is easily controlled with the tip of an index finger this is where a calm approach will save the day. First, *slow down*. If you now have control of the injury, communicate with your anesthesia colleagues and allow them to catch up. If the patient is hypertensive, ask them to lower his blood pressure to below 90 systolic. *Wait for your pitch*. Once the conditions are right, you can start to repair this large vessel by sewing under the tip of you finger with a 3-0 prolene and slowing advancing your finger backward over the injury. Take large bites and use pledgets if needed on the first stitch. Before you know it, the injury will be repaired. Remember that shunting or even ligation (with or without later reconstruction) is an option for most thoracic vessels.

Ascending aorta. These injuries are usually fatal at the scene but if small, can be survivable. The previous paragraph describes such an approach to this injury. Remember that the ratio of elastin to collagen in the proximal aorta is much higher. This means that the aorta in this region is more expansile but can tear very easily. Remember to use pledgets and take large bites. A DeBakey Bahnson clamp can be useful to side-bite the ascending aorta in order to get control while maintaining forward flow.

Proximal great vessels. When approaching these vessels through a median sternotomy, it is extremely important to get proximal control first. This means NOT diving into a hematoma in the superior mediastinum but opening the pericardium and marching up the ascending aorta. It is important to divide the left innominate vein between ligatures to expose this region (Fig. 16.2). As stated previously, it is o.k. to clamp the base of the innominate for repair of an innominate artery injury. Likewise, it is o.k. to clamp the base of a left common carotid injury. It is deadly to clamp both simultaneously. For elective situations, clamping both of these vessels would require the use of deep, hypothermic circulatory arrest and this won't be available to you on the frontline. You will have to do your best to individually repair these injuries. An alternative is to stage the repair by first sewing a 9-mm Dacron conduit to the ascending aorta and bypassing individually to the innominate artery, then going after the left common carotid injury with either suture repair or bypass depending on the circumstances.

Proximal left subclavian injuries are among the most challenging to handle due to their location. The ideal exposure for these injuries is a left posterolateral thoracotomy which is not a standard exploratory incision for trauma; you will usually be working from a sternotomy or anterior thoracotomy. Don't waste time and blood loss struggling to expose and repair the injury from these incision. Just reach your hand (or a sponge stick) up to the apex and compress the area of hemorrhage – this will stop the bleeding. You can now decide on how best to approach the injury. Adding an infraclavicular

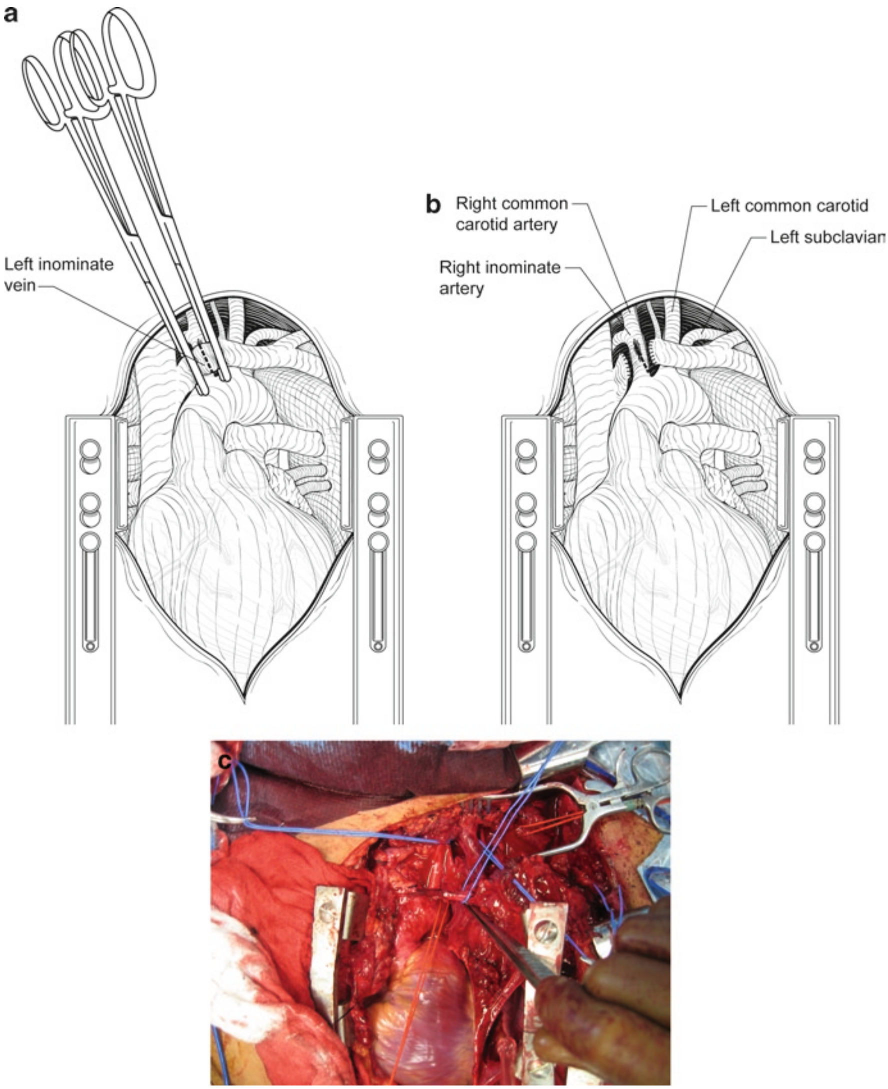

Fig. 16.2 (**a**) The left innominate vein overlying the proximal great vessels. (**b**) Great vessels exposed by ligation of the left innominate vein. The extension of the superiorly to the right neck can also improve exposure of the proximal innominate, right common carotid, and right subclavian vessels. (**c**) Intraoperative photo shows exposure of heart and great vessels, with forceps pointing to left innominate vein prior to division

incision to your median sternotomy with dislocation of the sterno-clavicular joint will provide adequate exposure. If you are in anterior thoracotomy position, you can hold pressure while repositioning the patient to lateral decubitus. If the patient is doing poorly or you have other injuries to deal with, ligate the artery; this will usually be well tolerated and if needed can be repaired or bypassed later.

Descending thoracic aorta. These are the most fun to repair and usually require only a suture repair or patch angioplasty for fragment wounds. For larger penetrating wounds, blast wounds, or blunt aortic tears you will usually need to perform a formal interposition graft (18 mm Dacron) as shown in Fig. 16.3. Remember that you have limited time to clamp this vessel (<30 min of hepatic and mesenteric ischemia), and if your clamp time exceeds this, you should consider removing the clamp intermittently (while controlling the injury with a finger tip) in order to give the liver a "drink" of the good kind, blood. You will need to accept the moderate blood loss that will be associated with this maneuver. A left posterolateral thoracotomy is ideal, but you may often need to do it through an emergent anterolateral thoracotomy. Good exposure and retraction of the heart and lung anteromedially is critical. Although the injuring mechanisms in combat are most commonly from projectiles, you may see blunt aortic injuries from ground or helicopter vehicular crashes. These are no different than their civilian counterparts, with the exception that you will not have the immediate option of cardiopulmonary bypass. Remember that these are rarely emergent, and can initially be managed with strict heart rate

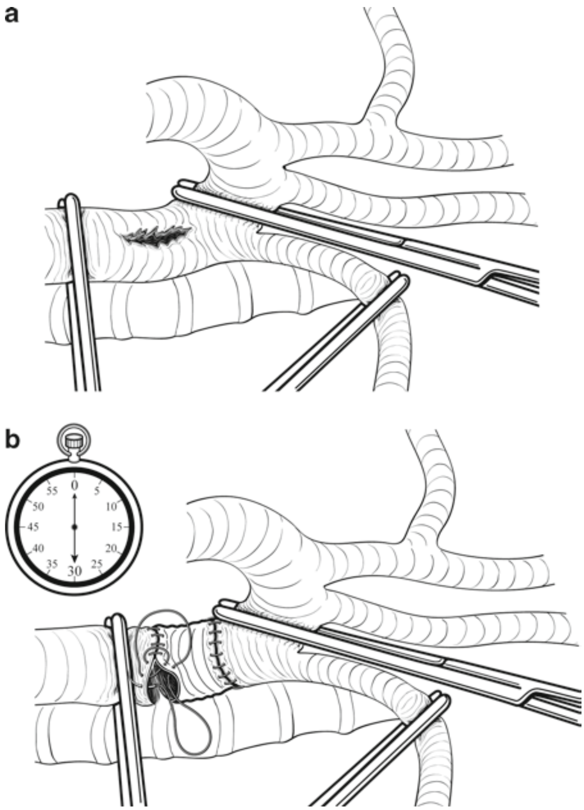

Fig. 16.3 Exposure and repair of a descending thoracic aortic injury with a prosthetic interposition graft

and blood pressure control. Approach them via a left posterolateral thoracotomy with single lung ventilation. The critical point is obtaining adequate proximal control, as the injury is typically just distal to (or involving) the takeoff of the left subclavian artery (Fig. 16.3). Gain control of the left subclavian artery before you attempt control of the proximal aorta, and be prepared to clamp the aorta proximal to the subclavian takeoff if needed.

SVC/IVC. These injuries are best approached through a median sternotomy and for more extensive injuries involving the supra-hepatic inferior vena cava, extending along the right costal margin and splitting the right hemidiaphragm. Supra-hepatic IVC injuries are incredibly lethal and even in the best of experienced hands carry a very high mortality rate. Careful control should be obtained, preferably with a side-biting vascular clamp to maintain blood flow to the right atrium. An alternative method of control is by placement of an atrio-caval shunt as described in Chap. 8. This is also usually facilitated by widely opening the pericardium and safely tracing them from the intra-pericardial portion at the junction with the right atrium, and then proceeding distally. Repair involves lateral venorrhaphy or patch angioplasty with 3-0 Prolene. You should try to avoid ligating either of these two veins at all costs due to the significant impact on venous pressure/edema and the decreased venous return to the heart.

Azygous vein. Although not thought of as a major vascular structure in the chest, injury to the azygous vein can be associated with a huge blood loss. The object of the game is to isolate and ligate this vessel. This often requires placement of sponge sticks proximal and distal to the injury through a right thoracotomy followed by ligation. Use a large prolene suture and drive the needle along the spine to encircle and ligate the vein.

Pulmonary arteries. My preferred method for control of these injuries is to place a large vascular clamp (DeBakey AG Aortic Clamp) across the pulmonary hilum until the injury can be identified and repaired (see Chap. 14). In the unstable patient with a complex injury to the pulmonary hilum, you are often better off performing a rapid stapled pneumonectomy.

Use of Heparin

We have initiated systemic heparinization (50–75 U/kg IV) in *stable* patients in whom vascular control of the injury has been quickly established, estimated pre-hospital blood loss is relatively low, and ongoing bleeding sources are minimal. Unstable patients with diffuse hemorrhage from bone fragments, torn muscle and additional injuries, and patients who are already hypothermic and coagulopathic, should not get systemic anticoagulation. Alternatively, local administration of heparinized saline solution directly into the injured vessel prior to repair may aid in preventing thrombotic complications. The decision to anti-coagulate is left to the discretion of the operating surgeon, who must be in close contact with the anesthesia providers in order to fully understand the patient's clinical status. In general, aortic injuries that can be repaired with a side-biting clamp or digital control don't require supplemental heparin due to the high flow in these vessels. If you find your repair is clotting and there is no technical defect, then you should proceed with systemic anticoagulation.

Shunts

In my opinion, shunts have a limited role in the management of thoracic vascular injuries. Temporary clamping of any of the great vessels individually is usually well tolerated due to collateral circulation. Clamping of both the innominate and left common carotid should be avoided at all costs due to the extreme risk of stroke. However, they may be extremely useful in the far-forward setting if you don't have the time, resources, and expertise to perform any type of vascular repair and maintaining forward flow is crucial.

If used appropriately, temporary intraluminal shunts allow for rapid restoration of blood flow to an ischemic limb or to the brain while other procedures to include wound debridement, external fixation of fractures or more life saving procedures such as trauma laparotomy or thoracotomy can be accomplished. Shunts may be easily and rapidly placed after proximal vascular control with either a pneumatic tourniquet or vascular clamp, and secured in place with Rummel tourniquets or simple silk ties to prevent dislodgement. After placement, patency should be confirmed with intra-operative Doppler of the shunt and distal flow. I recommend the specific use of Sundt shunts as their design minimizes risk of dislodgement when appropriately inserted. The Sundt shunt is lined with an inner coil to prevent kinking or collapse (Fig. 16.4). There is one small area within the shunt of discontinuous coils which should be used for clamping if needed. Clamping the shunt in any other location will crush the coil and occlude the shunt. In a pinch, any sterile hollow tube with adequate flow characteristics

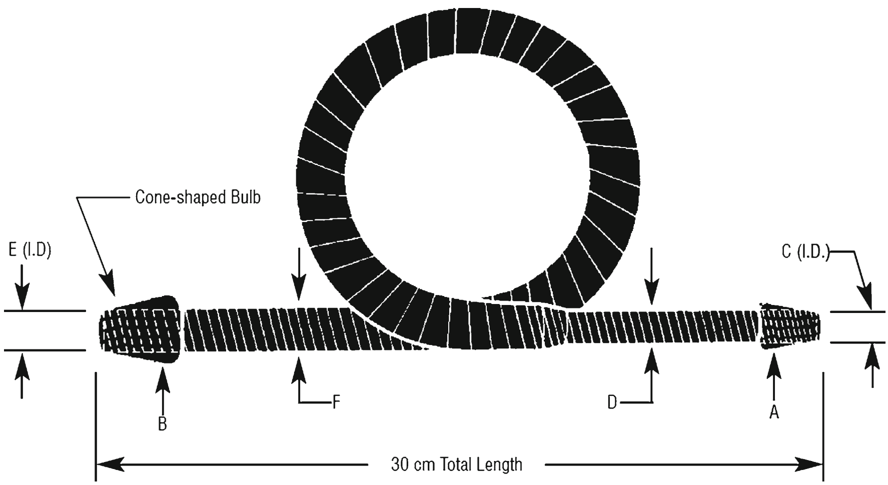

Fig. 16.4 The Sundt External Shunt (Integra Neurosciences™, Plainsboro, NJ) with inner coil reinforcement. The tapered ends make it easier to insert and secure in the vascular lumen

can be used as a shunt. For smaller vessels a nasogastric tube has frequently been used, and for larger vessels an appropriately sized chest tube may be utilized.

Surgical Technique

As with all vascular operations, there are several important elements for success. Key among these is careful handling of tissue, use of magnification loupes, adequate lighting and use of fine instruments with fine, mono-filament suture. These requirements are not always met on the battlefield and the operating surgeon can be faced with challenging circumstances beyond his/her control.

After exposure, injured vessels should be carefully debrided back to normal and healthy appearing tissue. Inflow and back bleeding should then be assessed. If there is no back bleeding, gentle thrombectomy with appropriate sized Fogarty embolectomy catheters should be performed. The use of a standard pulmonary artery catheter may be useful in this scenario if no standard catheters are available. Minimal manipulation of intima is imperative to prevent vessel thrombosis in the early post-operative setting. After adequate debridement, the vessels should be flushed with a heparinized saline solution both proximally and distally. A tension-free (but non-redundant) repair should then ensue. With combined injuries, arterial repair should precede venous repair except when venous repair requires little effort. The decision to repair venous injuries as apposed to ligation depends of the stability of the patient and demands to treat other injuries. Ligation of venous injuries is usually preferred in the chest unless dealing with the IVC or SVC.

Conduits

Key to the success of vascular repair in the combat setting is appropriate use of available conduit for reconstruction. It is widely held that the best alternative conduit for reconstruction is autologous saphenous vein. The saphenous vein is the workhorse for vascular surgeons and can be used in multiple locations but in the chest where the vascular structures are large, the utility of saphenous vein conduit diminishes. It is important to remember the concept of directional flow within veins and thus reverse or turn around the saphenous vein prior to using it as a conduit for revascularization. The saphenous vein may also be used as patch material and has been described to be re-fashioned in the form of panel or spiral grafts for re-construction of larger vessels. It is my opinion that spiral grafts and panel grafts should be avoided in the management of thoracic vascular injuries due to the excessive time required to create them. If used, the saphenous vein should always be recovered from an uninvolved lower extremity. Jugular veins are a suitable alternative for larger vessels, particularly if you are already in the neck.

Prosthetic conduits, when used to repair or replace blood vessels in the chest, should be made of Dacron and coated with collagen to aid in hemostasis. As stated before, the author uses 18×9 mm Dacron bifurcated grafts as the diameters of both the main body of the graft and the limbs can be used to replace anything in the chest.

Another useful patch material is either Bovine pericardium or the patients own pericardium. Don't hesitate to use prosthetic in the setting of esophageal injury with soilage. An infected graft can be dealt with later after saving the patient's life.

Closure of Incisions

A few comments should be made on closure of thoracotomy and sternotomy wounds after trauma. Remember to appropriately drain these wounds. These are large body cavities that can accumulate a lot of fluid and blood and impair ventilation and oxygenation not to mention cardiac contractility. For thoracotomy wounds, leave behind large (36 Fr) angled and straight chest tubes – two per hemithorax. For sternotomy wounds, don't hesitate to leave the chest open, especially if it has been a long operation and the patient has received a massive resuscitation. We typically use a plastic bovie holder wedged between the edges of the sternum followed by a sterile hand towel and iodine-impregnated adhesive drapes for the "damage control" sternotomy closure. All sternotomy wounds should be drained with 36 Fr straight mediastinal drains or Blake drains.

Endovascular Procedures

Although endovascular technology has arguably been the greatest advancement in vascular surgery in recent history, it has also resulted in a loss of basic vascular surgical skills among both staff and trainees. Remember that during the initial phases of any conflict, you may be operating with whatever instruments and equipments you can carry (Fig. 16.5). Chances are, you will not have access to a portable C-arm, power injector or the necessary equipment to perform endovascular procedures on the frontline. However, as the combat operations mature and consolidate your facility may become capable of performing advanced endovascular procedures. If you have access to this, consider yourself blessed. The endovascular revolution has dramatically changed the mortality for major thoracic vascular injuries. The ability to remotely place a clamp in the form of an occlusion balloon prior to resuscitation and repair is a huge advantage. Basic required equipment for endovascular surgery is listed at the bottom of Table 16.2. A few specific injuries deserve mention:

Blunt aortic injury (*BAI*). This injury is usually associated with rapid deceleration and blunt force trauma. Please remember that if the patient has hypotension or profound anemia, it is almost never associated with the BAI and one should seek out other causes for these phenomena. If BAI cuts loose into the left hemi-thorax, call the morgue, not the OR. These injuries can often be managed semi-electively with aortic stent grafting. Endovascular expertise is a requisite. The left subclavian artery can be covered with impunity to achieve adequate proximal seal. An example of pre and post-op images of BAI are pictured in Fig. 16.6.

Axillo-subclavian injuries. The management of these injuries in the past was associated with massive and lengthy operations. Today, in modern civilian trauma

Fig. 16.5 The 173rd Airborne Brigade, including the 250th Forward Surgical Team, stages on the tarmac for their initial combat jump into northern Iraq

Table 16.2 Required equipment for the management of vascular injuries in the field

Vascular surgical instruments	**All × 2 or more**
Gerald forceps 7 and 9 in.	Ryder needle drivers 5, 7 and 9 in.
Castro-Viejo needle drivers 7 in.	Deithrich Bulldog clamps 1.75 in. angled
Wiley Hypogastric clamps 7 in. × 6.5 cm	Satisnky-DeBakey clamps 9.75 in.
Profunda clamps 5.5 in.	Cooley pediatric vascular clamp 6.5 in.
Adson-Beckman retractor 12.5 in. hinged	Fogarty Embolectomy catheters 3 and 5 Fr
Jansen Mastoid retractor 4.5 in.	Potts-Smith scissors 7.5 × 45 degrees
DeBakey aortic clamp	DeBakey Bahnson aortic clamp
Supplies	
3-0 Prolene suture – 36 in. (90 cm) SH	6-0 Prolene suture – 30 in. (75 cm) RB-2
Umbilical tapes	Silastic vessel loops (small and large)
Rumel tourniquets	Sundt and Argyle shunts – 10, 12, 14 Fr
Teflon or Felt pledgets	19 g Butterfly needles
Three-way stopcock	30 cc Syringes
18 × 9 Bifurcated Dacron grafts	Ringed PTFE grafts – 6 and 8 mm
9 MHz Handheld Doppler	Plastic titest needle
Sternal retractor	Finochietto retractor
Lebsche knife	
Pharmacopia	
Heparin 1,000 U/ml, 10 ml vials	Papaverine 30 mg/ml, 10 ml vials
25% Mannitol 12.5 g/50 ml, 50 ml vials	Alteplase 2 mg vials
Ultravist contrast – 100 cc vial	Fibrin sealant (Flowseal)
Thrombin – 1,000 U/ml, 20 ml vial	Recombinant factor VII
Gelfoam	Heparin saline mix – 10 U/cc normal saline
Miscellaneous	
Headlight-Zipka	Magnification loupes

(continued)

Table 16.2 (continued)

Vascular surgical instruments	**All × 2 or more**
Endovascular supplies	
Access needle	Lunderquist DC wire – 300 cm (COOK)[a]
11 Fr Sheath	140 cm CODA Aortic Balloon (COOK)[a]
100 cm marking Pigtail catheter	Trilobed Snare
100 cm JB-1 5 Fr selective catheter	Viabahn[a] stent graft 7 mm and 8 mm × 5 cm
Bentson starter wire – 180 cm	Thoracic stent graft (Medtronic)[a]
Angled glidewire – 260 cm	22 mm × 11 cm Talent
Ultravist contrast	24 mm × 11 cm Talent

[a] COOK Incorporated (Bloomington, IN), Medtronic (Santa Rosa, CA), W.L. Gore (Flagstaff, AZ)

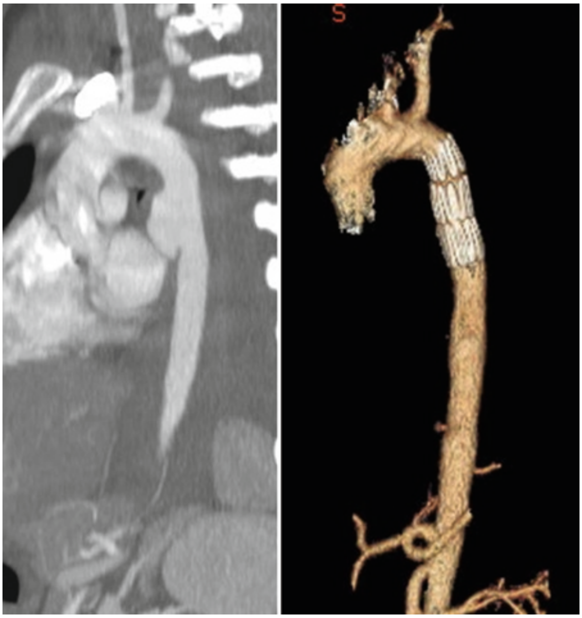

Fig. 16.6 CT scan reconstruction showing a typical blunt thoracic aortic injury with pseudoaneurysm formation (*left panel*) and the same vessel after placement of a thoracic endograft (*right panel*)

centers or even mature combat trauma facilities, these injuries can be managed in less than 30 min with an endovascular technique. Once identified, our approach is to expose the brachial artery at the antecubital crease on the side of the injury and place an 11 Fr sheath retrograde. Under fluoroscopic guidance, a wire is advanced across the injury and a catheter is advanced over the wire proximal to the injury. A contrast injection is performed and the extent of the injury identified. The injury can then easily be repaired with either a 7 or 8 mm covered self-expanding stent graft (Viabahn; W.L. Gore, Flagstaff, AZ). If the artery is completely transected, the wire will wander out into non-anatomic places. At that point, femoral access can be achieved and the ipsilateral subclavian vessel selected in the arch of the aorta. A tri-lobed snare can be advanced across the injury and the wire snared and pulled through the body creating a brachio-femoral wire. The stent-graft can now be easily advanced across this transection and repaired (Fig. 16.7).

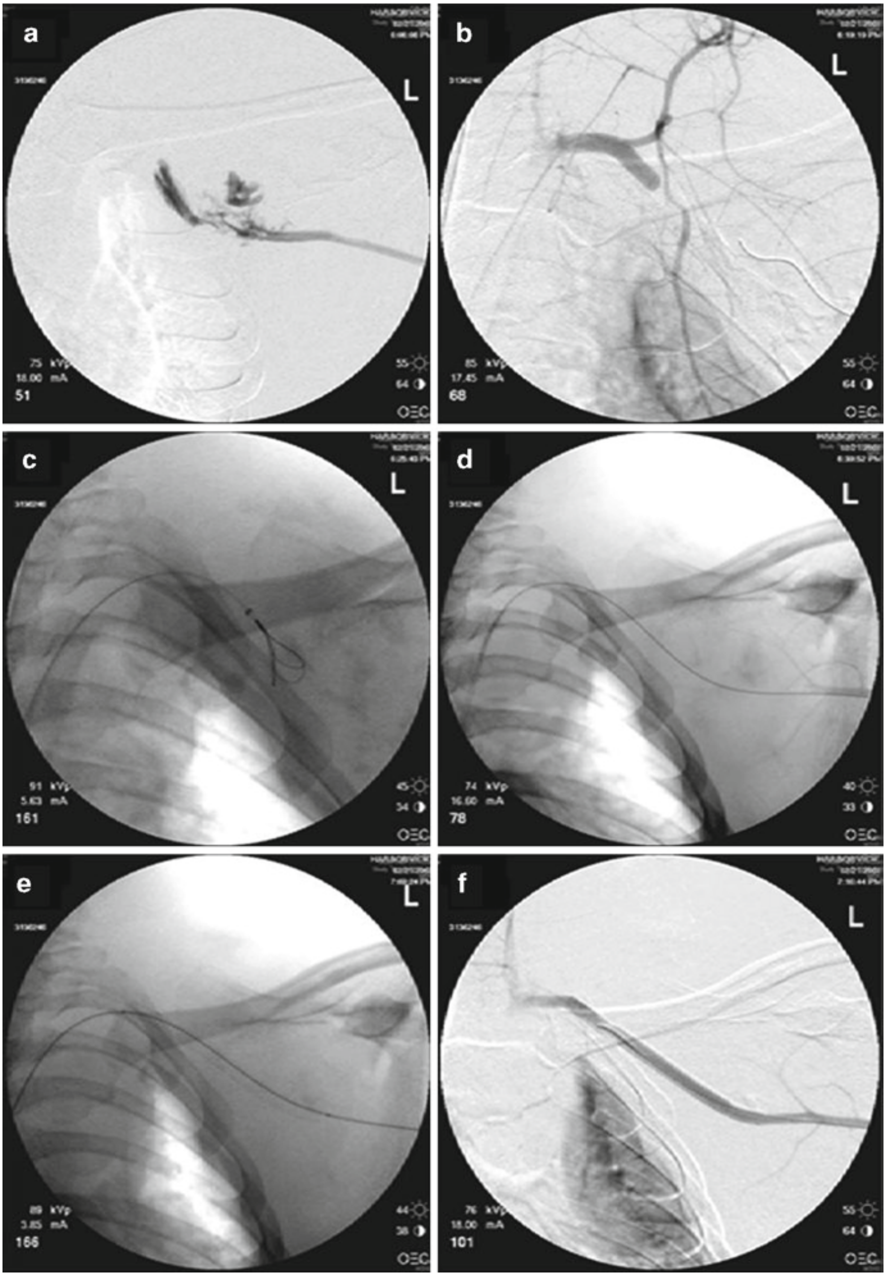

Fig. 16.7 *Panels* (**a–f**) depict repair of an Axillo-Subclavian injury using a purely endovascular technique. (**a**) Arteriogram through brachial sheath depicting extravasation and complete transection. (**b**) Arteriogram after selection of the left subclavian artery in the aortic arch. (**c**) Advancement of a tri-lobed snare across the injury. (**d**) Brachio-femoral wire spanning the injury. (**e**) Immediately post stent-graft deployment. (**f**) Completion Arteriogram

Required Equipment

Table 16.2 offers a list of suggested supplementary instruments and supplies for the performance of all basic vascular surgical procedures on the modern battlefield. All of these supplies fit easily into a single duffel bag or standard sized storage chest and are eminently transportable. This list has been compiled by the author over a period of 7 years and three combat deployments. It has proven useful to graduating residents and newly indoctrinated war surgeons. Access to portable X-ray and C-arm fluoroscopy is highly variable depending on the echelon of care and associated embedded capabilities. Most Forward Surgical Team and similar type units will not have this capability, but the majority of Combat Support Hospitals will.

In the FST, space is often limited and the availability of instruments to the surgeons can be limited. The author suggests placing individual instruments into "peel-packs" and hanging them on the operating room wall for ease of visibility, rapid acquisition and use. Your operative team may not be familiar with vascular instruments, techniques, or supplies. Conduct REALISTIC rehearsals for major vascular cases where you ask the scrub tech and circulator for all the instruments and supplies that you would normally need. Train your people well, and they will work wonders for you.

Summary

Using a calm and methodical approach, a majority of thoracic vascular injuries can be approached safely and repaired quickly. Choosing the right incision is half of the battle, and quickly obtaining vascular control without creating further injury gets you almost all of the way home. An understanding of the anatomy and different bail-out techniques outlined here is critical. You have all of the pre-requisites at your disposal to fix these injuries – just do it! Good luck.