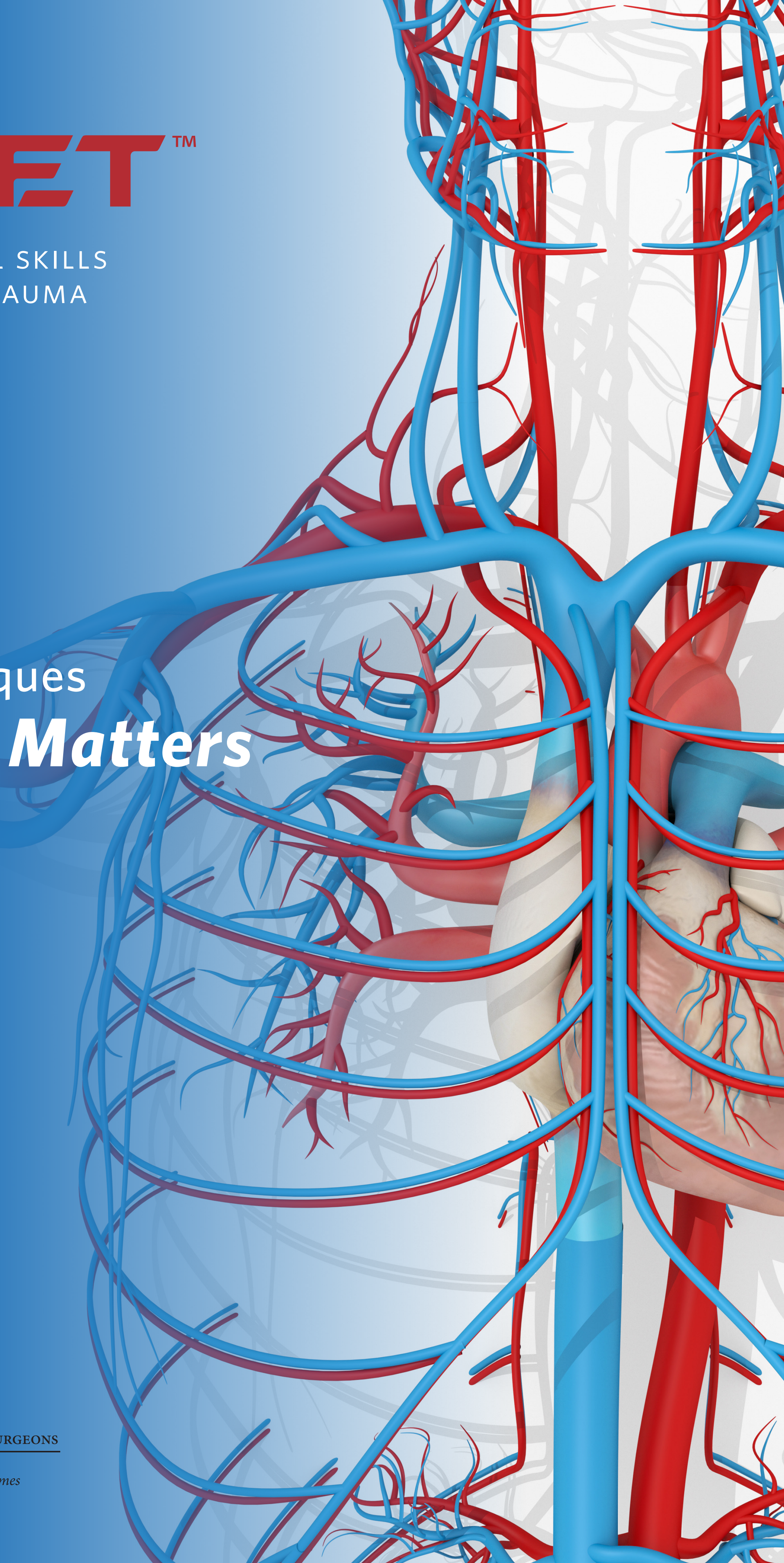
ASSET™

ADVANCED SURGICAL SKILLS
FOR EXPOSURE IN TRAUMA

Exposure Techniques
When Time Matters
2nd Edition



THE
COMMITTEE
ON **TRAUMA**

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2nd Edition

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Foreword

Since its inception in 2010, the Advanced Surgical Skills for Exposure in Trauma (ASSET) course has been a valuable resource to support surgical training for the complex operative intervention required for critically injured patients. The ASSET course provides the opportunity to learn the exposure to manage complex sources of life-threatening hemorrhage and reinforces damage control principles. Given the rarity of these injuries, this program is valuable for surgical residents, fellows, and experienced surgeons alike. It has proven especially valuable for military surgeons preparing for deployment.

This second edition provides the option for either a one- or two-day curriculum and adds several new modules including: damage control neurosurgery and orthopaedics, upper and lower extremity amputations, and emergency cesarean section and management of postpartum hemorrhage. As we, the Committee on Trauma, continue to work toward the goal of zero preventable deaths from injury across the globe, we encourage all surgeons to advance their education through this important program.

I want to acknowledge and thank all of the contributors who volunteered their time and talents to this exciting 2nd edition of the ASSET Course.

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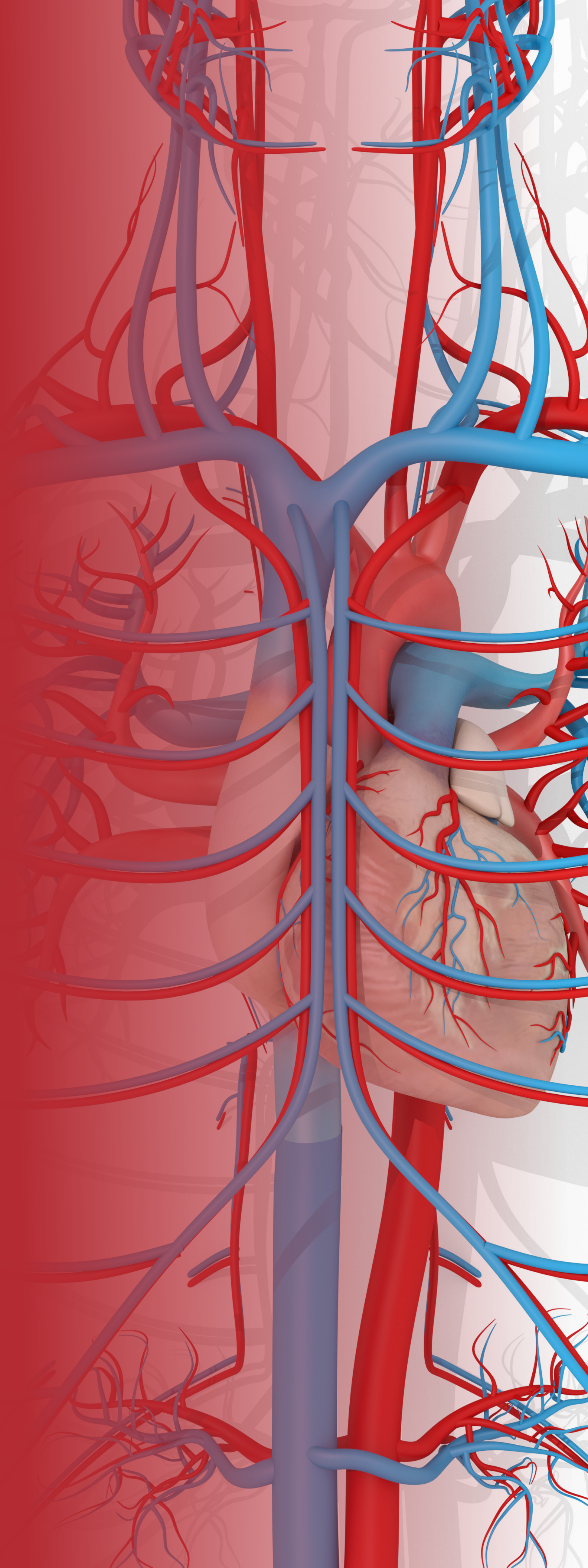
CHAPTER 1
VASCULAR TRAUMA: GENERAL PRINCIPLES



Vascular Trauma: General Principles

This chapter will review the general principles of vascular injuries to the extremities and torso. Historical consideration, etiology, diagnosis, and principles of management will be presented.

Learning Objectives

By the end of the ASSET course, participants should be able to do the following:

1. Discuss the historical aspects of vascular injury and the influence of military surgical experience on modern care.
2. Describe the types of injury to extremity and torso vasculature that require surgical intervention.
3. List the hard and soft signs used to decide the further management of extremity vascular injuries.
4. Describe the role of adjunctive imaging techniques in the management of vascular injury.
5. Relate the immediate and delayed consequences of vascular injury.
6. Discuss which vessels can be safely ligated.
7. Describe the role of tourniquets and hemostatic agents in the management of vascular trauma.
8. Describe the indications and techniques for temporary shunting of blood vessels.
9. Discuss the basic principles of vascular repair and bypass.

Introduction

- Extremity vascular injuries have been documented as far back as classical Greece and Rome, with amputation being the most likely result.
- Many of our current management principles for the treatment of extremity vascular trauma come from military experience:
  - During World War II, extremity arterial injuries were routinely ligated, with a resultant amputation rate of 73 percent for popliteal injuries.
  - Hughes and Spencer performed formal repair of vascular injuries during the Korean War.
  - Rich and associates further refined arterial repair during the Vietnam War, with the amputation rate for popliteal injuries decreasing to 32 percent.
  - Modern civilian series report amputation rates of 3–7 percent.
  - Recent conflicts in Iraq and Afghanistan, as well as recent civilian mass casualty events, have established the benefits of liberal use of tourniquets and shunting of vessels for damage control.
- Prompt recognition and management of arterial hemorrhage is essential to obtaining optimal outcomes.

Etiology

- Penetrating injuries from the following mechanisms:
  - Gunshots
  - Knives
  - Industrial incidents (e.g., nail gun injuries)
  - Iatrogenic (vascular access procedures)
- Blunt injuries from the following mechanisms:
  - Motor vehicle crashes
  - Falls/crush incidents
  - Assault
- Fractured long bones or dislocated joints are frequently associated with vascular injury.
- Posterior knee dislocation is associated with injury to the popliteal artery.
- The incidence of extremity vascular injuries varies with the affected vessels and is as follows, in descending order: femoral > brachial > popliteal > radial and ulnar > tibioperoneal vessels.

Pathophysiology

- The vascular tree (both arterial and venous) appears to have some natural protection from stretching and bending; therefore, there are fewer vascular injuries associated with blunt injury.

- The smooth muscle of the arterial media layer protects from both stretch-type injuries and minor puncture wounds, which heal spontaneously in most cases.
- When an artery is transected, vascular spasm and low systemic pressure appear to promote clotting at the site of the injury. Spasm may limit the amount of bleeding. Aggressive fluid resuscitation may dislodge this clot and should be avoided until control of hemorrhage is achieved. In the absence of traumatic brain injury, permissive hypotension should be considered until bleeding is controlled.
- The immediate consequences of vascular injury are hemorrhage and acute ischemia:
  - Ischemia results from interruption of blood flow.
  - Oxygen supply is inadequate to meet demand, and anaerobic metabolism ensues with associated lactic acidosis.
  - Cellular and humoral inflammatory pathways are activated, and cell death occurs if blood flow is not reestablished in time.
  - Skeletal muscle can withstand ischemia for three to six hours and still recover function.
  - Peripheral nerves are more sensitive to ischemia and may suffer irreversible damage after lesser times of ischemia.
  - Compartment syndrome develops, as discussed in chapter 5.
- Delayed presentations of vascular injury include the following:
  - Delayed ischemia can result from arterial thrombosis or compartment syndrome.
  - Arteriovenous fistula occurs when an artery and an adjacent vein are both injured and arterial blood finds its way directly into the venous circulation.
  - Partial disruption of an artery leads to a hematoma and formation of a pseudoaneurysm, which may present in a delayed fashion.
- If arterial supply is restored to ischemic tissue, the sudden release of inflammatory mediators can precipitate both local and systemic inflammatory response (reperfusion injury).
- In the case of reperfusion of a large mass of ischemic tissue, liberation of intracellular potassium and hydrogen ions can result in cardiac dysrhythmia and cardiovascular collapse.

Diagnosis

- The diagnosis of significant vascular injury is, by and large, made on physical exam looking for "hard" and "soft" signs of injury.
- The **"hard signs"** of vascular injury mandate immediate action:
  - Observed pulsatile bleeding
  - Visible expanding hematoma
  - Signs of distal ischemia (absent distal pulses; cold, pale limb)
  - Palpable thrill (vibration) by manual palpation
  - Audible bruit over or near the artery by auscultation
- The **"soft signs"** of vascular injury should prompt further diagnostic evaluation or continued close observation:
  - A history of significant hemorrhage at the scene
  - Proximity of the penetrating wound, bony injury, or blunt trauma to a major artery
  - Decreased pulse compared with the uninjured extremity
  - Peripheral nerve deficit
  - Small nonpulsatile hematoma
  - Abnormal (<0.9) ankle-brachial index (ABI)
  - Abnormal flow-velocity waveform on Doppler ultrasound
  - Shock that is not the result of other injuries
- The physical exam is augmented by measurement of the ABI, arterial pressure index, or injured extremity index.
  - Patients with penetrating or blunt injury, normal extremity pulse, and an ABI of 1.0 or more are very unlikely to have a significant arterial injury and need no further evaluation except observation.
  - Most authors advocate observation for ABI > 0.9 and further evaluation for values below 0.9.

- Vascular injuries must be suspected with the following orthopaedic injuries:
  - Clavicular fracture—subclavian artery
  - Shoulder dislocation—axillary artery
  - Supracondylar humerus fracture—brachial artery
  - Femur fracture—superficial femoral artery
  - Posterior knee dislocation—popliteal artery

Diagnostic Adjuncts

- Doppler ultrasound
  - The presence of a Doppler signal in a pulseless limb can provide a false sense of security and does not imply an absence of significant vascular injury.
- Duplex ultrasound is highly operator dependent, but in the right hands, it can detect the following:
  - Arterial disruption or occlusion
  - Intimal flaps
  - Venous occlusion
  - Hematoma
  - Pseudoaneurysm
  - Arteriovenous fistula
- Pulse oximetry—the reduction in oximeter readings from one limb to another—is suggestive of, but neither confirms nor excludes significant vascular injury.
- Plain films are helpful as a rapid means of determining the presence of fractures and foreign bodies.
- CT angiography (CTA) has evolved into a highly sensitive and specific modality for identification and characterization of vascular injury. It has become the initial diagnostic modality of choice in most patients with suspected vascular injury. The sensitivity of this study for vascular injury is dependent on the protocol of contrast administration and image acquisition.
- Angiography
  - Angiography has long been considered the gold standard for identification and characterization of vascular injury. Angiographic images are less significantly impacted than CTA by the presence of foreign bodies and also provide real-time indication of flow patterns in the imaged arterial segment.
  - Angiography can also be therapeutic with endovascular techniques used to manage vascular injury if expertise and facilities are present.

Management: Immediate Control of Hemorrhage

- Apply direct pressure over the site of injury.
- Avoid large, bulky dressings.
- Tourniquets should be used if bleeding cannot be controlled with direct pressure or wound packing (Figure 1).

Figure 1. Tourniquets have been applied to the lower legs of the two patients seen here to control active arterial hemorrhage as a result of blast injury (left) and a stab wound (right).

    - The use of tourniquets in recent conflicts has shown significant reduction in mortality, and their use is becoming commonplace in civilian prehospital care.
    - Tourniquets should be considered for initial intervention in patients with traumatic amputation and/or severe hemorrhage.
    - All health care providers should have a working knowledge on how to both apply and remove tourniquets.
- Blind clamping or probing in the depths of wounds is dangerous, likely to fail, and may injure other structures.
- A number of field dressings containing a variety of hemostatic agents have been approved for human use and are useful adjuncts for hemorrhage control.

Volume Resuscitation

- Prior to hemorrhage control, fluid resuscitation should be judicious (permissive hypotension), as raising blood pressure may "pop the clot," resulting in more bleeding and dilution of clotting factors.
- Two large-bore IVs should be placed in anticipation of resuscitation after hemorrhage control.
- After hemorrhage control is achieved, aggressive and balanced resuscitation with blood products should occur as necessary.

Operative Strategy/Considerations

- Vascular reconstruction (or restoration of flow with shunting) that occurs within three hours of injury is generally accepted to have the best outcome.
- The patient must be properly positioned on the operating table to allow on-table angiogram, exposure of all relevant vessels, and harvesting of vein grafts.
- The distal extremity (hand or foot) must also be prepped into the field as indicated to allow for assessment of distal perfusion
- The basic principle of all vascular surgery is attaining proximal and distal control of a vessel prior to exploring the injury. Obtaining both proximal and distal control may require separate incisions.
- Keep in mind that tourniquets can provide proximal control (Figure 1).
- Though it may be tempting to directly explore a wound that is not actively bleeding, this can dislodge a clot from the injury and result in profuse hemorrhage that obscures the field. So … "Don't poke a skunk!"
- Control is best achieved by vessel loops passed twice around the vessel. If clamps are used, they should be atraumatic and applied with a minimum of force.
- In some circumstances, intraarterial balloon occlusion (e.g., Fogarty or REBOA) can be used to gain control.
- Selected use of balloon tamponade is useful for temporary control of hemorrhage from junctional or deep, difficult-to-access areas.
- Venous bleeding is more easily controlled with pressure than with loops or clamps.
- Large veins should be repaired (or shunted), and small veins can be ligated. The rule of thumb is that if the vein is tense, it should be repaired.
- In the setting of polytrauma with physiologic compromise, or if the surgeon is not experienced in vascular repairs, the default should be damage control shunting.
- If it is elected to repair the injury, the technique chosen will depend on the extent of damage to the vessel and the expertise of the surgeon.
- The first step is to debride devitalized tissue and define the edges of the wound.
- Next, an assessment of inflow and outflow is made. If flow is inadequate, a balloon (Fogarty) catheter is passed proximally and distally to extract any thrombus. 10–15 mL heparinized saline at 50 units/mL can be used to flush vessels distal and proximal to the injury for regional anticoagulation.
- Systemic anticoagulation should be avoided in patients with polytrauma.
- All vascular repairs should be followed by an assessment of the repair site, bypass, and distal perfusion. The repair or graft can be evaluated with duplex ultrasound or angiography. Consider performing angiography of the distal outflow prior to repair in order to identify potential thromboemboli.

- Completion arteriography is performed using a small angiocatheter puncturing the artery proximal to the anastomosis. Contrast dye is rapidly injected followed by either real-time fluoroscopic images or a "one-shot" plain X ray.
- Baseline Doppler signals should be documented following repair, and the location of the signal should be marked on the skin so that others may easily perform routine vascular checks.
- The patient should be assessed for development of compartment syndrome. Pain with certain movements, particularly passive stretching of the muscles, is the earliest clinical indicator of compartment syndrome (see chapter 5).
- Fasciotomy should be used early and liberally.

Temporary Vascular Shunting

- Temporary vascular shunting is a damage control technique that should be considered for the following circumstances:
  - In a patient who has developed the lethal triad of trauma (acidosis, hypothermia, and coagulopathy), to allow time for stabilization in the ICU prior to definitive repair
  - To allow for the initial repair of orthopaedic injuries prior to definitive vascular repair
  - As a temporizing measure to allow transfer to a higher level of care with the required resources and expertise to perform definitive repair
  - In multiple casualty events when operative resources are limited
- When possible, both the artery and vein should be shunted (Figure 2).
- Prior to placing a shunt, the distal vessel should be allowed to back-bleed, and a Fogarty catheter should be passed distal and proximal.
- There are commercially available shunts, but you can use IV tubing or chest tubes as well.
- Shunts should be carefully secured (ties or, less frequently, slings or clamps) to prevent dislodgement, especially if transporting the patient with a shunt in place (Figure 3).
- The largest possible arterial intraluminal shunt should be inserted.
- If available, papaverine can be topically applied to the transected ends of the artery, which are usually in spasm. The use of papaverine and gentle dilation of the arterial lumen may allow for insertion of a larger shunt.
- The shunt should be 4 cm longer than the gap between the two vessels such that 1.5 to 2 cm can be inserted into the lumen of each transected end of the artery.

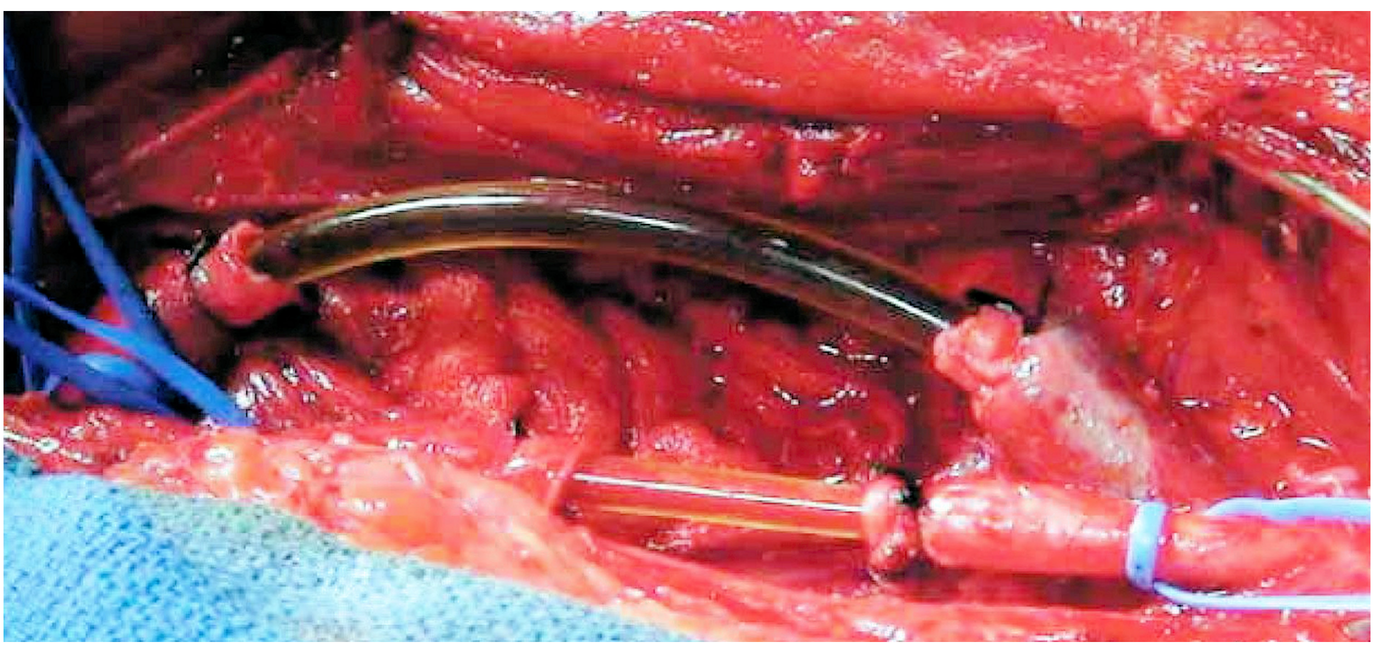


Figure 2. Temporary shunts using intravenous tubing have been placed in both the superficial femoral artery (red oxygenated blood) and the vein (dark blood) in this patient with vascular injury to the right thigh.

- Once the shunt has been trimmed to the desired length, a 2-0 silk tie is placed securely in the middle of the shunt, with an occluding hemostat placed at the same spot to both mark and control the shunt (Figure 3a).
- The shunt is placed first into the proximal end of the transected artery inserting the tubing at least 1.5 cm. The proximal end of the artery is then secured to the shunt with a 2-0 silk tie placed approximately 5 mm from the cut end of the vessel.
- The hemostat in the mid-portion of the shunt is removed and the proximal vessel control released to confirm pulsatile flow of blood. Once confirmed, the clamp on the hemostat is reapplied.
- The shunt is then inserted 1.5 cm into the lumen of the distal end of the transected vessel, and the vessel is compressed down onto the shunt and secured with another 2-0 silk tie placed about 5 mm from the cut edge of the vessel (Figure 3b).
- The ties on the proximal and distal ends of the vessel are then joined together under slight tension, stabilizing the shunt and helping avoid dislodgement or migration (Figure 3c).
- The distal vascular control is released, and pulsatile flow distal to the shunt is confirmed (Figure 3d).
- When removing the shunt prior to definitive repair, the vessel will need to be debrided back to healthy tissue beyond the point where the shunt was secured.

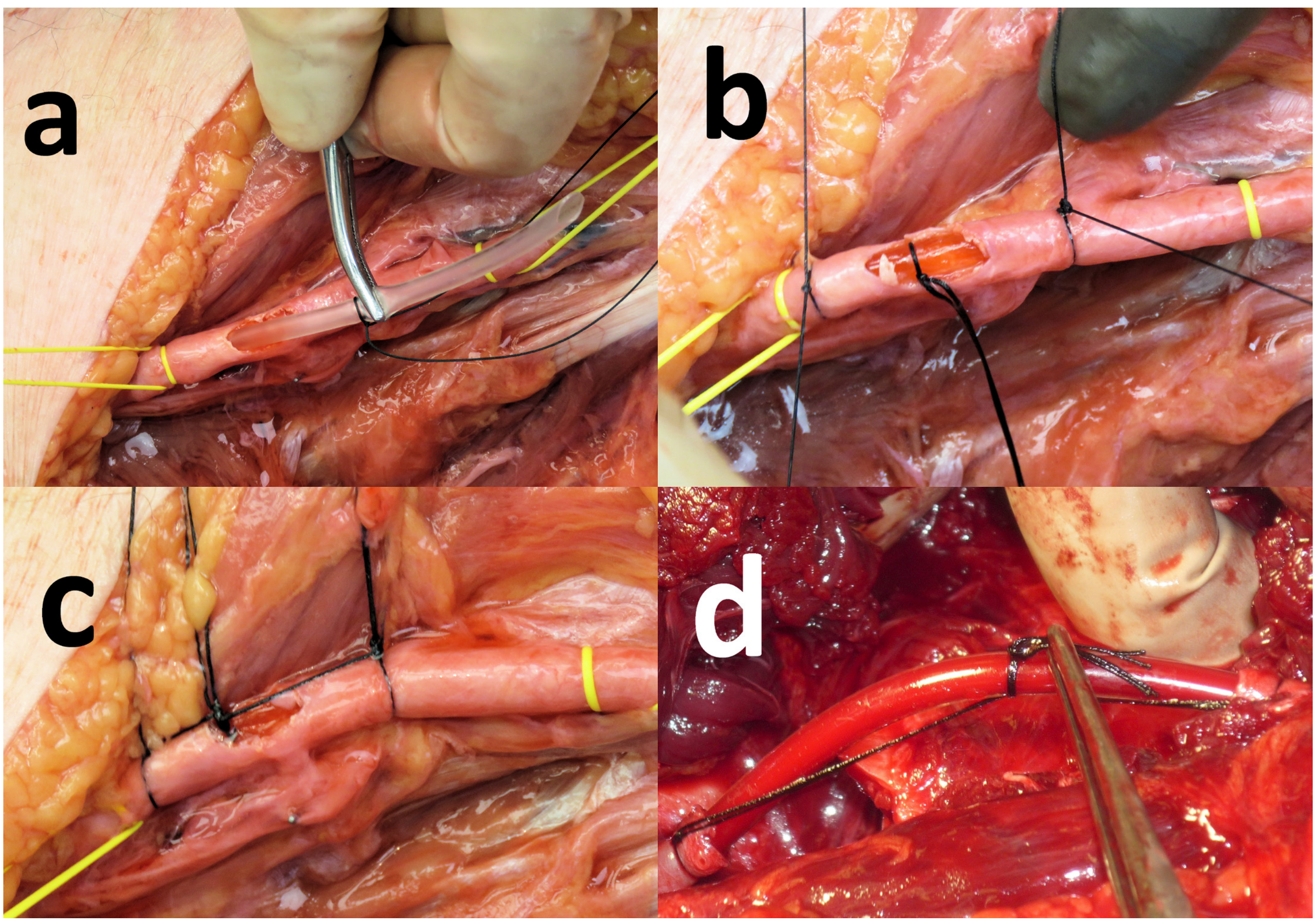


Figure 3. A temporary shunt has been fashioned out of sterile intravenous tubing cut to appropriate size, with slight beveling of the ends, a suture marking the midpoint of the shunt marked with a suture, and a clamp providing control via occlusion (a). The shunt is placed first into the proximal end (a) and then the distal end of the partially transected vessel (b). The vessel is tied securely to the tube distally and proximally (b), and the ties on the vessel are tied to the suture at the midpoint, as seen in the partially transected artery (c). In a different case, an artery with several centimeters missing has been bridged with a shunt (d).

- Shunts should be removed as soon as the patient's physiology will tolerate and appropriate vascular surgical expertise is available to perform definitive repair.
- It is not necessary to heparinize vascular shunts.
- Thrombosis rates for shunts placed in vessels below the elbow or below the knee are high, and limb loss rates are unchanged. This suggests that these vessels do not need to be shunted.
- Once a shunt is placed, it is important to document a thorough distal exam, as well as the time the shunt was placed.

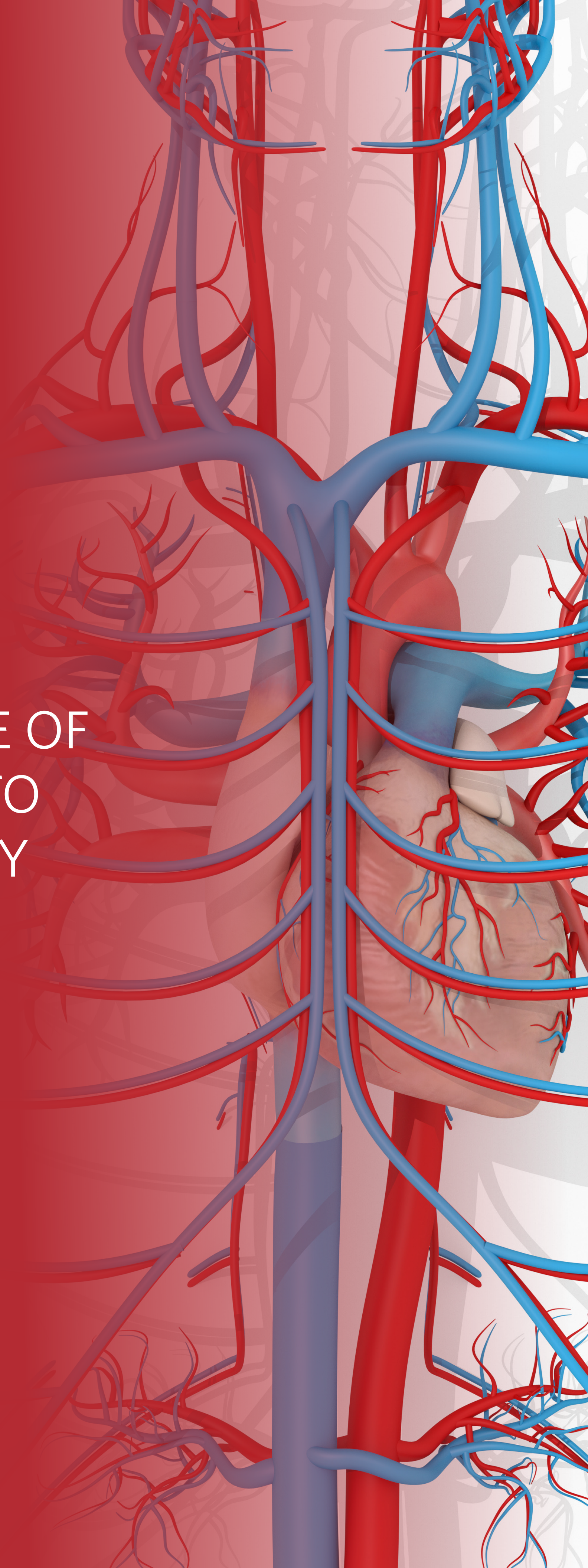
Ligation

- Occasionally, it will be impossible or impractical to shunt or repair a vessel, and that vessel may require ligation to control life-threatening hemorrhage.
- There are very few vessels that cannot be ligated in extremis, with varying consequences.
- Vessels in which ligation may be tolerated include the following:
  - Common and external carotid arteries
  - Subclavian artery (as long as ligated distal to thyrocervical trunk)
  - Axillary artery
  - Brachial artery (distal to profunda branch)
  - Ulnar or radial artery individually (radial better tolerated as ulnar is the dominant vessel in most patients)
  - Celiac trunk
  - Internal iliac artery
- Vessels in which ligation is, or may be, poorly tolerated (e.g., leading to stroke or critical ischemia) include the following:
  - Internal carotid artery (15–20 percent incidence of stroke)
  - Superior mesenteric artery
  - External iliac artery
  - Common femoral artery
  - Popliteal artery
- It must be kept in mind that ischemia is much more likely to occur around ligated vessels if there is significant soft tissue injury and destruction of supporting collateral circulation.
- Almost all veins, including the inferior vena cava, can be ligated. The popliteal vein should be repaired or shunted if possible.

Vascular Repair

- The specific techniques of definitive vascular repair are beyond the focus of this course and manual but include the following options:
  - Lateral arteriorrhaphy or venorrhaphy
  - Patch angioplasty
  - Resection with end-to-end anastomosis
  - Resection with interposition graft (vein, PTFE/Dacron, CryoVein, Artegraft, etc.)
  - Bypass graft
  - Extra-anatomic bypass
  - Stent–graft repair

CHAPTER 2
OPERATIVE EXPOSURE OF VASCULAR INJURIES TO THE UPPER EXTREMITY



Operative Exposure of Vascular Injuries to the Upper Extremity

This chapter will discuss techniques for exposure of actual or suspected injuries of the vasculature of the upper extremity. Though the major emphasis of this lab experience is operative exposure, the topics of preoperative considerations, positioning, and management of specific injuries will also be briefly discussed.

Learning Objectives

By the end of the ASSET course, participants should be able to do the following:

1. Demonstrate incisions to expose axillary, brachial, radial, and ulnar arteries.
2. Demonstrate the steps to achieve surgical exposure of axillary artery and vein.
3. Demonstrate knowledge of the anatomic relationship between the musculoskeletal structures of the arm and the brachial artery.
4. Demonstrate knowledge of the anatomic relationship between the brachial artery and median nerve.
5. Demonstrate surgical exposure of radial and ulnar arteries below the elbow and above the wrist.

General Considerations

- Blind clamping of vascular injuries in the emergency department often produces unnecessary nerve and vessel damage.
- Bulky, reinforced dressings rarely provide adequate hemostasis and are usually best replaced by direct manual pressure (or tourniquet).
- The injured arm should be extended on an arm board. The entire extremity should be prepped into the field, including the back of the arm and the fingers. Prepping the groin and thighs allows for saphenous vein harvest for interposition grafting.
- In the upper extremity, a separate proximal incision is not always necessary to gain proximal arterial control.
- During the initial dissection, bleeding generally can be controlled by direct pressure or tourniquet application proximal to the injury.
- If desired, a sterile tourniquet may be placed above the injury. Inflate it only as needed, for a few minutes, if bleeding is troublesome during exposure. If used, a tourniquet should be deflated promptly when vessels are controlled and should not be used for vascular control.
- It is useful to imagine one continuous line for exposure of vascular injuries to the upper extremity (Figure 1).
    - This line begins on the superior edge of the sternal notch, runs laterally on the superior aspect of the clavicle, crosses mid-clavicle to the inferior clavicular border, traces the deltopectoral groove and then the bicipital groove, crosses the elbow obliquely, and runs on the radial side of the volar forearm to the wrist crease.
    - Any vascular injury on the upper extremity can be exposed by making an incision on this line, extending at least six centimeters proximal and distal to the suspected location of vascular injury. The exception is the ulnar artery which is exposed by making a second longitudinal incision along the ulnar side of the volar forearm. (Figure 1).

RIGHT UPPER EXTREMITY

Figure 1. Incisions for exposure of the axillary, brachial, and radial arteries will be along the long line, centered on the site of injury. The ulnar artery is exposed via an incision on the short line.

AXILLARY ARTERY AND VEIN

Anatomy

- The subclavian artery becomes the axillary artery as it crosses the first rib.
- The axillary artery runs under the pectoralis major and minor muscles, becoming the brachial artery as it crosses the lower border of the teres major muscle.
- The pectoralis minor muscle divides the axillary artery into three sections (Figure 2).
- A single axillary vein typically runs with the artery and is usually found inferior and superficial to it.
- The brachial plexus is intimately associated with the axillary artery, and care must be taken to avoid nerve injury during rapid exposure.
- The configuration of the brachial plexus at this level is highly variable and can range from a single large trunk running parallel to the artery to two or three branches that intermittently cross over or under the artery. This can make it challenging to determine the structures, especially in the setting of a hematoma or lack of pulsation in the artery.

Exposure

- The incision typically begins at the inferior edge of the center of the clavicle and runs laterally in the groove between the deltoid and the pectoralis major, which is exposed after incision through the skin and subcutaneous tissues (Figures 3 and 4).
- The pectoralis muscles lie on top of the axillary vessels. When there is no shock or active bleeding, the pectoralis major muscle can often be retracted medially or split in the direction of its fibers (Figure 5), allowing quick functional recovery. However, if there is bleeding or concern about adequate exposure, the pectoralis major tendon can be divided two centimeters from its humeral insertion.
- After splitting or dividing the pectoralis major, the pectoralis minor is divided, providing the first view of the second portion of the axillary artery (Figure 6).

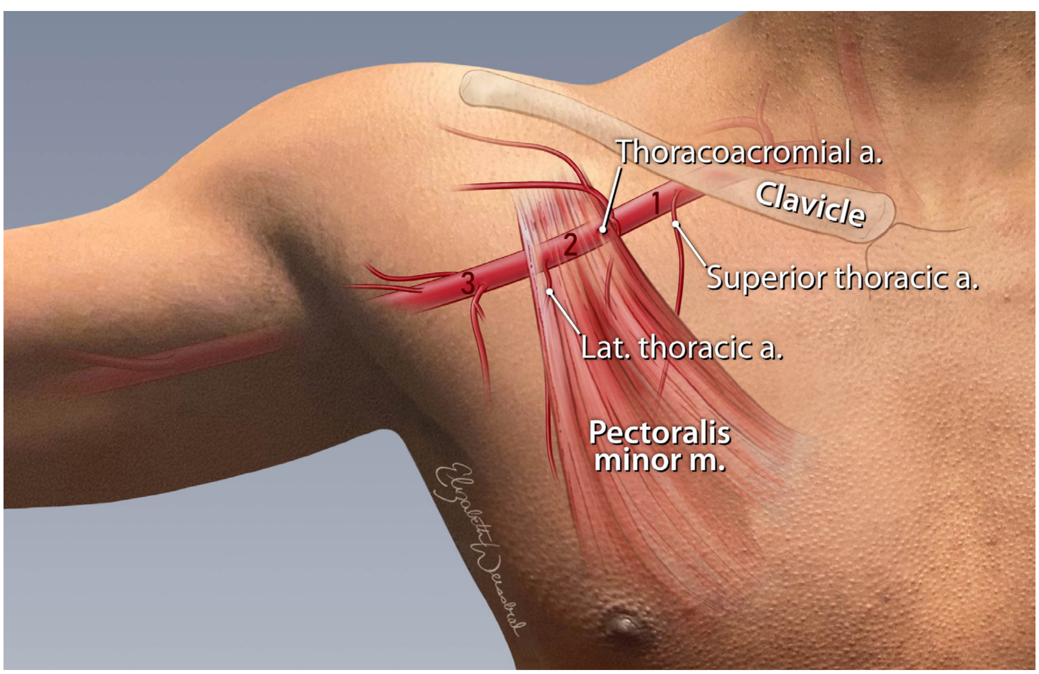


Figure 2. The pectoralis minor muscle divides the axillary artery into three parts and is the anatomic key to exposure of the artery.

RIGHT UPPER EXTREMITY – HEAD AT TOP

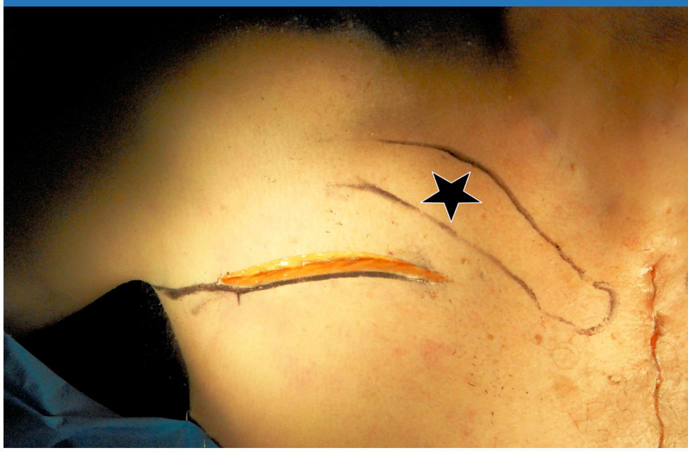


Figure 3. The incision, as seen here on the right side, runs below the clavicle (star) in the groove between the deltoid and pectoral muscles.

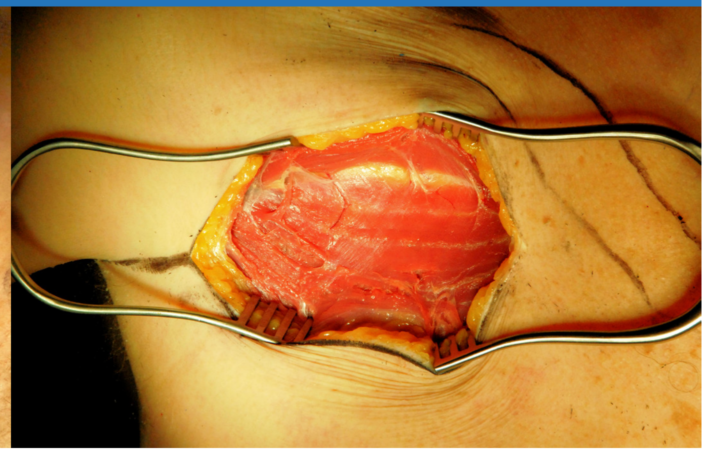


Figure 4. The incision is carried down through the subcutaneous tissues to expose the fibers of the pectoralis major muscle.

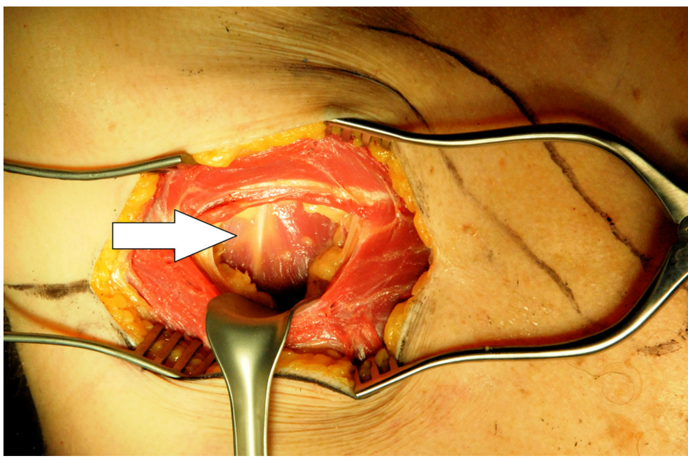


Figure 5. The pectoralis major muscle fibers have been split and retracted, revealing the underlying pectoralis minor muscle (arrow).

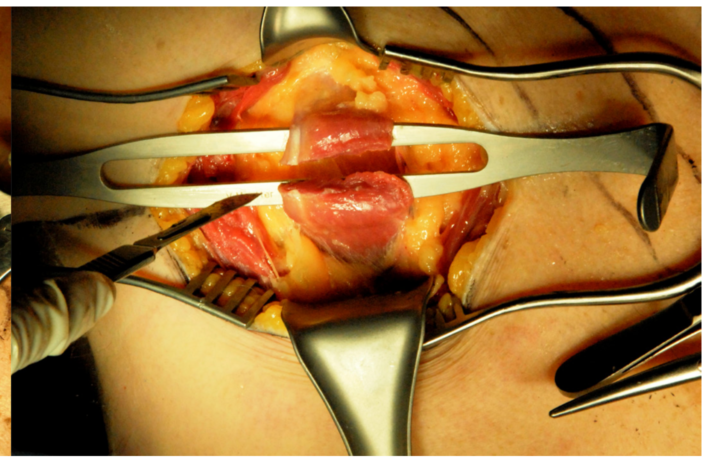


Figure 6. The pectoralis minor muscle is elevated (using a retractor in this case) and divided.

- A single axillary vein typically runs with and caudal to the artery. The brachial plexus is intimately associated with the axillary artery and can be confused for the artery when a pulse is absent. Care must be taken to avoid nerve injury during rapid exposure. These anatomical relationships are shown in Figures 7 and 8.

Pitfalls

- Slow, incomplete, or piecemeal division of pectoral muscles delays hemorrhage control. This problem can be avoided by inserting a finger, clamp, or retractor under the entire muscle/tendon and dividing it quickly and completely.
- An inadequate incision makes exposure and hemostasis difficult. More distally, the vessels are superficial and exploration is typically quicker, with little risk of exsanguination during exploration. In the axilla, however, a generous incision is warranted to ensure quick vascular control.

BRACHIAL ARTERY

Anatomy

- The brachial artery has a collateral system with one or more branches in the upper third of the arm (Figure 9) and is in close proximity to the median nerve (Figure 10).

UPPER EXTREMITY – HEAD AT TOP

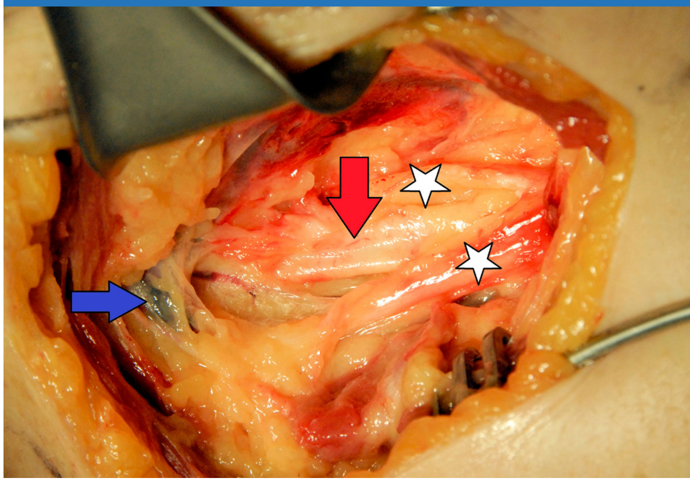


Figure 7. The right axillary artery (red arrow) is exposed and separated from the branches of the brachial plexus (stars). The axillary vein (blue arrow) is found caudally.

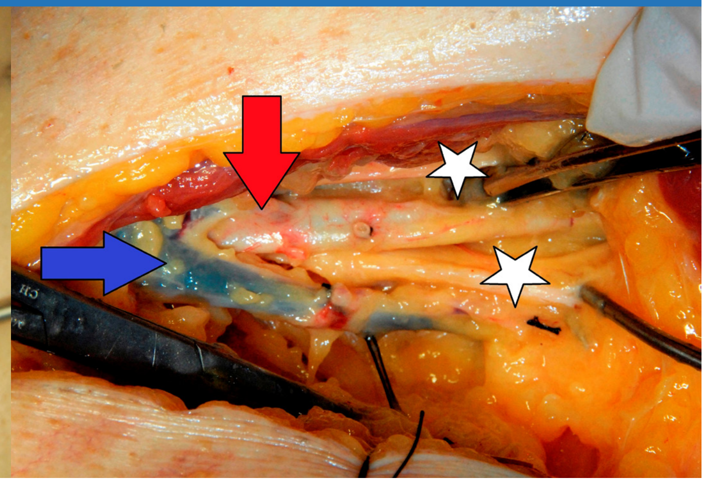


Figure 8. The left axillary artery (red arrow) is exposed and separated from the branches of the brachial plexus (stars). The axillary vein (blue arrow) is found caudally.

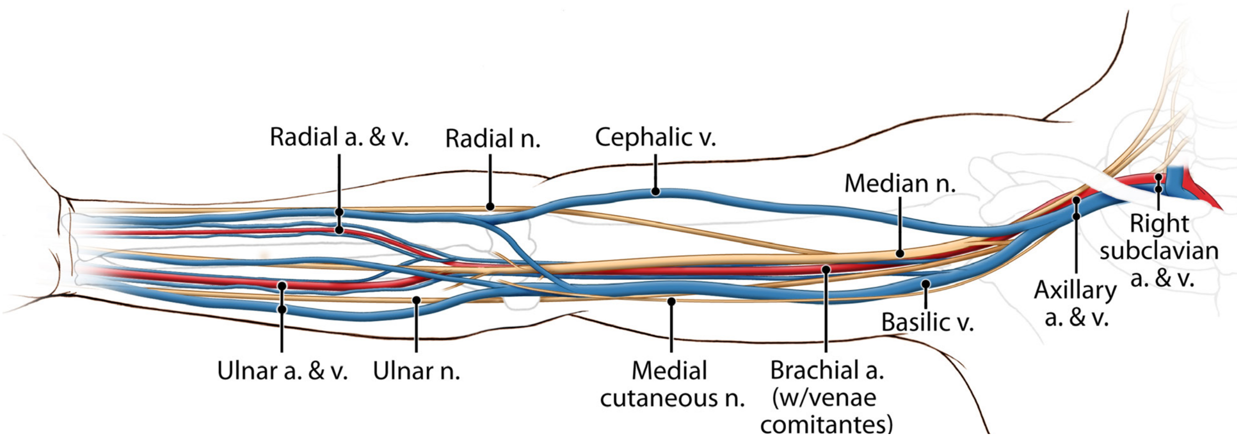


Figure 9. The anatomical relationships of the right upper extremity arteries (a.), veins (v.), and nerves (n.).

LEFT UPPER ARM – AXILLA TO LEFT

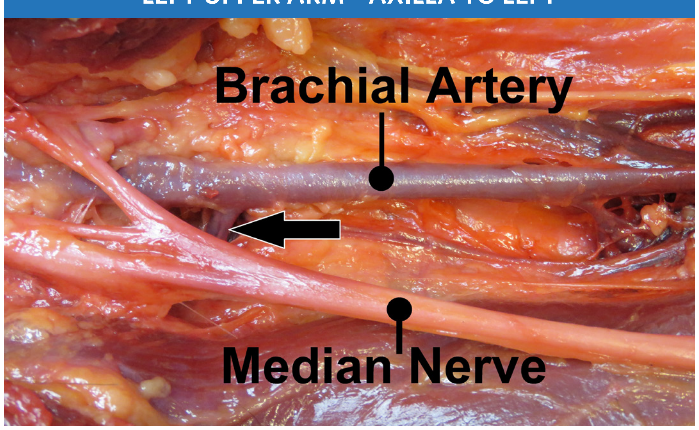


Figure 10. The anatomical relationships of the upper extremity vessels and nerves. A collateral system of the profunda brachial artery is seen (arrow).

- This collateral system may provide adequate perfusion to the hand even in instances of brachial artery transection or occlusion. Thus, the brachial artery can be ligated if necessary in select patients.
- In such cases, perfusion must be carefully monitored, with a low threshold for fasciotomy.
- The brachial artery is subcutaneous throughout its course in the upper arm, running in the groove between the biceps and triceps muscles in the medial arm (Figure 11).
- The radial, ulnar, and brachial arteries are each accompanied by two venae comitantes, usually one on each side of the artery. Multiple connecting branches from these veins form a web over the arteries; these veins may need to be ligated and divided to isolate the artery.
- In the mid-arm, the brachial venae comitantes are joined by the basilic vein as it penetrates the deep fascia and continues as the axillary vein. The cephalic vein courses superficially over the biceps muscle and enters the axillary vein in the deltopectoral groove.
- Proximally, the brachial artery lies between the median nerve anteriorly and the ulnar nerve posteriorly. Halfway down the upper arm, the median nerve crosses the artery and runs along the inferior-medial (ulnar) side of the artery.

Exposure

- The biceps and triceps muscle bellies are usually palpable on the medial aspect of the arm, and a generous incision is made in the groove between them (Figure 11). The neurovascular bundle is generally encased in fat, and "following the fat" between the muscle bellies aids in exposure.

RIGHT UPPER EXTREMITY – HEAD AT TOP

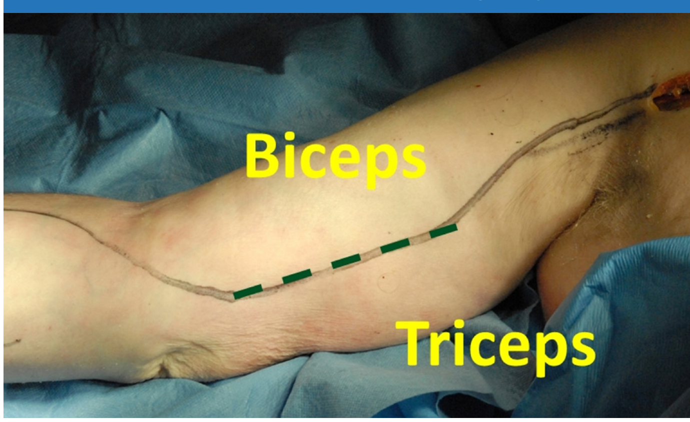


Figure 11. The incision to expose the brachial artery is made in the groove between the biceps and triceps muscles.

Figure 12. The incision is extended obliquely across the antecubital crease to allow exposure of the arterial bifurcation.

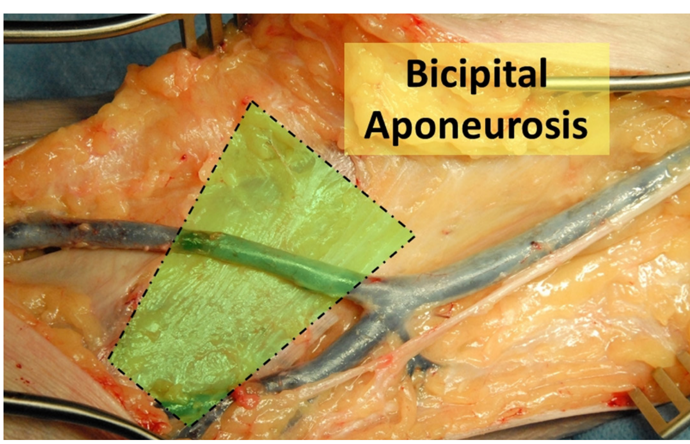


Figure 13. The bicipital aponeurosis overlies the bifurcation of the artery and lies under the median cubital vein.

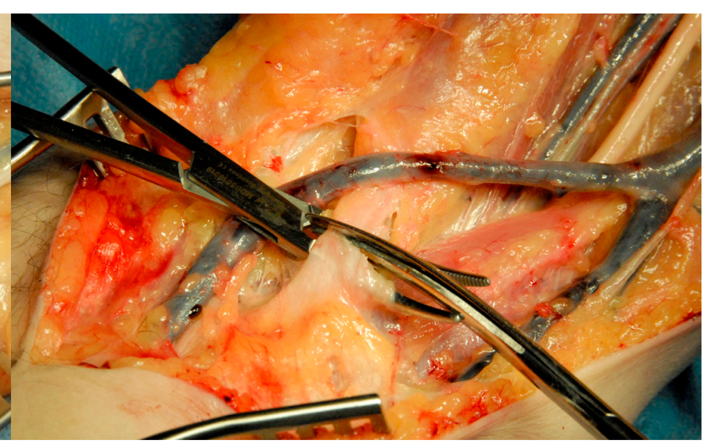


Figure 14. Division of the bicipital tendon will allow for exposure of the bifurcation of the brachial artery into the radial and ulnar arteries.

- If needed, the incision is extended obliquely across the antecubital crease in a lateral direction, exposing the brachial artery bifurcation, the proximal radial artery, and the proximal ulnar artery (Figure 12).
- Between the antecubital crease and the arterial bifurcation, there is a dense, fibrous extension of the bicipital tendon (the bicipital aponeurosis) that can be divided along with the tendon to expose the bifurcation (Figures 13 and 14).
- Other than bicipital aponeurosis and tendon, the brachial neurovascular bundle is covered only by skin and subcutaneous tissue.
- In the mid-upper arm, the median nerve may be injured by careless dissection, as it runs directly on the artery. Knowledge of the anatomic relationships of the median nerve to the artery and its closely adherent paired veins is important to prevent iatrogenic injury (Figures 15 and 16).
- Sometimes, an injured brachial or basilic vein can be resected and used as an arterial conduit. If this procedure is planned, care should be taken not to harm the vein further during dissection or harvest.
- The brachial artery of a young, healthy patient can be surprisingly small when in spasm.
- If there is question as to whether the true brachial artery has been found, it should be followed proximally for confirmation.

Pitfalls

- In a pulseless extremity, a common mistake is to confuse the medial antebrachial cutaneous nerve (Figure 15) as the median nerve. The median nerve is quite large and is generally found inferior and superficial to the brachial artery and its paired vena comitans (Figure 16).
- If the dissection is carried below the biceps/triceps groove, the ulnar nerve will be found and can be mistaken for the median nerve.
- Likewise, if the dissection is above the biceps/triceps groove, the radial nerve will be found and can be mistaken for the median nerve.
- The level at which the brachial artery bifurcates is highly variable, ranging from well above the elbow to the mid-forearm. A generous incision (with extension as needed) will help avoid confusion of the anatomy.

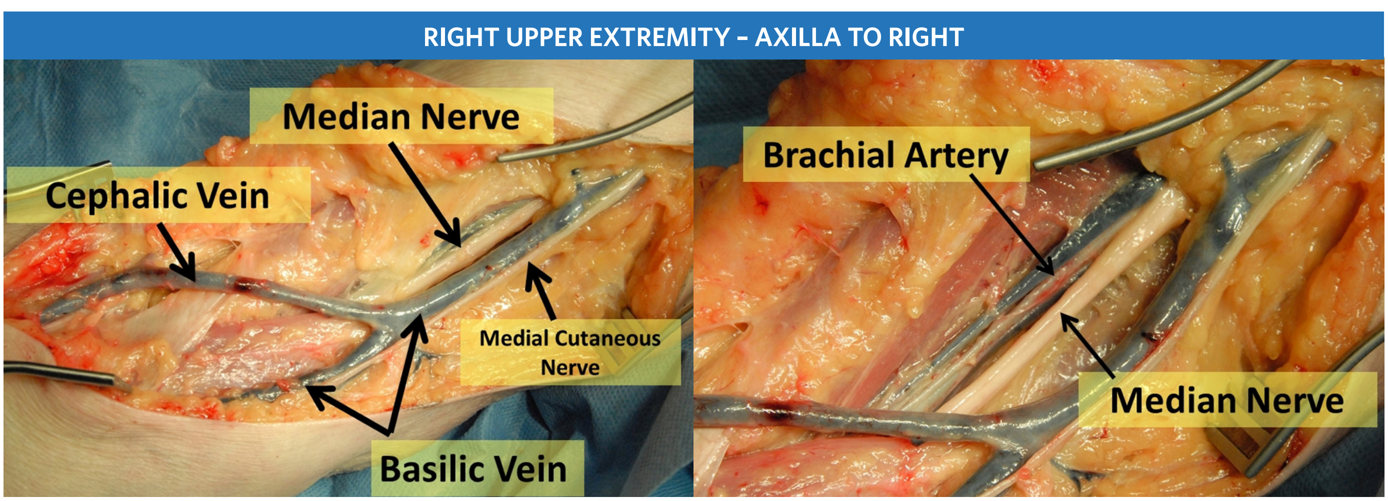


Figure 15. The median nerve lies directly over the brachial artery in the mid-arm and is superior to the basilic vein, seen here with the medial antebrachial cutaneous nerve inferior.

Figure 16. Further dissection exposes the brachial artery and its paired veins deep and superior to the median nerve.

RADIAL AND ULNAR ARTERIES

Anatomy

- The brachial artery bifurcates into the radial and ulnar arteries just distal to the antecubital fossa, with the radial artery continuing in the same direction as the brachial artery, and the ulnar artery appearing to be a branch (Figures 17 and 18).
- As discussed above, the level at which the brachial artery bifurcates is highly variable and a generous incision (with extension as needed) will assist in sorting out anatomical variations.
- The ulnar artery is most commonly the dominant vessel to the hand. Careful evaluation of the hand and digital perfusion is required to determine the need for vascular repair versus ligation.
- The radial artery is covered by the brachioradialis muscle in the proximal forearm but is superficial in the distal forearm. At the wrist crease, the radial artery dives laterally under the thumb abductor and extensor tendon group.
- Two venae comitantes follow the radial artery throughout its course and may need to be ligated for complete arterial exposure.
- After arising from the brachial artery, the ulnar artery travels medially and parallel to the ulnar nerve. They are closely apposed for the remainder of the ulnar artery's course in the arm.
- In the upper forearm, the ulnar artery and nerve lie under the superficial and deep flexor muscles. These muscles arise from the medial epicondyle and cross the artery in a medial to lateral direction. Distally, the artery emerges from underneath these muscles. It is palpable and superficial in the distal forearm before crossing over the flexor retinaculum at the wrist and becoming the superficial palmar arch.

LEFT FOREARM

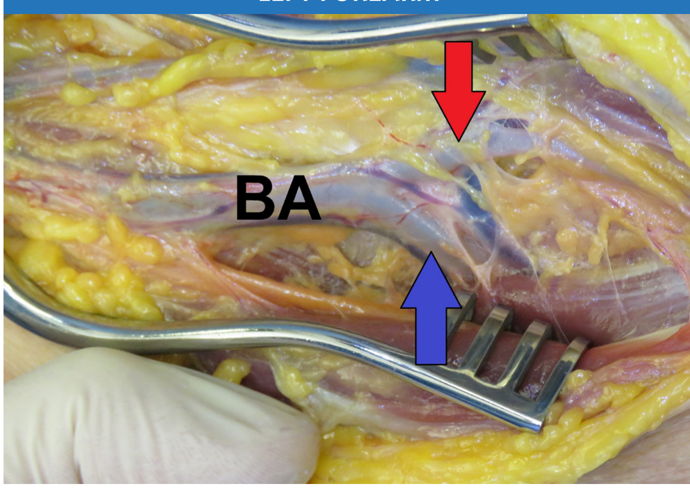


Figure 17. The left brachial artery (BA) bifurcates into the radial (red arrow) and ulnar (blue arrow) arteries.

RIGHT FOREARM

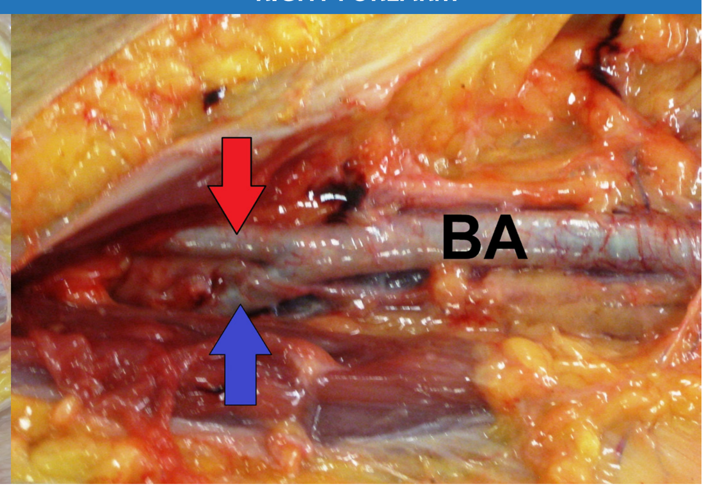


Figure 18. The right brachial artery (BA) bifurcates into the radial (red arrow) and ulnar (blue arrow) arteries.

Exposure

- To expose the proximal radial artery, an incision is made on the radial side of the volar forearm along the inferior and medial border of the brachioradialis (Figure 19a).
- If more proximal exposure is needed, the incision will travel obliquely across the antecubital fossa, as described above (Figure 12).
- The brachioradialis muscle is retracted radially (Figure 19b) to expose the fat pad between the brachioradialis and muscles (Figure 20a).
- Further dissection of this fat pad will expose the proximal radial artery and nerve (Figure 20b).
- The proximal ulnar artery can be exposed, as seen above in Figures 17 and 18.
- The remainder of the ulnar artery is exposed via a separate incision beginning just anterior to the medial epicondyle and traveling straight down the ulnar side of the volar forearm to approximately one fingerbreadth from the ulnar limit of the forearm (the point where the ulnar artery is typically palpated) (Figure 21a).
- The fat pad between the flexor digitorum superficialis and flexor carpi ulnaris muscles will contain the neurovascular bundle (Figure 21b).
- Further dissection of the fat pad will expose the ulnar nerve and artery, with associated veins lying on top of the flexor digitorum profundus muscle (Figure 22).

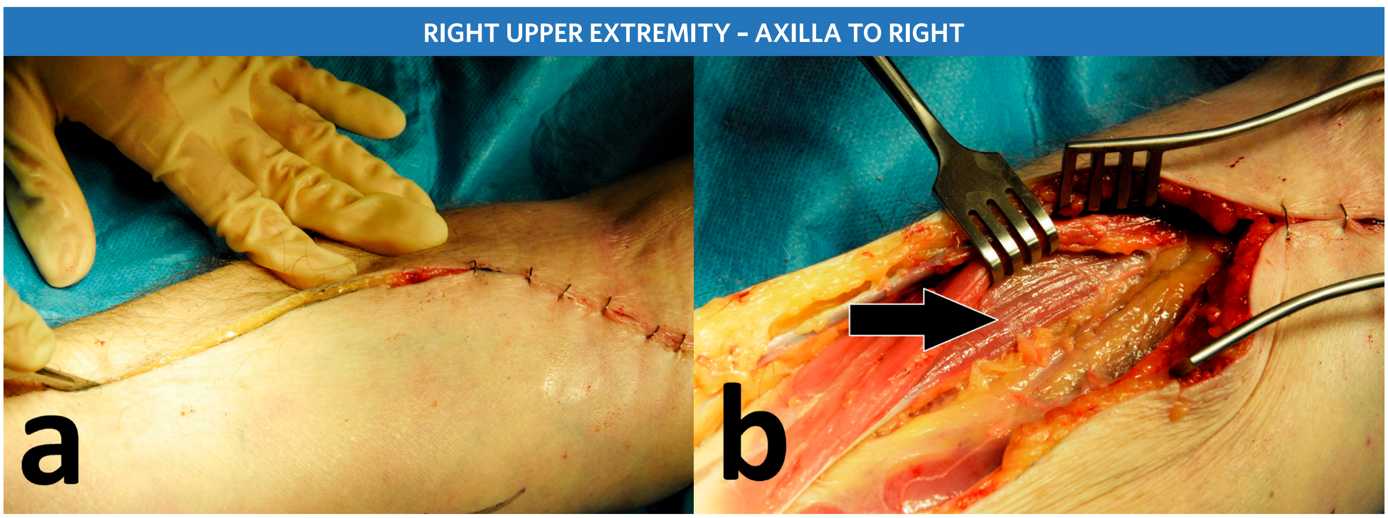


Figure 19. Exposure of the radial artery in the forearm is accomplished by an incision along the medial border of the brachioradialis muscle (a). The muscle belly is retracted in the radial direction (b).

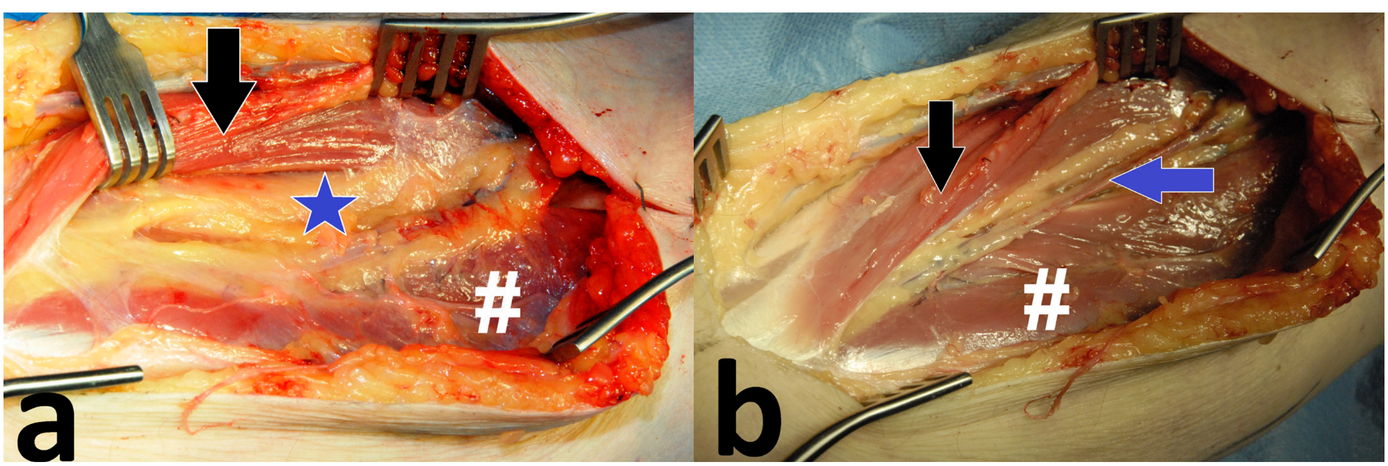


Figure 20. The fat pad (blue star) between the brachioradialis (black arrow) and pronator teres (#) muscles is identified (a). Dissection allows for identification, exposure, and control of the proximal radial artery (blue arrow) (b).

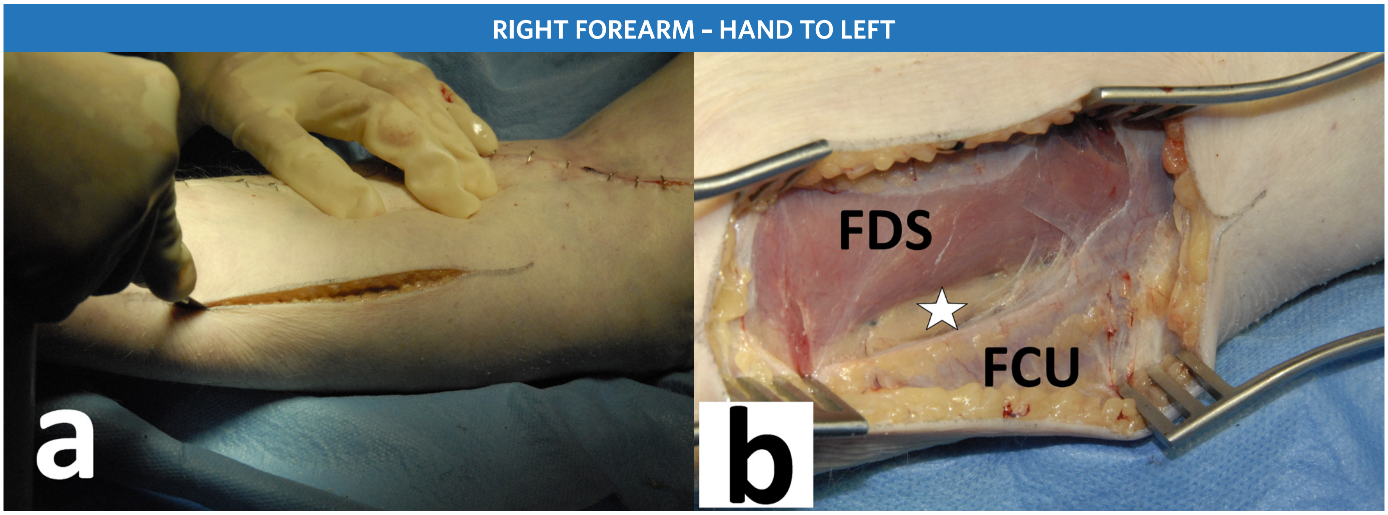


Figure 21. Exposure of the ulnar artery in the forearm is accomplished by an incision along the ulnar side of the volar forearm (a). Exposure of the fat pad (white star) between the flexor digitorum superficialis (FDS) and flexor carpi ulnaris (FCU) muscles (b).

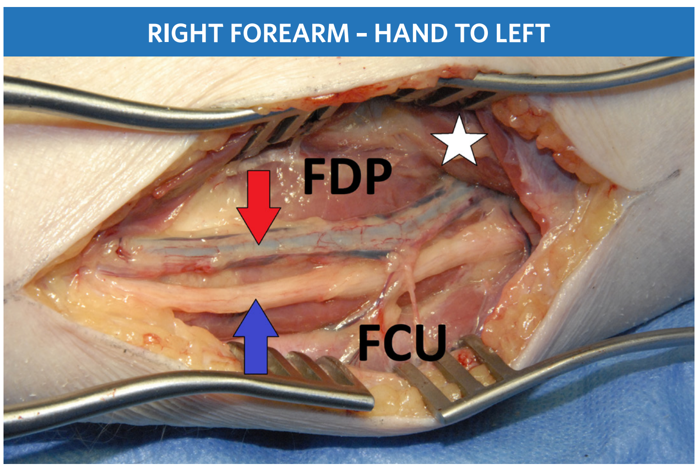


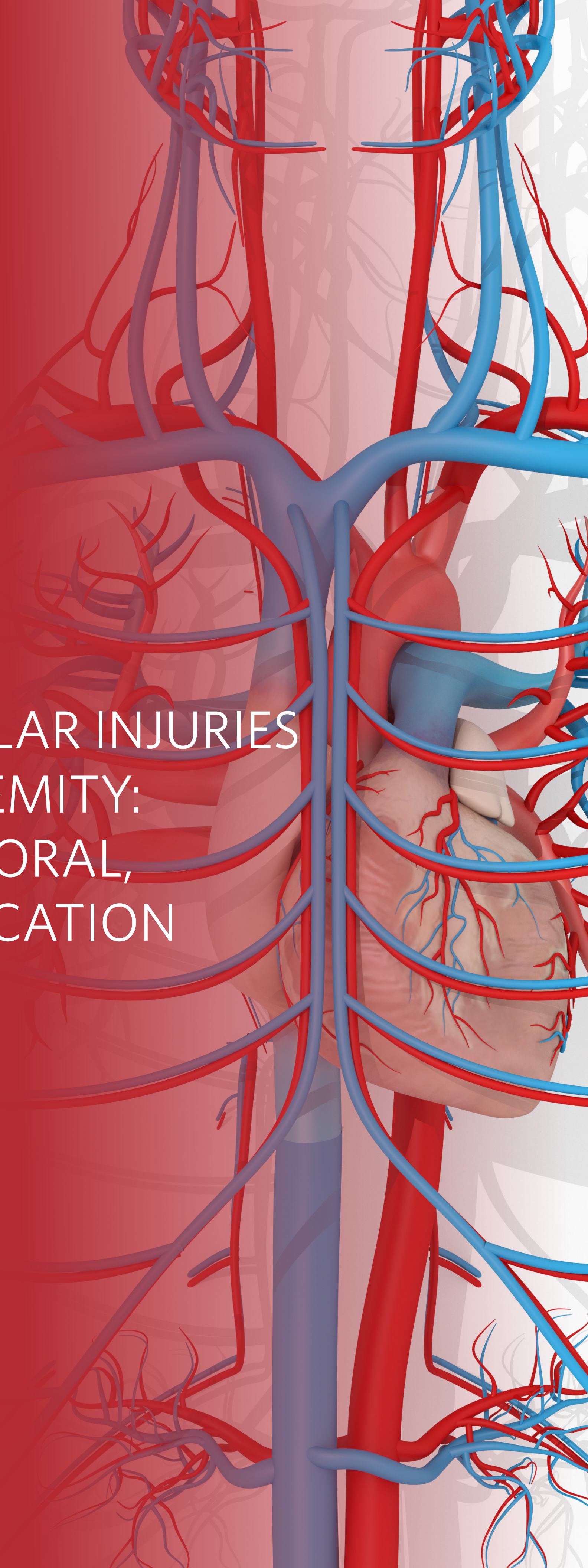
Figure 22. Retraction of the flexor digitorum superficialis (star) and dissection of the fat pad between it and the flexor carpi ulnaris (FCU) exposes the ulnar nerve (blue arrow), as well as the ulnar artery and accompanying veins (red arrow), which lie on top of the flexor digitorum profundus (FDP) muscle.

Pitfalls

- The ulnar artery and nerve run closely together in the distal forearm. The nerve can be damaged by careless dissection.
- The ulnar artery in the mid forearm may be covered by significant muscle in muscular individuals. An injury to the ulnar artery may be missed if the artery is not fully exposed.
- Upper extremity fasciotomy should be considered with long ischemia times or in cases where the brachial artery is ligated (chapter 5).

CHAPTER 3

EXPOSURE OF VASCULAR INJURIES TO THE LOWER EXTREMITY: ILIAC, COMMON FEMORAL, AND FEMORAL BIFURCATION



Exposure of Vascular Injuries to the Lower Extremity: Iliac, Common Femoral, and Femoral Bifurcation

This chapter will discuss techniques for exposure and proximal control of injuries to the vasculature of the lower extremity, from the iliac arteries to the femoral artery and its bifurcation. Though the major emphasis of this lab is operative exposure, the topics of preoperative considerations, positioning, and management of specific injuries will be briefly discussed.

Learning Objectives

By the end of the ASSET course, participants should be able to do the following:

1. Describe and demonstrate the groin incision used to gain exposure of the common femoral, profunda femoral, and superficial femoral arteries.
2. Demonstrate surgical exposure of the iliac artery and vein in the retroperitoneum using an incision above the inguinal ligament.
3. Demonstrate further exposure of the iliac and common femoral arteries by extension of the above incision across the inguinal ligament and down onto the leg ("hockey stick" incision).

General Considerations

- Exposure of the vessels of the pelvis and lower extremities is needed for definitive bleeding control and for preparation for reconstruction of damage to lower extremity vasculature.
- Ligation of the internal iliac vessels can also be used as a damage control adjunct for uncontrolled hemorrhage accompanying a pelvic fracture.
- Preoperatively, bleeding should be controlled with direct pressure.
- Blind clamping of structures should be avoided in the emergency department, as this often results in additional injury.

Prepping and Positioning

- Patients should be prepped and draped from "neck to knees" to ensure adequate breadth of field. The involved leg(s) should be prepped to include the foot to allow for evaluation of distal flow and fasciotomy if indicated.
- Access to bilateral groins should be anticipated for saphenous vein graft harvesting.
- For femoral and iliac exposure, the patient should be supine.
- If time permits, a small roll may be placed under the buttock of the operative side to elevate the pelvis 10–15° to aid exposure.
- For femoral exposure, the thigh should be in abduction and in slight external rotation.

EXPOSURE OF THE ILIAC ARTERY AND VEIN

Common Iliac

- Access to the common iliac for emergent control of bleeding is best accomplished through the abdomen, a process covered in chapter 19.

External Iliac

- Though the external iliac can be exposed via a transabdominal approach with entry into the pelvis, it is often more expedient to gain control from a retroperitoneal approach above the inguinal ligament, especially if proximal control is needed.
- The classic injury in which the retroperitoneal approach is useful is injury to the femoral artery just below the inguinal ligament (the "Blackhawk Down" injury), which requires rapid proximal control.
- A curvilinear incision (similar to the incision used during kidney transplantation) is made from a point about one to two fingerbreadths above the anterior superior iliac spine (ASIS) and extending to a point just above the inguinal ligament (Figure 1).

RIGHT GROIN WITH HEAD TO UPPER LEFT

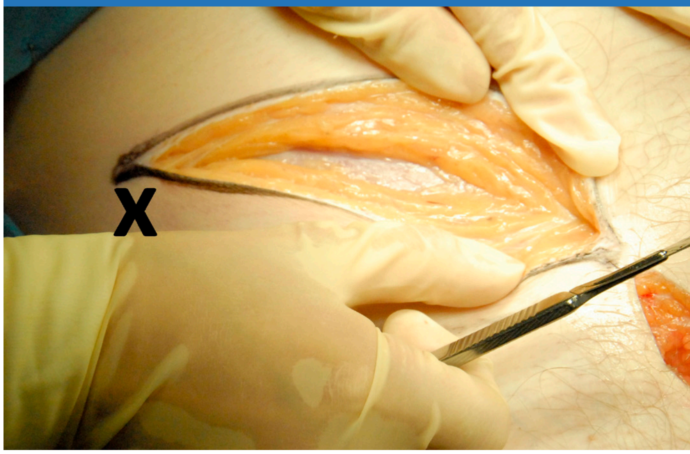


Figure 1. The incision to gain retroperitoneal exposure of the iliac vessels extends in a curvilinear fashion from above the ASIS (X) to just above the inguinal ligament.

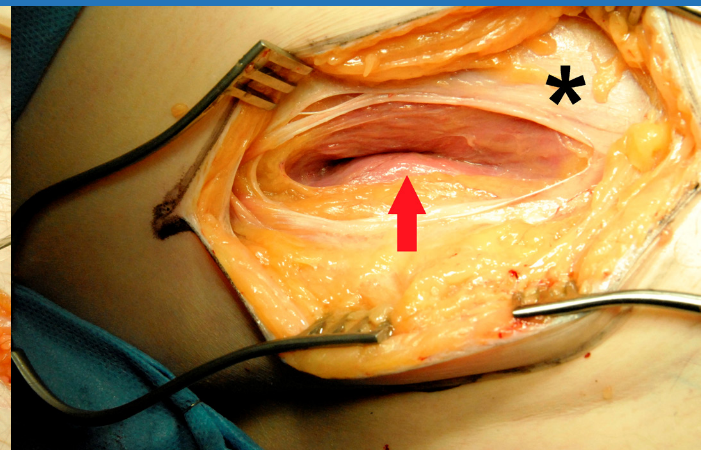


Figure 2. The external oblique fascia (*) is divided, and the external and internal oblique muscles (arrow) are separated in a muscle-splitting fashion to enter the retroperitoneal space.

LEFT GROIN WITH HEAD TO RIGHT

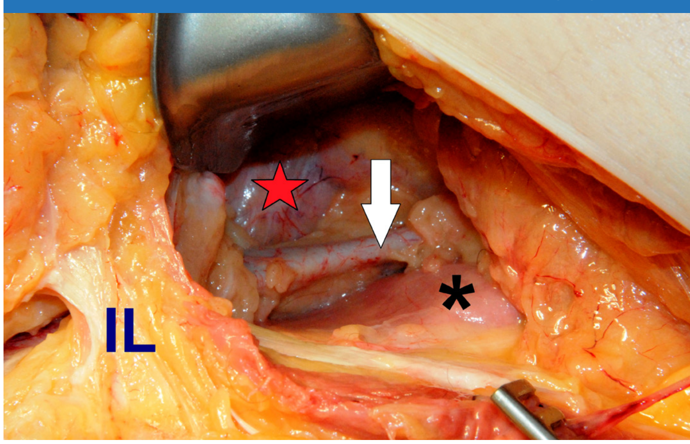


Figure 3. The peritoneum (star) is retracted medially to expose the iliac artery (arrow) above the inguinal ligament (IL) and medial to the psoas muscle (*).

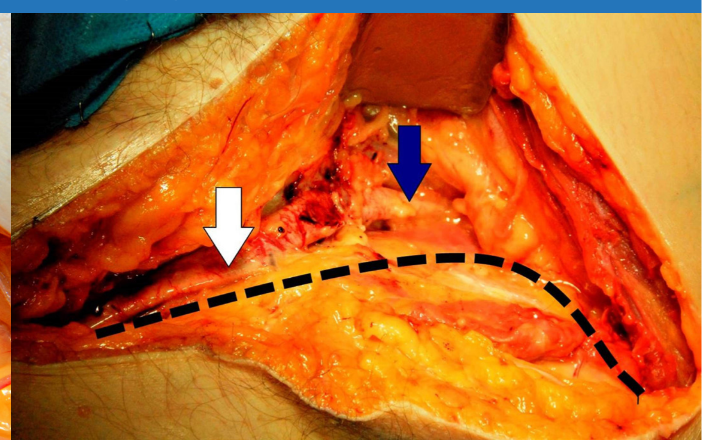


Figure 4. The incision is extended across the inguinal ligament onto the thigh to create the so-called "hockey stick" incision, allowing for exposure of the iliac (blue arrow) and common femoral (white arrow) arteries.

- This incision is carried down through the skin and subcutaneous tissues to expose the external oblique fascia. The fascia is incised, and the oblique transversus muscles, as well as the transversalis fascia, are opened laterally while avoiding entry into the peritoneum. This dissection allows entry into the retroperitoneal space (Figure 2).
- The peritoneum is left intact and retracted medially to allow exposure of the pelvic retroperitoneal space and control of the iliac vessels (Figure 3).
- If needed, this incision can be extended down onto the thigh by dividing the inguinal ligament ("hockey stick" incision), allowing exposure of the distal external iliac and proximal common femoral arteries (Figure 4).

Potential Pitfalls to the Retroperitoneal Approach

- Injury to iliac veins and branches
- Injury to ureters
- Injury to spermatic cord
- Iatrogenic injury to inferior epigastric or circumflex iliac branches when dividing the inguinal ligament (and failure to recognize these injuries)

COMMON FEMORAL ARTERY AND VEIN

Exposure

- The femoral artery runs from the inguinal ligament (Poupart's ligament), through the adductor (Hunter's) canal, to the popliteal fossa.
- The femoral artery lies superficially at the inguinal ligament and becomes deeper and more medial along its course to the eak popliteal fossa.
- The inguinal ligament, which courses from the ASIS to the pubic tubercle, is used to define the upper limit of the incision (Figure 5).
- A common mistake is to believe that the crease where the lower abdominal skin joins the groin represents the inguinal ligament. This results in an incision that is made too low onto the thigh and dissection of the underlying superficial femoral artery (SFA) rather than the common femoral artery (CFA).
- The incision to expose the CFA should be made from a point approximately two fingerbreadths lateral to the pubic tubercle and 1–2 cm above the pubic tubercle, extending caudally along the medial border of the sartorius muscle and down onto the upper thigh (Figure 5).
- The edges of the femoral triangle are formed by the inguinal ligament, the medial edge of the sartorius muscle, and the medial border of the adductor longus (Figure 6).
- Expedient exposure of the CFA is an important adjunct for individuals practicing resuscitative endovascular balloon occlusion of the aorta (REBOA), which is described in detail in chapter 22.
- Using the lower edge of the inguinal ligament as a landmark, the femoral vessels are exposed in the femoral triangle (Figure 7).
- Within the femoral triangle, the femoral sheath is opened anteriorly while remaining on top of the femoral artery to expose the CFA and the bifurcation (Figure 8).
- Deep dissection of the artery should be lateral to the saphenous vein and inguinal nodes.

RIGHT GROIN WITH HEAD TO UPPER RIGHT

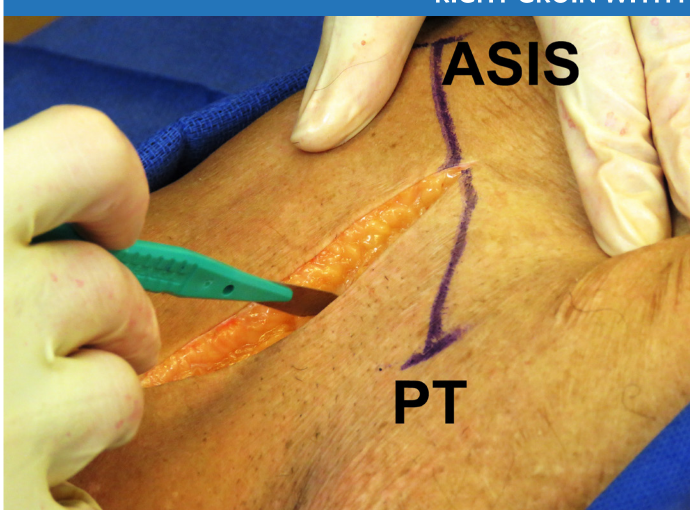


Figure 5. The inguinal ligament (line) runs from the ASIS to the pubic tubercle. The incision to expose the CFA is depicted.

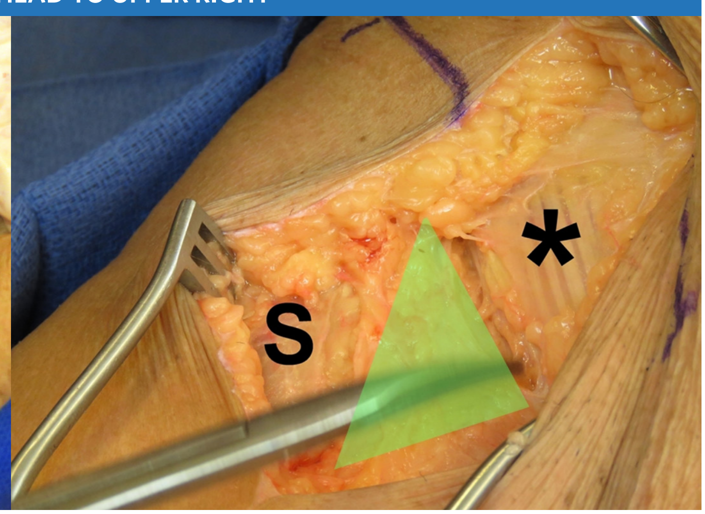


Figure 6. The lower edge of the inguinal ligament (*) and the medial edge of the sartorius muscle (S) form two of the borders of the femoral triangle (green triangle), which contains the femoral neurovascular structures.

RIGHT GROIN HEAD AT TOP

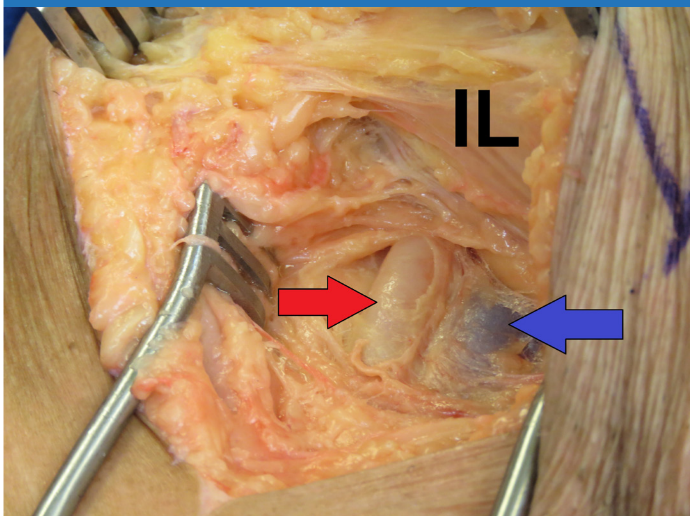


Figure 7. The CFA (red arrow) and the femoral vein (blue arrow) are found in the femoral triangle just below the inguinal ligament (IL).

RIGHT GROIN HEAD TO LEFT

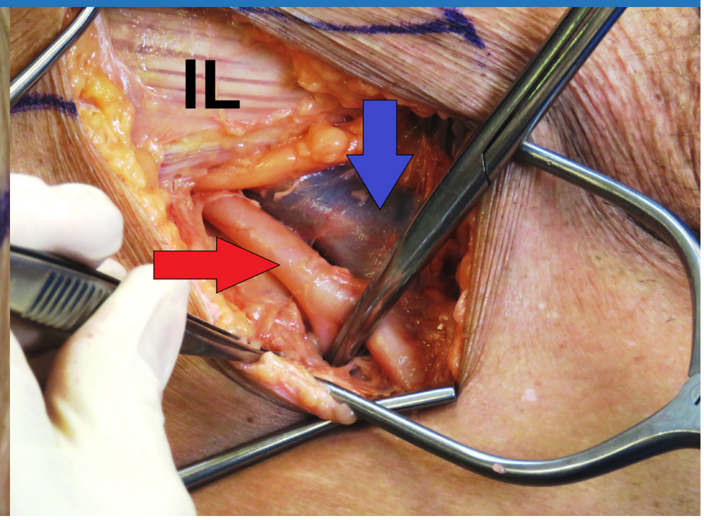


Figure 8. Further dissection in the femoral triangle on top of the CFA (red arrow) and the femoral vein (blue arrow) enables exposure.

PROFUNDA AND PROXIMAL SUPERFICIAL FEMORAL ARTERY

Anatomy

- The profunda femoris (deep femoral) artery (PFA) is the largest branch of the CFA and is usually found 4–6 centimeters below the inguinal ligament. It follows a posterolateral course (Figure 9).
- The superficial femoral artery (SFA) is a continuation of the CFA. It descends into the adductor (Hunter's) canal from the femoral triangle and courses anteromedially through the thigh to the popliteal fossa.
- The lateral femoral circumflex vein (often referred to as the "vein of woe") crosses the origin of the PFA and should be avoided, as it is easily injured and will bleed profusely (Figure 9).

RIGHT GROIN WITH HEAD TO LEFT, FOOT TO RIGHT

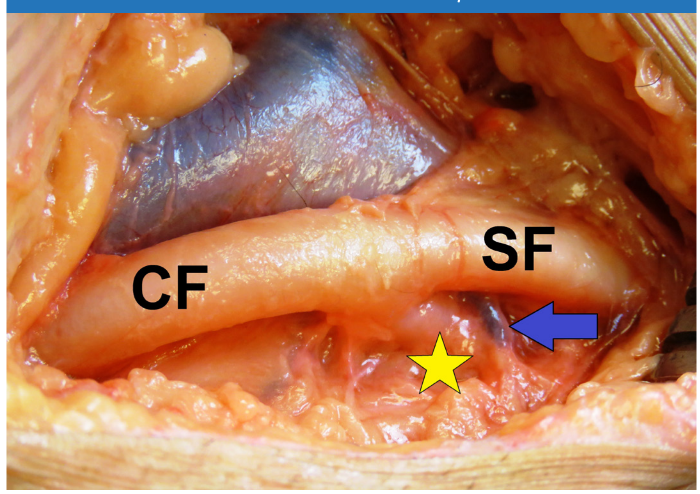


Figure 9. The common femoral (CF) artery has been dissected below the inguinal ligament, revealing its bifurcation into the superficial femoral (SF) and profunda femoris (yellow star) arteries lateral to the large femoral vein. The lateral femoral circumflex vein (blue arrow) is found close to the origin of the PFA and can be easily injured during attempted dissection.

Exposure of the SFA and PFA

- The CFA and SFA are gently dissected free from the surrounding tissues, while staying close to the vessel.
- The origin of the PFA is marked by an abrupt change in the diameter of the CFA (Figure 9) and is typically found 4–6 cm below the inguinal ligament.
- Upward traction on the CFA and SFA with vessel loops can help locate the origin of the PFA.
- Rather than dissecting out the PFA and risking injury to the lateral femoral circumflex vein, it is safer to encircle the origin of the vessel by passing a vessel loop or tape under the CFA above the PFA and passing the other end under the SFA to encircle and control the origin of the PFA without actually dissecting it free (Figures 10–12).
- This technique is shown in a detailed, stepwise fashion in Figure 11.
- Using this technique, the CFA, SFA, and PFA can all be controlled with vessel loops while avoiding injury to the lateral femoral circumflex vein (Figures 11 and 12).
- In hemodynamically stable patients, the proximal PFA should be repaired because of its collateral supply to the lower extremity; however, it may be ligated in unstable patients, if necessary.
- The SFA supplies a significant portion of blood flow to the lower leg, and ligation of this vessel is likely to result in critical ischemia and/or amputation. As such, it should be repaired or, in unstable patients, shunted. If possible, the superficial femoral vein should also be repaired or shunted as well.
- Patients with injuries to the femoral vessels are at increased risk of compartment syndrome, and strong consideration should be given to performing a fasciotomy of the lower leg.

Potential Pitfalls to Exposure of the Femoral Vessels

- If the groin crease is mistaken for the inguinal ligament, the incision will be made too low for adequate exposure of the CFA. The SFA will then be mistaken for the CFA.
- Femoral vein injury if dissecting too far medially
- Femoral nerve injury if dissecting too far laterally

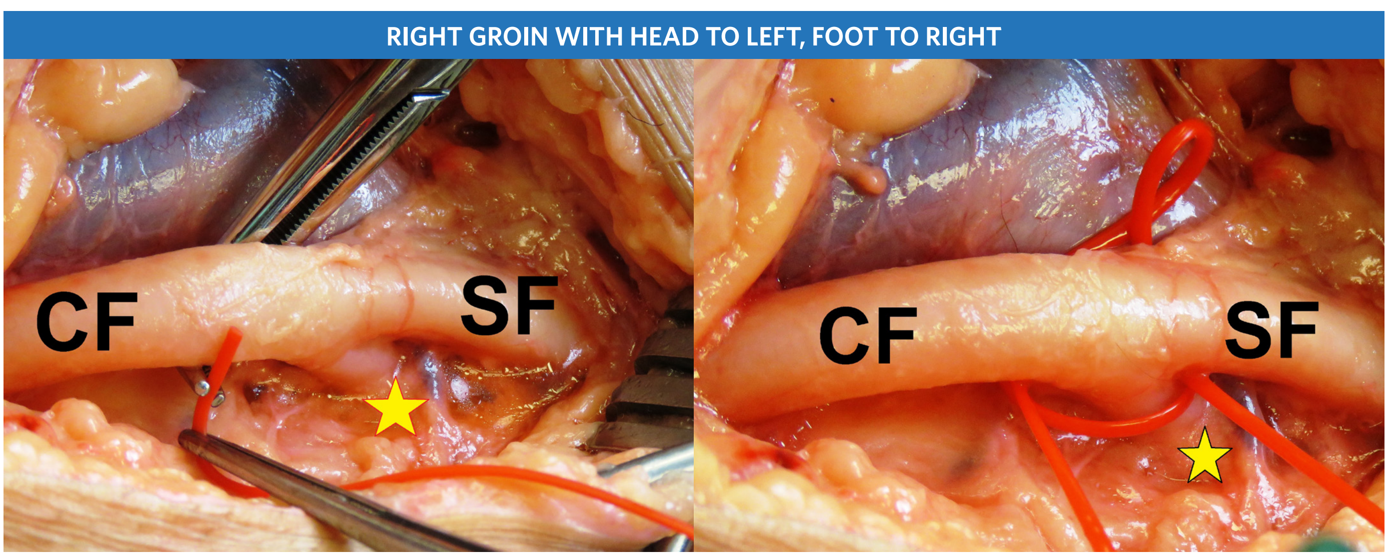


Figure 10. A vessel loop is passed under the common femoral (CF) artery above the PFA (yellow star), as seen on the left, and then under the superficial femoral (SF) artery, allowing for control of the PFA at its origin without further dissection, as seen on the right.

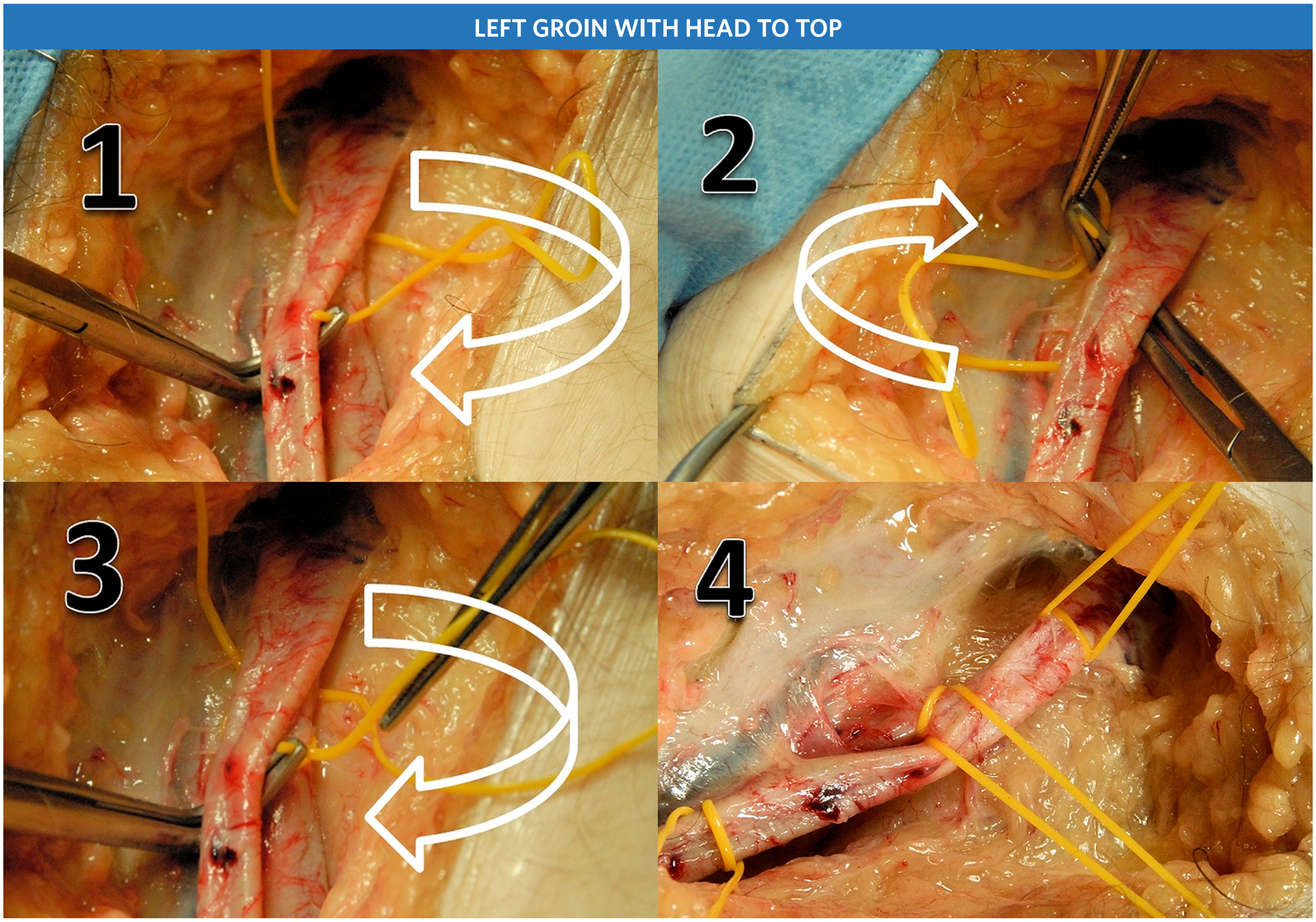


Figure 11. The technique to control the origin of the PFA without dissecting it out is detailed above (in the left groin). Step 1 involves passing a vessel loop under the CFA cephalad to the PFA from medial to lateral and then under the SFA caudal to the origin of the PFA. In steps 2 and 3, the vessel loop is used to encircle the origin of the PFA twice. Step 4 involves looping both the SFA and CFA to control all three vessels.

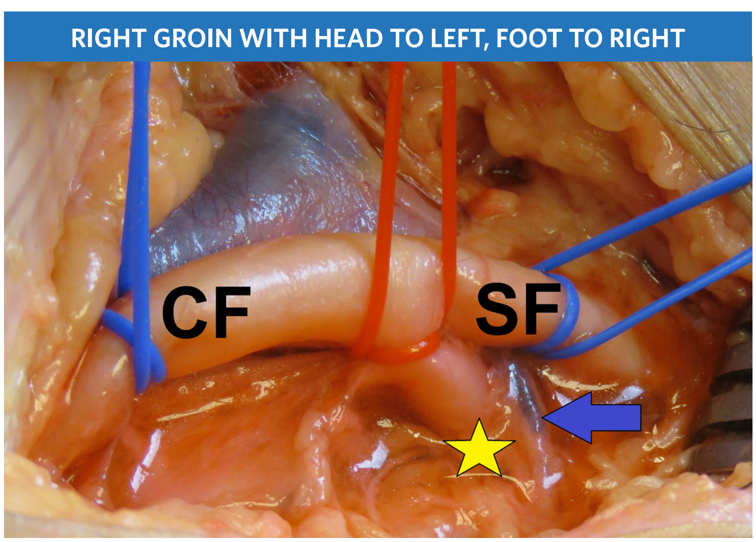
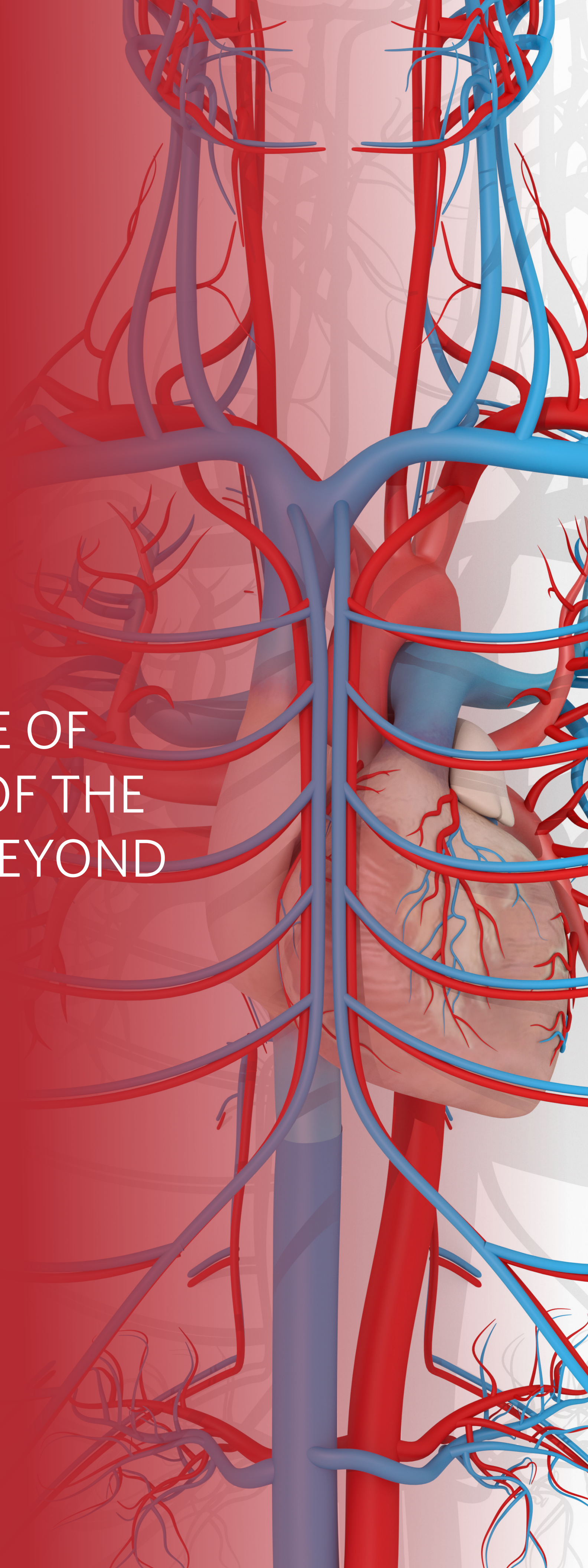


Figure 12. Vessel loops (or vascular clamps) can be used to obtain control of the common femoral artery (CF), profunda (yellow star), and superficial femoral (SF) arteries thus obtaining proximal vascular control prior to exposure and repair of more distal injuries. The lateral femoral circumflex vein (blue arrow) is also well seen in this picture.

CHAPTER 4
OPERATIVE EXPOSURE OF VASCULAR INJURIES OF THE LOWER EXTREMITY: BEYOND THE BIFURCATION



Operative Exposure of Vascular Injuries of the Lower Extremity: Beyond the Bifurcation

This chapter will discuss techniques for exposure of injuries to the vasculature of the lower extremity beyond the bifurcation of the femoral artery down the leg. Though the major emphasis is operative exposure, the topics of perioperative considerations, positioning, and management of specific injuries will also be briefly discussed.

Learning Objectives

By the end of the ASSET course, participants should be able to do the following:

1. Describe proper patient positioning for distal superficial femoral and popliteal artery exposure.
2. Demonstrate surgical exposure of the distal superficial femoral artery at the adductor hiatus.
3. Demonstrate surgical exposure of the popliteal artery above and below the knee using a medial approach.
4. Demonstrate surgical exposure of the trifurcation vessels below the knee.

Considerations

- Incisions should be generous enough to allow proximal and distal control of the injured vessel(s).
- Self-retaining retractors are helpful, especially when adjusted at each level of exposure.
- Dissection should progress directly down to the vessel surface, followed by circumferential dissection once the vessel is identified. This approach helps avoid injury to associated structures (smaller branch vessels) and allows safe dissection of the vessel from its natural bed.
- The posterior approach to the popliteal artery is described in elective vascular surgery but does not have a role in the acute management of traumatically injured patients.
- Injuries to the vessels around the knee have a high likelihood of developing compartment syndrome, and therefore a low threshold should be maintained to perform fasciotomy. If fasciotomy is to be performed, the incision placed below the knee to expose the popliteal should also be used for medial fasciotomy.

Prepping and Positioning

- Extensive skin preparation and sterile draping are needed to ensure adequate proximal and distal access to the injured vessel(s).
- The groin, the abdomen up to the xiphoid, and both lower extremities (including the feet) should be prepped and draped.
- Do not tuck the arms. Both arms should be abducted to allow more room for the operating surgeon and to provide vessel access for anesthesia. Ensure that the table and positioning will allow for fluoroscopy without breaking the sterile field.
- Place the patient in a supine, anatomic position with full access to both lower extremities. There is no role for prone positioning in the acute care of a trauma patient with popliteal injury.
- Hip abduction and slight lateral rotation improve access to the saphenous vein and the popliteal vessels when using the medial approach.
- Placing a bump, usually a stack of several sterile towels, under the knee helps maintain appropriate positioning (Figure 1).

Figure 1. Proper positioning of the right leg for exposure of the distal superficial femoral artery and the popliteal artery above and below the knee is accomplished by abduction and slight rotation of the hip and by the placement of a bump under the knee.

Exposure of the Distal Superficial Femoral Artery (SFA)

- The SFA is a continuation of the common femoral artery that descends into the subsartorial canal on the anteromedial aspect of the thigh and then into the popliteal canal.
- Proximal control of the SFA and the common iliac artery may be necessary and is described in chapter 3.
- Full exposure of the SFA is most easily achieved through an incision that parallels the inferior border of the sartorius muscle (Figure 2).
- The blood supply to the sartorius muscle (found on the muscle's inferior medial border) should be preserved if possible, as this is the vascularized tissue of choice for coverage of SFA repair when there has been significant tissue loss (Figure 3).
- The adductor hiatus (Hunter's or popliteal canal) is a fascial cleft located medial to the vastus muscles and lateral to the adductor muscles in the mid-thigh.
- The sartorius is retracted medially to expose the roof of the adductor (Hunter's) canal; this allows subsequent unroofing of the canal and exposure of the superficial femoral vessels (Figure 4).
- The saphenous nerve should be identified and protected during dissection.
- After exiting the adductor hiatus, the SFA becomes the suprageniculate popliteal artery.

LEFT MEDIAL THIGH JUST ABOVE KNEE

Figure 2. The superficial femoral artery is exposed in the mid-thigh through an incision that parallels the sartorius muscle.

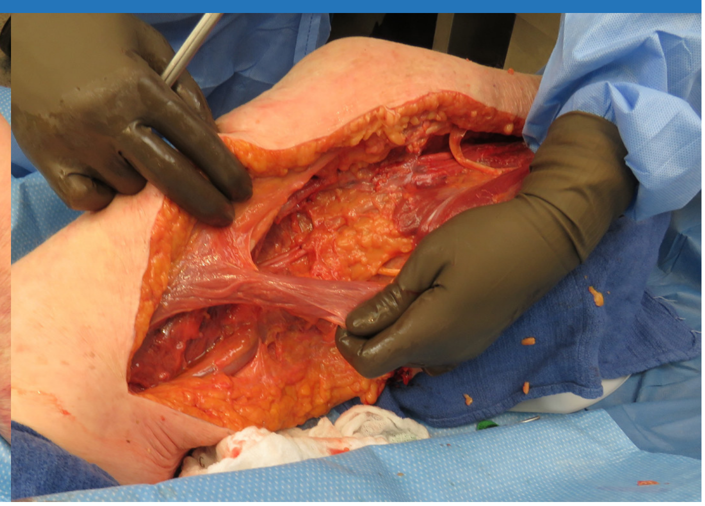


Figure 3. The sartorius muscle can be used as a vascularized flap to cover vascular repairs.

LEFT MEDIAL THIGH JUST ABOVE KNEE

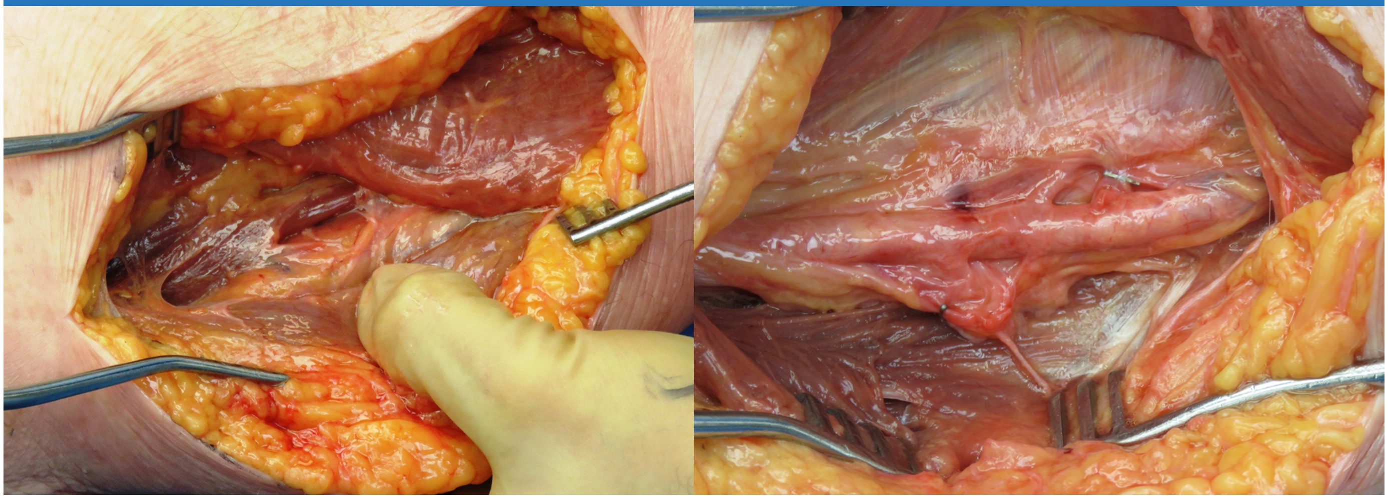


Figure 4. The adductor canal is unroofed, allowing for exposure and control of the SFA in the mid-thigh.

Potential Pitfalls

- Injury to the SFA may result in significant bleeding or hematoma that precludes a standard groin incision and dissection.
- In such circumstances, it may be necessary to gain control more proximally, as described in the previous chapter.
- Once bleeding is controlled (by direct pressure or pneumatic tourniquet, if available), proximal dissection and control is performed, followed by distal dissection and control.
- Venous injury often accompanies arterial injury. After arterial control is gained, the venous injury will need to be addressed before formal repair of the artery.
- If there is an injury to the deep vein(s), then ligation, shunting, or repair—depending on the injury and patient's physiologic status—should be performed prior to restoration of arterial flow, as significant bleeding may ensue.

POPLITEAL ARTERY EXPOSURE

Anatomy

- The popliteal artery is a direct continuation of the SFA, coursing posteriorly behind the knee and splitting into the anterior tibial artery and tibioperoneal trunk (TPT).
- The SFA becomes the popliteal artery once it exits the adductor (Hunter's) canal and runs in close proximity to the joint capsule of the knee as it spans the intercondylar fossa.
- The popliteal artery gives off five genicular branches that supply the knee joint capsule and ligaments.
- Below the knee, the popliteal artery is sandwiched between the gastrocnemius and popliteus muscles, with the anterior tibial artery branching off at the lower border of the popliteus muscle.
- From a medial perspective, the semitendinosus (and its confluence with the gracilis and sartorius muscles to form the pes anserinus) and semimembranosus muscles cover the popliteal fossa and popliteal vessels.
- A small fat pad lies between the knee joint and the popliteal vessel sheath. Dissection of this fat pad aids in the identification, mobilization, and control of the vessels.
- The suprageniculate popliteal artery and vein are enclosed in a common sheath, with the artery found anterior in more than 90 percent of individuals.
- The popliteal veins are adherent to the popliteal artery with very little space between them, which can make the dissection tedious.

Exposure of the Popliteal Artery above the Knee

- With the leg positioned as in Figure 1, a generous skin incision is made on the medial aspect of the lower thigh in the palpable groove between the vastus medialis and sartorius muscles.
- The incision is carried down through the skin and subcutaneous tissues, keeping the saphenous vein in the posterior flap.
- Injury to the saphenous vein should be avoided if possible, as it is an important outflow vessel for the lower extremity.
- The vastus medialis and sartorius are identified with the popliteal fat pad containing the vascular sheath found between the muscle bellies (Figure 5).
- The distal adductor canal is opened by dividing the intermuscular fascia between the vastus medialis and the sartorius. Occasionally, the tendon of the adductor magnus muscle must also be divided.
- The popliteal artery is usually deeper than expected, being well-protected behind the femur.
- One way to quickly find the vascular sheath is to bluntly insert a forefinger into the popliteal fossa fat pad just above the sartorius muscle and push the finger across the thigh. The finger is then flexed such that the tip touches the underside of the femur. In this manner, the popliteal vascular sheath can be "hooked" with the finger and gently elevated into the wound (Figure 6).
- When opening the vascular sheath above the knee, the first structure that will be encountered is the popliteal artery, as it is found medial to the vein (Figure 7).
- The popliteal vein is carefully dissected free from the artery, taking care to preserve the small network of veins surrounding the artery, as well as the genicular arteries, of which there are three in the popliteal fossa.

RIGHT MEDIAL THIGH JUST ABOVE KNEE (TO LEFT)

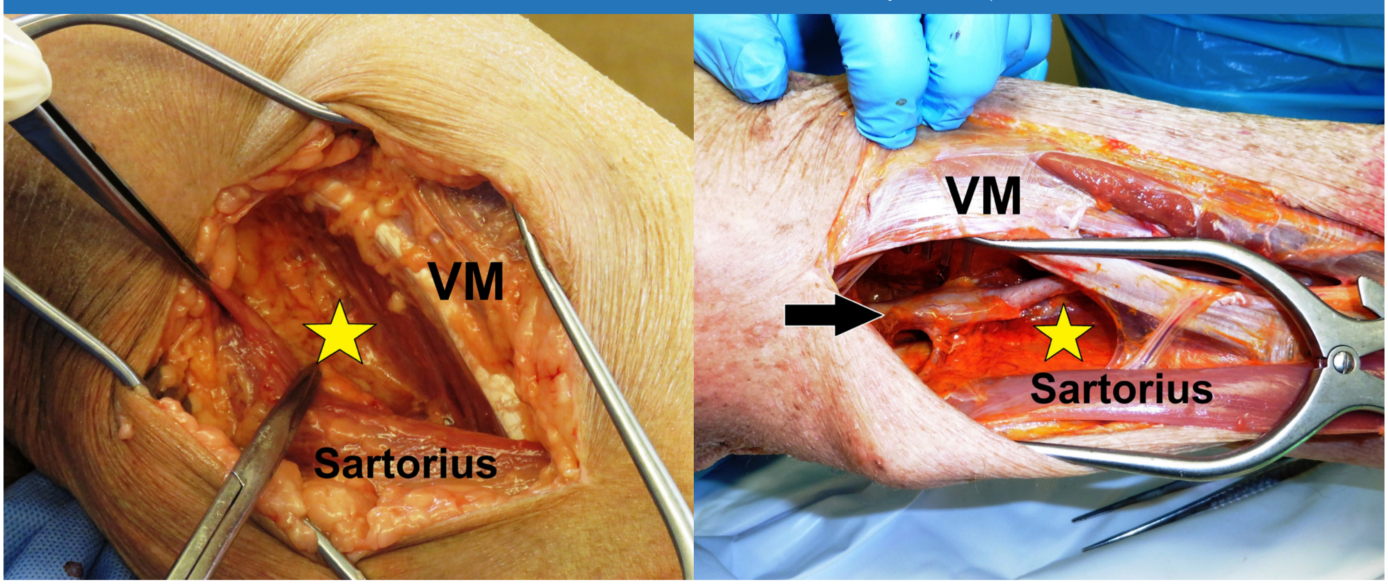


Figure 5. The suprageniculate popliteal artery is found between the vastus medialis (VM) and sartorius muscles on the lower medial thigh. The popliteal fossa fat pad (star) is found between the muscle bellies and is the gateway to exposing the vascular sheath (arrow).

RIGHT MEDIAL THIGH JUST ABOVE KNEE (TO LEFT)

Figure 6. The popliteal vascular sheath is "hooked" by gently inserting the index finger into the popliteal fossa fat pad and flexing the finger up and under the femur to bring the vessels into the wound.

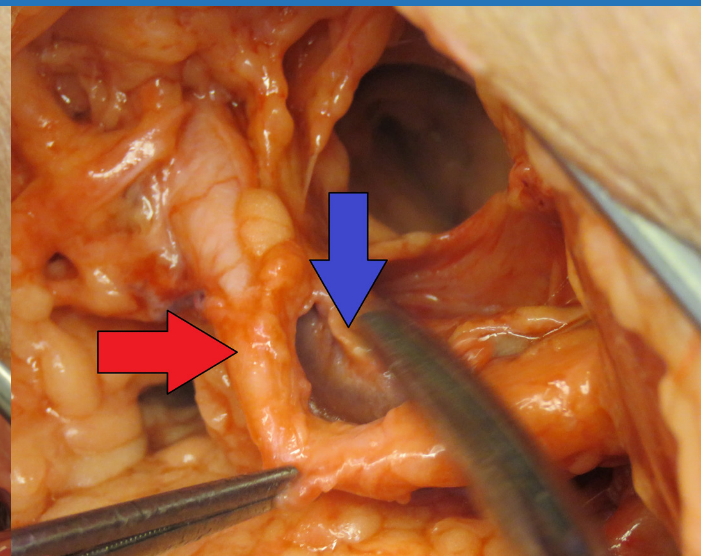


Figure 7. The popliteal vascular sheath is opened to first reveal the popliteal artery (red arrow) medially, which is dissected carefully away from the popliteal vein (blue arrow).

Exposure of the Popliteal Artery below the Knee

- Exposure of the popliteal artery below the knee is usually accomplished through a separate incision.
- The leg is positioned as in Figure 1. The incision that is classically described to expose the infrageniculate popliteal artery is made 1–2 cm distal to the medial femoral condyle and 1 cm (a thumb width) behind the tibia; it measures about 10 cm in length (Figure 8).
- In the setting of vascular injury to the popliteal artery, there is a high likelihood that either a therapeutic or prophylactic fasciotomy will be indicated. If fasciotomy is needed, the incision to expose the infrageniculate popliteal artery should be the same as used to perform a medial fasciotomy (as described in chapter 5).
- Full exposure of the popliteal vessels below the knee requires that the gastrocnemius muscle be retracted inferiorly, the popliteus muscle retracted anteriorly, and the soleus muscle taken down from the tibia (Figures 9–12 and 14).
- Frequently, the distal popliteal vein is represented by anterior and posterior tibial veins that have not yet joined to form a single popliteal vein. Regardless of whether the popliteal vein is single or multiple, the location of the largest vessel will be medial to the artery and will be the first structure encountered (Figures 10, 11, and 13).
- The vein(s) is/are carefully dissected away from the artery after further division of the origin of the soleus from the tibia to expose the anterior tibial artery and the TPT, which subsequently divides into the peroneal and posterior tibial arteries (Figure 12).
- The tibial nerve is located posterior-medial to the vessels and should be avoided throughout the dissection.
- To gain further access to the vessels, the incisions above and below the knee can be connected (Figure 15).
- Division of these medial tendons can be safely performed with little postoperative disability if re-approximation is accomplished at the end of the case.

LEFT MEDIAL LOWER LEG - KNEE TO LEFT

Figure 8. The infrageniculate popliteal vessels are exposed through an incision made one thumb behind the tibia on the medial lower leg, just below the knee.

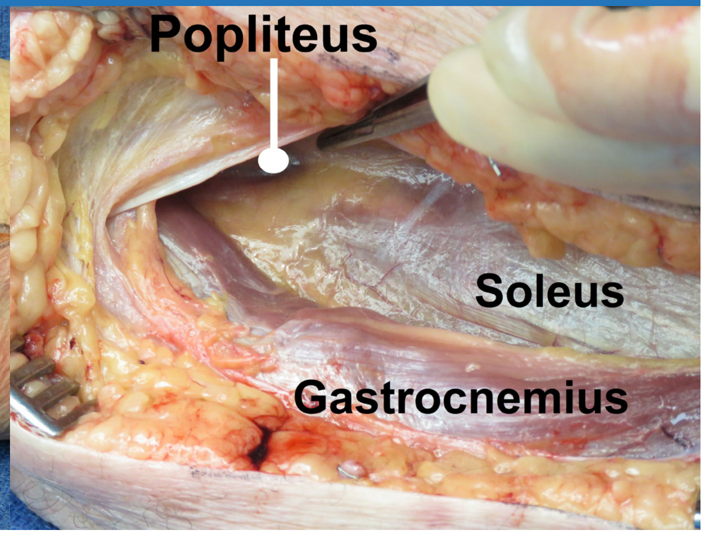


Figure 9. The gastrocnemius muscle is retracted inferiorly and the popliteus muscle is retracted anteriorly to expose the fibers of the soleus muscle.

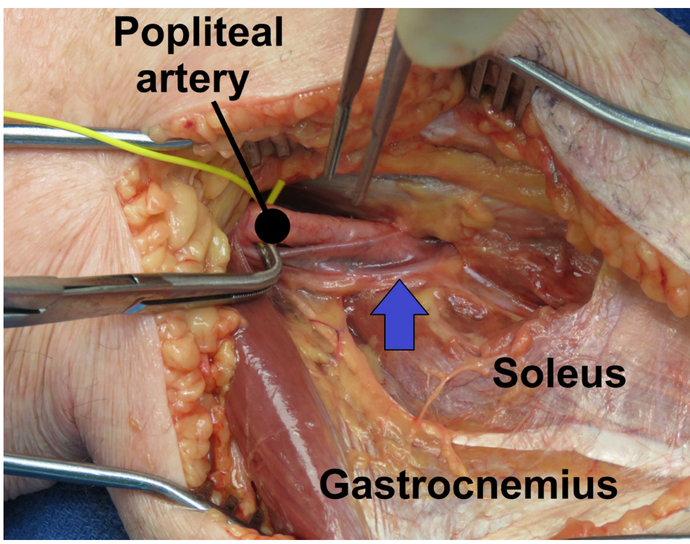


Figure 10. The soleus muscle fibers have been partially taken down from the tibia allowing exposure of the infrageniculate popliteal artery. The artery is found deep to the popliteal vein (blue arrow), which must be gently dissected from the artery.

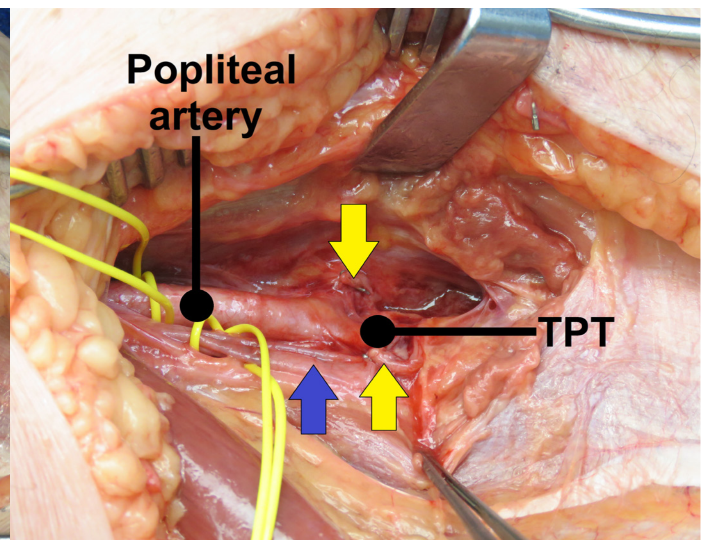


Figure 11. Dissection of the popliteal vein (blue arrow) off of the artery and division of the anterior tibial vein (cut ends represented by yellow arrows) further expose the popliteal artery and its division into the anterior tibial artery and tibioperoneal trunk (TPT).

LEFT MEDIAL LOWER LEG - KNEE TO LEFT

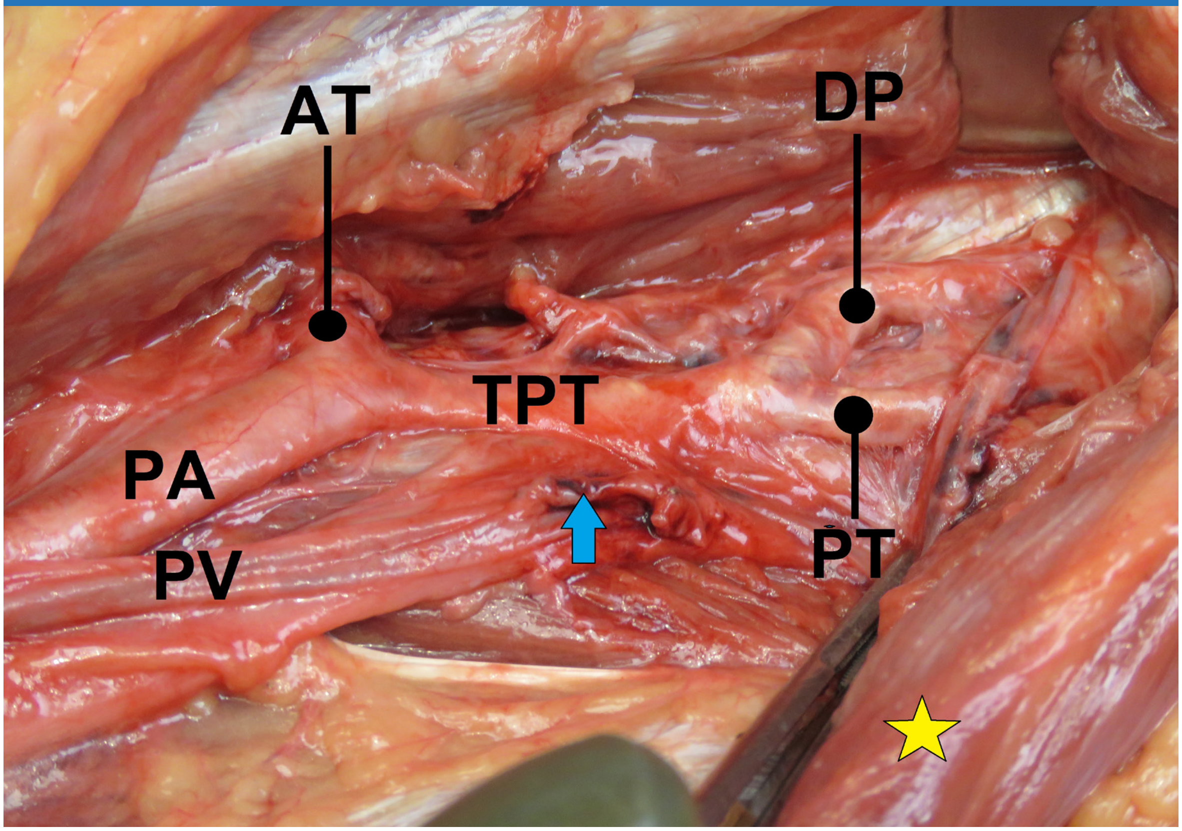


Figure 12. Division of the anterior tibial vein (blue arrow) and further division of the origin of the soleus (yellow star) from the tibia aid in exposure to the distal popliteal artery (PA) and vein (PV). The popliteal artery divides into the anterior tibial artery (AT) and the tibioperoneal trunk (TPT), which subsequently divides into the deep peroneal (DP) and posterior tibial (PT) arteries.

RIGHT MEDIAL LOWER LEG - KNEE TO RIGHT

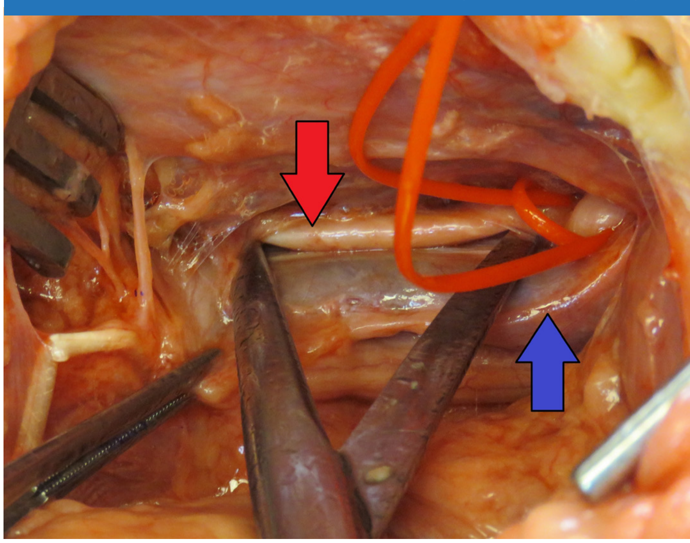


Figure 13. The infrageniculate popliteal vein (blue arrow) is encountered first and gently dissected away from the popliteal artery (red arrow).

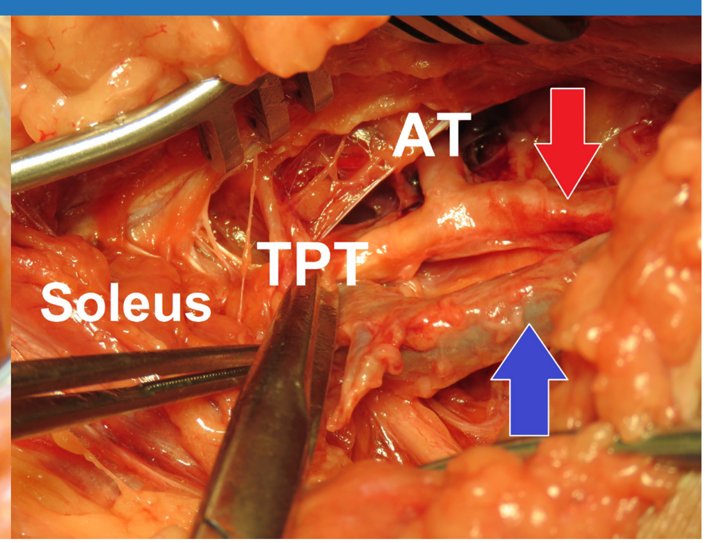


Figure 14. Further division of the soleus muscle fibers from the underside of the tibia further delineates the popliteal vein (blue arrow) and the popliteal artery (red arrow) as it branches into the anterior tibial (AT) and tibioperoneal trunk (TPT).

LEFT MEDIAL LEG - HEAD TO LEFT

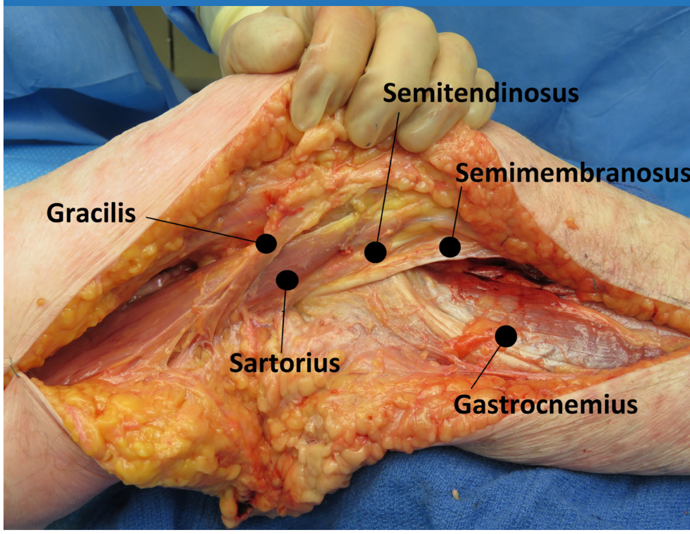


Figure 15. The incisions above and below the knee can be joined with exposure of the pes anserinus (composed of the gracilis, sartorius, and semitendinosus tendons) and the semimembranosus tendon, which can then be divided for further exposure.

RIGHT MEDIAL LEG - HEAD TO RIGHT

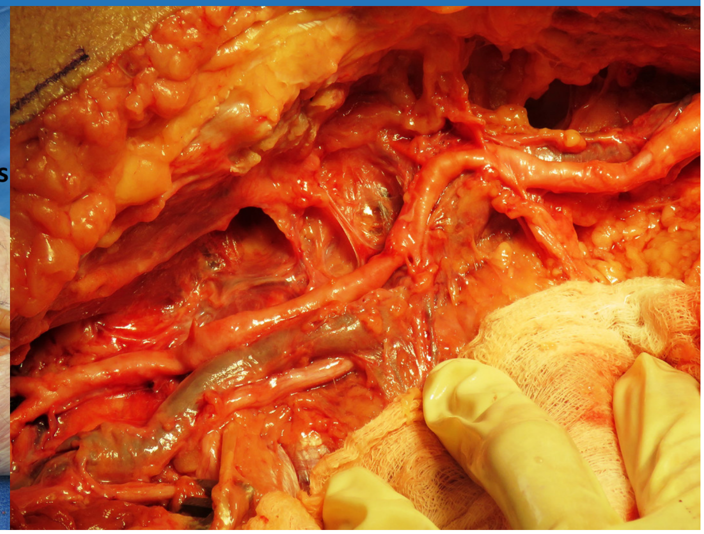


Figure 16. The entire lengths of the popliteal vessels are exposed on the medial aspect of the right leg above and below the knee after taking down the medial tendons.

- The pes anserinus, which is composed of the conjoined tendons of the sartorius, gracilis, and semitendinosus, is divided along with the tendon of the semimebranosus muscles (Figure 15) to fully expose the length of the popliteal vessels (Figure 16).

Arterial Trifurcation and Beyond

- The trifurcation is exposed as described above, by identifying the infrageniculate popliteal artery as it crosses over the popliteus muscle between the gastrocnemius and soleus muscles (Figures 10–12 and 14).
- The anterior tibial artery is the first branch and comes off just after the popliteal crosses the inferior border of the popliteus muscle (Figures 10–12 and 14). The anterior tibial courses laterally and lies anterior to the interosseous membrane.
- The TPT continues under the soleus muscle and branches into the peroneal (fibular) artery laterally and the posterior tibial artery medially (Figures 12, 14, and 17).
- In roughly 5 percent of the population, there is a true trifurcation, where all three leg vessels branch from the distal popliteal artery.
- Only one intact vessel to the foot is needed to ensure tissue viability. The posterior tibial, anterior tibial, and peroneal (fibular) arteries have extensive collateral connections.
- The mid-portion and distal anterior tibial artery can be exposed through an incision on the lateral aspect of the leg made one finger in front of the fibula, in the same manner (though shorter) than the incision used for fasciotomy of the lower extremity (see chapter 5).
- The anterior compartment is opened and the anterior tibial neurovascular bundle is exposed by developing a plane between the tibialis anterior and extensor digitorum longus muscles (Figure 18).

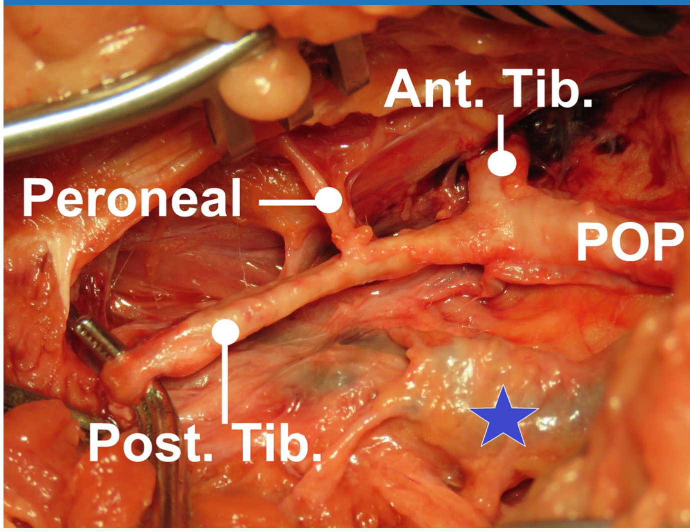
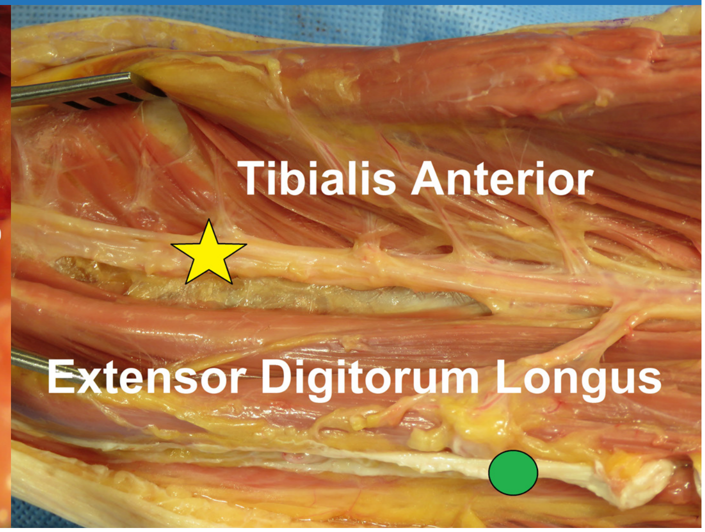
RIGHT MEDIAL LOWER LEG	LEFT LATERAL LOWER LEG
	

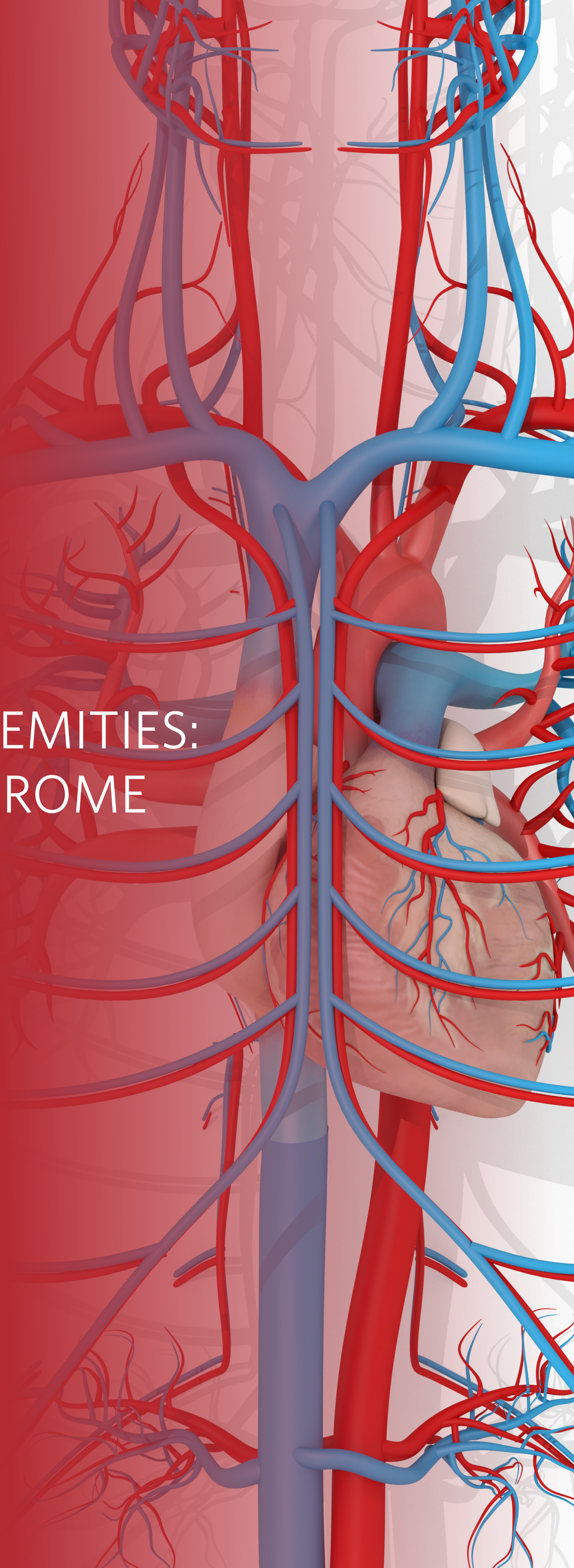
Figure 17. The distal branches of the right popliteal (POP) artery include the anterior tibial (Ant. Tib.), peroneal, and posterior tibial (Post. Tib.) arteries. The popliteal vein (star) has been dissected free.

Figure 18. The anterior tibial artery (star) is exposed on the lateral aspect of the lower leg in the anterior compartment, where it is found between the tibialis anterior and extensor digitorum longus muscles. The intermuscular septum dividing the anterior from the lateral compartment is marked by the green circle.

Pearls and Pitfalls of Popliteal Artery Exposure

- Avoid injury to the saphenous vein. It should remain in the posterior flap of your proximal skin incision.
- Though it is not absolutely necessary to repair muscles and tendons divided for exposure, re-approximation should be considered when the patient's physiology permits.
- Nerve injury is more common below the knee than in the thigh. Try to avoid injury to tibial and common peroneal (fibular) nerves.
- Avoid division of collateral geniculate vessels.
- Keep the salvageability of the limb in mind when dealing with severe popliteal trauma.
- When only one or two of the trifurcation vessels are injured, ligation is a viable option. If the patient is stable or if all three vessels are injured, then exposure and repair should be considered.
- Angiographic embolization is an acceptable alternative to surgical control of hemorrhage, particularly in locations that are difficult to access or in patients who might benefit from a less invasive procedure.
- If repair is needed, it is best accomplished with the help of an experienced vascular or trauma surgeon.
- If experienced vascular help is not available or the patient's physiology does not allow definitive repair, the popliteal vessels can be shunted to maintain limb viability until definitive repair can be accomplished.
- Preoperative or intraoperative angiography is helpful to delineate the distal vasculature and to determine if formal repair or ligation will be needed.
- A proximal pneumatic tourniquet is a useful adjunct to consider.
- The most straightforward solution, using the most accessible artery that provides the best soft tissue coverage, is the ideal.

CHAPTER 5
INJURIES TO THE EXTREMITIES: COMPARTMENT SYNDROME AND FASCIOTOMY



Injuries to the Extremities: Compartment Syndrome and Fasciotomy

This chapter will discuss anatomical considerations and techniques for performing fasciotomies of the upper and lower extremities. Additionally, the pathophysiology and diagnosis of compartment syndrome will be presented.

Learning Objectives

By the end of the ASSET course, participants should be able to do the following:

1. Describe the pathophysiology of compartment syndrome.
2. Describe key elements of clinical assessment for compartment syndrome.
3. Describe tissue pressure measurements consistent with compartment syndrome in the lower extremity.
4. Describe the key anatomical features that enable successful fasciotomy.
5. Demonstrate surgical fasciotomy of the lower leg, utilizing medial and lateral incisions.
6. Demonstrate fasciotomy incisions of the thigh and buttock.
7. Demonstrate fasciotomy of the upper extremity, including the hand.
8. Describe the management of fasciotomy wounds.
9. Describe the pitfalls and potential complications of fasciotomies and untreated or inadequately treated compartment syndrome.

Considerations

- Compartment syndrome (CS) is a limb-threatening—and potentially life-threatening—condition.
- Long-bone fractures and vascular injuries are the most frequent antecedents to CS. Burns, crush injuries, bleeding into a compartment, external compression of the limb, thrombotic or embolic events, ischemia reperfusion, envenomation, electrocution, allergic reactions, intravenous (IV) infiltration, muscle overuse, nephritic syndrome, and intramuscular injection have also been implicated.
- If untreated, CS leads to tissue necrosis (Figure 1), permanent functional impairment, and, in severe cases, renal failure and death.
- CS has been found wherever a compartment is present: hand, forearm, upper arm, abdomen, buttock, thigh, calf, and foot. The lower extremity below the knee is most commonly involved (>60 percent of cases), followed by forearm, thigh, and upper arm.

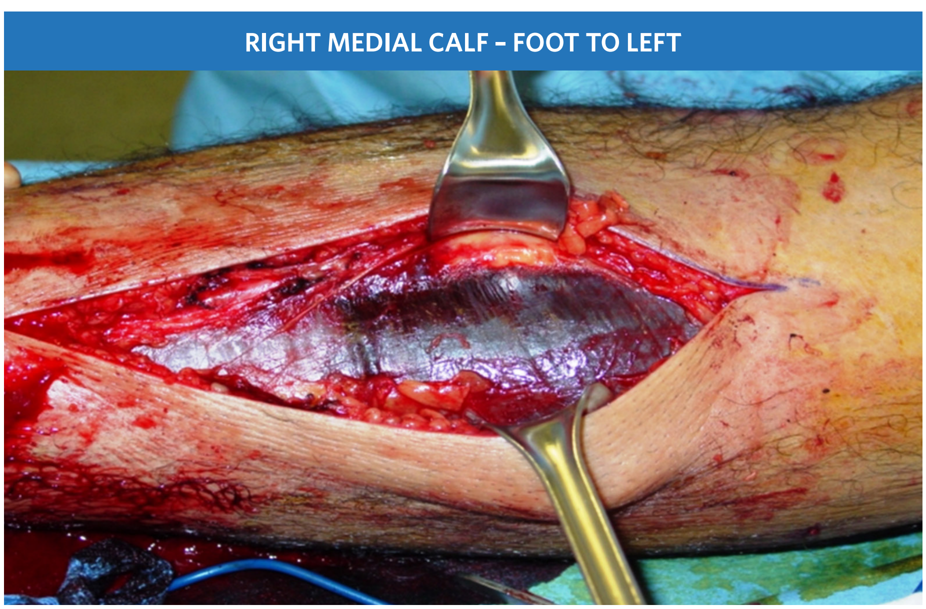


Figure 1. Necrotic muscle is seen below fascia during fasciotomy for CS.

Pathophysiology

- Groups of muscles (with associated nerves and vessels) are surrounded by rigid osseofascial structures that define various compartments in the extremities. These osseofascial compartments have a relatively fixed volume.
- If fluid is introduced into a fixed volume, the pressure rises. Introduction of excess fluid or extraneous constriction increases pressure and decreases tissue perfusion until no oxygen is available for cellular metabolism. This complication can happen by one of the following mechanisms:
  - Reduction in volume—from application of a tight cast, constrictive dressings, or pneumatic antishock garments
  - Increase in contents—hemorrhage secondary to fracture, blunt trauma, coagulopathy, IV infiltration, ischemia/reperfusion, etc.
  - Vascular reperfusion after arterial repair with resultant edema, or restoration of hemodynamics after a profound hypotensive episode
- The general consensus is that measured intracompartmental pressures greater than 30 mmHg (in the absence of hypotension) require intervention.
- Patients with low blood pressure suffer irreversible injury at lower absolute tissue pressures compared with patients with normal blood pressure. Therefore, poly-trauma patients are at **increased** risk of CS due to associated hypotension.

Diagnosis

CLINICAL ASSESSMENT

- Maintain a high level of suspicion in any injury that causes limb pain.
- The five Ps—pain, pallor, paresthesia, paralysis, and pulselessness—are pathognomonic of CS. However, with the exception of pain, these findings are usually **late signs**, and extensive and irreversible tissue damage may have already taken place by the time these signs are manifested.
  - The presence of pulses and normal capillary refill does **not** exclude CS.
- The earliest and most important symptom of CS is **pain greater than expected** due to the injury alone.
- Severe pain at rest or with any movement should raise a red flag.
- Pain with certain movements, particularly passive stretching or extending of the muscles, is the earliest clinical indicator of CS.
- Compression on the deep peroneal (fibular) nerve results in loss of sensation in the web space between the first two toes and is an early finding in CS of the lower leg.
- The affected limb/compartment may begin to feel tense or hard.
- Compare the affected limb to the unaffected limb.
- Open wounds or open fractures do not exclude CS. In fact, open fractures are at higher risk of CS than closed fractures.
- One must have a higher index of suspicion in poly-trauma patients with associated head injury, drug and/or alcohol intoxication, early intubation, spinal injuries, use of paralyzing drugs, extremes of age, unconsciousness, and/or low diastolic blood pressures. In these patients, pressure measurements of suspected compartments may help make the diagnosis.
- Ultrasound is not helpful in the diagnosis of CS.
- Serial assessments and surveillance for CS should be performed in at-risk patients.

Tissue Pressure Measurements

- Measurement of tissue pressure (compartment pressure) should be dictated by history, clinical signs, and index of suspicion.
- A rule of thumb is that if one starts to think about tissue pressure measurements, one should probably be doing them.
- Pressures can be measured using the Stryker STIC® Monitor (Figure 2) or using a needle attached to an arterial line setup.

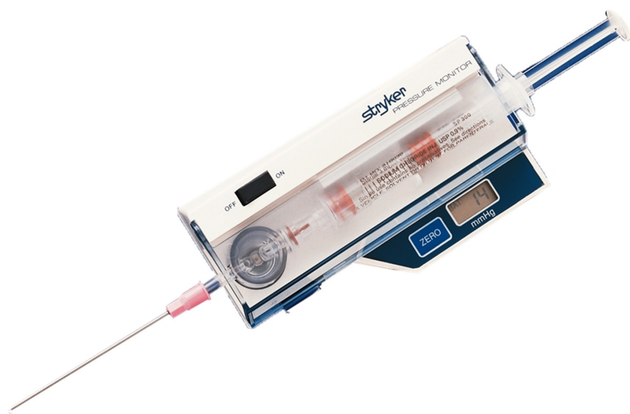


Figure 2. The Stryker STIC® Monitor is designed to measure compartment pressures.

- The pressure threshold for fasciotomy is controversial.
  - Most authors recommend 30 mmHg (40 cm H_2O) as the threshold for performing a fasciotomy.
  - In patients with hypotension, consider using the *delta-p method*, in which the compartment pressure is subtracted from the patient's diastolic pressure. If the delta-p is below 30 mmHg, fasciotomy should be considered.
  - Some urge prophylactic fasciotomy in high-risk patients at normal pressures to prevent CS, especially when transfer of the patient is needed.
- Other factors to consider are length of time of transport to definitive care and ability to do serial exams.
- "Normal" compartment pressures **should not** preclude fasciotomy in patients with obvious clinical findings of CS.
- All compartments in the affected extremity must be measured, as one compartment can be high while the others are not.
- Knowledge of compartment anatomy is necessary to measure pressure in all potentially involved compartments.

Surgical Fasciotomy

LOWER- LEG FASCIOTOMY

- The lower leg is the most common site for CS requiring fasciotomy.
- The lower leg has four major tissue compartments bound by investing fascia (Figure 3).
- The most reliable technique for treating or preventing CS in the lower extremity is a **two-incision, four-compartment fasciotomy**, which utilizes a lateral incision to open the anterior and lateral compartments and a medial incision to open the superficial and deep posterior compartments (Figure 4).
- There is **no indication for a single-incision fasciotomy** of the lower extremity in traumatically injured patients.
- Proper fasciotomy requires a thorough understanding of the underlying anatomy. The landmarks for each incision should be marked prior to incision, as distortion of the anatomy is likely to occur once the incisions are made.

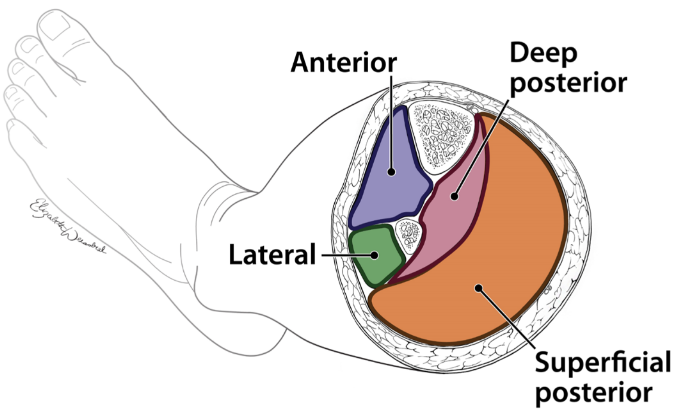


Figure 3. Cross-sectional anatomy of the mid-portion of the left lower leg, depicting the four compartments that must be released when performing a two-incision, four-compartment fasciotomy of the lower leg.

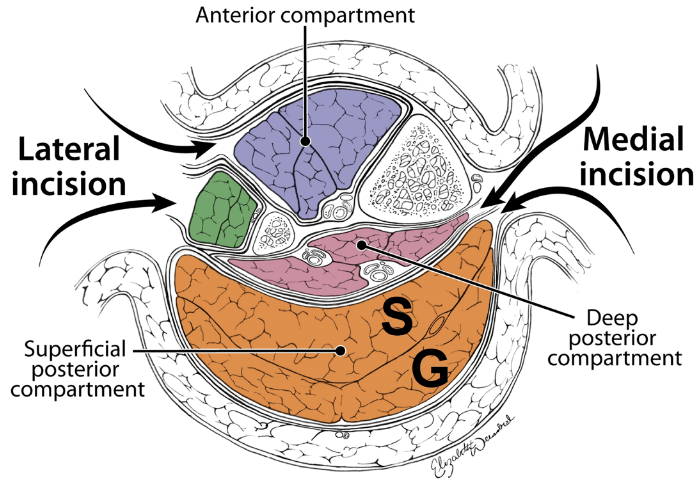


Figure 4. Two-incision, four-compartment fasciotomy. The lateral incision provides access to the anterior (purple) and lateral (green) compartments. The medial incision provides access to the superficial posterior compartment, which contains the soleus (S) and gastrocnemius (G) muscles (orange) and the deep posterior compartment (pink).

The Lateral Incision

- The lateral incision of the two-incision, four-compartment fasciotomy is made in a line one fingerbreadth (1–2 cm) anterior to the edge of the fibula. In a swollen extremity, the fibula may not be easily palpable; therefore, a line is drawn from the fibular head to the lateral malleolus to mark the course of the fibula (Figure 5).
- The lateral incision extends from two to three fingerbreadths below the tibial plateau to two to three fingerbreadths above the lateral malleolus, with extension of the skin incisions as needed to ensure that the skin does not serve as a constricting band.

LATERAL ASPECT RIGHT LOWER LEG

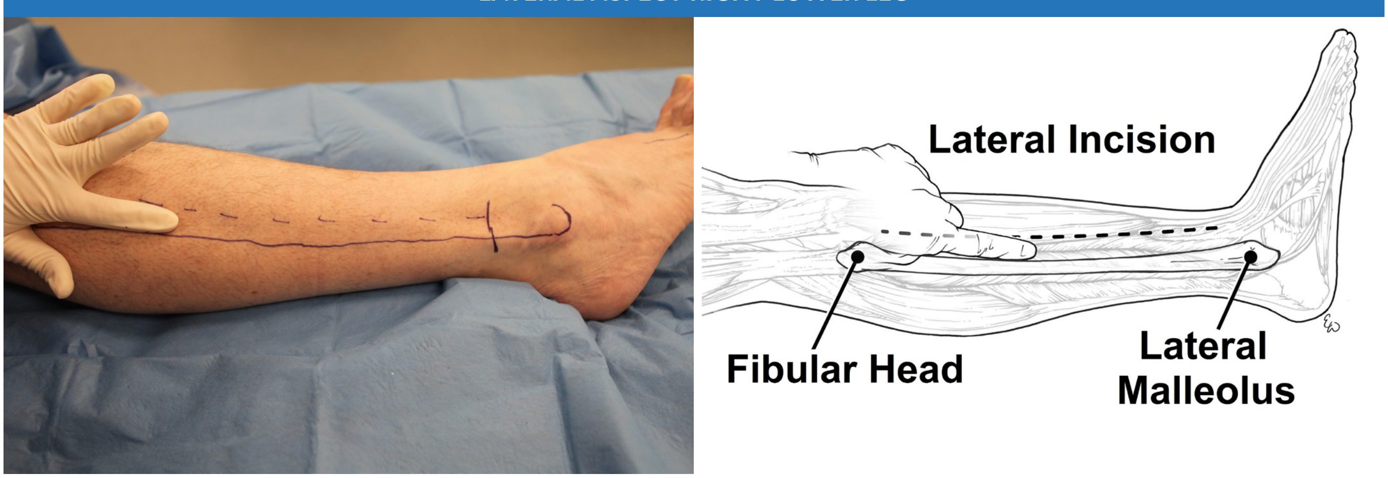


Figure 5. The fibular head and lateral malleolus are used as reference points to mark the edge of the fibula (solid line). The lateral incision (dotted line) is made a fingerbreadth in front of the fibula, as shown on the right lower extremity in both the photo on the left and the drawing on the right.

- The lateral incision is carried down through the skin and subcutaneous tissues until fascia is exposed. Care is taken to avoid the lesser saphenous vein and the peroneal nerve (also referred to as the *fibular nerve* in newer anatomy texts).
- The intermuscular septum is identified and serves as a landmark dividing the anterior and lateral compartments (Figure 6).
- The intermuscular septum can be very difficult to appreciate in a swollen, damaged, or deformed extremity. In this setting, it is useful to follow perforating vessels to the fascia, as they enter into (and can help identify) the intermuscular septum (Figure 6).
- The fascia of the anterior and lateral compartments are opened with scissors in an "H"-shaped fashion, with the cross piece of the "H" made across the intermuscular septum and the legs of the "H" extending the full length of the fascial compartments (Figure 7).
- The scissor tips should be turned away from the septum (Figure 7), taking care to avoid the superficial peroneal (fibular) nerve; this nerve originates around the head of the fibula and runs in the lateral compartment about 2/3 to 3/4 of the way down the leg, where it becomes more superficial and crosses over into the anterior compartment (Figure 8).

LATERAL ASPECT RIGHT LOWER LEG – FOOT TO RIGHT

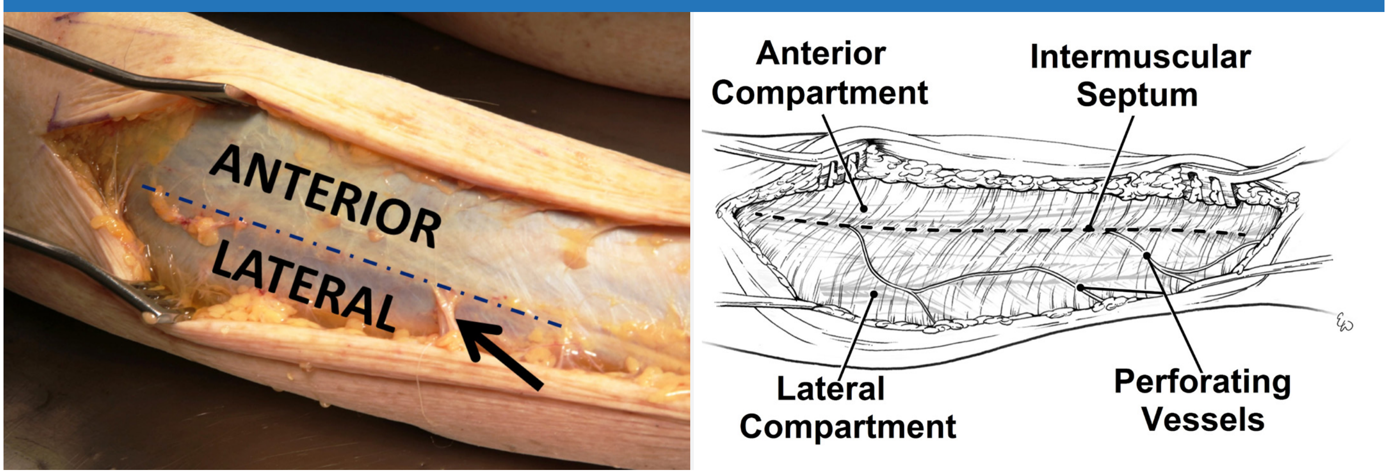


Figure 6. The lateral incision on the right lower extremity demonstrates the intermuscular septum (dotted line), which separates the anterior and lateral compartments of the lower leg. Note one of the perforating vessels (arrow on left, labeled on right), which enters into (and helps identify) the septum.

LATERAL ASPECT RIGHT LOWER LEG – FOOT TO RIGHT

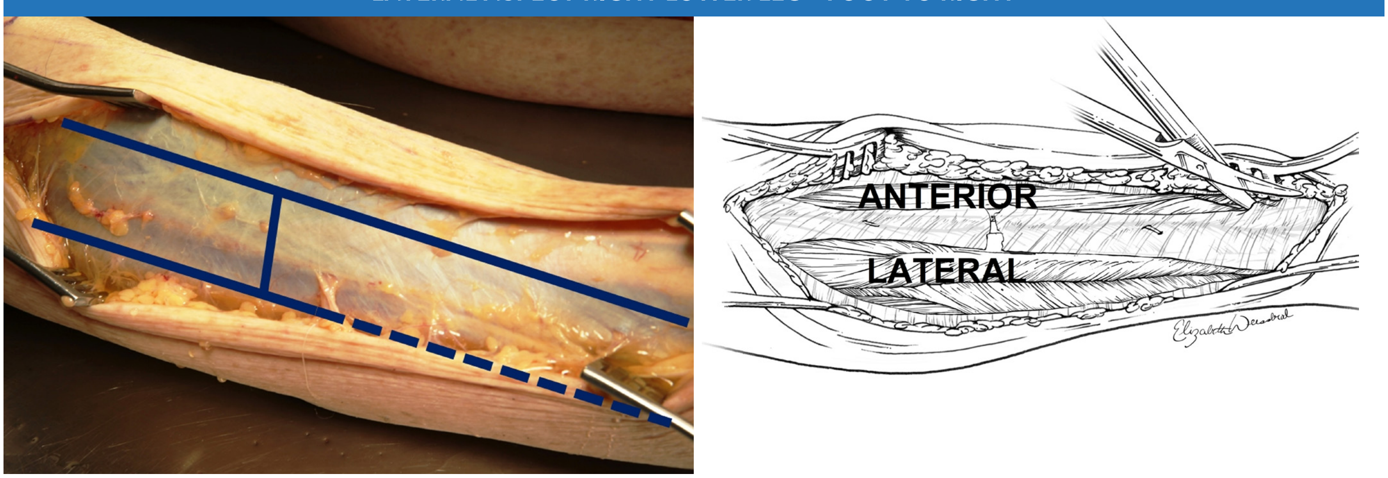


Figure 7. The fascia of the lateral lower leg is classically opened in an "H"-shaped fashion for the length of the compartments using scissors turned away from the septum, as seen on the right.

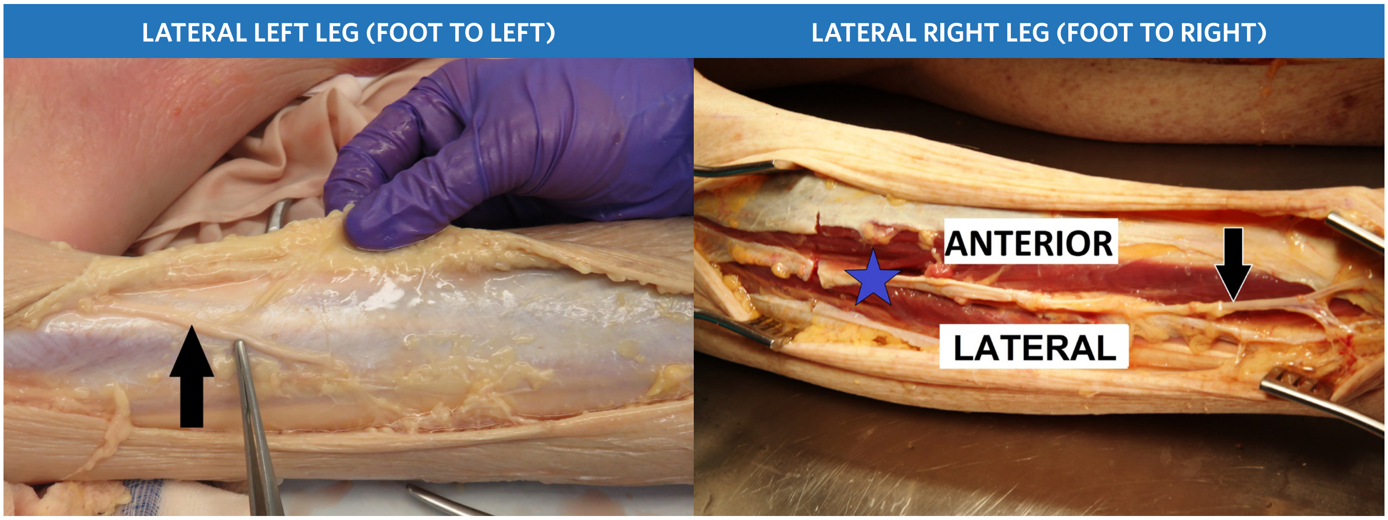


Figure 8. The superficial peroneal (fibular) nerve (arrows) runs in the lateral compartment from the knee and crosses over the septum (star) into the anterior compartment 2/3 to 3/4 of the way down the leg, toward the ankle. This must be carefully avoided by keeping the scissor tips pointed away from the septum and by looking for the nerve as the fasciotomy is extended to the lateral malleolus.

Pitfalls of the Lateral Incision

- Improper or incomplete performance of fasciotomy is unfortunately common, with loss of limb and life as a consequence.
- The anterior compartment is the most commonly missed compartment when performing a fasciotomy of the lower extremity.
- The most common reason the anterior compartment is missed is that the incision is made too far posterior, either over or behind the fibula.
- If the incision is made too far posterior, the intermuscular septum between the lateral and superficial posterior compartments is mistaken for the septum between the anterior and lateral compartments, and thus the anterior compartment is not opened (Figures 9 and 10).
- The superficial peroneal (fibular) nerve can be easily transected if one is not careful to keep the tips of the scissors an adequate distance and turned away from the intermuscular septum.
- Inadequate length of the fascial or skin incisions can result in failure to reduce compartment pressures to acceptable levels.

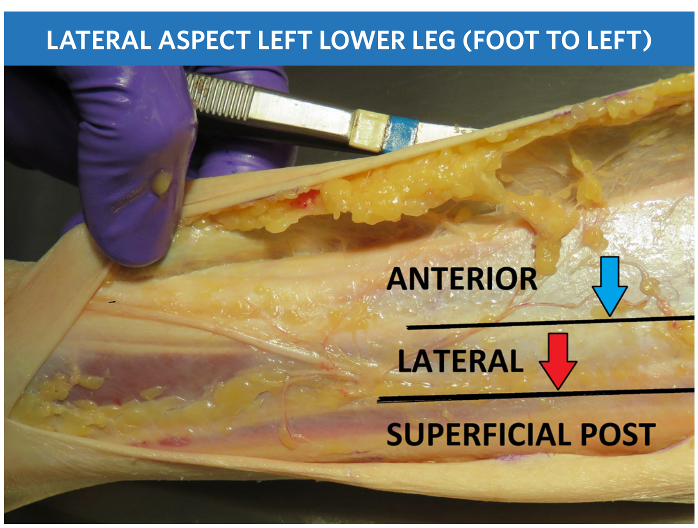


Figure 9. There is an intermuscular septum (red arrow) between the lateral and superficial posterior (post) compartments; this septum can be mistaken for the septum between the anterior and lateral compartments (blue arrow) if the incision is made too far posterior.

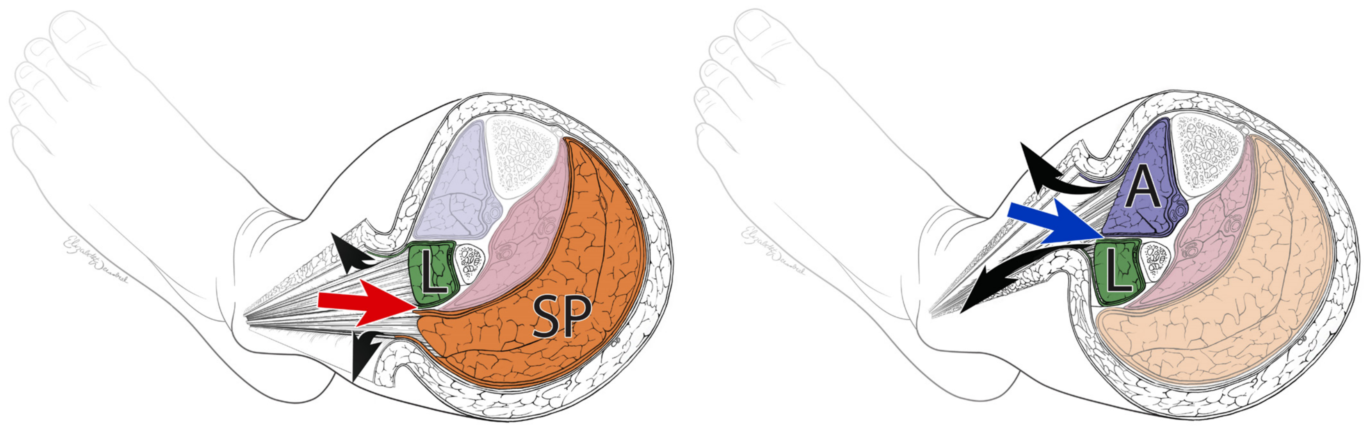


Figure 10. If the lateral incision is made too far posterior, the intermuscular septum (red arrow) between the lateral (L) and superficial posterior (SP) compartments can be mistaken for the septum (blue arrow) between the anterior (A) and lateral (L) compartments, resulting in the anterior compartment being missed.

The Medial Incision

- The medial incision is made one fingerbreadth posterior to the medial edge of the tibia and should be generous in length (Figure 11).
- The medial skin incision should extend from two to three fingerbreadths below the tibial plateau to two to three fingerbreadths above the medial malleolus.
- The incision is carried down through the skin and subcutaneous tissues, taking care to identify and preserve the saphenous vein.
- Care should be taken to identify and ligate the saphenous vein tributaries, as they can bleed profusely.
- The fascia underlying the incision is opened the length of the compartment, decompressing the superficial posterior compartment (Figure 12).
- Entry into the deep posterior compartment is accomplished by bluntly and sharply taking down the fibers of the soleus muscle off the edge of the tibia (Figure 13).
- Identification of the neurovascular bundle confirms entry into the deep posterior compartment (Figure 14).

MEDIAL ASPECT LEFT LOWER LEG

Figure 11. The medial incision (dotted line) is made one fingerbreadth below the medial edge of the tibia (solid line).

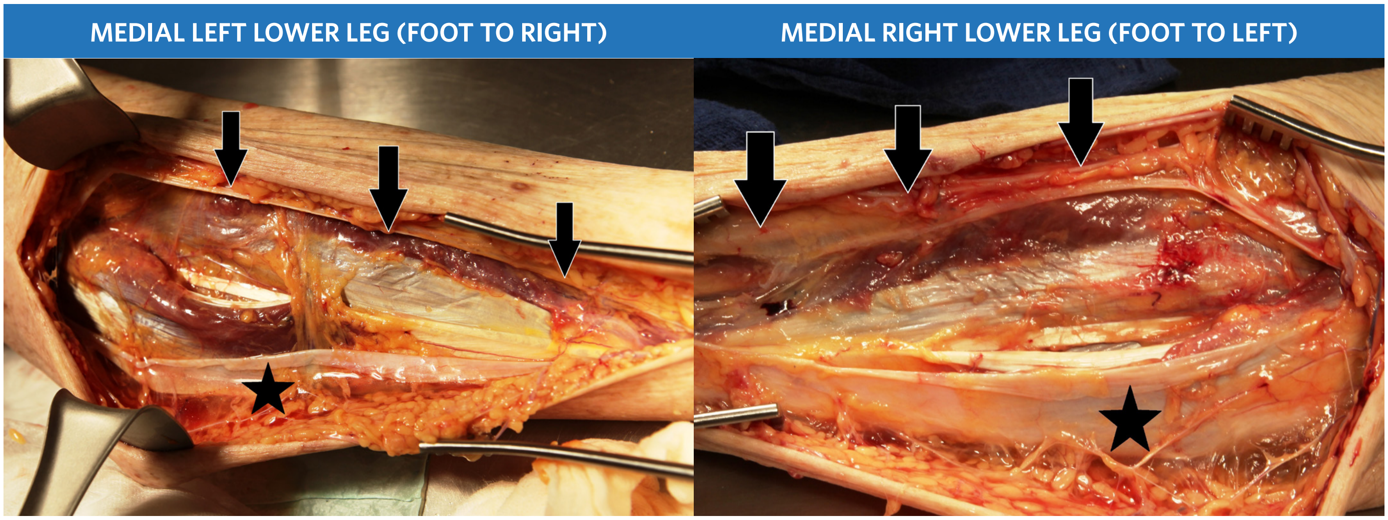


Figure 12. The superficial posterior compartment is exposed by opening the superficial fascia (star) below the edge of the tibia (arrows).

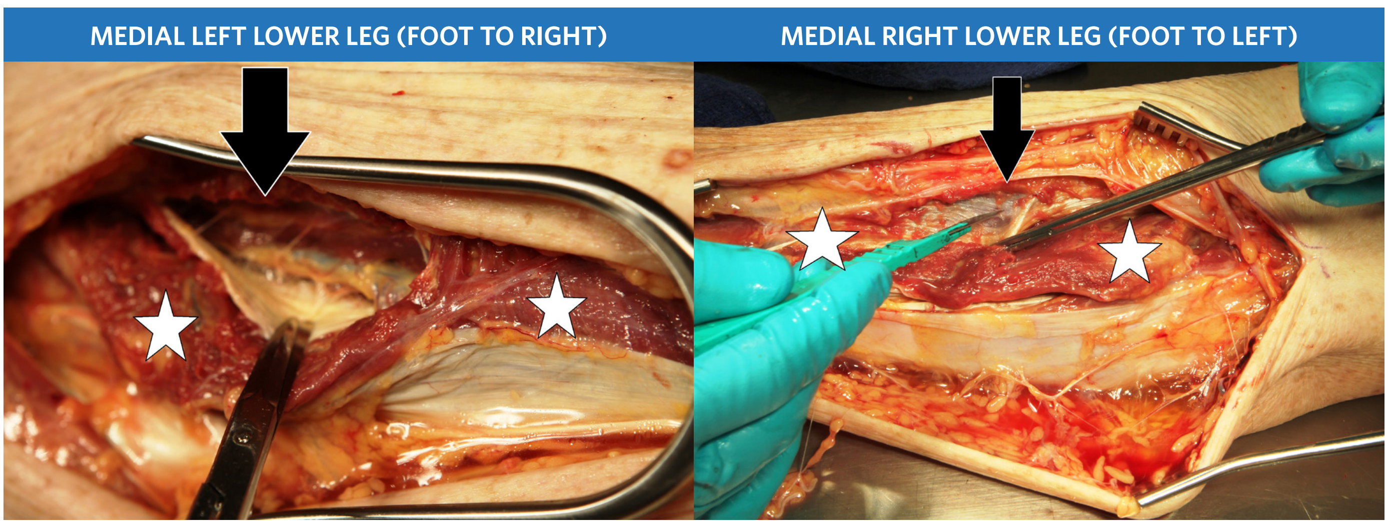


Figure 13. The deep posterior compartment is opened by taking the fibers of the soleus muscle (stars) down from the underside of the tibia (arrow).

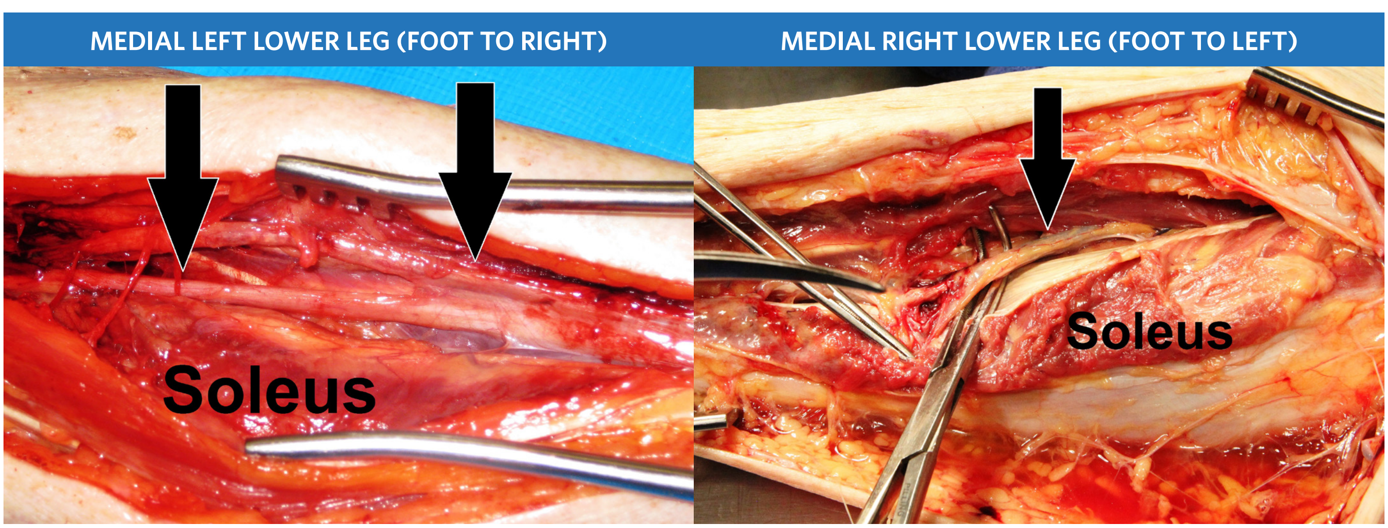


Figure 14. Identification of the posterior tibial neurovascular structures (arrows) confirms entry into the deep posterior compartment after taking the soleus muscle down from the edge of the tibia.

Pitfalls of the Medial Incision

- The deep posterior compartment is the second most commonly missed compartment when performing a fasciotomy of the lower extremity.
- The most common situation in which the deep posterior compartment is missed occurs when the dissection plane is made between the gastrocnemius and soleus muscles; this can lead to mistakenly opening the fascia over the soleus muscle rather than properly opening the deep posterior compartment (Figure 15).
- In an injured extremity, a prominent plantaris tendon (also known as the *intern's nerve*) may be mistaken for the posterior tibial neurovascular bundle, leading one to erroneously believe that the posterior compartment has been entered and decompressed (Figure 16).
- Inadvertent injury to the saphenous vein can cause significant bleeding and may result in venous insufficiency if the deep venous system has also been injured.
- Inadequate length of the fascial or skin incisions can result in failure to reduce compartment pressures to acceptable levels.
- The muscles in each compartment should be assessed for viability. Viable muscle is pink, contracts when stimulated, and bleeds when cut (Figure 17).
- Skin incisions should be generous, as the skin can act as a constricting element to an otherwise well-performed fasciotomy.
- Fascial incisions should be carried the full extent of the fascial compartment.

MEDIAL LEFT LOWER LEG

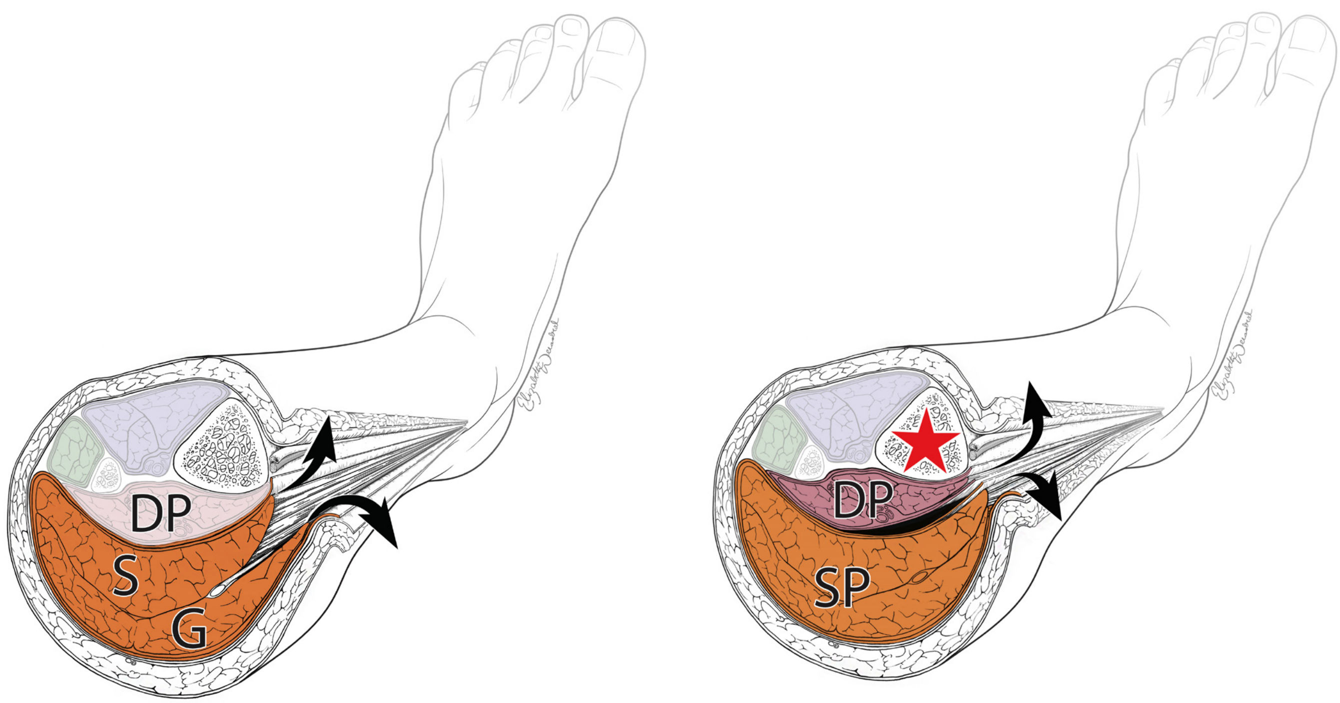


Figure 15. If the dissection plane is made between the soleus (S) and gastrocnemius (G) muscles, the deep posterior (DP) compartment is not opened (left). The soleus fibers must be taken down from the underside of the tibia (star) to separate the superficial posterior (SP) from the deep posterior compartment (right).

MEDIAL ASPECT RIGHT LOWER LEG – KNEE TO RIGHT

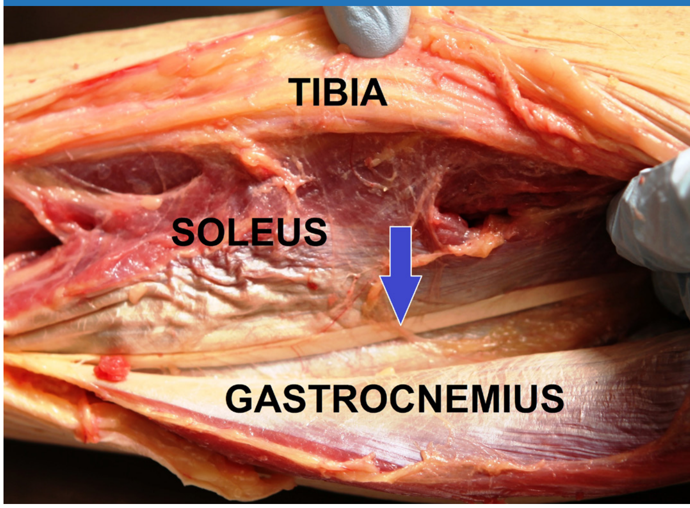


Figure 16. The plantaris tendon (arrow) is found in the plane between the soleus and gastrocnemius muscles and may be mistaken for the posterior tibia neurovascular bundle.

LATERAL ASPECT OF LEFT LOWER LEG – KNEE TO LEFT

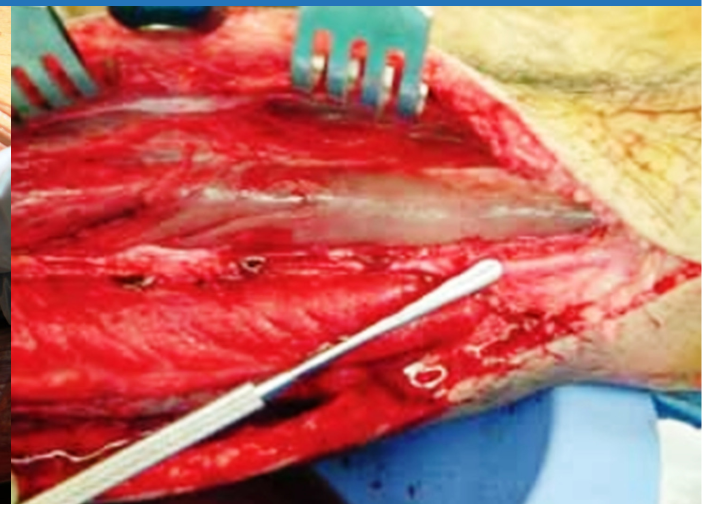
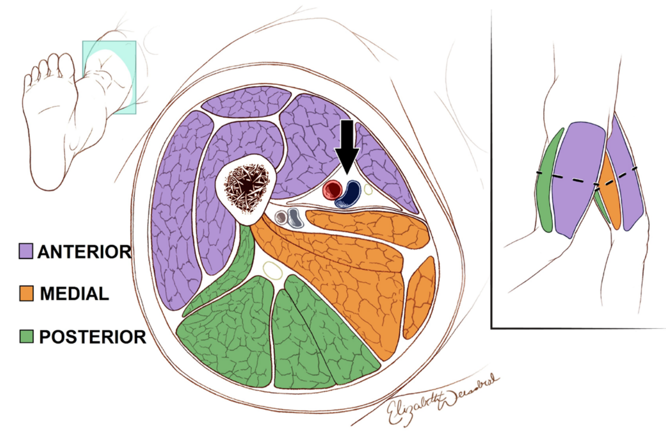


Figure 17. Dead muscle is seen above the probe in the anterior compartment of the left lower leg on re-exploration for an incomplete fasciotomy.

Compartment Syndrome of the Thigh

- CS is uncommon in the thigh because of the large volume required to cause an increase in pressure in these compartments.
- The fascial compartments of the thigh blend anatomically with the hip, allowing for extravasation of blood or fluid out of the compartments.
- Predisposing factors include intramedullary nailing of femoral fractures, severe blunt trauma or crush injury to the thigh, vascular injury, iliac or femoral deep vein thrombosis, and external compression of the thigh.
- Approximately 90 percent of thigh CS cases are attributable to blunt trauma, with about half of these cases associated with femur fractures.
- The thigh contains three compartments: anterior, posterior, and medial (Figure 18).
- The anterior (not the medial) compartment contains the femoral artery and vein and is the most likely to develop CS.
- Two incisions (lateral and medial) are required to decompress all three thigh compartments (Figure 19).
- The lateral incision of the thigh is performed first and is usually adequate to relieve CS of the thigh.
- After the anterior and posterior compartments have been decompressed via the lateral incision, measure the pressure of the medial compartment; if elevated, make a medial incision to release the compartment.
- The lateral incision of the thigh extends from the intertrochanteric line to the lateral epicondyle of the femur to expose the iliotibial band, or fascia lata, which is opened the length of the incision.
- The vastus lateralis muscle is reflected superiorly and medially to expose the lateral intermuscular septum (between the anterior and posterior compartments), which is opened the length of the incision.
- The medial compartment can be opened through a medial incision (Figure 19) placed along the course of the saphenous vein. This is followed by rotation of the sartorius muscle and incision of the medial intermuscular septum between the medial and anterior compartments.

CROSS SECTION MID RIGHT THIGH



RIGHT MID THIGH LOOKING TOWARDS FOOT

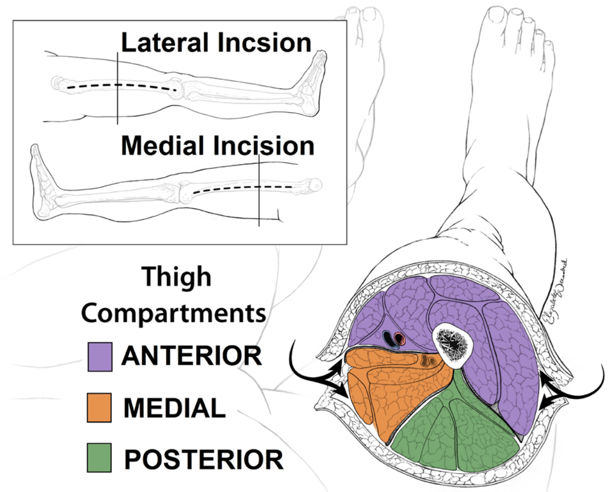


Figure 18. The three compartments of the right thigh are shown here: anterior (purple), medial (orange), and posterior (green). Note that the femoral artery and vein (arrow) are found in the anterior compartment.

Figure 19. The two incisions (dotted lines in inset) required to decompress the compartments of the thigh are depicted, with the anterior (purple) and posterior (green) compartments opened via the lateral incision and the medial (orange) compartment opened through the medial incision.

Gluteal Compartment Syndrome

- Gluteal CS is uncommon and can be misdiagnosed as a gluteal contusion. Untreated, it can lead to sciatic nerve palsy, muscle necrosis, rhabdomyolysis, acute renal failure, and death.
- The most commonly cited etiologies are prolonged immobilization and as a complication of intraoperative positioning.
- Other less common causes of gluteal CS include contusion; gluteal artery rupture associated with hip dislocation, acetabular fracture, or displaced pelvic fractures; as a complication of vascular procedures; as a complication of iliac crest bone harvest; infection; intramuscular drug use; leukemia; and, as recently seen in military populations, from blast injury to the buttock (Figure 20).

RIGHT BUTTOCK

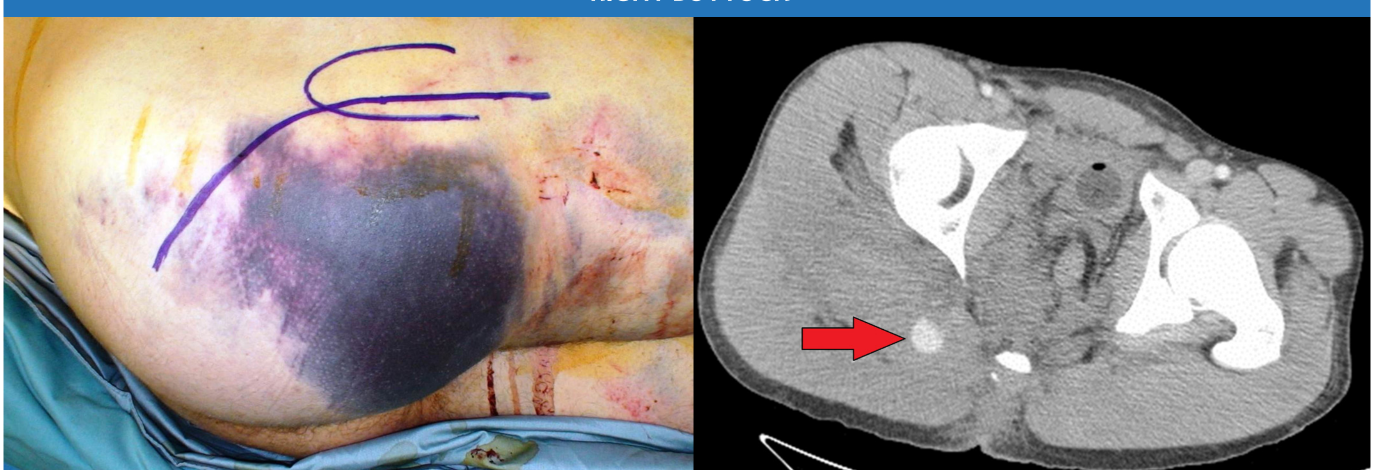


Figure 20. Large right buttock hematoma associated with a blast injury in which a soldier driving an armored vehicle drove over an explosive device, with resultant arterial extravasation (red arrow) and CS from a gluteal artery injury.

- The gluteal region contains three distinct compartments (Figure 21):
  - **Tensor compartment:** Comprised of the tensor fasciae latae muscle enclosed by the superficial and deep portions of the fascia lata; innervated by the superior gluteal nerve and vessels
  - **Medius/minimus compartment**: Composed of the gluteus medius and minimus muscles bounded by the iliac wing and combined layers of fascia lata; supplied by the superior gluteal nerve and vessels
  - **Maximus compartment**: Contains the gluteus maximus muscle enclosed by iliac bone and fascia; supplied by the inferior gluteal nerve and vessels
- Each of the distinct compartments is at risk for developing CS.
- Physical examination findings of gluteal CS include buttock numbness, pain with passive stretch of the gluteal muscles, tense swelling of the buttock region, and sciatic nerve symptoms.
- Clinical suspicion should prompt measurement of intracompartmental pressures, with pressures >30 mmHg (or a delta-p of <30 mmHg) confirming the diagnosis.
- If the mechanism of injury is thought to be related to gluteal artery rupture, efforts to control the bleeding through the use of interventional radiology should be considered prior to fasciotomy (Figure 22).

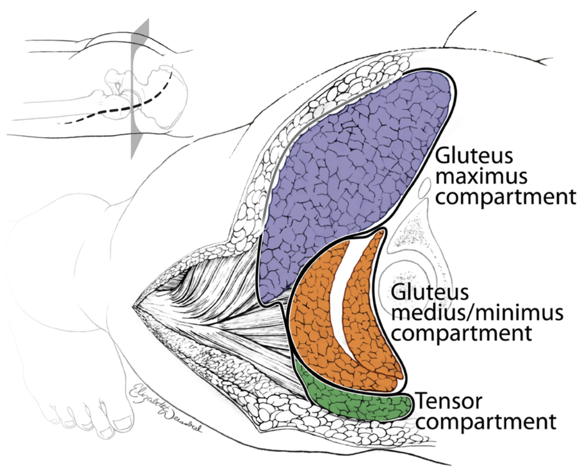


Figure 21. The three compartments of the gluteal region include the tensor (green), medius/minimus (orange), and maximus (purple) compartments as seen above on the right buttock.

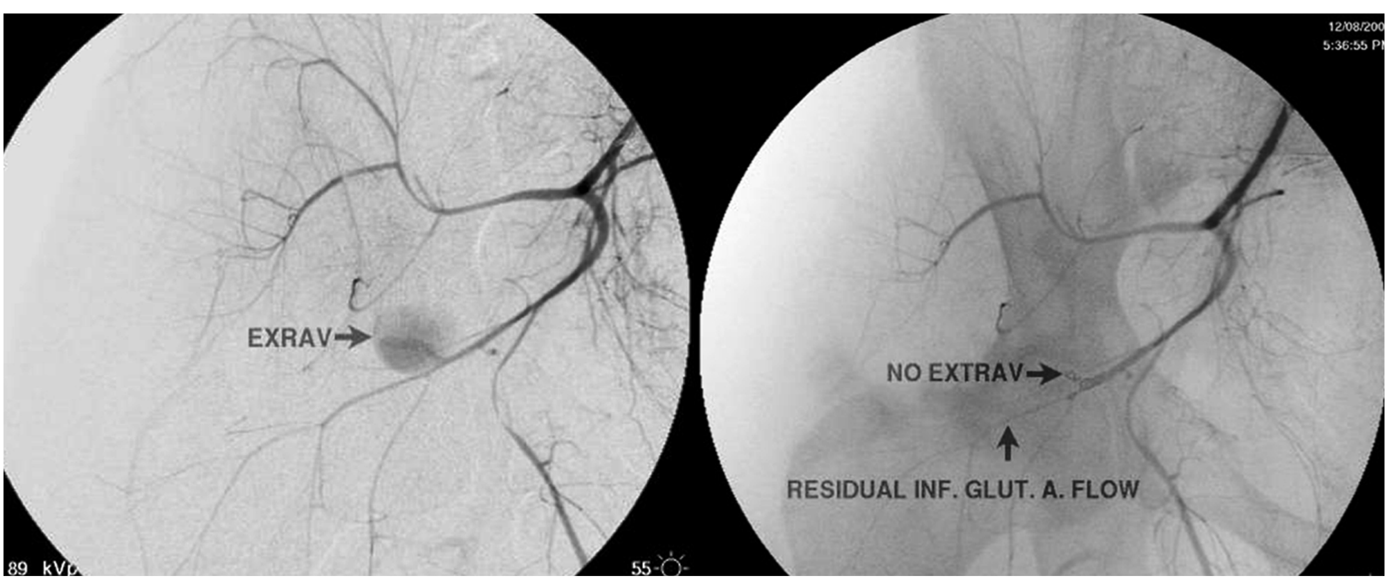


Figure 22. Angiogram of right gluteal region of the patient also seen in Figure 20 with gluteal arterial extravasation (EXRAV) on the left, and following successful coil embolization on the right.

Gluteal Fasciotomy

- The most commonly cited technique is a posterior (Kocher-Langenbeck) approach to the hip.
- In this approach, the patient is placed in the lateral decubitus position, and the hip is flexed to 90° (Figure 23).
- A line is drawn in a curvilinear fashion from the posterior superior iliac spine to the greater trochanter and down the femur, with the incision extending from about 8 cm above the greater trochanter to about 6 cm down the shaft of the femur (Figure 23).
- The gluteal fascia is incised in the same plane as the underlying muscle (superior medial to inferior lateral) to decompress the gluteus maximus, which requires multiple epimysiotomies (opening the fascia overlying the muscle). This is accomplished by using blunt dissection to split the gluteus maximus in line with the fibers, taking care not to disrupt neurovascular structures (Figure 23).
- Superior retraction of the maximus will reveal the fascia overlying the gluteus minimus. The medius/minimus compartment is released by incising this fascia.
- At this point, compartment pressures should be measured to confirm adequate decompression and to measure the tensor compartment, which can be decompressed through the same incision if needed.
- An alternative approach described in the literature is a question-mark-style incision that begins at the posterior superior iliac spine and follows along the curve of the buttock down onto the greater trochanter below the gluteal cleft (Figures 24 and 25).

RIGHT BUTTOCK HEAD TO THE TOP

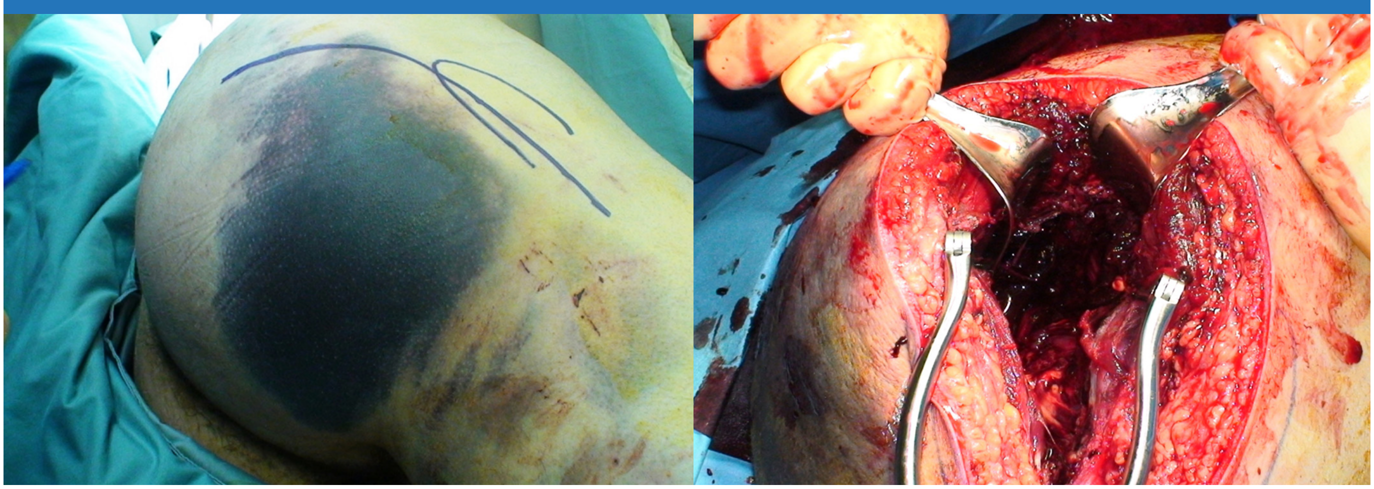


Figure 23. The incision to relieve buttock CS extends from just below the posterior superior iliac spine in a curvilinear fashion over the greater trochanter and down onto the femur (left). The compartments are opened with a combination of sharp fascial incision and muscle splitting, with evacuation of the hematoma and decompression of the affected compartments.

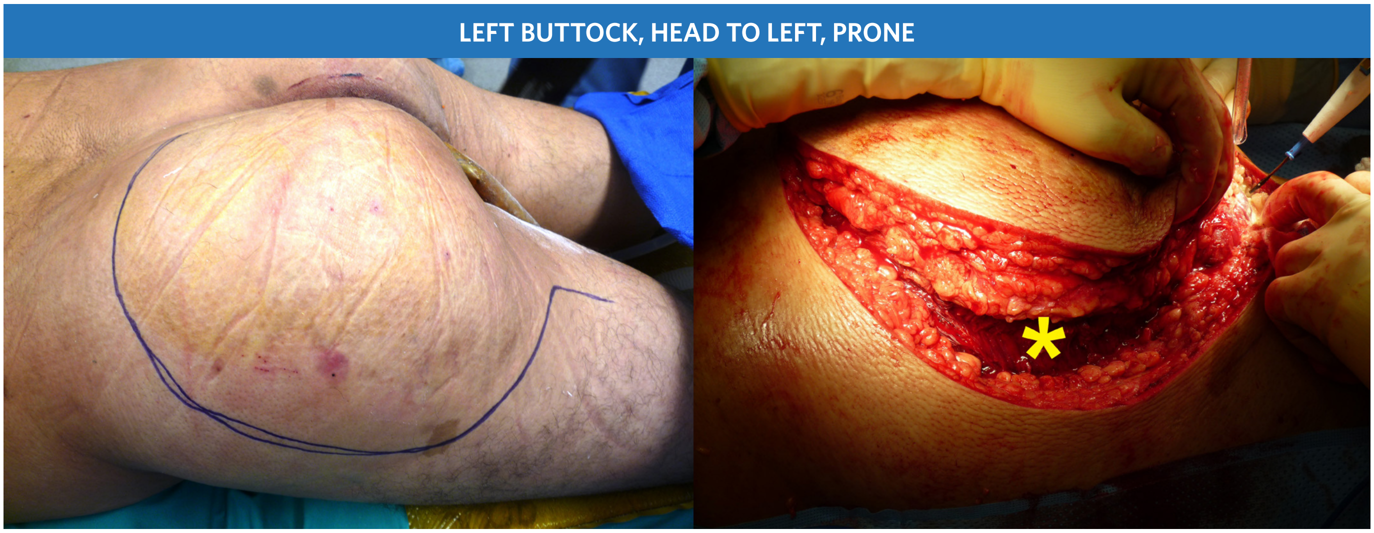


Figure 24. An alternative "question-mark" incision to relieve buttock CS is made from the posterior upper buttock, then medially around the side of the buttock onto the gluteal cleft, and then down over the posterior thigh. The fascia overlying the gluteus maximus muscle (*) is opened using multiple epimysiotomies.

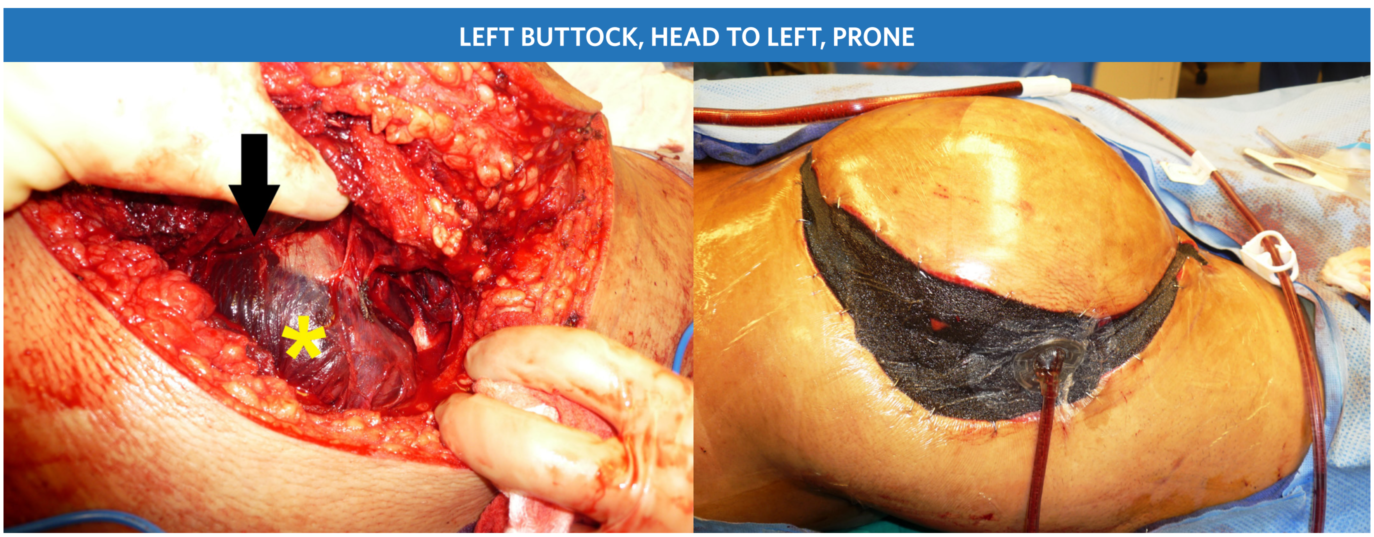


Figure 25. Completion of the "question-mark" incision to relieve buttock CS is accomplished by superior retraction of the gluteus maximus (arrow) to expose the gluteus minimus (*), the overlying fascia of which is opened to decompress the medius-minimus compartment (left). The tensor compartment is evaluated and decompressed if indicated, followed by dressing of the wound (right).

Compartment Syndrome of the Foot

- CS of the foot requiring fasciotomy is uncommon but can cause significant morbidity if missed.
- Both calcaneal fractures and crush injuries of the foot (e.g., Lisfranc fractures) may have between 10 percent and 40 percent risk of associated CS.
- Unlike the leg or forearm, there are no classic signs of CS in the foot. Pain on passive stretch and diminished pulses are not consistent physical findings.
- Tense tissue bulging of the dorsum or plantar space may be the most reliable finding.
- Maintain a high index of suspicion.
- Pressure measurement of all major compartments is required. Absolute pressures greater than 30 mmHg (or delta-p of less than 30 mmHg) are indications for decompression.
- Early involvement of subspecialty consults (orthopaedics or podiatry) is highly recommended.

- There are four compartments of the foot: interosseous, lateral, central, and medial (Figure 26).
- Three incisions are used to decompress the foot compartments when CS is diagnosed (Figure 27).
- Two incisions are made on the dorsum of the foot, with the first just medial to the second metatarsal and the second just lateral to the fourth metatarsal (Figure 27).
- The extensor tendons are identified on top of the foot through the incisions; a blunt clamp (or scissor tips) is used to push beyond and then spread on either side of the tendons and between the metatarsal bones to decompress the interosseous compartment.
- The remaining three compartments are decompressed through an incision placed on the medial aspect of the foot in the arch, with the clamp or scissors pushed under the arch of the bony structures of the foot from medial to lateral to open the medial, central, and lateral compartments in turn (Figure 27).

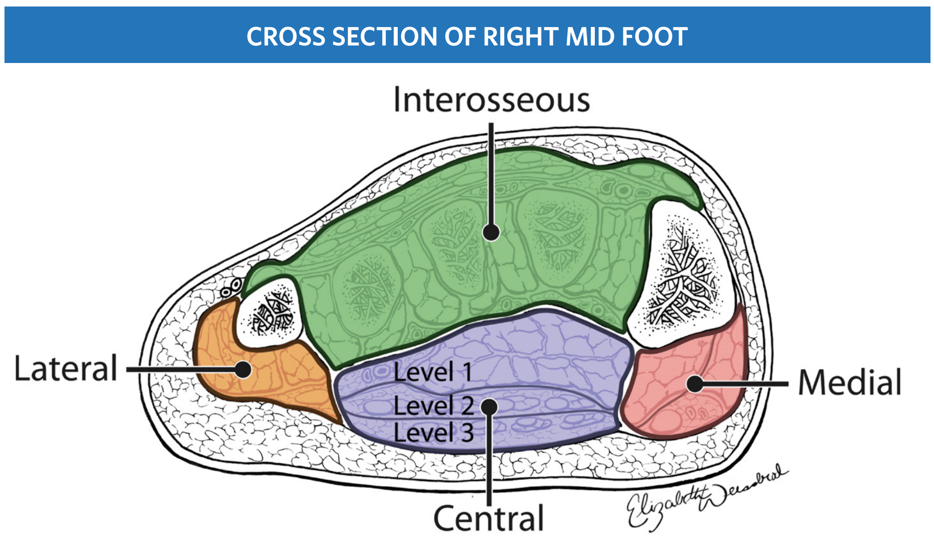


Figure 26. The four compartments are shown here on a cross section of the right foot.

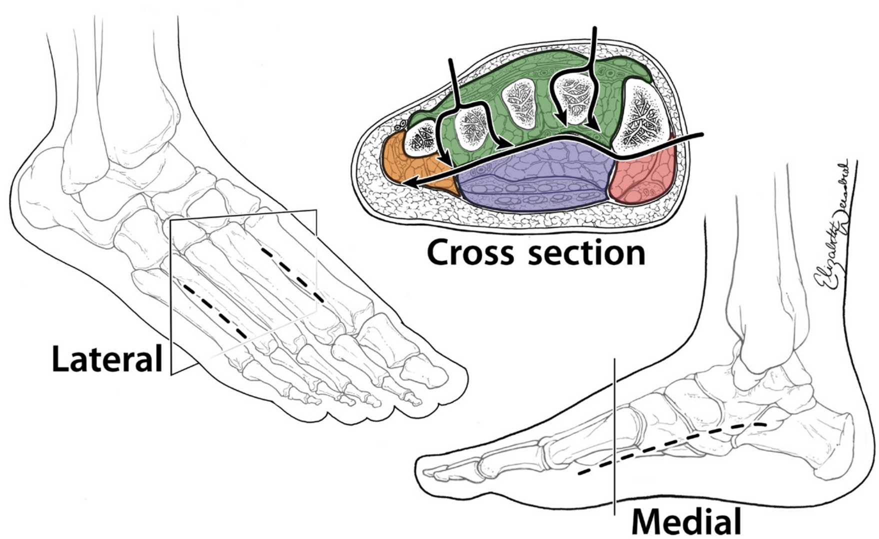


Figure 27. The foot compartments are decompressed through three separate incisions as seen on the right foot: two on the dorsum of the foot, over the second and fourth metatarsals, and one on the medial aspect along the arch.

Compartment Syndrome of the Forearm and Hand

- CS of the forearm and hand is much less common than in the lower extremity.
- Forearm CS most commonly follows a supracondylar fracture of the humerus but has also been associated with more distal fractures, crush injury, burns, or vascular injury.
- The forearm has three main compartments: The anterior (or volar) compartment (which many orthopaedic surgeons subdivide into superficial and deep volar compartments); the mobile wad compartment; and the dorsal compartment.
- The compartments of the forearm are much less well defined and more closely interconnected than those of the lower leg. As such, some practitioners have advocated that complete forearm decompression can be accomplished with a single volar incision.
- Given the above, the volar incision should be made first and the dorsal compartment reassessed prior to making the dorsal incision; however, one should have an extremely low threshold for making the dorsal incision.
- Multiple approaches to the volar incision have been described in the literature; the most commonly recommended/described incision is depicted in Figure 28. This incision crosses the antecubital fossa in a curvilinear fashion to the radial aspect of the upper forearm and then is carried toward the ulnar aspect down to the wrist, then across the wrist in a transverse fashion and onto the palm to release the carpal tunnel.
- This volar incision allows for decompression of the anterior (volar) and mobile wad compartments, as well as the carpal tunnel. This incision is preferred because of potentially better cosmetic results, maintenance of adequate skin blood supply between this and the dorsal incision, and maintenance of a vascularized skin flap to cover the median nerve and flexor tendons at the wrist.

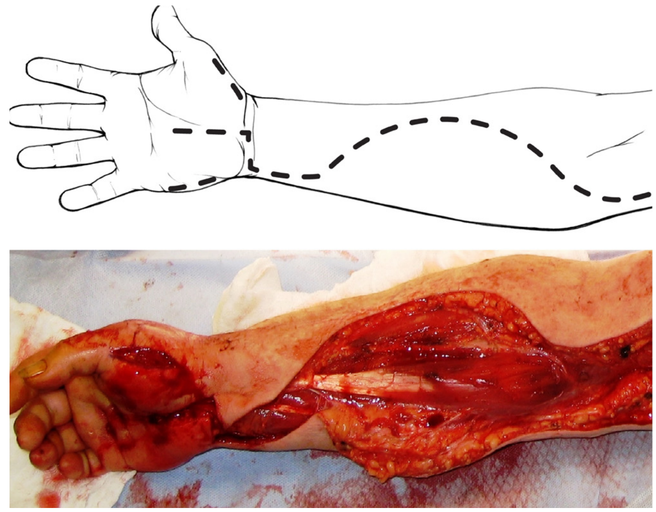


Figure 28. The volar incision as seen on the right arm (bottom), enabling decompression of the anterior (volar) and mobile wad compartments. A separate thenar incision is also seen on the hand in the clinical drawing (top).

- The dorsal incision extends from the level of the lateral epicondyle to the radial aspect of the wrist (Figure 29).

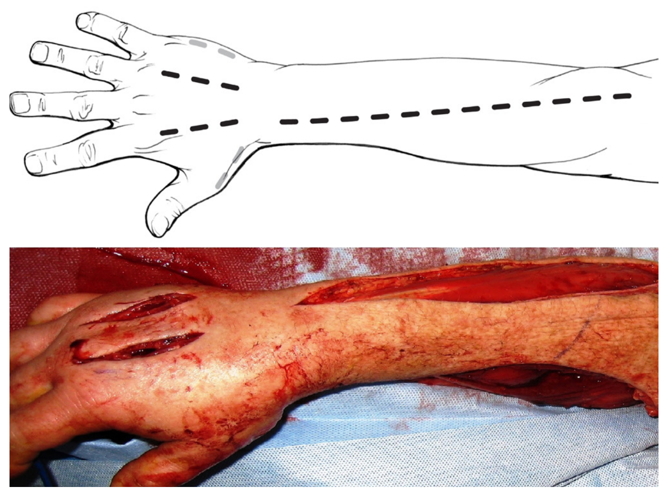


Figure 29. The dorsal incision as seen on the right arm, with additional incisions on the hand enabling decompression of the dorsal compartment of the forearm and the interosseous compartments of the hand.

- To ensure that the compartments of the forearm are completely decompressed, it is important to do a complete epimysiotomy of each of the muscles to expose the muscle bellies in the entire length of the forearm (Figure 30).
- The transverse carpal ligament is generally wider than one might expect (> 2 cm), and there is a haptic and audible crunch that accompanies its division. If one "cuts until the crunch is gone," the carpal tunnel is fully opened.
- In most cases of suspected CS of the forearm, the carpal tunnel should be opened completely at the wrist. This is accomplished by identifying the median nerve at the wrist crease and using scissors with the opened blades on either side of the transverse carpal ligament above the median nerve, guiding subsequent division (Figure 31).
- If CS of the hand is present or suspected, two additional incisions are made on the dorsum of the hand over the second and fourth metacarpals, as seen in Figures 29 and 32.

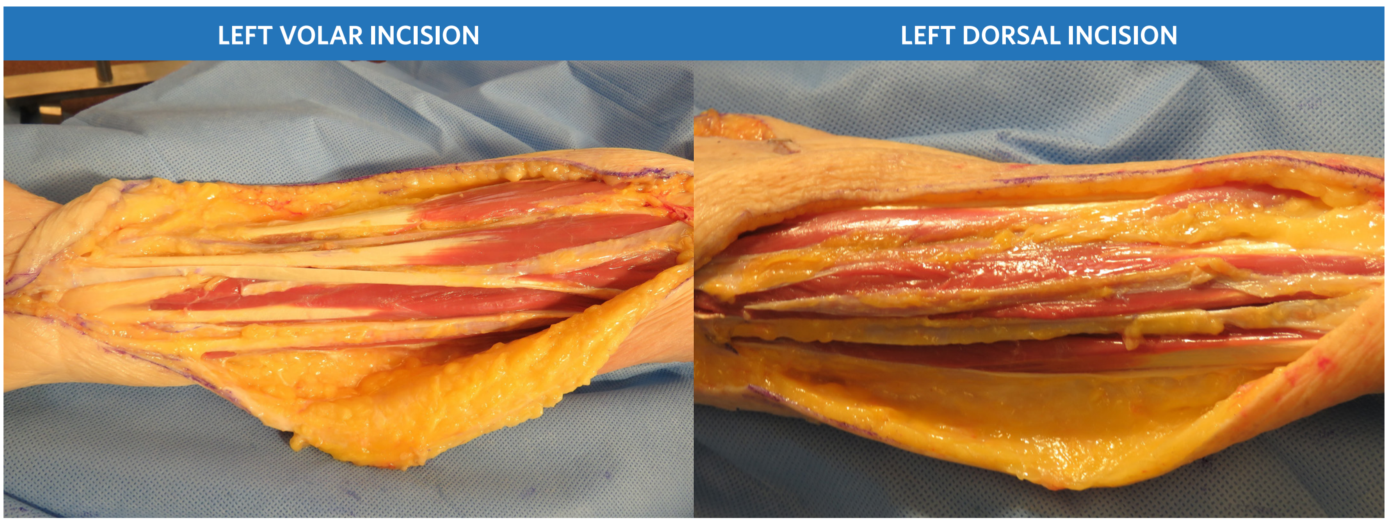


Figure 30. A complete epimysiotomy exposing each of the muscles the entire length of the forearm in the volar incision (left) and the dorsal incision (right), as seen on this left arm, ensures that the compartments have been completely opened.

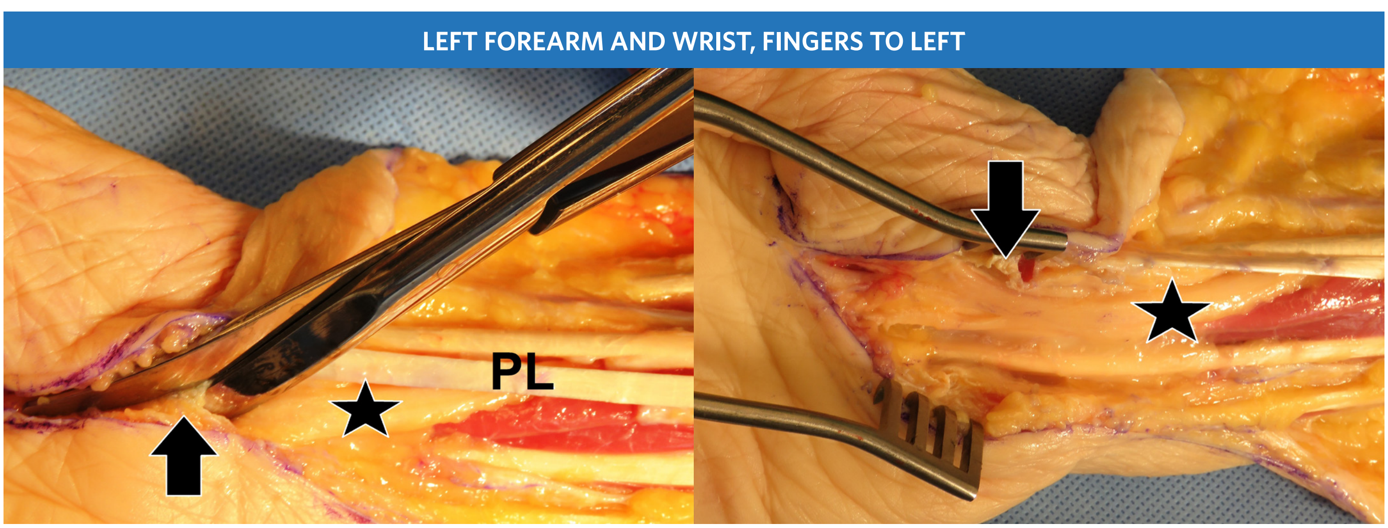


Figure 31. The median nerve (star) is identified at the wrist crease running under the palmaris longus (PL) tendon. Scissors are placed above and below the transverse carpal ligament (arrow), which is divided to completely open the carpal tunnel.

- CS of the hand can occur from trauma but most often occurs from iatrogenic injuries (arterial line complication or infiltration of IV medications).
- The hand contains 10 osseofascial compartments: the thenar, hypothenar, adductor, and seven interosseous compartments (Figure 32).
- The interosseous and adductor compartments are decompressed through the two dorsal incisions. Decompression of the thenar and hypothenar compartments may require additional incisions, as depicted in Figure 32.
- Symptoms of CS in the hand do not include abnormalities of sensory nerves, as there are no nerves within the compartment. The most consistent clinical finding is a tense, swollen hand in the intrinsic minus position (metacarpophalangeal joints extended and interphalangeal joints flexed).
- The pressure threshold for CS in the hand is much less than in the legs; 15–20 mmHg is an indication for surgical release.
- A high index of suspicion must be maintained, and if available, early involvement of a hand specialist is recommended.

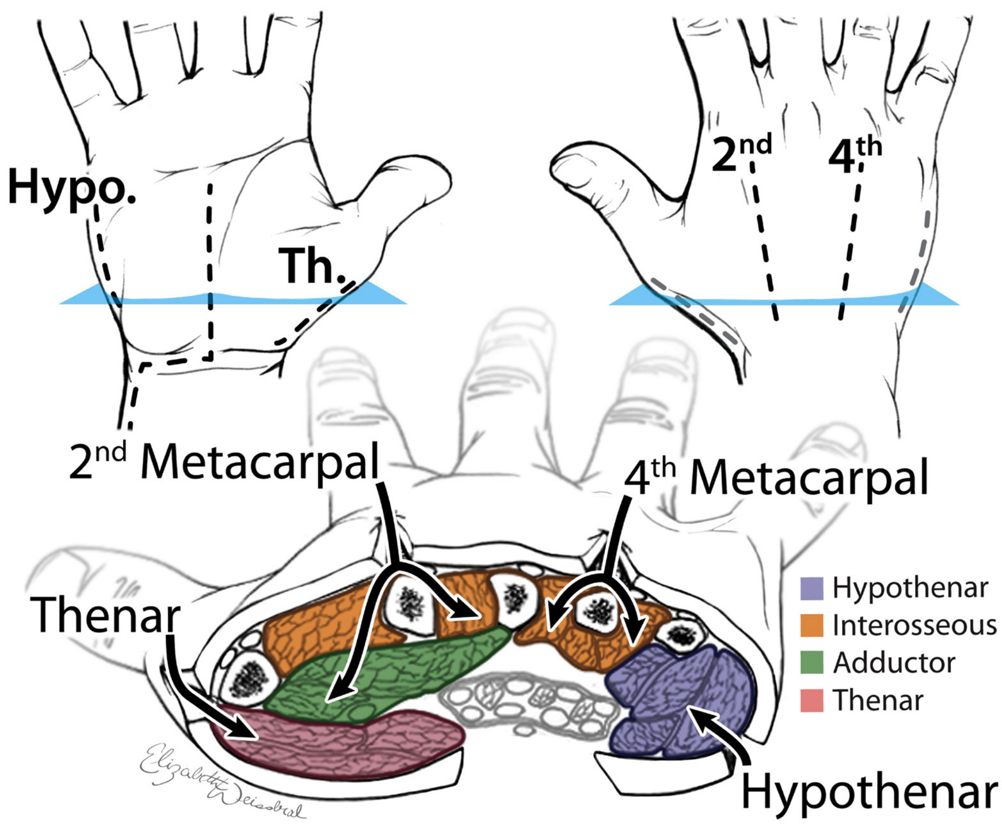


Figure 32. Fasciotomies of the hand are accomplished with dorsal incisions over the second and fourth metacarpals to decompress the interosseous and adductor compartments. If needed, the hypothenar and thenar compartments are decompressed through separate incisions.

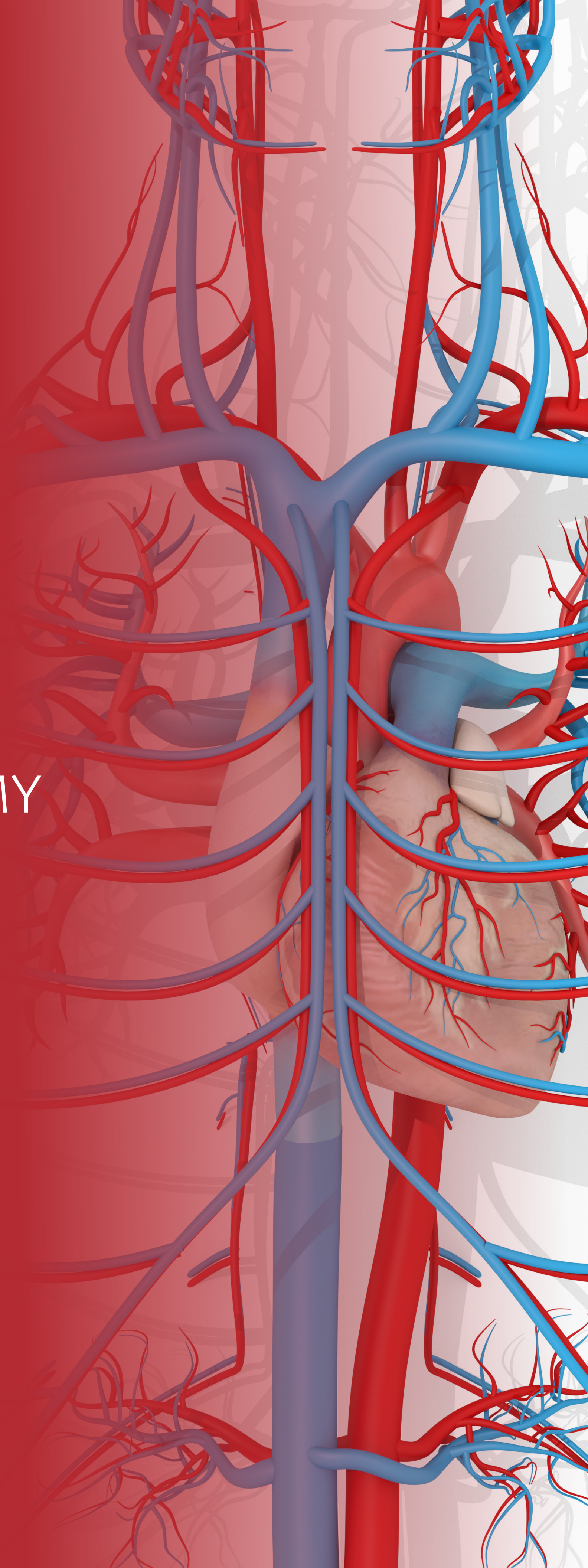
After Care

- Necrotic muscle should be debrided at the time of original fasciotomy.
- Open wounds should be covered with nonadherent dressing or moist gauze.
- The wound(s) should be frequently reevaluated, with further debridement as indicated.
- Negative pressure wound therapy is useful once the wound has been adequately debrided and may reduce time to wound closure.
- Delayed primary closure or split-thickness skin grafting may be performed after the acute process subsides.
- Monitor for rhabdomyolysis. High serial creatine phosphokinase (CPK) levels, worsened acute renal failure, or unexplained acidosis should prompt reinspection of the fasciotomy and may be an indicator of incomplete fasciotomy or new necrotic tissue.

Complications

- Surgical site infection
- Incomplete fasciotomy
- Missed compartment
- Loss of limb
- Permanent nerve damage
- Vascular injury, bleeding
- Cosmetic deformity from fasciotomy
- Multisystem organ failure and rhabdomyolysis from missed or incompletely treated CS

CHAPTER 6
SURGICAL AIRWAY: CRICOTHYROIDOTOMY



Surgical Airway: Cricothyroidotomy (Cricothyrotomy)

This chapter will discuss the indications for a surgical airway, or cricothyroidotomy. The relevant anatomy required to successfully and safely perform the technique will be reviewed. The positioning of the patient, the equipment needed, and the steps for a classically performed cricothyroidotomy will be presented in a detailed, stepwise fashion. Finally, the pitfalls associated with this procedure will be briefly discussed.

Learning Objectives

By the end of the ASSET course, participants should be able to do the following:

1. Describe the indication for a surgical airway.
2. Describe the anatomical features and landmarks that will enable success.
3. List the minimal equipment needed to perform an emergency cricothyroidotomy as well as common adjuncts.
4. Correctly demonstrate the steps required for a cricothyroidotomy.
5. Understand the potential pitfalls of this procedure.

General Considerations

- Cricothyroidotomy is an emergent procedure and, although rarely performed, is a critical lifesaving skill.
- Rates of cricothyroidotomy have decreased in recent years, attributable to adoption of advanced video laryngoscopy, improved noninvasive airway rescue techniques, and the presence of adequately trained airway specialists.
- Given the increasing rarity of this procedure, it is imperative that all clinicians be well versed in the technique and frequently practice for the occasional case in which cricothyroidotomy will be required.
- Cricothyroidotomy is indicated when an emergency airway is required and orotracheal or nasotracheal intubation is either unsuccessful or contraindicated.
- Conditions associated with the need for cricothyroidotomy include massive oral and nasopharyngeal hemorrhage, profound emesis in the airway, trismus, obstructing lesions (e.g., tumor, polyp, laryngeal edema, infection, Ludwig's angina), and a broad range of traumatic and congenital deformities, any of which may prevent successful orotracheal or nasotracheal intubation.
- There are no absolute contraindications to emergency cricothyroidotomy in adults.
- Relative contraindications include a possible or known transection of the trachea, laryngeal fracture, or laryngeal-tracheal disruption. In such cases, tracheostomy or stabilization of the distal tracheal segment followed by direct intubation would likely be the preferred approach.
- The age at which one can safely perform a cricothyroidotomy on a child is not well established, and recommendations vary from five to 12 years old, with the size of the child and presence of palpable landmarks taking precedence over chronologic age.
- If it is clear that a surgical airway is needed, it should be done without delay to avoid hemodynamic collapse, cardiac arrest, and cerebral anoxia due to untreated hypoxemic respiratory failure. Cricothyroidotomy provides the fastest and safest route and requires only basic equipment.
- Cricothyroidotomy is always accompanied by bleeding, and entry into the airway will result in wide dispersal of blood and airway secretions. As such, it is imperative that all members of the team have adequate personal protective equipment, including face and eye protection.

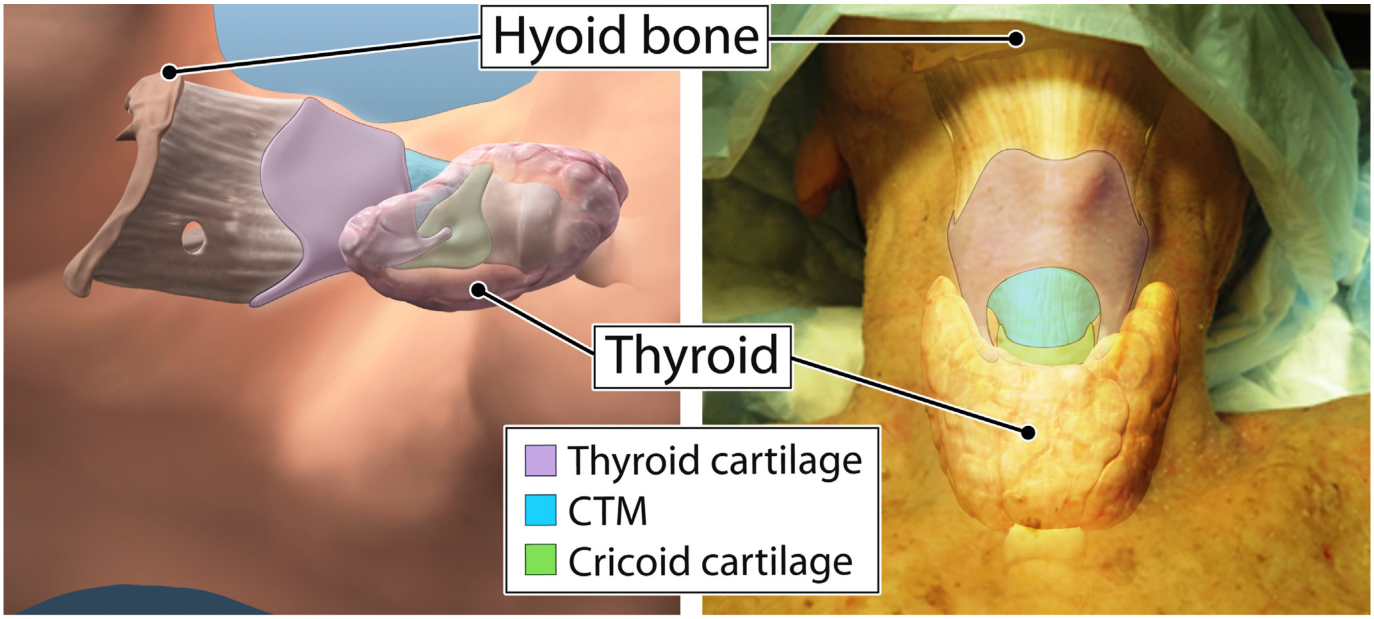


Figure 1. The cricothyroid membrane (CTM), located between the thyroid and cricoid cartilages, is the portion of the airway closest to the skin and is the ideal location for emergent surgical access to the airway.

Anatomy and Anatomical Considerations

- Proper performance of a cricothyroidotomy depends on an understanding of the relevant anatomy and the ability to identify the cricothyroid membrane (CTM).
- The CTM is the logical choice for an emergent airway: it is the part of the airway that is closest to the skin, and there are no critical structures between it and the skin.
- The boundaries of the CTM are the thyroid cartilage superiorly, the cricoid cartilage inferiorly, and the cricothyroid muscles laterally on both sides (Figure 1).
- The thyroid cartilage (also known as the "Adam's apple") is usually the most reliable landmark, and the laryngeal prominence at the superior border has a *V*-shaped notch that can be used to orient the anatomy.
- With the patient supine, the CTM is generally 4 fingerbreadths above the sternal notch.
- Identification of the CTM is not always straightforward. Obesity compounds the problem.
- Given the challenges of identifying the CTM, it is preferable to make the skin incision in a vertical (as opposed to horizontal) fashion, as this enables extension either superiorly or inferiorly if the level of the CTM is misidentified. Repeated palpation of the landmarks is essential.
- The cricothyroid arteries are branches of the superior thyroid arteries and course along both sides of the CTM. They anastomose in the midline, just below the thyroid cartilage. Therefore, the CTM should be incised in its inferior third if possible, although this may be difficult to do in emergent setting.
- While there is significant variation in the size of the CTM, the average dimensions are roughly 8–12 mm vertically (from bottom of thyroid cartilage to top of cricoid cartilage) by 20–30 mm horizontally. This gap between the cricothyroid muscles is adequate for insertion of a tube into the trachea.
- The mean internal diameter of the airway at the level of the CTM is roughly 12 mm in women and 15 mm in men. This should be kept in mind when making the incision so as not to injure the back wall, as well as when considering the size

of the tube to be used.

- The dimensions of the CTM and the diameter of the airway have a bearing on the size of tube used. It is recommended that a tube of no more than 9–10 mm outer diameter (which corresponds to a 7 mm internal diameter) be used. A good rule of thumb is to choose a tube that is 1 mm smaller than would be used for orotracheal intubation.
- The preferred tube for emergency airways is a number 6 or 6.5 endotracheal tube.
- If a Shiley™ tracheostomy tube is used, it should not exceed a size 4 (9.4 mm outer diameter).

Technique for Cricothyroidotomy

- Several variations of technique for performing a surgical cricothyroidotomy are described. The classical technique shown in this manual was chosen because of the need for minimal equipment, the ability to extend if the anatomy is unclear, and the rapidity with which it can be performed once mastered.
- All members of the team should use standard precautions to protect against blood and body fluid exposure.
- The equipment required to perform a cricothyroidotomy (Figure 2) is minimal, and the entire procedure can be done with just a scalpel, a tube, and a syringe. Common equipment adjuncts include a tracheal hook, a Trousseau dilator or spreader, a Kelly clamp, and a bougie (tracheal tube introducer).
- The patient should be placed in a supine position.
- Unless there is concern for cervical spine injury, extend the patient's neck to help identify the anatomical landmarks.
- If the patient is being ventilated, once the incision is made in the airway, the airway bag mask ventilations should be discontinued, as this can insufflate the soft tissues of the neck and expel blood into the face of the operator.
- If time permits, the skin of the anterior neck is prepped and the relevant landmarks are marked (Figure 3).
- If the patient is conscious, time permitting, consider using local anesthesia in the skin,

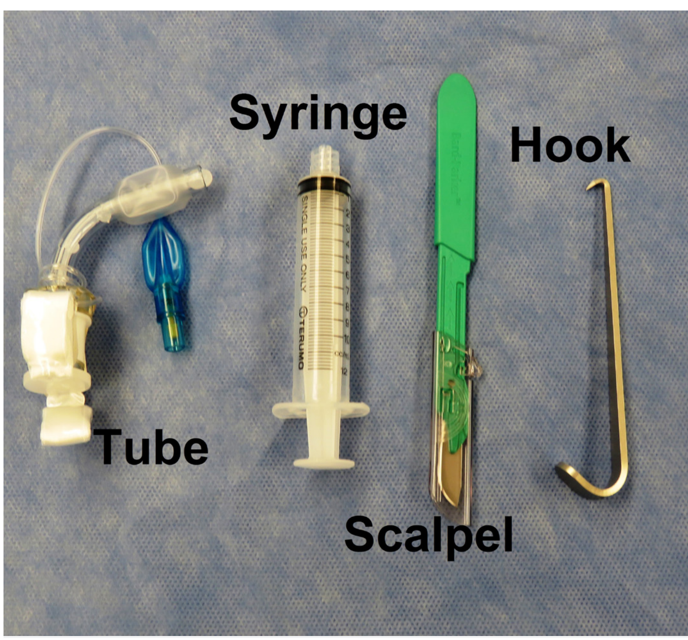


Figure 2. The minimum equipment needed to perform a cricothyroidotomy includes a tube, a syringe, a scalpel, and (if desired) a tracheal hook.

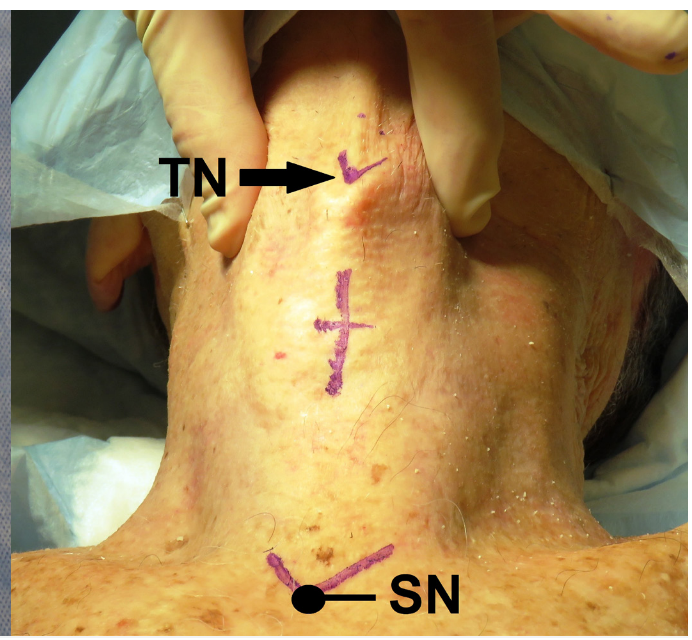


Figure 3. If time permits, landmarks are marked to include the notch of the thyroid cartilage (TN), the sternal notch (SN), and the incision (vertical line) made on the midline and centered over the area of the CTM (horizontal line).

Figure 4. The thumb and middle finger are used to stabilize the larynx and the index finger is used to palpate the cricothyroid membrane.

subcutaneous tissues, and CTM.

- The operator should stand on the side of the patient corresponding to the operator's dominant hand (if right-handed, stand on patient's right side).
- The thyroid cartilage is grasped with the nondominant hand using the thumb and middle finger to stabilize the thyroid cartilage, and the index finger is used to palpate the CTM (Figures 3 and 4). The larynx should be stabilized in this manner throughout the procedure to preserve the anatomical relationships. At this point, it is advisable to not let go with the nondominant hand.
- A vertical incision (3–5 cm in length) is made through the skin and subcutaneous tissues overlying the CTM (Figure 5).
- The index finger is then placed into the wound to palpate and confirm the location of the CTM

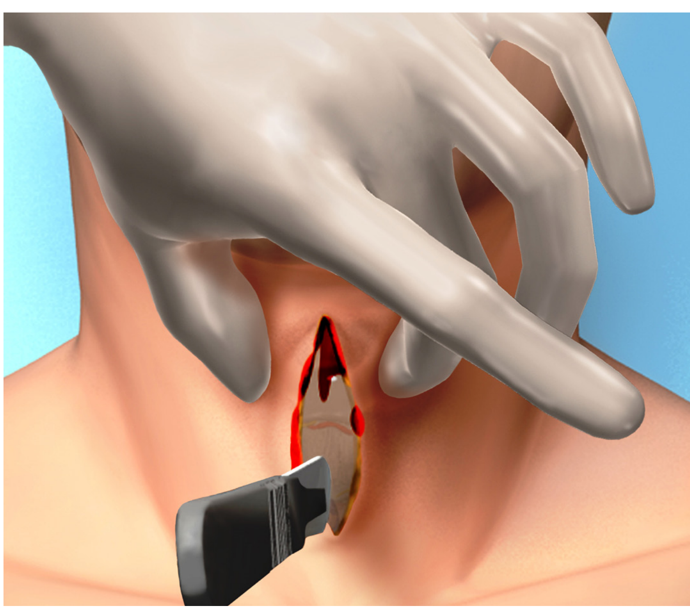


Figure 5. With the larynx stabilized with the nondominant hand, a 3–5 cm incision is made in the midline, centered over the cricothyroid membrane.

Figure 6. While maintaining stabilization of the larynx, the index finger is used to confirm by palpation the location of the cricothyroid membrane.

(Figure 6).

- A 1 cm horizontal incision is made in the CTM (Figure 7).
- The incision through the CTM should be made with care in the lower third of the membrane to avoid the arteries, aimed in a caudad direction to avoid the vocal cords, and limiting the depth of the scalpel to avoid injury to the back wall.
- The scalpel handle can be used to dilate the incision by flipping the scalpel handle 180° and placing the apex of the handle into the wound and rotating it (Figure 8).
- Alternatively, a Trousseau dilator or Kelly clamp can be used to enlarge the incision.
- The selected tube can now be inserted either without (Figure 9) or with (Figure 10) the assistance of a tracheal hook placed under the thyroid cartilage and retracted towards the patient's head.
- If a dilator or tracheal hook is used, care must be taken when removing the implement to prevent damage to the balloon or accidental

Figure 7. A horizontal incision 1 cm in size is made in the cricothyroid membrane with a scalpel.

Figure 8. The scalpel is flipped 180°, and the apex of the handle is inserted into the incision and rotated to dilate the opening.

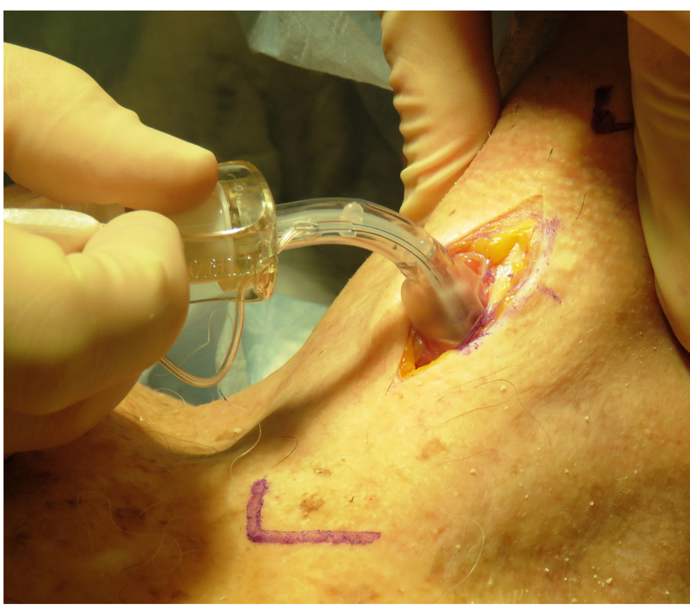


Figure 9. While stabilizing the larynx, a tracheostomy tube is inserted and angled towards the feet.

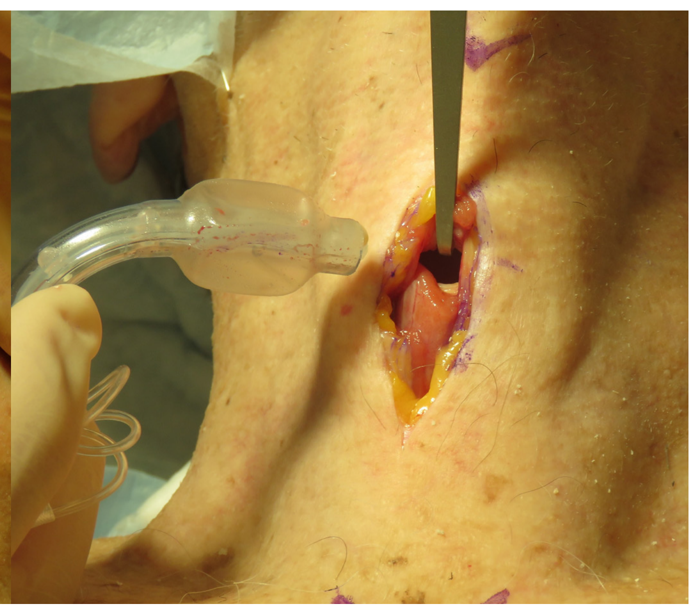


Figure 10. A tracheostomy hook has been placed under the thyroid cartilage and used to retract in a cephalad direction to assist tube placement.

dislodgement of the tube.

- Once the tracheostomy tube has been placed into the airway, the obturator is removed and replaced by the inner cannula.
- If a tracheostomy tube is not available, an endotracheal tube can be used, taking care not to insert it too far (which can create a right main-stem intubation). The endotracheal tube is advanced until the balloon passes distal to the CTM.
- The cuff of the tube should then be inflated with air from a 10 cc syringe (Figure 11). The balloon is inflated until the airway is fully occluded. Take care not to overinflate, as this risks pressure-related injury to the tracheal mucosa.
- The tracheal tube is connected to the mechanical ventilator or bag-valve device. Presence of end tidal CO_2 should be confirmed by colorimetric device or wave capnography, and bilateral breath sounds should be confirmed by auscultation. After confirming that the tube is properly positioned in the trachea, the tube is secured with circumferential ties around the neck (Figure 12).
- The technique described above is by no means the only way of performing a surgical cricothyroidotomy, but it represents a standardized, consensus-driven approach that requires minimal equipment and can be done rapidly and with minimal complications by appropriately trained individuals.

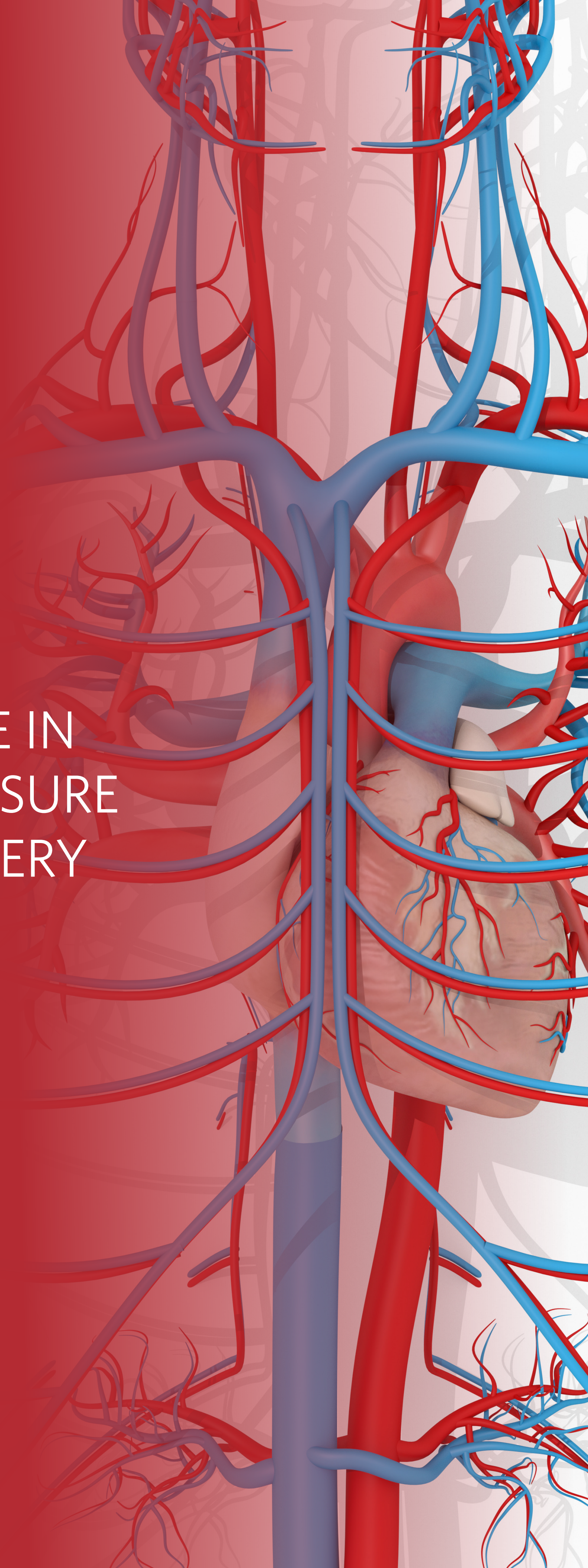
Figure 11. The cuff on the tracheostomy tube is inflated with a 10 cc syringe.

Figure 12. The tube is secured with circumferential ties around the neck.

Pitfalls and Complications

- Cricothyroidotomy is a lifesaving procedure performed infrequently, in the setting of a patient likely to die unless the procedure is rapidly and correctly performed. As such, there are a number of potential early complications associated with this procedure, as follows:
  - Bleeding/hematoma
  - Incorrect placement and creation of a false passage in the neck tissues
  - Subcutaneous emphysema
  - Posterior tracheal wall perforation
  - Esophageal or mediastinal perforation
  - Thyroid injury and bleeding
  - Vocal cord injury
  - Laryngeal injury
  - Aspiration
  - Airway obstruction
  - Pneumothorax
  - Tube migration or dislodgement
  - Right main-stem intubation if an endotracheal tube is chosen and inserted too deeply
- A number of late complications are also associated with this procedure, including the following:
  - Dysphonia
  - Infection
  - Glottic or subglottic stenosis
  - Laryngeal stenosis
  - Tracheoesophageal fistula
  - Tracheomalacia

CHAPTER 7
OPERATIVE EXPOSURE IN NECK TRAUMA: EXPOSURE OF THE CAROTID ARTERY AND JUGULAR VEIN



Operative Exposure in Neck Trauma: Exposure of the Carotid Artery and Jugular Vein

This chapter will discuss exposure of actual or suspected injuries to the carotid artery and jugular vein in the neck. Though the major emphasis is operative exposure, general review of the principles of diagnosis and management will also be presented.

Learning Objectives

By the end of the ASSET course, participants should be able to do the following:

1. Identify the three zones of the neck using anatomical landmarks.
2. Describe the diagnostic modalities available for injuries of the neck.
3. Describe how to position and prep patients undergoing operative exploration of the neck.
4. Demonstrate surgical exposure of the internal jugular veins and carotid arteries.

Considerations

- Penetrating injuries to the neck require operative intervention more commonly than blunt force injuries.
- Physical examination is helpful in determining the likely injury and determining the surgical approach.
- Findings such as carotid bruit, hematoma, tracheal deviation, active bleeding, neurologic deficit, and associated facial or thoracic injuries will dictate the management sequence and choice of incision.
- The neck is classically divided into three zones (Figure 1). The zone of the neck involved will influence the subsequent evaluation, surgical exposure, and management.
- Initial care should be focused on securing the airway with rapid intubation or a surgical airway.
- Cricothyroidotomy or tracheostomy may be difficult with anterior triangle hematomas.
- Stable patients will benefit from CT angiogram (CTA) or formal angiogram to evaluate for vascular injuries.
- Unstable patients or patients with hard signs of vascular injury should have emergent surgical exploration once the airway has been secured.

Positioning and Prep

- The patient's arms should be tucked at the sides.
- A roll should be placed behind the shoulders and the head rotated to the contralateral side (Figure 1). If cervical spine injury is suspected, the head should be maintained in a neutral position, which makes exposure more difficult.
- The entire neck, anterior torso, and groin should be prepped in the event that median sternotomy or saphenous vein harvest is needed.

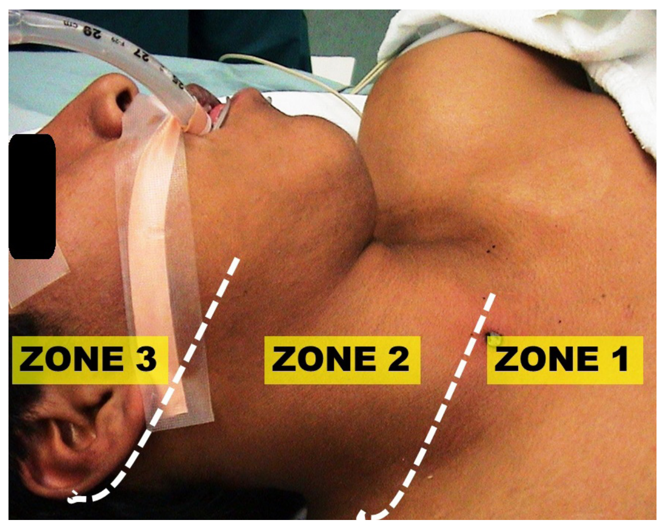


Figure 1. The classic zones of the neck. Zone 1 extends from the inferior aspect of the cricoid cartilage to the thoracic outlet. Zone 2 extends from the cricoid to the angle of the mandible. Zone 3 extends from the angle of the mandible to the base of the skull.

Surgical Exposure

ZONE 1

- Zone 1 of the neck extends from the inferior aspect of the cricoid cartilage to the thoracic outlet.
- Suspected vascular (and other) injuries to Zone 1 of the neck usually require entry into the chest via sternotomy or anterior thoracotomy, as described in chapters 10 and 12.
- Some injuries to Zone 1 can be managed with a supraclavicular approach, as described in chapter 14, or an infraclavicular approach, as described in chapter 2.

ZONE 2

- Zone 2 of the neck extends from the cricoid to the angle of the mandible.
- Zone 2 is a target-rich environment. It contains the jugular veins, the distal common carotid arteries and their bifurcation, the proximal portions of the external and internal carotid arteries, the vertebral arteries, the thyroid gland, the larynx, the proximal esophagus, the spinal cord, and the vagus, phrenic, and recurrent laryngeal nerves.
- Zone 2 is the most surgically accessible region of the neck, and penetrating injuries to this region often require operative exploration.
- Historically, Zone 2 injuries required mandatory surgical intervention. The use of adjuncts (in a stable patient) such as arteriography (CT or formal), bronchoscopy, laryngoscopy, and esophagoscopy have allowed for a selective nonoperative approach.
- The classic incision for unilateral exploration of Zone 2 injuries is a longitudinal incision made along the anterior border of the sternocleidomastoid muscle, extending from the retromandibular area near the mastoid to the clavicular head (Figure 2).
- The sternocleidomastoid is then separated from the underlying vascular sheath by sharp dissection on its medial border.
- Exposure of the carotid artery requires division of the omohyoid muscle and division and ligation of the common facial vein (Figure 3). The common facial vein generally lies over the carotid bifurcation.

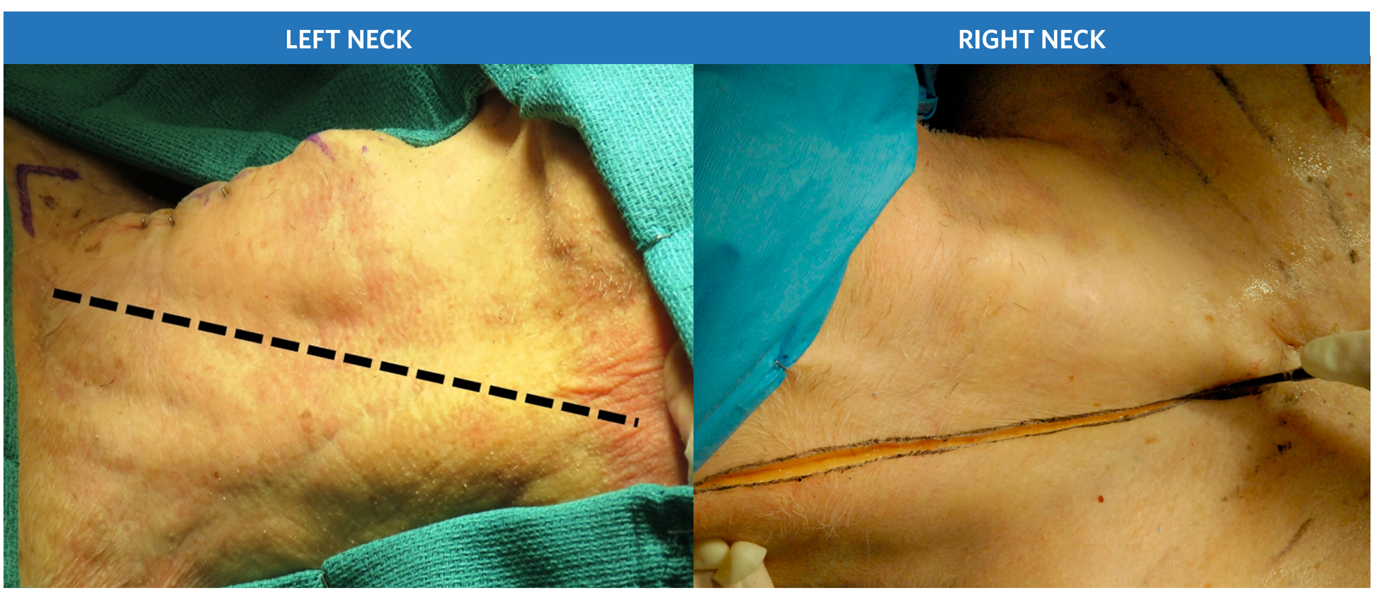


Figure 2. The classical incision for Zone 2 neck exploration is made on the anterior border of the sternocleidomastoid muscle, extending from the retromandibular area to the clavicular head, as seen on the left neck (left) and the right neck (right).

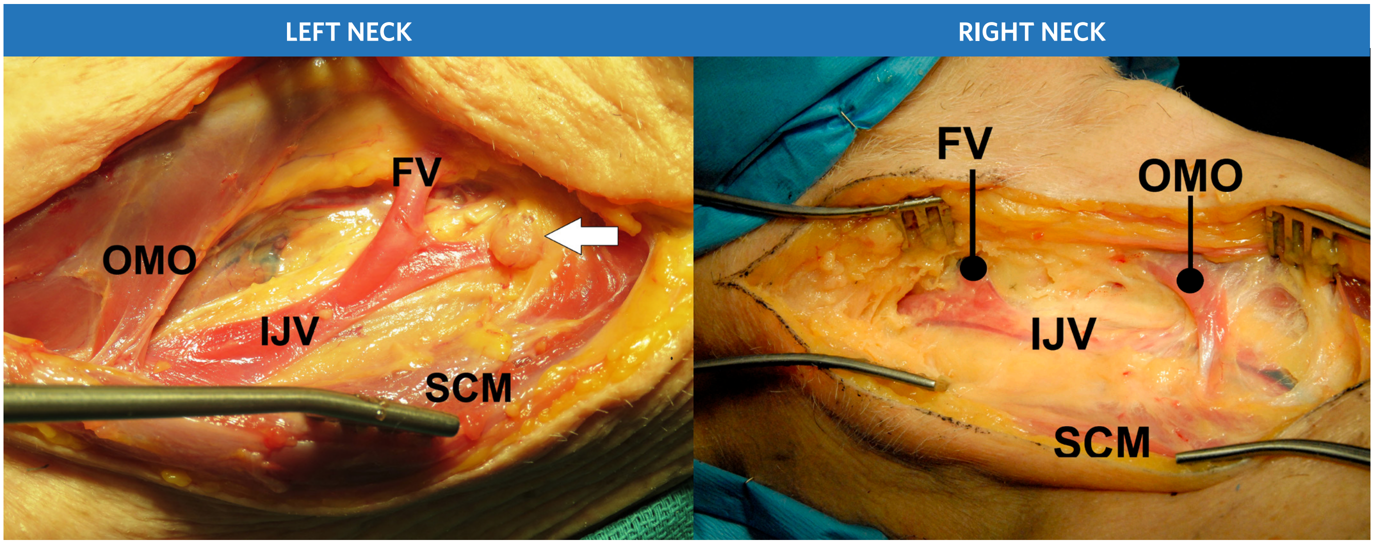


Figure 3. The sternocleidomastoid (SCM) is dissected free from the vascular sheath along its medial border and retracted laterally to expose the internal jugular vein (IJV), the facial vein (FV), and the omohyoid muscle (OMO), as seen in dissection on both the left and right sides of the neck. The white arrow marks the lateral horn of the hyoid cartilage.

- The vascular sheath is opened inferiorly in the plane anterior to the omohyoid muscle, and the internal jugular vein is dissected free after division of the omohyoid muscle and common facial vein (Figure 4).
- The bifurcation of the carotid artery into the external and internal branches occurs at variable levels in the neck. A low bifurcation on the left side of a neck and a high bifurcation on the right side of a neck can be seen in the figure below (Figure 4).
- The external carotid artery is identified by the presence of branches, of which there are seven.
- If exposure of both sides of the neck is required in Zone 2, a collar incision carried across the base of the neck at the level of the trachea can be used (chapter 8). An alternative is to perform a second incision on the anterior border of the sternocleidomastoid muscle in the contralateral neck.
- Injuries with ongoing hemorrhage in Zone 2 of the neck can be difficult to visualize, and proximal control in the chest may be required.

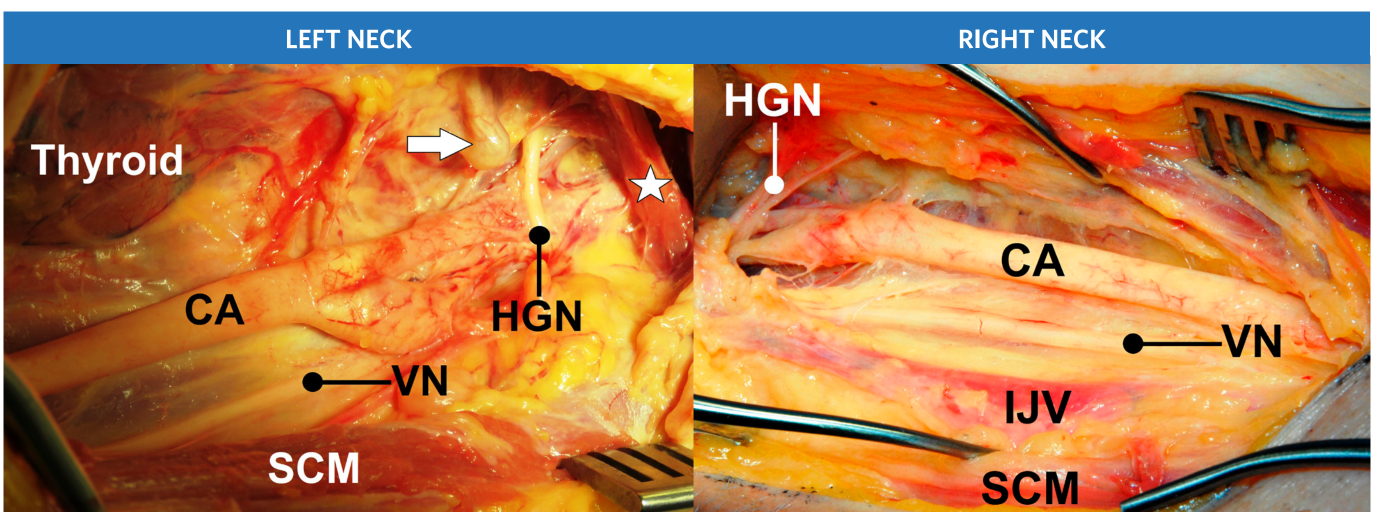


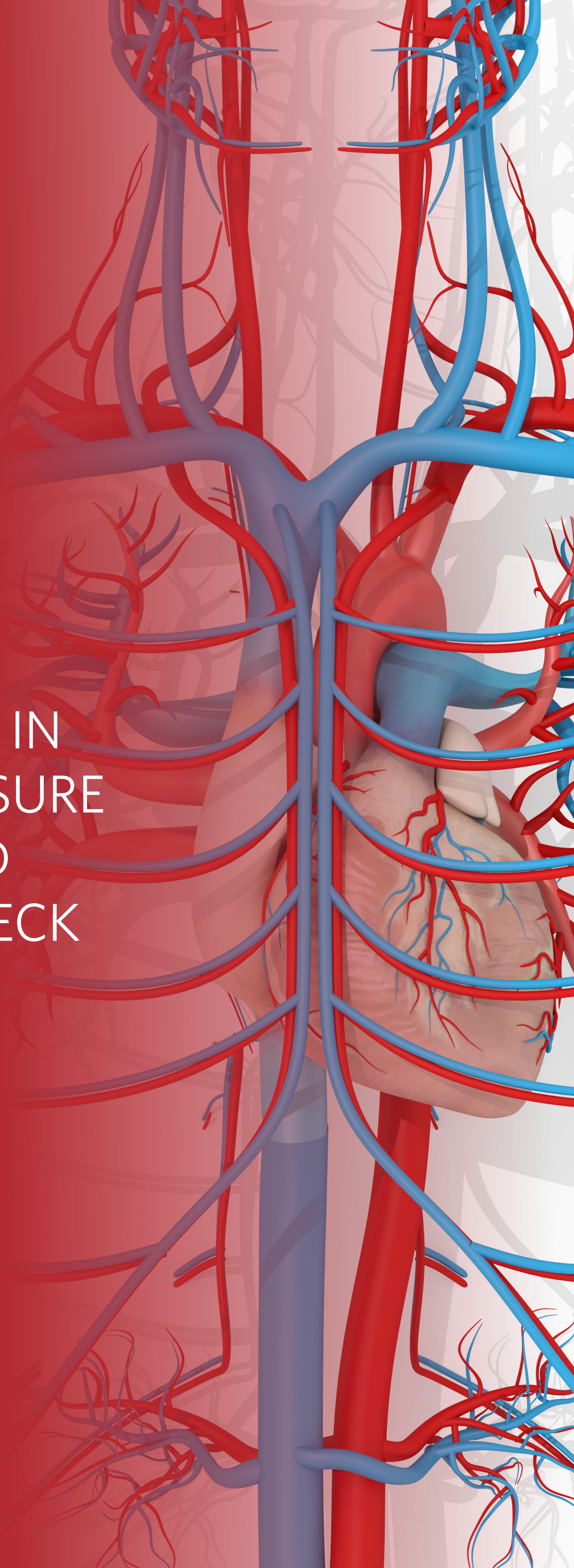
Figure 4. Division of the omohyoid muscle and common facial vein, along with further lateral retraction of the sternocleidomastoid (SCM), allows for exposure of the carotid artery (CA) and the vagus nerve (VN), which lies between the CA and the internal jugular vein (IJV). As seen in the dissection of the left neck, the thyroid gland, hyoid cartilage (white arrow), and digastric muscle (white star) are also exposed during this dissection, as is the hypoglossal nerve (HGN), which is also well seen on the right neck dissection.

- If the carotid artery is injured, it is preferable to repair it rather than ligate. If vascular repair expertise is not available, or in damage control situations, the carotid artery can also undergo temporary shunting.
- The artery may be ligated in situations of extremis from exsanguinating hemorrhage from a carotid artery injury.
- Ligation of the common carotid is usually well tolerated due to the presence of collateral flow across the face from the contralateral external carotid.
- Ligation of the internal carotid artery will likely result in stoke if the circle of Willis is not intact, which occurs in about 15 percent of the population.

ZONE 3

- Zone 3 is the smallest region of the neck and is bound by the bony structures of the skull and mandible.
- The contents of Zone 3 include the pharynx, vertebral arteries, and distal internal carotid arteries.
- The mainstay for hemorrhage control in most Zone 3 injuries is endovascular control.
- If there is active bleeding from a penetrating Zone 3 injury, balloon tamponade (Foley or Fogarty) may provide temporary control of bleeding.
- Surgical exposure of Zone 3 is challenging and may require disarticulation of the temporomandibular joint, partial resection or division of the mandible, and/or craniotomy to expose injured structures. Such techniques are beyond the scope of this manual and are best relegated to specialists with the requisite expertise.

CHAPTER 8
OPERATIVE EXPOSURE IN NECK TRAUMA: EXPOSURE OF THE TRACHEA AND ESOPHAGUS IN THE NECK



Operative Exposure in Neck Trauma: Exposure of the Trachea and Esophagus in the Neck

This chapter will discuss exposure of actual or suspected injuries to the trachea and esophagus in the neck. Though the major emphasis of this lab experience is operative exposure, general review of the principles of diagnosis and management will also be presented.

Learning Objectives

By the end of the ASSET course, participants should be able to do the following:

1. Describe signs and symptoms of tracheal and esophageal injuries.
2. Describe diagnostic modalities to identify injuries to these structures.
3. Describe and demonstrate recommended position and prep for surgical exploration.
4. Demonstrate the incision options to expose the trachea and esophagus.
5. Demonstrate steps in surgical exposure of the trachea and esophagus in the neck.

Considerations

- Injuries to the trachea can occur from either blunt or penetrating mechanisms. Penetrating injuries to the neck are more common and require operative intervention.
- Hematomas can cause extrinsic compression of the airway.
- The most common cause of esophageal injury is iatrogenic (e.g., from endoscopy); otherwise, penetrating mechanisms are much more common than blunt.
- Physical signs suggesting tracheal and laryngeal injury include stridor, hoarseness, hemoptysis, and subcutaneous emphysema.
- Physical signs suggesting esophageal injury include dysphagia, odynophagia, blood in the oropharynx, and subcutaneous emphysema.
- Finding air in the mediastinum or deep neck on CT or plain film is also suggestive of injury to the trachea or esophagus.
- Initial priority is control of the airway and further diagnostic evaluation by bronchoscopy, endoscopy, or CT imaging, based on stability and suspected injury.
- Broad-spectrum antibiotics should be initiated early.
- Position and preparation are the same as for vascular exposure (see chapter 7).

Surgical Exposure

TRACHEAL INJURIES (CERVICAL)

- Cervical tracheal (upper third) injuries are best exposed through a collar incision made 1–2 cm above the sternal notch and extended laterally beyond the medial border of the sternocleidomastoid muscles. If the injury extends into or involves the thoracic trachea, the incision can be extended into the chest via a sternotomy (Figure 1).
- The platysma is divided in the same orientation to expose the strap muscles, taking care to avoid or control the anterior jugular veins.
- The subplatysmal flaps are raised superiorly and inferiorly, and the strap muscles are separated or divided at the midline. This allows for exposure of the anterior portion of the thyroid gland, portions of the cervical trachea, and the bilateral carotids (Figure 2).
- Exposure of the remainder of the trachea requires division of the thyroid isthmus and extension into the chest via a partial or full median sternotomy (Figure 3).
- When exposing the trachea, it is important not to devascularize it circumferentially, as successful repair is dependent on good blood supply.
- The principles of surgical treatment of tracheal injuries are debridement of devitalized tissue (including cartilage), end-to-end anastomosis with absorbable suture, and flexion of the neck to avoid tension on the anastomosis.
- Simple, clean injuries without devascularization can be repaired primarily with simple absorbable sutures.

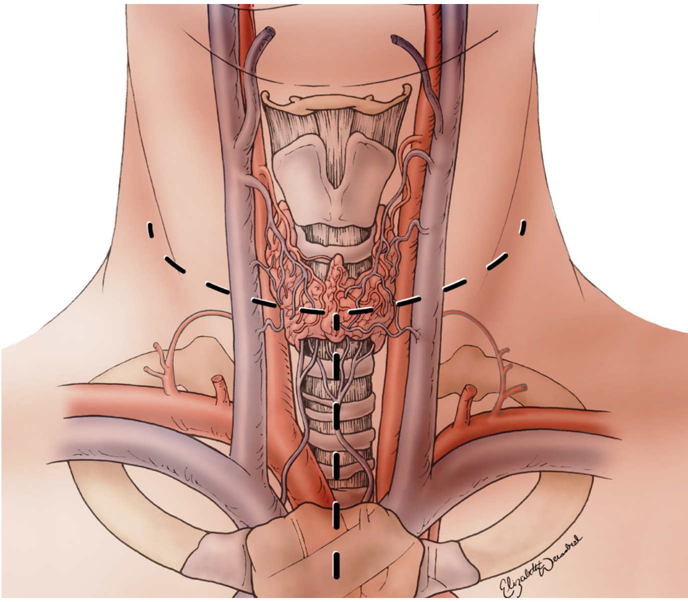


Figure 1. The cervical trachea is approached via a collar incision extended into chest if indicated.

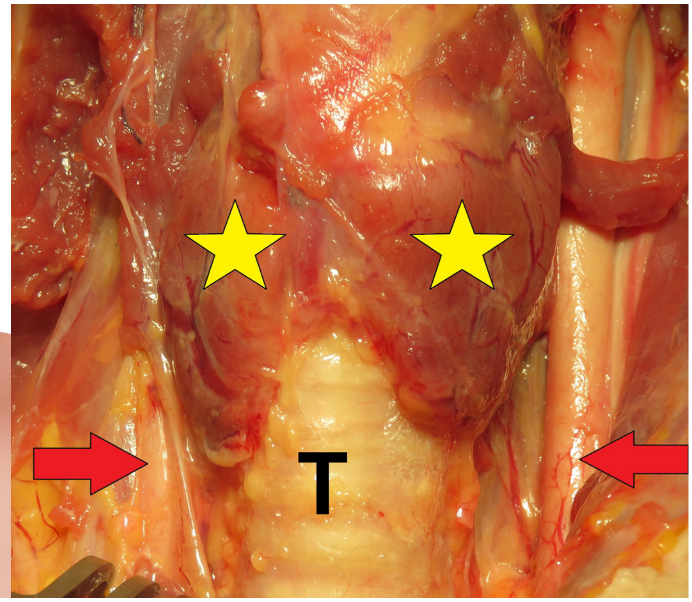


Figure 2. Exposure of the cervical trachea (T), the bilateral carotid arteries (arrows), and the thyroid gland (yellow stars) via a collar incision in the lower neck.

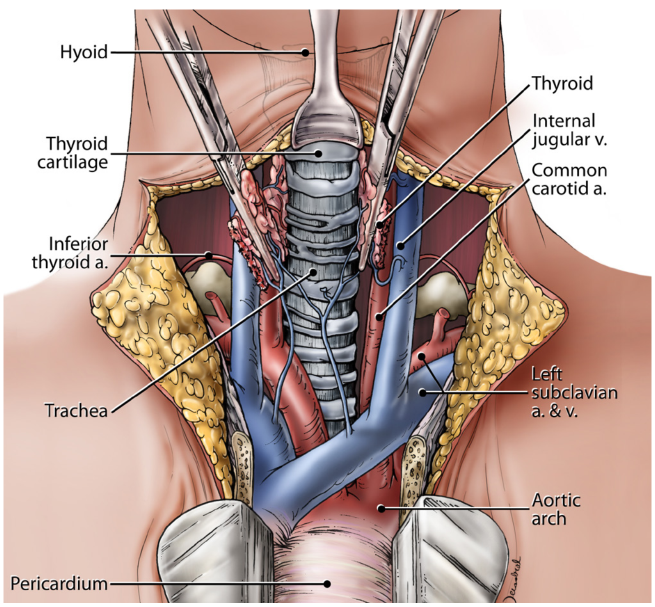


Figure 3. Exposure of the trachea after division of the thyroid isthmus and the associated anatomy following a collar incision extended into a partial sternotomy.

ESOPHAGEAL INJURIES (CERVICAL)

- The esophagus is optimally exposed through an incision anterior to the sternocleidomastoid muscle.
- Though the esophagus can be accessed through either side of the neck, an incision on the left is preferable, as the upper esophagus resides predominantly in the left neck.
- The esophagus is formed at the inferior portion of the cone-shaped cricopharyngeal muscles, and encircling the esophagus can only be accomplished below these muscles. As such, the esophagus is generally found lower in the neck than one might expect and is often most easily encircled at the level of the clavicle.
- Dissection of the esophagus is facilitated by passage of either a nasogastic or orogastric tube.
- The carotid sheath should be mobilized laterally and the trachea medially, allowing for visualization of the upper esophagus from the cricopharyngeus to its entry into the posterior mediastinum (Figures 4 and 5).

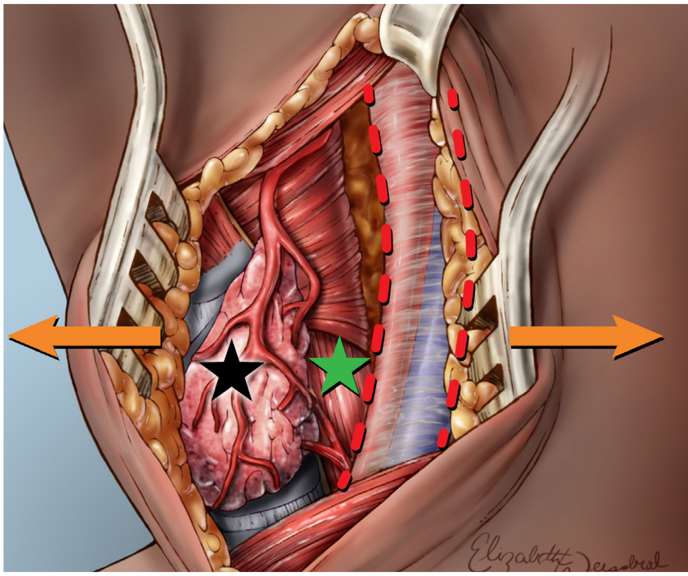


Figure 4. The esophagus (green star) is exposed by mobilizing the carotid sheath (contained by red dotted lines) laterally and the thyroid gland (black star) medially.

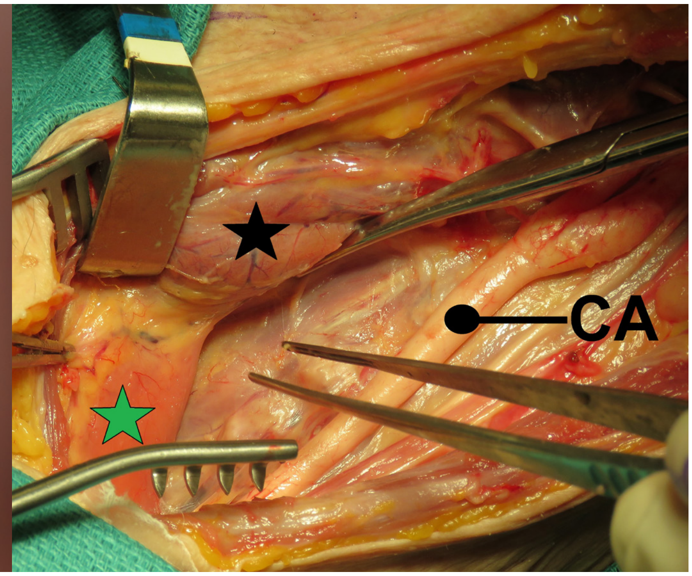


Figure 5. The esophagus (green star) is exposed by mobilizing the carotid artery (CA) laterally and the thyroid gland (black star) medially.

- Mobilization of the thyroid medially may require division of the middle thyroid vein and inferior thyroid artery. Care should be taken to avoid injury to the recurrent laryngeal nerve, which runs in the tracheoesophageal groove (Figure 6). If the nerve is not readily visible, do not make an effort to visualize it, as this risks unnecessary injury.
- To prevent stretch injury to the recurrent laryngeal nerve, the thyroid retraction should be anterior and medial. Superior retraction of the thyroid gland must be specifically avoided.
- Once the subfascial plane has been entered, dissection with a right angle clamp is undertaken. The tip of the right angle should hug the muscular layer of the esophagus to develop a circumferential plane around it, working first behind and then anterior to this structure.
- The esophageal dissection should be done well below the cricoid cartilage and cricopharyngeal muscles with gentle medial traction of the trachea to avoid injury to the recurrent laryngeal nerve.
- Using a right angle clamp, a Penrose drain is passed around the esophagus. Using the drain, the esophagus is gently retracted laterally and superiorly (Figures 6–9), and a combination of sharp and blunt dissection is used to further dissect the esophagus.
- Care must be taken to avoid injury to the posterior tracheal wall while performing this dissection.
- The entire cervical esophagus can also be approached through a collar incision, as described previously for tracheal injuries.
- Injuries to the esophagus can be primarily repaired.
- If either the trachea or esophagus has required repair, vascularized muscle (strap muscles) should be used to cover the repair. This is especially important with combined injuries to prevent breakdown and fistulation between the two structures.

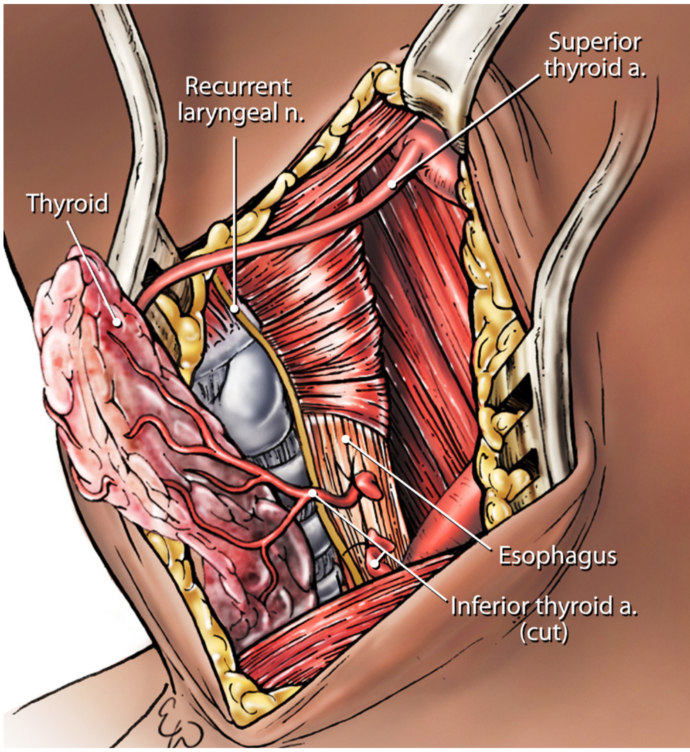


Figure 6. The thyroid gland is retracted medially, and if necessary the inferior thyroid artery is divided.

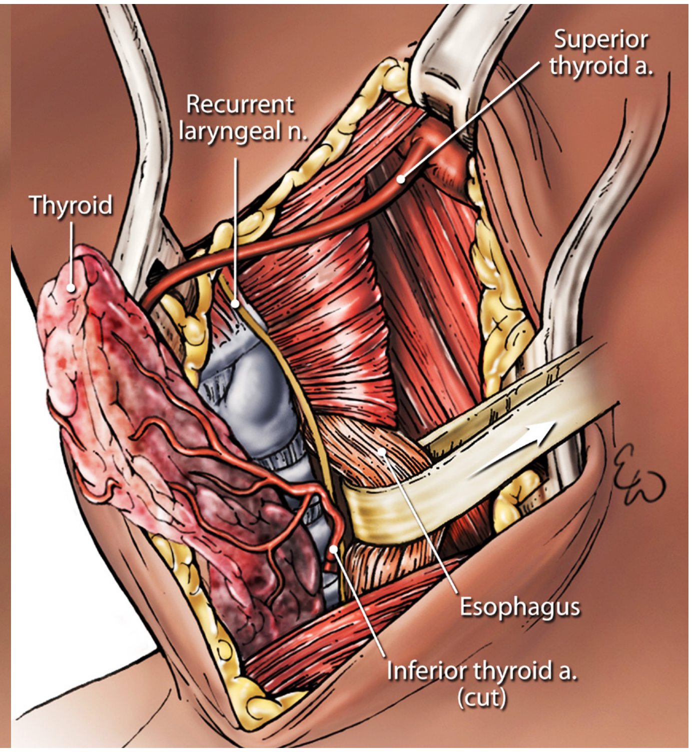


Figure 7. The esophagus is encircled with a Penrose drain, taking care to avoid the recurrent laryngeal nerve.

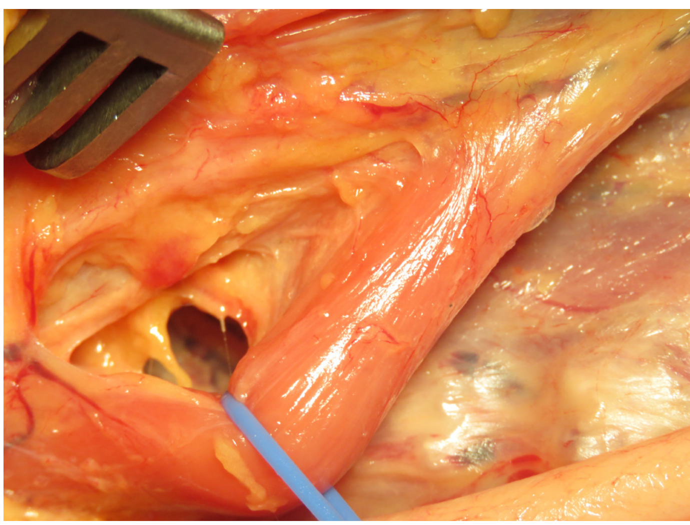


Figure 8. A circumferential dissection plane has been created around the esophagus.

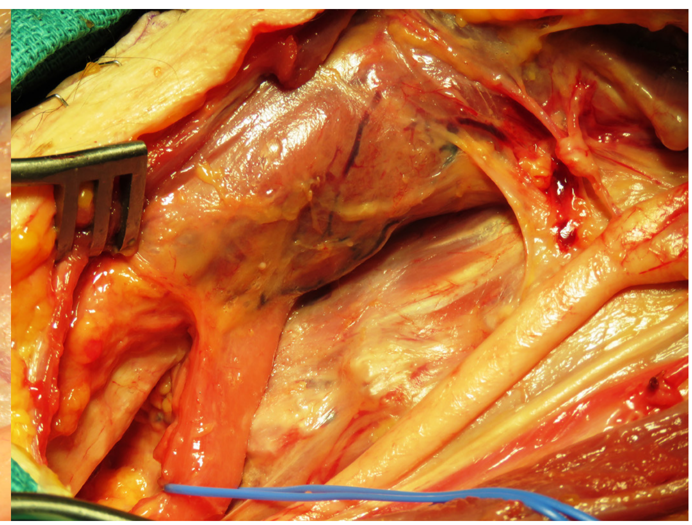
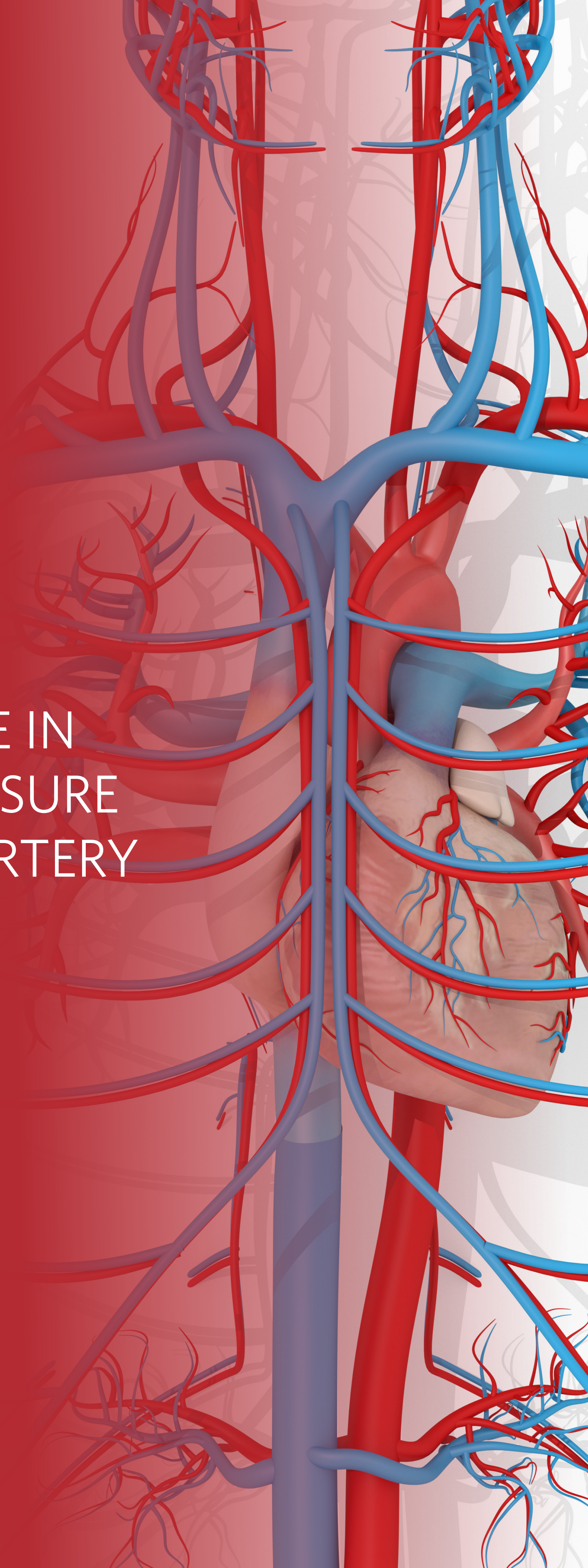


Figure 9. Further dissection and mobilization of the esophagus.

CHAPTER 9
OPERATIVE EXPOSURE IN NECK TRAUMA: EXPOSURE OF THE VERTEBRAL ARTERY IN THE NECK



Operative Exposure in Neck Trauma: Exposure of the Vertebral Artery in the Neck

This chapter will discuss exposure of actual or suspected injuries to the vertebral arteries in the neck. Though the major emphasis of this lab experience is operative exposure, a general review of the principles of diagnosis and management will also be presented.

Learning Objectives

By the end of the ASSET course, participants should be able to do the following:

1. Describe the four zones of the vertebral artery.
2. Demonstrate surgical exposure of the first portion of the vertebral artery in the neck.

Considerations

- Injuries to the vertebral arteries can occur from either blunt or penetrating mechanisms, with penetrating (e.g., gunshot wounds) being the most common.
- Blunt traumatic mechanisms that can result in vertebral artery injury include basilar skull fractures, axial injuries to the spine, ligamentous disruption, direct blows to the neck, chiropractic manipulation, yoga exercises, central line insertion, angiography, and spine operations.
- Except for its first portion, the vertebral artery is protected by the cervical vertebrae and the skull, so it is not easily exposed surgically (Figure 1). As such, the primary method for diagnosing and controlling bleeding is endovascular.
- Paired veins follow the course of the arteries, and multiple small bridging veins are present. As arterial injuries are frequently associated with venous injury, an arteriovenous fistula may occur.

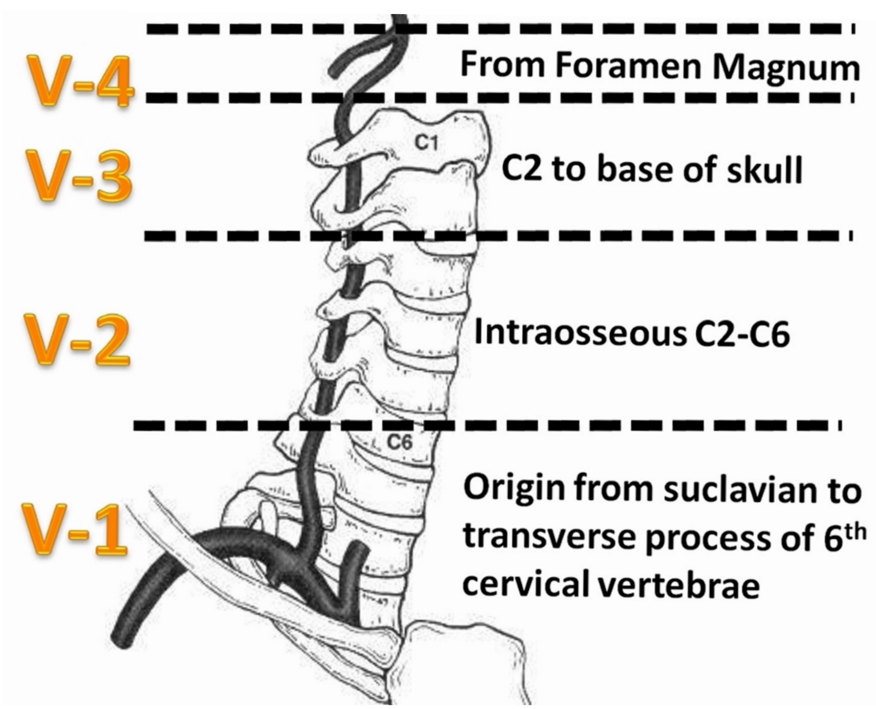


Figure 1. Most of the vertebral artery is surgically inaccessible, with only the first portion (V-1) lending itself to operative exposure by a nonspecialist surgeon.

Surgical Exposure

- There are two main options to expose the most proximal portion (segment V-1) of the vertebral artery: the transverse supraclavicular approach and the vertical anterior cervical approach.
- The supraclavicular approach is perhaps the easiest and provides excellent exposure of the vertebral artery at its origin. This exposure is also used to expose the subclavian artery above the clavicle (see chapter 14). Once the subclavian artery is identified, it is followed medially to expose and identify the origin and first portion of the vertebral artery (Figure 2).

RIGHT NECK WITH HEAD TO LEFT

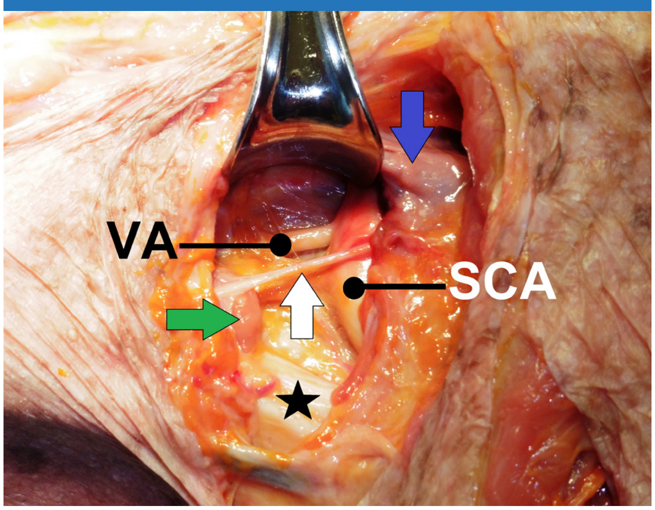


Figure 2. Using a supraclavicular approach on the right neck, the anterior scalene muscle (green arrow) has been divided—taking care to preserve the phrenic nerve (white arrow)—allowing visualization of the subclavian artery (SCA), which is followed medially to find the origin of the vertebral artery (VA). The jugular vein (blue arrow) has been retracted medially to facilitate exposure, and the brachial plexus (star) is seen laterally.

- The vertical anterior cervical approach can also be used for exposure of segment V-1 of the vertebral artery. It is initially similar to the standard incision for neck exploration made along the anterior border of the sternocleidomastoid muscle (see chapter 7). The carotid sheath is retracted medially and the scalene fat pad laterally. This exposes the anterior scalene muscle, which is then retracted or divided to allow exposure of the vertebral artery.
- Injuries to segment V-2 are technically accessible, but the bony canal must be unroofed to expose it, and such exposure is best left to surgeons with appropriate specialty experience.
- Acute hemorrhage from segment V-2, as seen from a stab wound to the posterior triangle of the neck (Figure 3), can be extremely challenging to control and can be temporized with a Foley balloon placed in the wound as a bridge to endovascular control (Figure 4).
- Exposure of segments V-3 and V-4 also requires specialty expertise and is beyond the scope of this course.

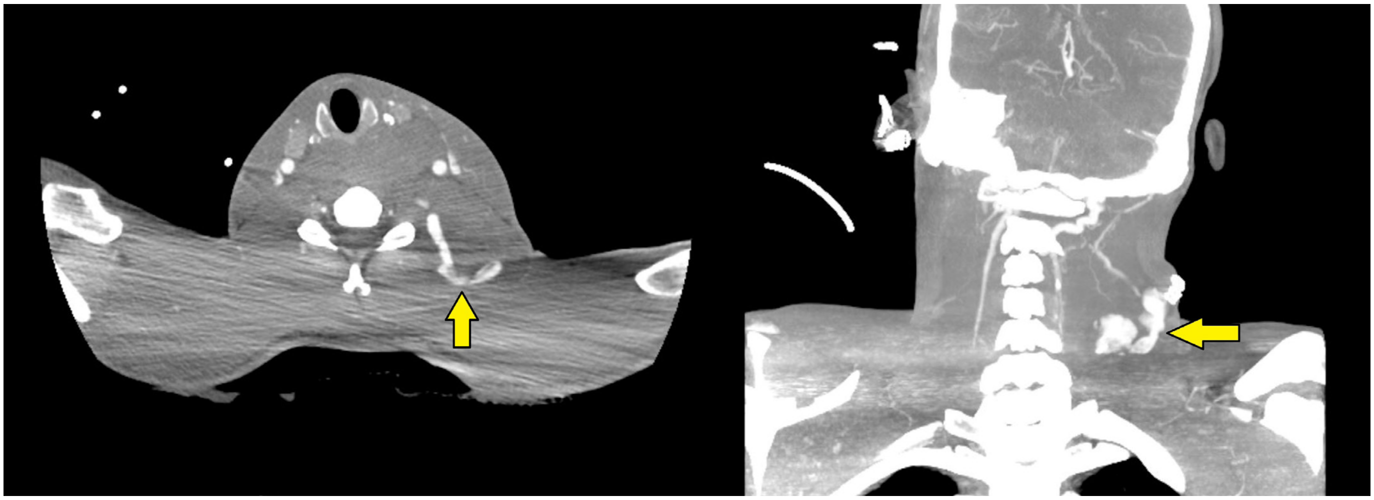
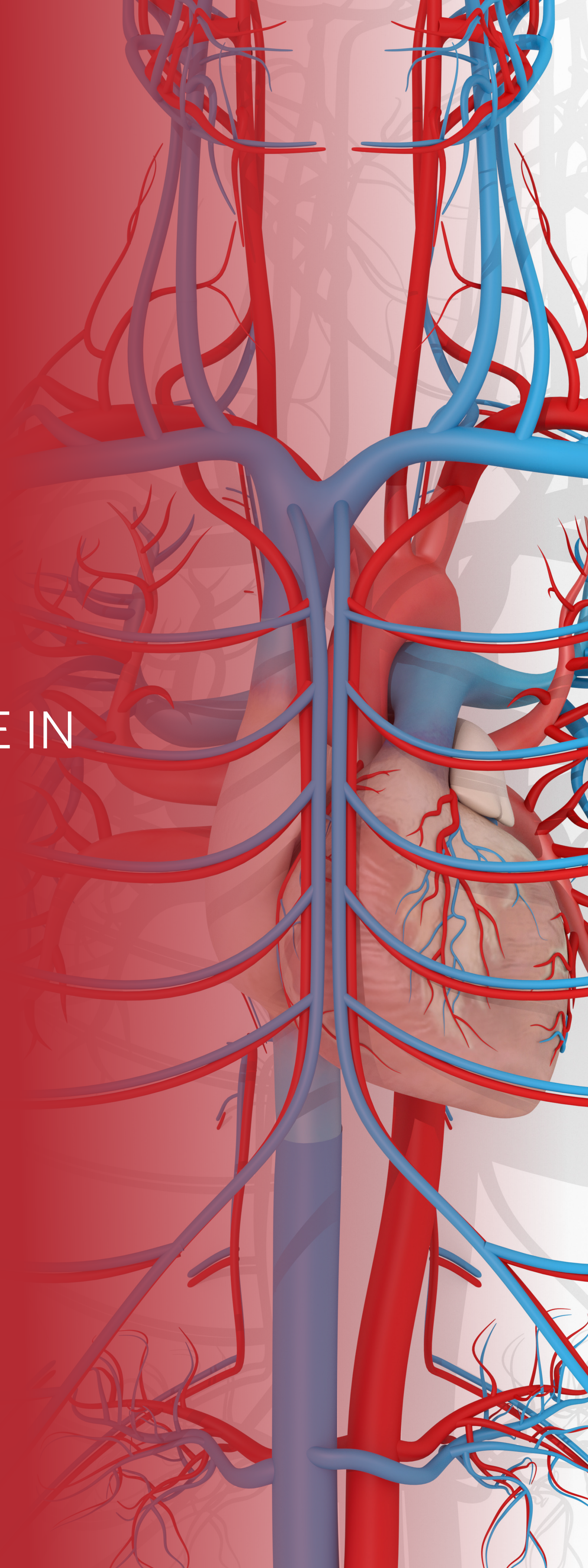


Figure 3. CT angiogram of a patient with active extravasation of contrast (arrow) from a stab wound to the left vertebral artery in segment V-2.

Figure 4. A Foley balloon has been inserted into a stab wound in posterior Zone 2 of the left neck to provide temporary control of bleeding from the vertebral artery.

CHAPTER 10
OPERATIVE EXPOSURE IN THORACIC TRAUMA: INCISIONS



Operative Exposure in Thoracic Trauma: Incisions

This chapter will discuss common thoracic exposures, including median sternotomy, left anterolateral (or resuscitative) thoracotomy, and the "clamshell" incision. The use of these incisions for exposures of specific injuries will be discussed in subsequent chapters.

Learning Objectives

By the end of the ASSET course, participants should be able to do the following:

1. Describe indications for median sternotomy and demonstrate the surgical technique.
2. Demonstrate use of the Lebsche knife.
3. Describe indications for resuscitative thoracotomy and demonstrate the technique.
4. Demonstrate the technique to open the pericardium while preserving the phrenic nerve.
5. Demonstrate the surgical technique to expose and clamp the descending thoracic aorta.
6. Describe indications for clamshell thoracotomy.
7. Demonstrate the surgical technique of extending a resuscitative thoracotomy into a clamshell thoracotomy.

MEDIAN STERNOTOMY

Considerations

- The patient must be stable enough to make it to the operating room; otherwise, resuscitative thoracotomy should be performed (refer to the following section).
- This incision is generally reserved for access to the anterior mediastinum or great vessels. However, it provides limited exposure of the left subclavian.
- This is the ideal incision for parasternal cardiac stab wounds with cardiac tamponade (i.e., within the cardiac box).
- Cervical extension provides excellent exposure of both carotid arteries.
- If cardiac tamponade is confirmed or suspected, large-volume resuscitation should be avoided, as this will increase preload and make the tamponade worse.

Technique

- Prep the patient from chin to mid-thigh. Make a vertical midline skin incision, centered over the sternum, from 1 cm superior to the manubrium to the tip of the xiphoid process (Figure 1). Continue down through the decussation of pectoralis fascia onto the sternum with electrocautery.
- The interclavicular ligament is incised, and the soft tissues lying superior and deep to the manubrium are digitally cleared from their attachments to the bone. This procedure moves the innominate vein and surrounding tissue posteriorly so that they are not inadvertently divided with the saw (Figure 2).
- The fat and nearby peritoneum are bluntly detached from the xiphoid process, which is either excised or divided at the midline. The index fingers of each hand are then inserted below the sternum, at the manubrium and the xiphoid, allowing soft tissues to be bluntly dissected free from the underside of the sternum (Figure 3).
- The sternum is divided taking great care to stay in the midline, as failure to do so can make closure difficult. It is useful to mark the midline with electrocautery to help guide the division.
- The sternum is most commonly (and easily) divided using a powered sternal saw (Figure 4). When using a sternal saw, care must be taken to avoid injury to the underlying heart and great vessels by lifting the saw while "toeing" the right angle piece at the end of the saw blade upward.
- The sternotomy is most easily done with a power saw. If this is not available, the sternum can be opened with a Lebsche knife (Figures 9 and 10).

ANTERIOR CHEST WITH HEAD AT THE BOTTOM

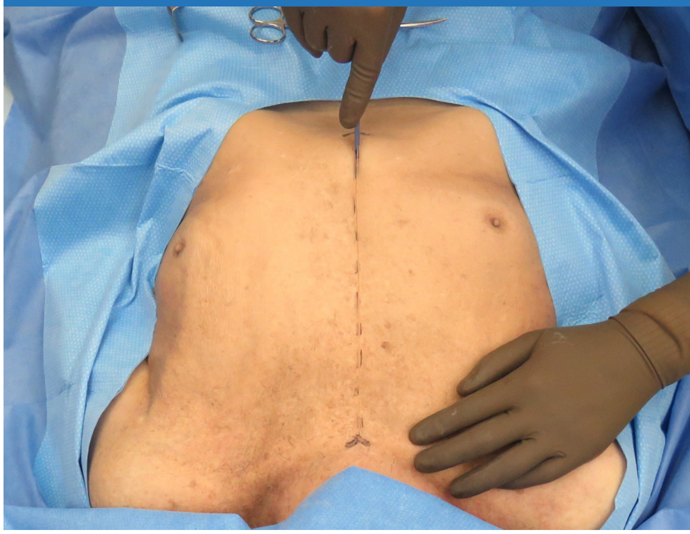


Figure 1. The median sternotomy incision.

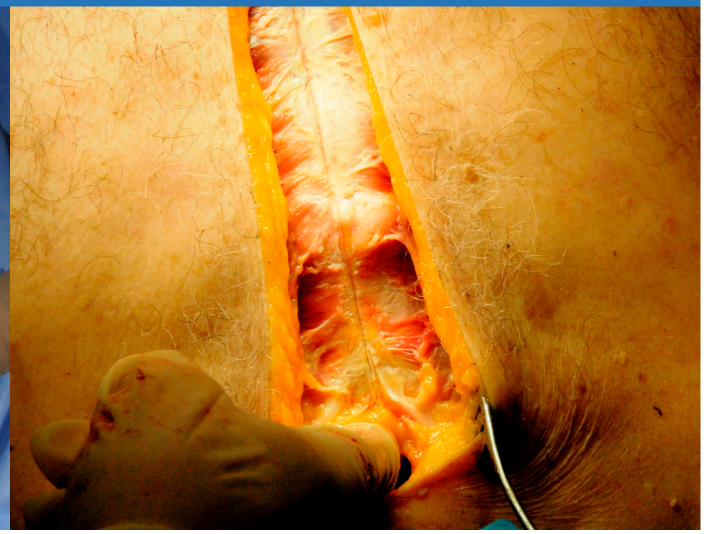


Figure 2. Clearing the soft tissues superior and deep to the manubrium.

ANTERIOR CHEST WITH HEAD TO RIGHT

Figure 3. The underside of the sternum is bluntly dissected with the index fingers of each hand.

Figure 4. The sternal saw is used to open the sternum (from superior to inferior), with the saw lifted and the toe tilted upward.

- When using the Lebsche knife to divide the sternum, it is best to start at the xiphoid process and advance to the manubrium (Figure 10). The reason for this is that the hammer must be swung hard to efficiently divide the sternum, and when starting at the top of the sternum, the patient's head and chin will be in the way of this motion.
- Great care should be taken to stay on the midline of the sternum when using the Lebsche knife, as closure of the sternum is greatly complicated if the sternum is not opened along the midline.
- Other tools to cut through the sternum include a bone cutter, a Gigli saw, and trauma shears.
- Once the sternum has been divided, a chest spreader (Finochietto retractor) is placed in the chest, positioning the handle such that the incision can be extended either into the neck or the abdomen if needed (Figure 5).
- As the chest spreader is opened, adventitial tissue will need to be bluntly dissected from the underside of the sternum to expose the thymic tissue and the pericardium (Figure 6).

ANTERIOR CHEST WITH HEAD TO RIGHT

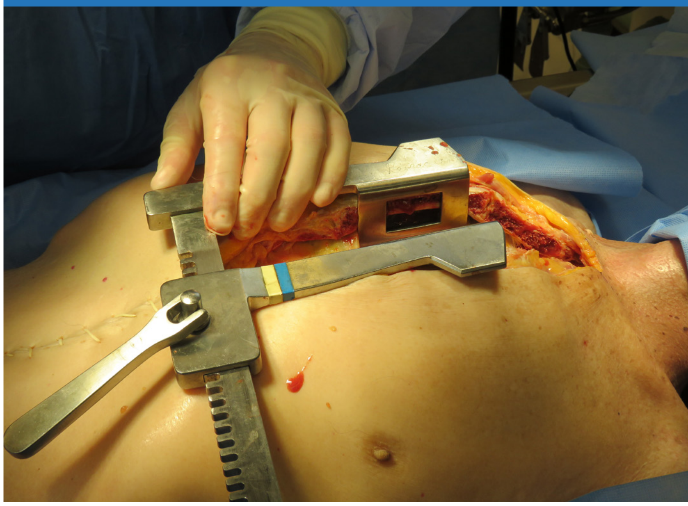


Figure 5. The chest spreader is placed with the bar towards the abdomen, allowing for extension into the neck if needed.

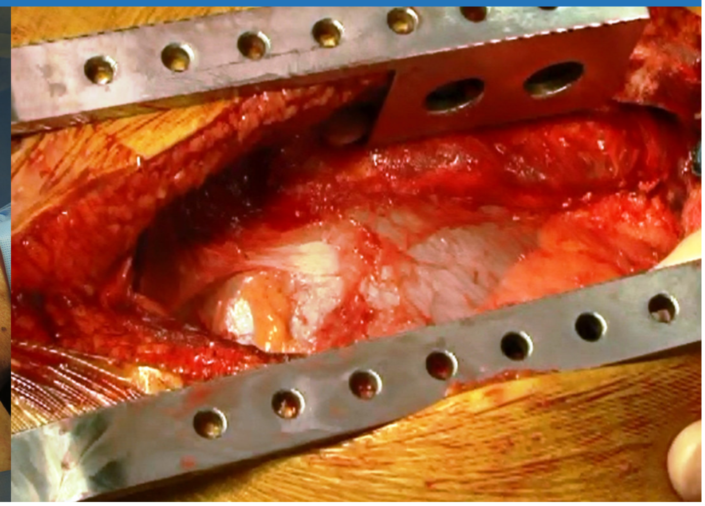


Figure 6. The chest spreader has been further opened and the pericardium exposed.

- In the setting of pericardial tamponade, the pericardium should be opened initially with a scalpel (scissors will generally not work), taking care not to further injure the underlying heart (Figure 7). The remainder of the pericardium is then opened with scissors (Figure 8).
- The pericardium should be opened all the way to the top, with a finger inside the pericardium as a guide. The pericardiotomy incision should be carried inferiorly to the base of the heart and then extended horizontally for a short distance on either side to make an "inverse T" incision, taking care to avoid the phrenic nerve.
- Repair of cardiac injuries is discussed in chapter 11.
- Exposure of the heart and mediastinum is facilitated by placing interrupted sutures from the edge of the pericardium to the skin. This will raise the heart anteriorly in the chest, facilitating evaluation and repair.

ANTERIOR CHEST WITH HEAD TO RIGHT

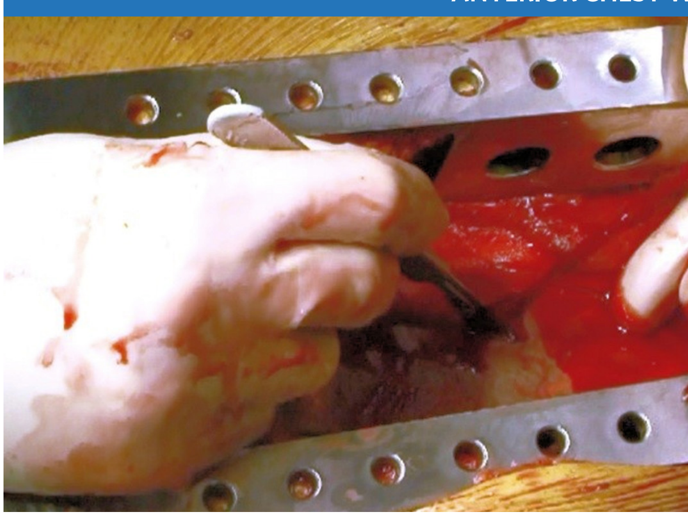


Figure 7. The pericardium in this patient with pericardial tamponade is opened initially with a scalpel.

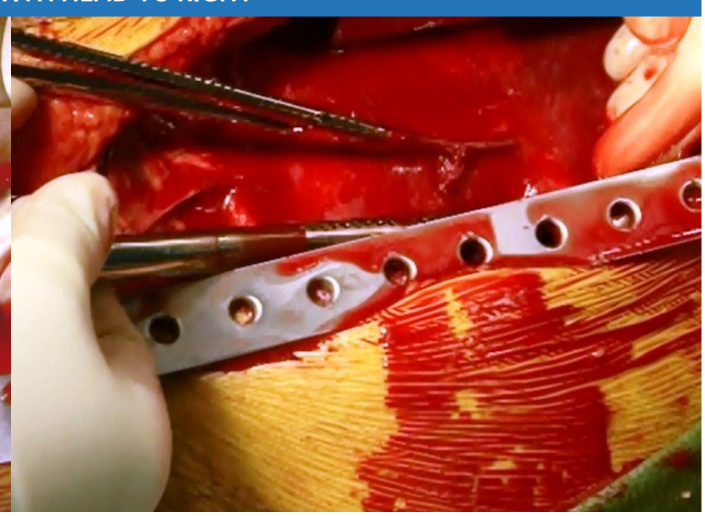


Figure 8. The pericardiotomy is extended with scissors.

ANTERIOR CHEST WITH HEAD TO RIGHT

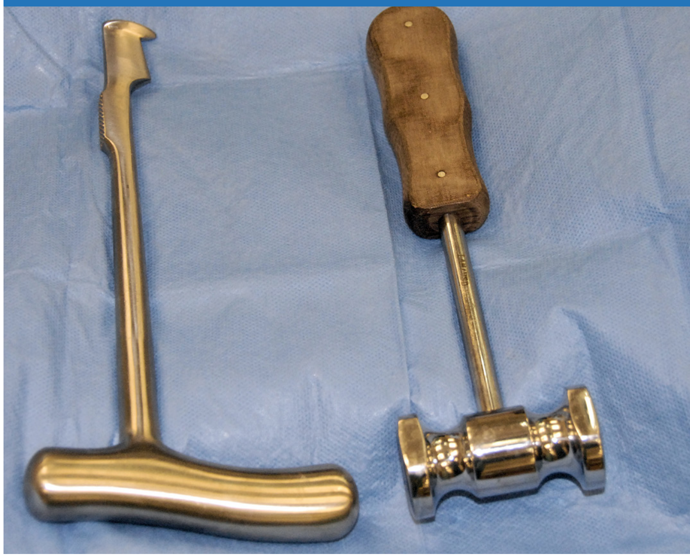


Figure 9. The Lebsche knife (left) and the mallet/hammer (right).

Figure 10. Opening the sternum with the Lebsche knife.

RESUSCITATIVE (LEFT ANTEROLATERAL) THORACOTOMY

Resuscitative thoracotomy (RT) provides exposure of the heart, distal descending thoracic aorta, left lung, and distal esophagus. It allows for rapid opening of the pericardium, open cardiac massage, repair of many cardiac injuries, cross-clamping of the descending thoracic aorta, and control of the left lung hilum.

Considerations

- It is important to have the required equipment in place and be sure that members of the trauma team know their individual responsibilities.
- RT is performed rapidly in the setting of controlled chaos, and it is important that all team members are protected from bodily fluids and inadvertent injury from sharp instruments or the sharp ends of broken ribs.
- Keeping the number of individuals around the bed to the minimum required to perform the procedure will limit the potential of injury or contact with bodily fluids.
- In the setting of penetrating trauma, it is important to rapidly expose all of the patient to include evaluation of the back. This step can help identify other wounds, which would allow prediction of trajectory and may also reveal additional fatal injuries (e.g., transcerebral gunshot wound) that may preclude performance of RT.
- Simultaneous control of the airway, IV access, balanced blood product resuscitation, and placement of a right chest tube should be undertaken by other available team members.

Technique

- The left arm should be positioned above the patient's head.
- RT is performed using an incision in the fourth interspace, just superior to the fifth rib. The area just below the nipple (in males) and in the inframammary crease (in females) will correlate with the appropriate interspace in most individuals.
- The incision should extend from the edge of the sternum to the posterior axillary line, following the curve of the rib posteriorly and aiming for the tip of the scapula (Figure 11).
- The incision should be made with a scalpel and not electrocautery, as time is of the essence. If possible, the incision should be made just below the inferior border of the pectoralis major, as cutting sharply through this muscle will cause unnecessary bleeding and disability.

- A useful technique is to cut down rapidly on top of the center of the fifth rib and follow the rib medially and laterally, exposing the anterior surface (Figure 12). The intercostal space is then entered sharply **above** the rib to avoid injury to the neurovascular bundle, and scissors are then used to divide the intercostal muscles.
- Care should be taken to avoid injury to the intercostal neurovascular bundle, which courses immediately inferior to the rib. Although the latissimus muscle does not have to be transected, the intercostal muscle incision should be extended as posterior as possible. This step will help spread the ribs. The rib spreader is inserted with the handle toward the bed so that it won't be in the way if the incision needs to be quickly extended to a clamshell (Figure 13).
- Once in the chest, check the pericardium first. If pericardial tamponade is the reason for cardiovascular collapse, prompt opening of the pericardium provides the best chance for survival. The pericardium should be opened with a scalpel, staying anterior to the phrenic nerve (Figure 14) and taking caution not to lacerate the underlying heart.

LEFT LATERAL CHEST WITH HEAD TO RIGHT

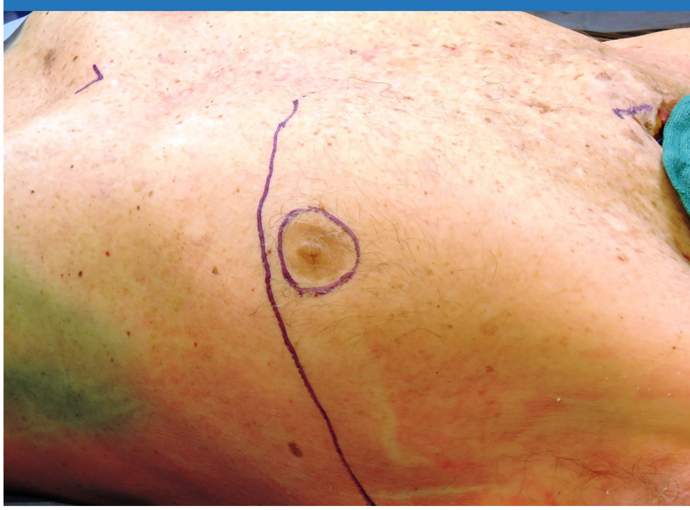


Figure 11. The RT incision is made from the edge of the sternum to the bed in the fourth intercostal space, following the curve of the rib.

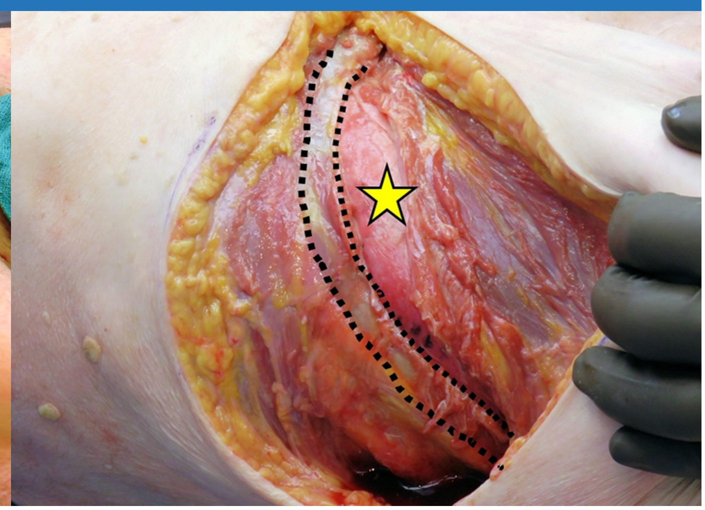


Figure 12. The rib (dotted line) is exposed, and the intercostal space is entered above the rib, enabling entry into the thoracic cavity with exposure of the underlying lung (yellow star).

LEFT LATERAL CHEST WITH HEAD TO RIGHT

Figure 13. The rib spreader is placed with the handle to the bed so that it is not in the way should extension of the incision to the right chest be required.

Figure 14. The pericardium should be opened anterior to—and taking care to avoid—the phrenic nerve.

- After opening the pericardium with a scalpel (Figure 15), scissors are used to open it longitudinally (Figure 16) from the aortic root to the apex of the heart, taking care to preserve and stay anterior to the left phrenic nerve (Figure 14).
- The pericardium should be fully opened such that the heart can be delivered out of the pericardial sac for manual massage, as well as to prevent herniation of the heart through a small pericardotomy.
- Cardiac massage is performed by squeezing the heart between the palms of both hands or, alternatively, using one palm behind the heart to compress it against the sternum.
- After opening the pericardium, the next step is to clamp the descending thoracic aorta.
- Clamping the descending aorta is usually not as easy as it sounds. The lung must be retracted anteriorly to expose the descending aorta. This may require mobilization of the lung by taking down the inferior pulmonary ligament (see chapter 15).
- The descending aorta is covered by a thick parietal pleura, which must be opened in order to place a clamp. The descending aorta sits just anterior to the thoracic spine, and the parietal pleura can be opened safely by placing scissors against the spine just posterior and parallel to the aorta. Using the scissor tips to "spread, cut, spread" at this level allows for a window to be opened between the spine and the underside of the aorta (Figure 17).
- This process is repeated anterior to the aorta between the aorta and the esophagus. Identification of the esophagus is facilitated by placement of a nasogastric tube, if time and resources allow.
- The anterior and posterior windows in the parietal pleural are further bluntly developed so that a noncrushing aortic clamp (DeBakey) can be placed across the aorta from left to right (Figure 18).
- The aorta should not be completely encircled with dissection, as this risks injury to the spinal arteries.

LEFT LATERAL CHEST WITH HEAD TO RIGHT

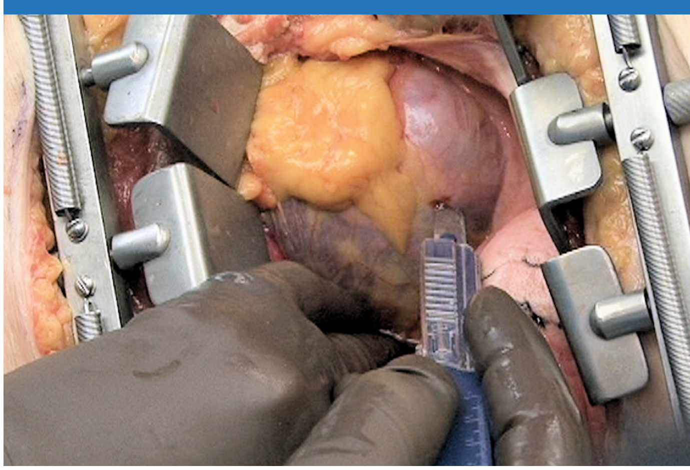


Figure 15. The pericardium should initially be opened with a scalpel anterior to the phrenic nerve.

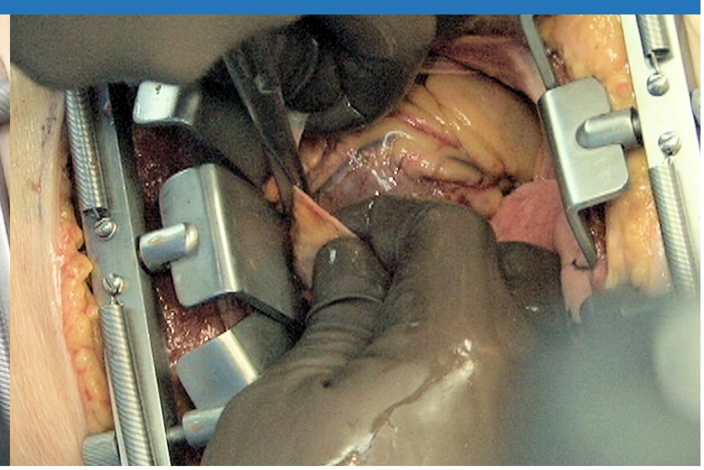


Figure 16. Scissors are then used to fully open the pericardium to visualize the heart.

LEFT LATERAL CHEST WITH HEAD TO RIGHT

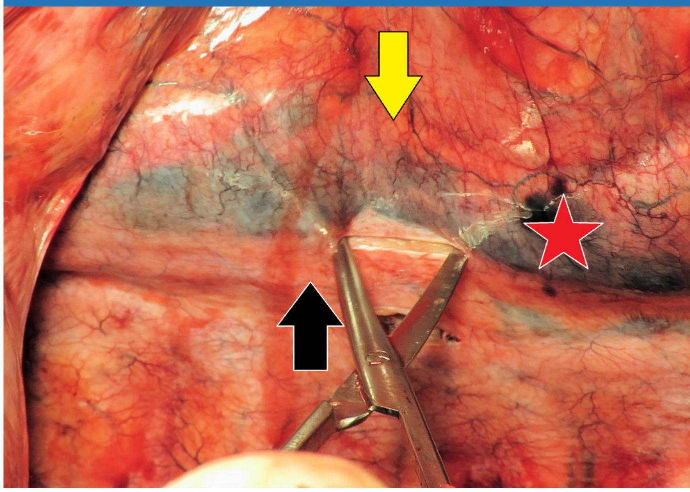


Figure 17. The parietal pleura is opened posterior and parallel to the aorta (red star) using scissors spread against the thoracic vertebra (black arrow). This maneuver is then repeated, spreading between the anterior aorta and esophagus (yellow arrow).

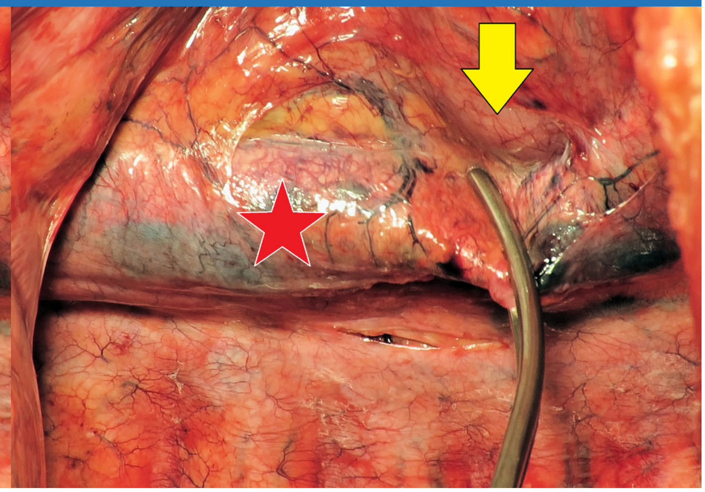


Figure 18. With the parietal pleura opened anterior and posterior to the aorta (red star), a clamp can be placed, taking care to avoid the esophagus (yellow arrow).

CLAMSHELL BILATERAL THORACOTOMY

- This incision is indicated for cases in which you need to access both sides of the chest (e.g., massive right hemothorax, insufficient exposure) to delineate and control injury after RT.
- The clamshell incision is an extension of the RT across the sternum into the right chest, performing a mirror image thoracotomy on the right side.
- The sternum is transected with a Lebsche knife; if that is not available, a rib cutter, heavy scissors, or a Gigli saw can be used (Figure 19).
- If available, a second rib spreader is placed in the right chest, and attachments to the underside of the sternum are dissected free (Figure 20).
- If a second retractor is not available, the rib spreader from the RT incision can be moved over to the sternum to fully open the chest (Figure 21).
- The clamshell thoracotomy provides an unparalleled view of the mediastinum and the great vessels, as well as the lungs on both sides. There are few injuries that cannot be exposed with this approach, as seen in Figures 22 and 23.
- If the patient regains cardiac output, the internal mammary arteries must be identified and clamped, or they will be a source of blood loss.

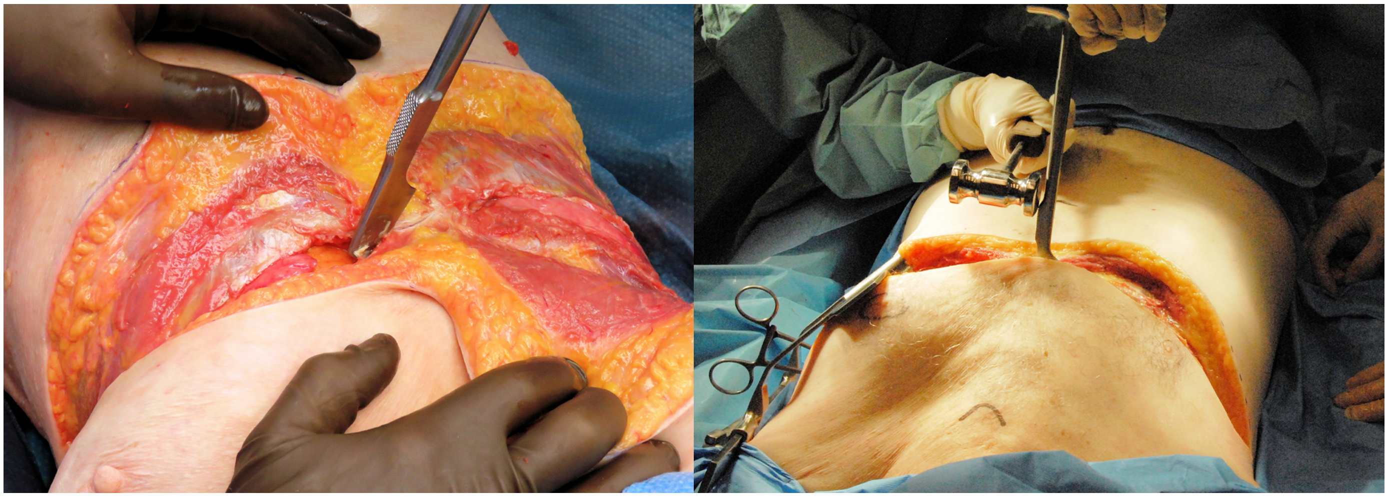


Figure 19. The clamshell incision is a bilateral anterior thoracotomy made in the inframammary fold in women (left) and just below the nipples in men (right). A Lebsche knife is then used to divide the sternum.

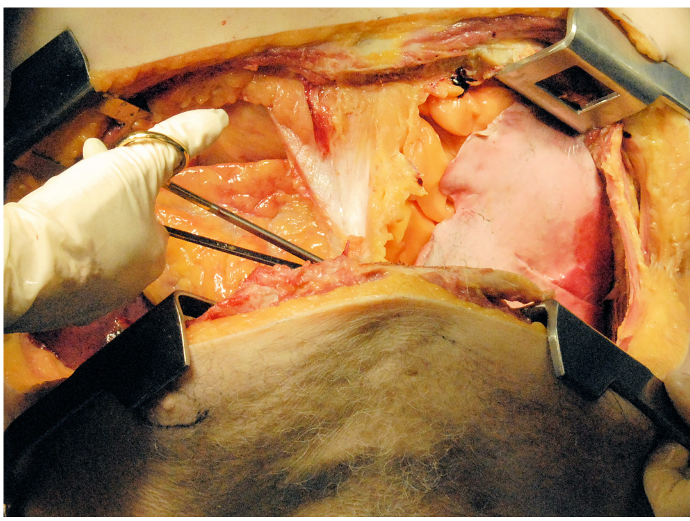


Figure 20. Opening the clamshell incision by inserting a second rib spreader in the right chest and taking down attachments from the sternum (head to bottom).

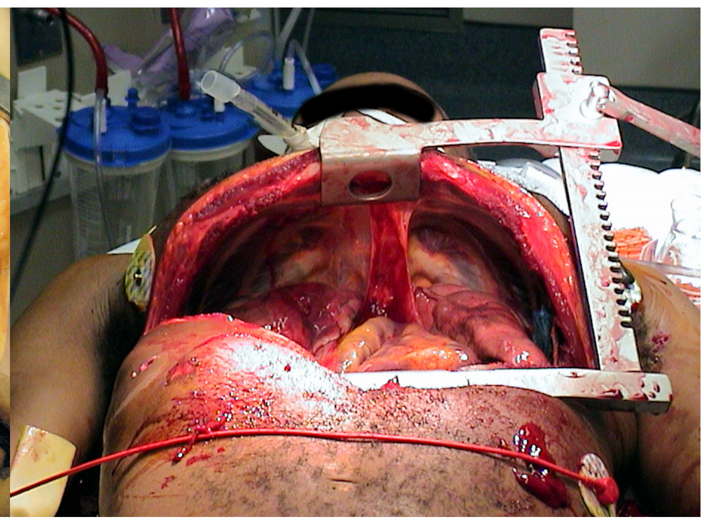


Figure 21. Opening the clamshell incision using a single rib spreader.

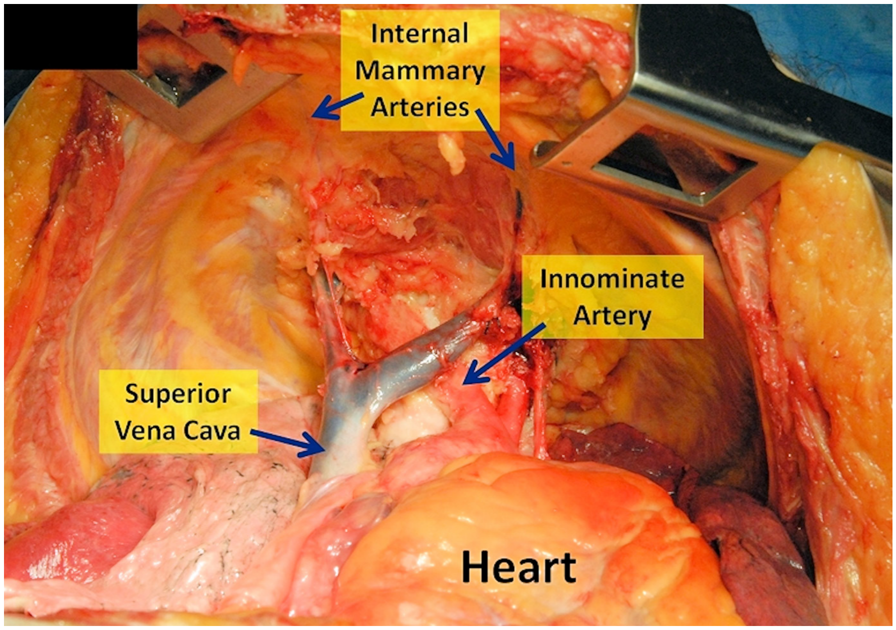


Figure 22. The clamshell incision provides excellent exposure of the heart, lungs, and great vessels of the chest. If circulation is restored, the internal mammary arteries will need to be ligated.

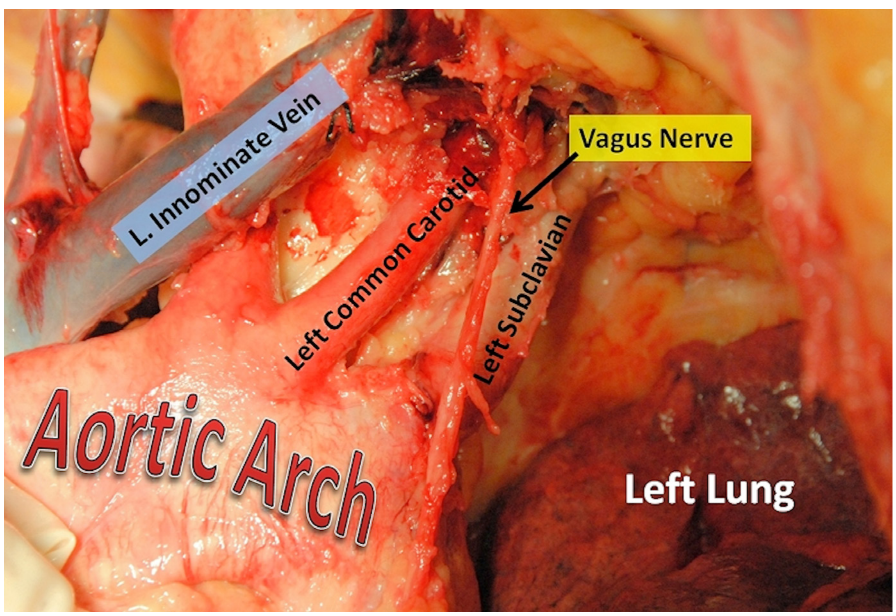
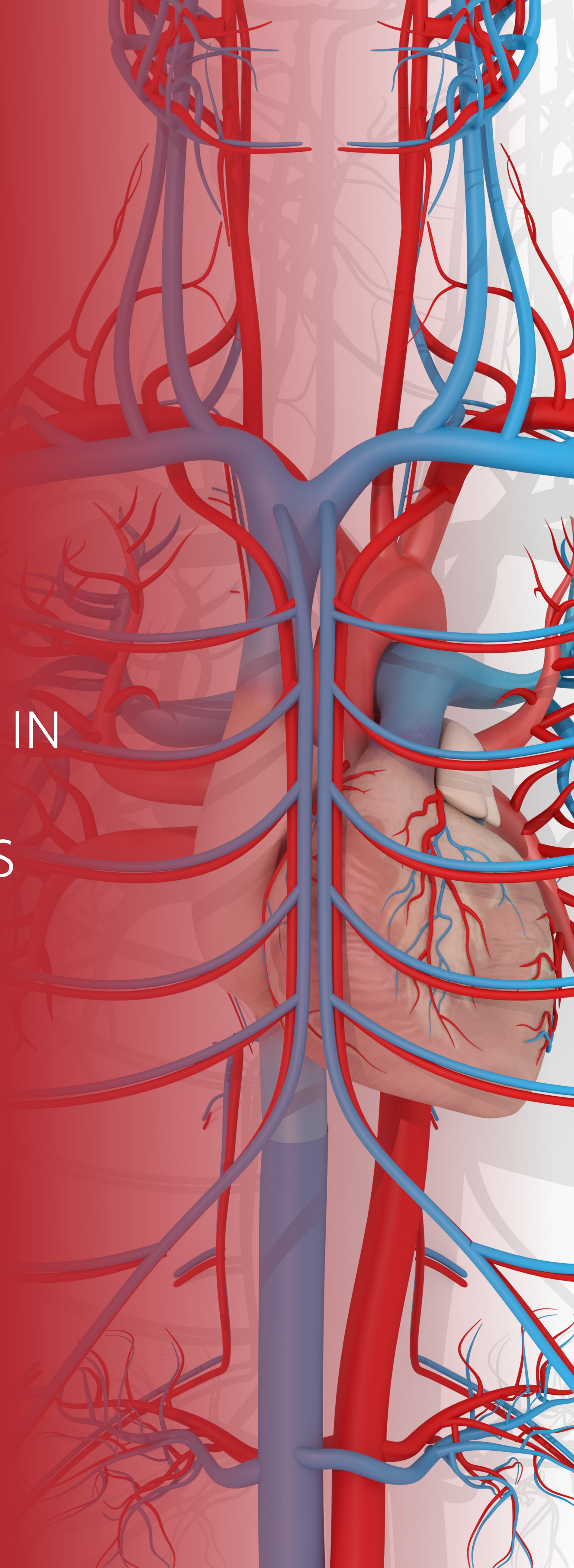


Figure 23. The clamshell incision also provides excellent exposure of the upper mediastinum and apices of the chest. The branches of the aortic arch are clearly seen.

CHAPTER 11
OPERATIVE EXPOSURE IN THORACIC TRAUMA: EXPOSURE OF INJURIES TO THE HEART



Operative Exposure in Thoracic Trauma: Exposure of Injuries to the Heart

This chapter will discuss exposure of actual or suspected injuries to the heart. Though the major emphasis is operative exposure, management of specific injuries to the heart will also be briefly covered.

Learning Objectives

By the end of the ASSET course, participants should be able to do the following:

1. Describe the signs and symptoms of pericardial tamponade.
2. Describe the clinical indications for median sternotomy, left anterolateral thoracotomy (resuscitative thoracotomy), and "clamshell" bilateral thoracotomy.
3. Demonstrate the surgical technique of pericardial window.
4. Describe the techniques for controlling hemorrhage from atrial and ventricular cardiac injuries.
5. Describe the surgical technique to repair ventricular wounds that are in juxtaposition to the coronary arteries.
6. Describe techniques to expose the posterior heart for evaluation.

Considerations

- Every penetrating injury to the chest—especially to the precordium, or "cardiac box" (Figure 1)—should raise suspicion of a cardiac injury until proven otherwise, especially if associated with hypotension.
- The combination of hypotension, distended neck veins, and distant cardiac sounds (Beck's triad) is variably present in patients with cardiac tamponade.
- Unexplained tachycardia and hypotension are the most common clinical findings. In rare occasions with small cardiac wounds and short prehospital times, the patients may not be hypotensive on admission.
- Patients with tamponade are often very anxious and do not want to lie down. They may become combative if forced to do so and may arrest due to loss of sympathetic tone.
- In patients with tamponade and severe blood loss, the neck veins may not be distended.
- Cardiac sounds are usually distant in cases of cardiac injury, but this finding is often missed in a noisy trauma bay.
- Consideration should be given to whether cardiopulmonary bypass and assistance from a cardiac surgeon might be required.

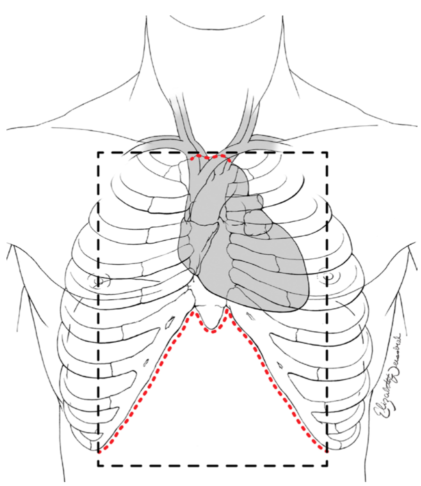


Figure 1. Penetrating injuries within the cardiac box (dotted square) have a high likelihood of associated cardiac injury.

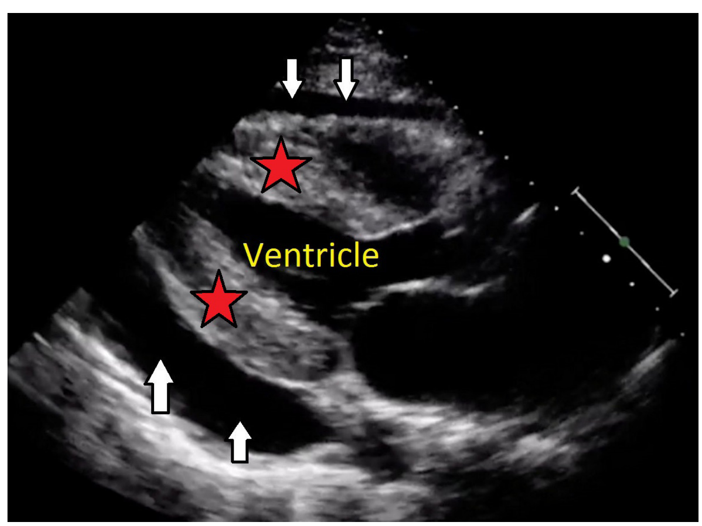


Figure 2. Ultrasound of the heart showing tamponade, with blood (arrows) between the cardiac muscle (stars) and the pericardium.

Investigations

- Focused assessment with sonography in trauma (FAST) in the emergency room is the most reliable investigation.
- A positive FAST in the presence of hypotension is an absolute indication for immediate operation (Figure 2).
- There is no role for pericardiocentesis in the treatment of cardiac tamponade.

Incisions

- The choice of incision in cases of suspected cardiac injury will be dictated by the stability of the patient, the suspected location of the injury, the setting, the equipment available, and the surgeon's experience.
- The median sternotomy (chapter 10) provides excellent exposure for isolated injuries to the anterior heart and great vessels but requires more equipment and time to perform than an anterolateral thoracotomy (resuscitative thoracotomy, or RT).
- RT is the incision of choice for patients who present in extremis (chapter 10). It provides rapid access to the chest with a minimum of equipment.
- The RT is best suited for rapid relief of cardiac tamponade and will allow for exposure of the inferior and posterior portions of the heart and portions of the left chest, as well as cross-clamping of the descending thoracic aorta.
- The "clamshell" bilateral thoracotomy is used as an extension to the RT when additional exposure of the heart is needed or if there are concomitant injuries in the right chest.

The Pericardial Window

The subxiphoid transdiaphragmatic pericardial window is an excellent diagnostic adjunct to rule out cardiac injury in hemodynamically stable patients with suspected cardiac injury when the FAST exam is not available or is nonconfirmatory.

- Hemodynamically unstable patients with suspected cardiac tamponade should **not** have a pericardial window performed but should undergo urgent median sternotomy or RT.
- The pericardial window is often performed during an exploratory laparotomy to rule out pericardial fluid.

TECHNIQUE

- An incision is made on the midline over the xiphoid process and is extended several centimeters down onto the abdominal wall. A plane is developed between the underside of the xiphoid and the peritoneum just inferior to the central tendon of the diaphragm.
- The central tendon of the diaphragm (directly over the heart) is grasped with two Allis clamps, and a small (1 cm) window is made into the pericardium with scissors (Figure 3).
- If the pericardial window reveals blood, the chest is opened (usually median sternotomy) to allow inspection of the heart and cardiac repair.
- If the procedure does not reveal any blood, the pericardium should be irrigated with warm saline to look for clot. The window can be closed, or it may be drained to monitor for bleeding from the pericardium.

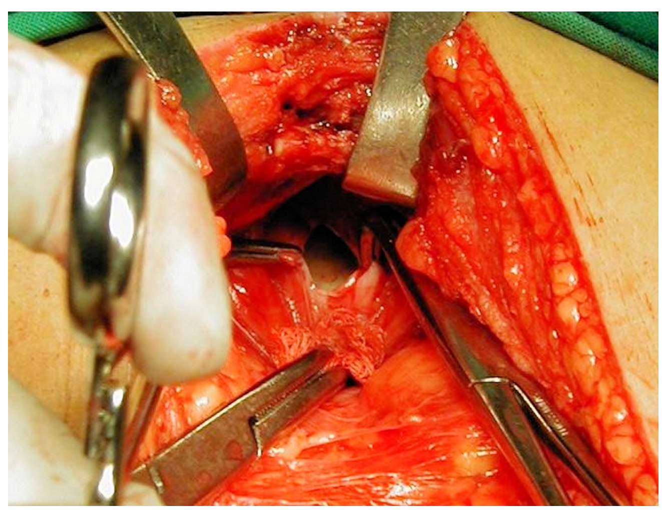


Figure 3. The subxiphoid transdiaphragmatic pericardial window allows for evaluation of the pericardial sac for the presence of fluid when cardiac injury is suspected in a hemodynamically stable patient.

Pericardial Window Pitfalls

- If care is not taken to minimize bleeding during the dissection, or if the peritoneum has been opened in a patient with hemoperitoneum, the pericardial window may be falsely positive from blood external to the pericardial sac.

Atrial Injuries

- Atrial wounds can be occluded by digital pressure, approximation of the edges with a vascular clamp (Figure 4), or forceps (DeBakey or Russian).
- A simple running suture with 2-0 or 3-0 polypropylene (with or without pledgets) is generally sufficient to repair the heart (Figure 5). Care should be taken, as the walls of the atria are thin and can easily tear. The lumen of the atria can be significantly reduced without consequence as long as the inflow and outflow are not compromised.
- Alternatively, a surgical stapler can be used to repair an atrial injury.
- The right atrium is more anterior and therefore more commonly injured by stab wounds. The right atrium is well visualized through a left lateral anterior thoracotomy or a sternotomy.
- The left atrium is more difficult to repair, due to its posterior position.
- Patients with atrial injuries should be placed in the Trendelenburg position to decrease the possibility of air embolism.

Ventricular Injuries

GENERAL CONSIDERATIONS

- The major mistake made by surgeons who do not frequently operate on the heart is to perform interventions too quickly. As long as the heart is beating, the approach to a ventricular injury should be methodical and measured.
- If the heart is not beating, restoration of cardiac function should be a priority, with open heart massage (between the palms), ongoing resuscitation, cardiac drugs, and cardioversion, as indicated.
  - If appropriate suture and expertise are available, rapid repair of the wound prior to restoration of cardiac function may be considered.
  - It is tempting to repair injuries prior to restarting the heart, but this may take longer than anticipated, and the longer the heart is not beating, the more likely the patient is to die from the injury.
- If the heart has been restarted, it is likely to be irritable, and immediate attempts to suture may exacerbate this irritability. It is advisable to allow a couple of minutes for the heart to recover and for anesthesia to catch up before sticking it with a needle.
- Maintain open communication with the anesthesia team, and discourage them from giving vasopressors or excessive resuscitative products.

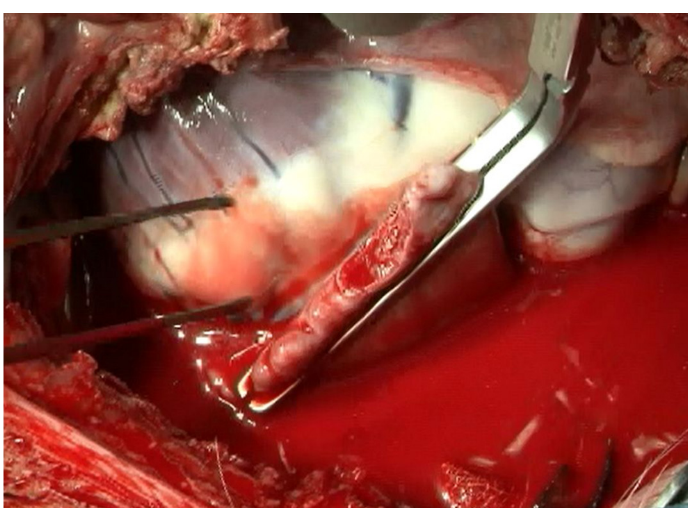


Figure 4. Injury to the atrial appendage is easily controlled with a vascular clamp.

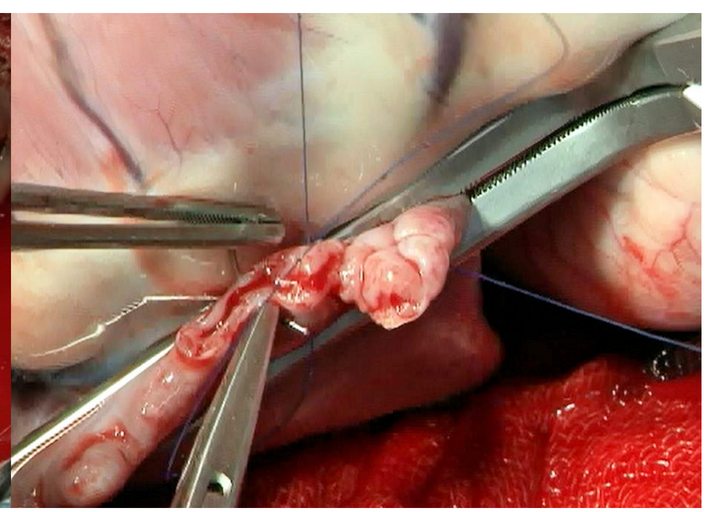


Figure 5. Injury to the atrial appendage is repaired with a simple running monofilament suture.

- The right ventricle is a thin-walled and low-pressure chamber, and as such the vast majority of wounds there can be initially controlled with gentle fingertip occlusion alone (Figure 6).
- The walls of the left ventricle are thick, and in the case of stab wounds, they are often not actively bleeding and can be easily controlled with digital pressure.
- The use of a Foley balloon placed into the ventricle to obtain temporary control of bleeding is well described. This is almost never needed, however, and its use has the risk of making the injury bigger if care is not taken to avoid pulling up on the catheter too aggressively.
- Skin staples have also been described as a quick way to temporarily control bleeding from ventricular injuries, but these tend to cause more injury to the cardiac muscle and are unlikely to be superior to simple fingertip occlusion. Additionally, skin staples are more likely to pull through the epicardium during cardiac massage or if the heart becomes distended.
- The use of pledgets is controversial but useful to prevent tearing of the suture through the cardiac muscle, especially for surgeons who infrequently operate on the heart.
- Teflon pledgets are generally used, but if not available, one can use the patient's pericardium to fashion pledgets. When using the patient's pericardium, the key is to pass the suture though the edge of the pericardium **prior** to cutting out the pericardial pledget. The sequence is to pass the double-armed suture through the pericardium on one side, then across the cardiac injury, and then through the pericardium on the opposite side prior to cutting out the pieces of pericardium.
- Ventricular injuries are repaired with monofilament sutures, such as 2-0 or 3-0 polypropolene (usually with pledgets), with either a mattress or running suture, dependent on the injury (Figure 7).
- Sewing on a full left ventricle can make the wound bigger.
- Injuries to the posterior left ventricle are technically challenging, because they require lifting of the heart to expose and repair. Lifting the heart can cause arrhythmias and even arrest by cutting off venous return.
- Several techniques are described for obtaining access to the posterior wall of the heart, including the following:
  - Slowly lifting the heart
  - Sequentially placing gauze pads behind the heart
  - Placing a clamp or suture on the posterior pericardium and retracting it caudally

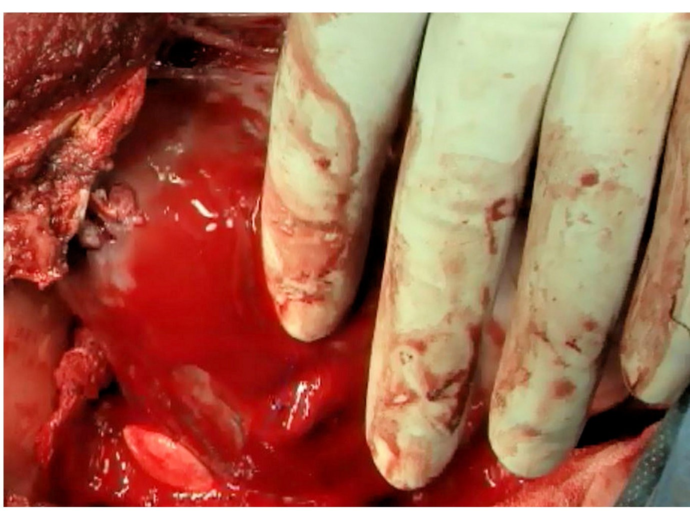


Figure 6. Injury to the ventricle can usually be controlled with fingertip occlusion.

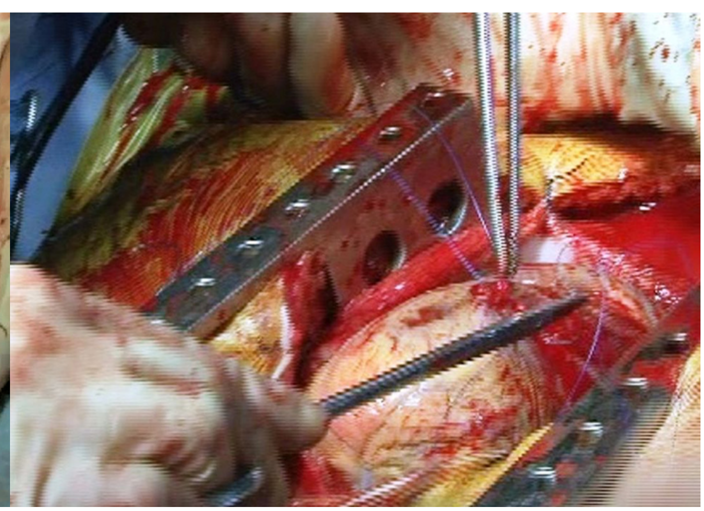


Figure 7. Injury to the ventricle is repaired with a pledgeted monofilament suture.

- If an injury to the posterior wall of the heart can be controlled with digital pressure and extreme cardiac instability results from attempts to lift the heart, the use of cardiopulmonary bypass may be indicated.
  - Extension of a sternotomy laterally to a left thoracotomy may aid in exposure of the posterior heart.
  - If bypass is not available, temporary inflow occlusion of the inferior and superior vena cavae (Figures 8 and 9) will empty the heart and enable expeditious repair of the now-empty left ventricle.
  - Keep in mind that once inflow occlusion is accomplished, the heart will stop, so it is important to have sutures ready. Quickly throw one suture, and then allow the heart to recover; repeat as needed to effectively repair the wound.

Juxtacoronary Injuries

- The repair of ventricular wounds adjacent to coronary arteries is performed by placing "U" sutures or horizontal mattress sutures such that the suture does not occlude the coronary arteries (Figures 10 and 11).
- The function of the myocardium distal to the repair, as well as the intraoperative electrocardiogram, should be monitored to identify (and prevent) coronary artery occlusion and ischemia.
- Partial transection of a major coronary artery in the distal third of the coronary artery can be treated by ligation.
- If the coronary artery injury is proximal or on a major branch, ligation may be fatal. Optimal repair is best achieved with the help of a cardiothoracic surgeon.

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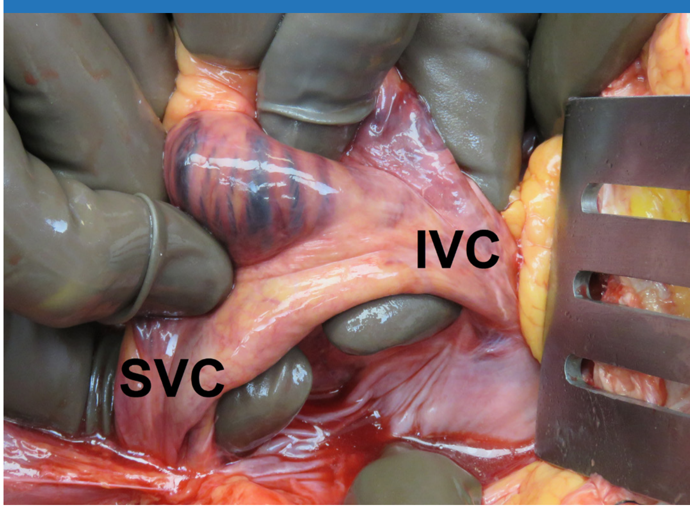

Figure 8. The inferior vena cava (IVC) and superior vena cava (SVC), as seen from the right side of the chest, can be encircled and occluded within the pericardial sac.

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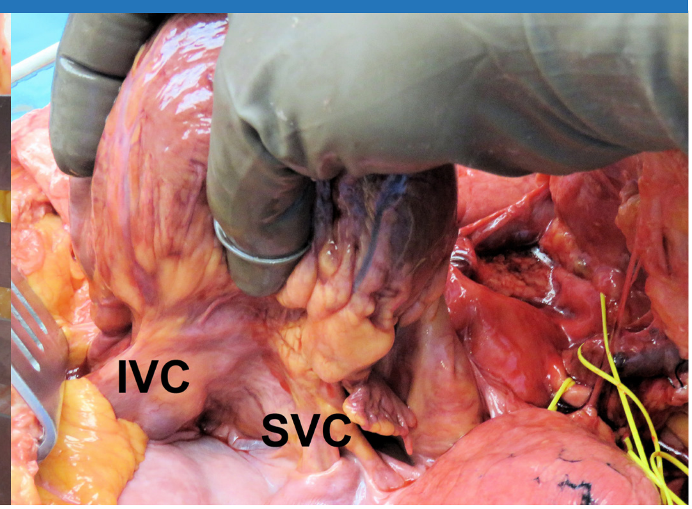


Figure 9. The inferior vena cava (IVC) and superior vena cava (SVC), as seen from the left side of the chest, can be encircled and occluded within the pericardial sac.

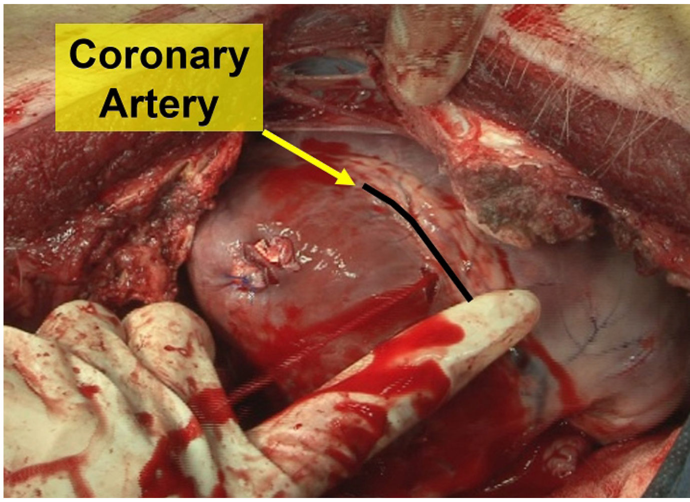


Figure 10. Injury to the ventricle that is in close proximity to the coronary artery.

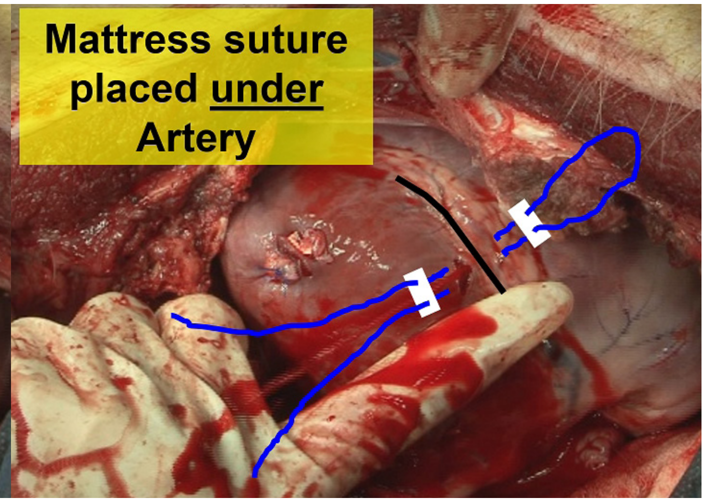
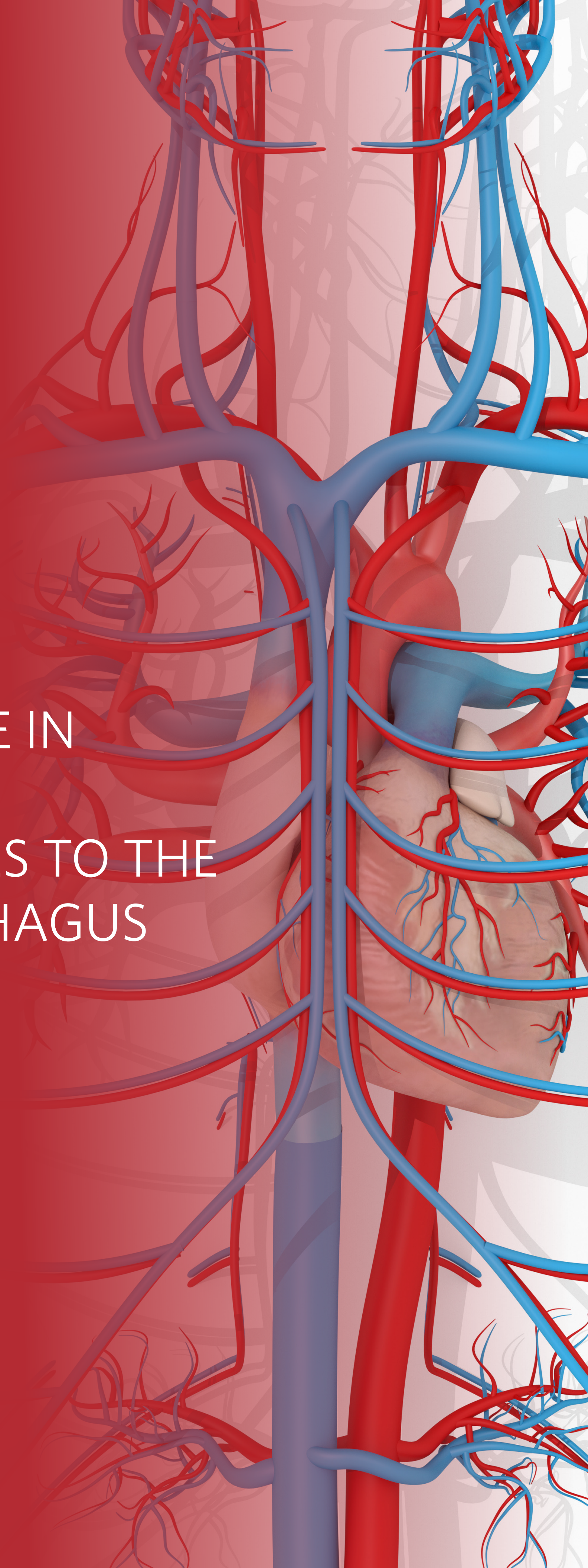


Figure 11. This injury must be repaired in such a manner that the coronary is not occluded. This is accomplished by placing a horizontal mattress suture beneath the artery.

Blunt Myocardial Rupture

- Cardiac rupture due to blunt trauma is almost always fatal, except for atrial rupture, which is relatively rare.
- This injury should be suspected in a blunt trauma patient with a positive pericardial ultrasound.
- Intracardiac valvular injuries or papillary injuries should be repaired at a later time, under controlled settings, with the aid of the cardiothoracic team.

CHAPTER 12
OPERATIVE EXPOSURE IN THORACIC TRAUMA: EXPOSURE OF INJURIES TO THE TRACHEA AND ESOPHAGUS



Operative Exposure in Thoracic Trauma: Exposure of Injuries to the Trachea and Esophagus

This chapter will discuss the thoracic exposure of injuries of the trachea and esophagus. It should be noted that portions of the esophagus and trachea are best approached in the neck, and details of those exposures are discussed in chapter 8 of this manual.

Learning Objectives

By the end of the ASSET course, participants should be able to do the following:

1. Detail the physical findings associated with injuries to the thoracic esophagus and trachea.
2. Discuss the diagnostic options for injuries to the thoracic esophagus and trachea.
3. Demonstrate exposure of the thoracic trachea and esophagus.
4. Describe the incision(s) best suited to injuries of the distal trachea (carina).
5. Describe the incision(s) best suited for exposure of thoracic esophageal injuries.

General Considerations

- The majority of injuries of the intrathoracic trachea are due to penetrating trauma.
- Only 1–2 percent of patients with penetrating thoracic trauma will have significant tracheobronchial trauma.
- Blunt trauma involving the intrathoracic trachea and main stem bronchi is commonly associated with additional (and potentially life-threatening) major injuries.
- Distal tracheal injuries are much less common than cervical tracheal injuries due to the protection afforded by the chest wall.
- Despite the importance of identifying tracheoesophageal injuries, they are often diagnosed in a delayed fashion.
- Dyspnea, hemoptysis, and respiratory distress are the most frequent symptoms of tracheobronchial injury.
- Findings of deep cervical emphysema and pneumomediastinum are suggestive of tracheobronchial injury, and approximately 70 percent of affected patients will have a pneumothorax. A pneumothorax that persists or has excessive air leakage after placement of a chest tube should increase suspicion of an intrathoracic tracheal or bronchial injury.
- A high index of suspicion of injuries to the tracheobronchial structures will allow operative planning for exposure and repair of these uncommon but devastating injuries.
- In most cases, CT scan is the diagnostic modality of choice for stable patients.
- In a hemodynamically unstable patient, CT scan is contraindicated.
- A nondiagnostic CT **does not** obviate the need for bronchoscopy, esophagoscopy, contrast esophagogram, and/or laryngoscopy to identify the injury and its location.
- Consider timely subspecialist consultation (thoracic surgery and/or ENT).
- In patients with significant injury, surgical treatment should be undertaken as early as possible.

INJURIES TO THE TRACHEA

Exposure of the Trachea

- The proximal half of the trachea can be reached by a low collar incision, and the cervical esophagus via a left neck incision, as described in chapter 8.
- The middle third of the trachea and the upper thoracic esophagus can be exposed with a collar ("T") incision or a neck incision extended to a partial or complete sternotomy (Figures 1 and 2).
    - Dividing the subcutaneous tissues exposes the manubrium. The midline of the manubrium is then marked using electrocautery, and the upper sternum can be split (Figure 2) using a powered sternal saw or a Lebsche knife, taking care not to injure the underlying innominate vein.

- Partial (upper) sternotomy allows for complete exposure of the middle third of the trachea (Figure 2). Completing the sternotomy adds little to tracheal exposure but may be indicated to fully evaluate the great vessels. Though most of the proximal (cervical) trachea can be accessed via a cervical incision, exposure of the middle third of the trachea will require more caudal exposure.
- The distal third of the trachea, the carina and right main-stem bronchus, the azygos vein, the superior vena cava, the right atrium, and most of the intrathoracic esophagus can be easily approached by a right thoracotomy; optimal exposure is obtained through a right posterolateral thoracotomy, which may not be practical in acute trauma.
  - Upon entering the pleural cavity, the trachea can be identified in the posterior mediastinum.
  - It is helpful to have a double-lumen endotracheal tube or a bronchial blocker if the patient is stable. In an unstable patient, the orotracheal tube can be advanced into the left main-stem bronchus (with or without bronchoscopic guidance) to allow deflation of the right lung.
  - The upper-posterior mediastinal pleura is incised between the esophagus (posteriorly) and the trachea (anteriorly). Placing an NG tube may make the esophagus easier to identify.
  - In many cases, the azygos vein will need to be divided to completely expose the most distal trachea, carina, and bilateral main-stem bronchi.
- Left thoracotomy provides exposure to the left main-stem bronchus, the distal part of aortic arch, the descending thoracic aorta, the proximal left subclavian artery, and the distal esophagus.
  - It is hard to reach the proximal left main-stem bronchus, carina, distal trachea, or right main-stem bronchus through a left thoracotomy due to the overlying aortic arch.
- It is important to be flexible and extend or make additional incisions to gain necessary exposure.
- Alternatively, a "clamshell" incision can be utilized to visualize the upper thoracic portion of the trachea, as well as the first portion of the esophagus in the chest (Figures 3 and 4). Division of the innominate vein will assist in the exposure.

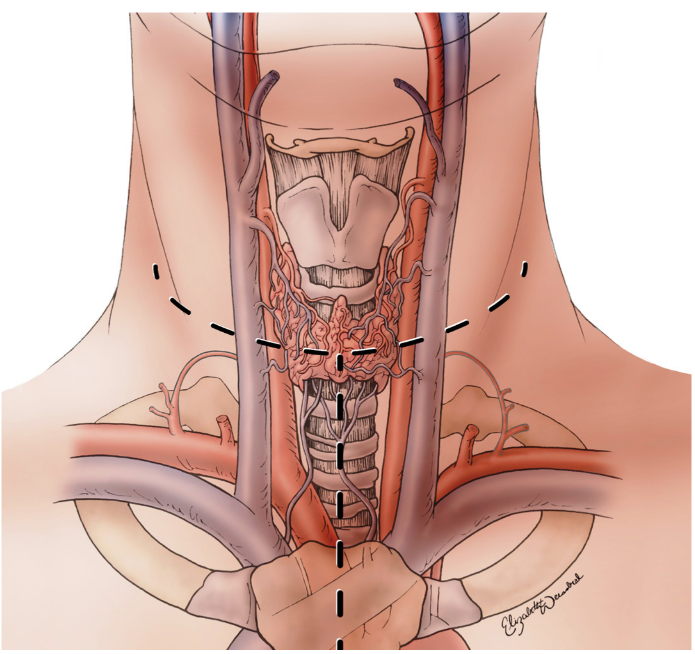


Figure 1. The collar incision in the neck can be extended in a "T" incision into the chest to expose the anterior trachea.

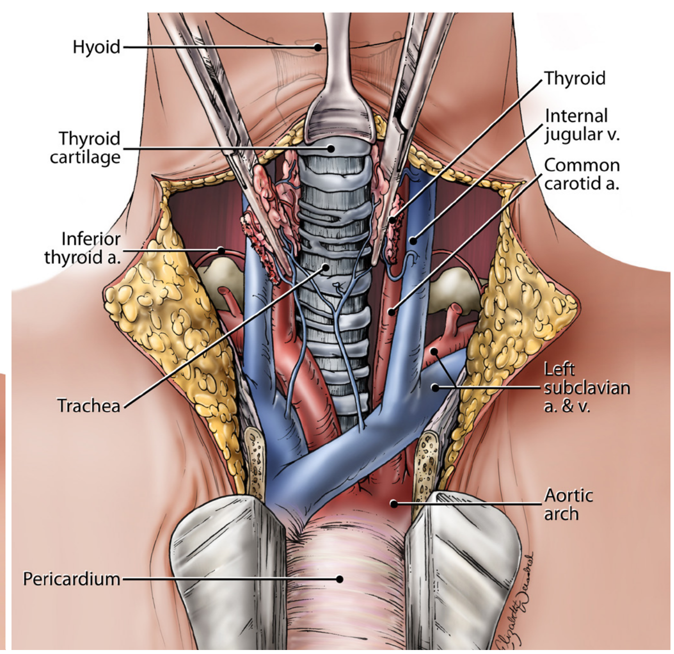


Figure 2. Division of the upper sternum provides exposure of the middle third of the trachea and the great vessels.

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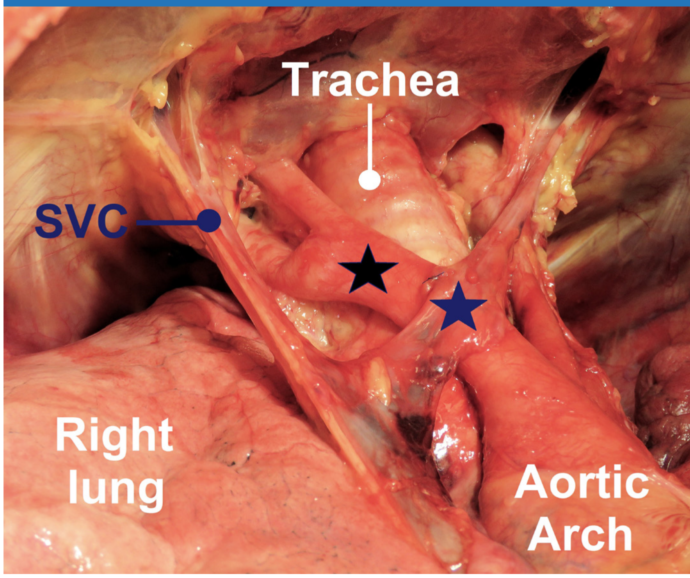


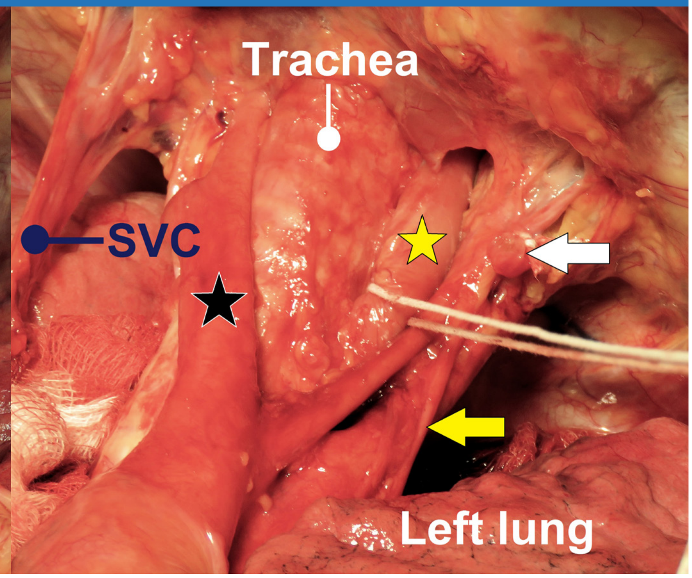


Figure 3. The anterior trachea can be exposed via a clamshell thoracotomy, which also provides good visualization of the arch vessels, including the innominate vein (blue star), brachiocephalic artery (black star), and superior vena cava (SVC).

Figure 4. Division and ligation of the innominate vein (white arrow) and further dissection will expose the upper thoracic esophagus (yellow star). Also seen are the vagus nerve (yellow arrow), superior vena cava (SVC), and brachiocephalic artery (black star).

Technical Considerations

- Preserve tracheal length at all costs, and minimize dissection to avoid devascularization.
- Simple, clean lacerations can be repaired with interrupted absorbable suture.
- Routine tracheostomy is not necessary in most patients and may complicate healing of the repair.
- In cases with serious tracheobronchial damage, all devitalized tissue should be debrided, taking care to preserve as much viable airway as possible. Circumferential resection and end-to-end anastomosis is preferable to partial wedge resection, except in the carina.
  - Injuries to the carina should be repaired primarily if at all possible, as resection and reconstruction are difficult. If complex repair is required, involvement of thoracic surgery and/or ENT is warranted.
  - Only 3–4 cm of the airway, including the carina, can be safely resected and still enable reconstruction. There are a variety of tracheobronchial releasing maneuvers described to enable a tension-free repair, but these are best relegated to specialist care.
  - If resection and primary anastomosis is required, the neck should be maintained in flexion postoperatively.
  - The posterior membranous portions of the trachea should be reconstructed with pleural or pericardial flaps.

Pearls and Pitfalls

- Concomitant esophageal repairs should be separated from tracheal repairs via the placement of a vascularized muscle pedicle between the two repairs.
  - In the neck, the sternal head of the sternocleidomastoid is preferred. In the thorax, a vascular intercostal flap is generally the best option.
- Stenosis occurs in approximately 5 percent of cases and may be managed with dilation and stenting but generally requires airway resection and reconstruction in three to six months.
- Other potential complications include tracheoinnominate and tracheoesophageal fistulae.

INJURIES TO THE ESOPHAGUS

General Principles

- Injuries to the esophagus can occur from a variety of mechanisms, including penetrating, blunt, iatrogenic, or ingestion (e.g., of a sharp object or caustic substance).
- Symptoms of esophageal injury are highly variable and can range from relatively minor (dysphagia, pain, tachycardia, fever) to severe sepsis, mediastinal abscess, empyema, and death.
- These injuries may be difficult to diagnose, and multiple diagnostic modalities may be required.
  - Chest radiographs may show mediastinal air or pleural fluid.
  - Chest CT with oral contrast may demonstrate extravasation, pleural fluid, or mediastinal air.
  - Contrast study of the esophagus should be done if the CT is suspicious but not conclusive. (Remember, Gastrografin has a high false-positive rate and is much more toxic to the lungs if aspirated; barium, while more sensitive, creates intense local reaction with extravasation).
- Esophagoscopy may show an injury but has a significant incidence of false-negative results.
- Surgical procedures to repair the esophagus range from simple closure to total resection with later reconstruction.

Exposure of the Esophagus

- The upper thoracic esophagus is classically exposed via a right fourth interspace posterolateral incision.
- The lower thoracic esophagus is classically exposed via a left fifth or sixth interspace posterolateral thoracotomy.
- In an unstable patient, posterolateral positioning may be contraindicated, and a “clamshell” incision may be more useful.
- Placing a double-lumen endotracheal tube or a bronchial blocker aids in exposure of the esophagus. If the operation is more urgent, the endotracheal tube may be advanced into the main-stem bronchus.
- The posterior mediastinal pleura is incised directly over the esophagus. Placement of a nasogastric tube or bougie will help with identification of the esophagus.
- The most distal portion of the esophagus can be visualized from either the left chest (Figure 5) or the abdomen.

HEAD TO RIGHT

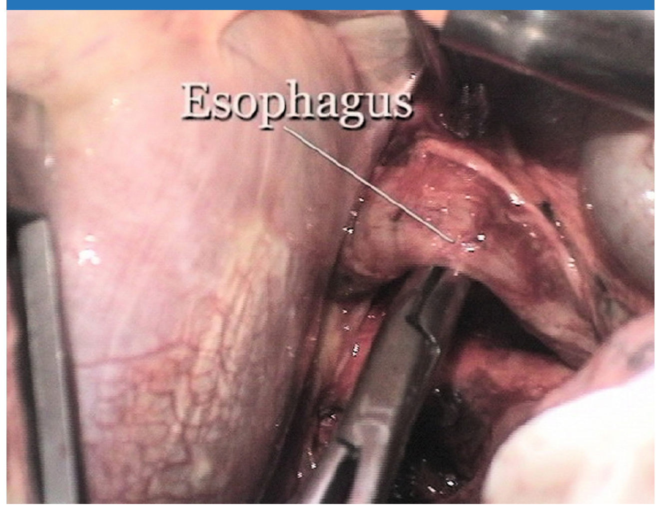


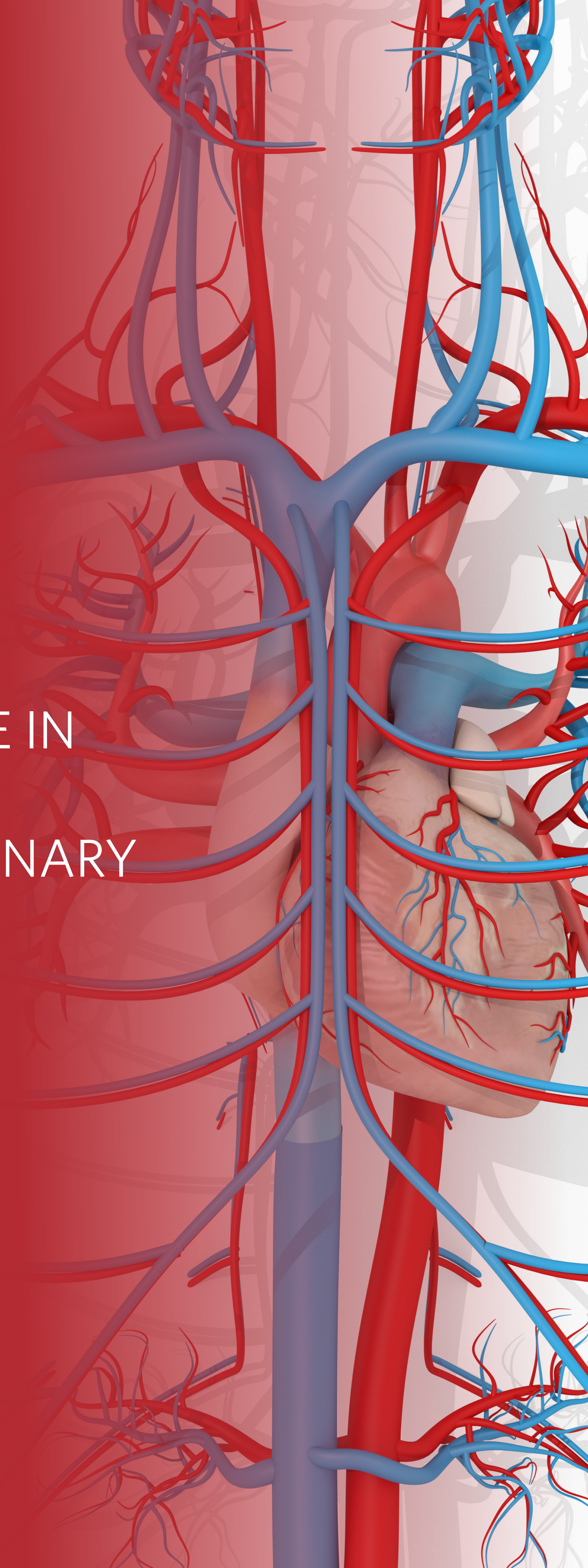
Figure 5. The distal esophagus is easily visualized just above the diaphragm in the left chest. The vagus nerve is seen on the surface of the esophagus.

Pearls and Pitfalls

- Most injuries can be repaired primarily with a two-layer (mucosa and muscle) closure. Care should be taken to identify the true extent of the mucosal injury, which may require extending the injury to the muscular layer of the esophagus.
- Through-and-through esophageal injuries should be ruled out.
- All repairs should be buttressed with local tissue, ideally a muscle flap. Pericardial or pleural flaps have also been described but are often less robust.

- Patients with delayed diagnosis or extensive contamination occasionally require more complex techniques, including diversion with a cervical esophagostomy, wide drainage, or exclusion. In these cases, involvement of a thoracic surgeon may be warranted. A T-tube placed in the injury, as well as multiple chest tubes, will allow for the formation of a contained fistula. Distal feeding access should be established.
- Outcomes are best with early diagnosis. Any concern for esophageal injury should prompt immediate and thorough workup.
- Diversion or drainage should be limited to cases where there is widespread contamination and/or a significant delay in diagnosis.
- Cervical esophagostomy is rarely indicated.
- An isolated esophageal injury is rarely immediately life-threatening. This allows time to plan the appropriate procedure with appropriate expertise.
- Covered stent placement combined with pleural drainage is an evolving modality that may be considered.

CHAPTER 13
OPERATIVE EXPOSURE IN THORACIC TRAUMA: EXPOSURE OF PULMONARY AND HILAR INJURIES



Operative Exposure in Thoracic Trauma: Exposure of Pulmonary and Hilar Injuries

This chapter will discuss the exposure of actual or suspected injuries of the lungs and pulmonary hilum. Additionally, the techniques of pulmonary tractotomy, nonanatomic pulmonary resection, hilar control, and lobectomy will be presented.

Learning Objectives

By the end of the ASSET course, participants should be able to do the following:

1. Describe patient positioning and incision options.
2. Demonstrate how to divide the left and right inferior pulmonary ligaments and the proper exposure for pulmonary injuries.
3. Demonstrate a lung tractotomy.
4. Describe the techniques of nonanatomical lung resection, formal lobectomy, and pneumonectomy.
5. Describe and demonstrate the steps to obtain pulmonary hilar control.

Considerations

- Most primary lung injuries (approximately 85 percent) do not require operative intervention and can be managed with tube thoracostomy alone.
- The primary indications for thoracotomy for lung injury include the following:
  - Massive bleeding from the lung, especially in the setting of hypotension
  - Ongoing blood loss (classically, > 200 cc/hr for at least four hours)
  - Large acute retained hemothorax
  - Tracheobronchial injury that interferes with ventilation or oxygenation
- Pulmonary injuries are frequently found in conjunction with other thoracic injuries that require thoracotomy.
- The lung is made up of distinct bronchopulmonary segments, each containing a bronchus, artery, and vein.
- A working knowledge of the hilar anatomy and the orientation of the bronchi, pulmonary arteries, and veins is essential (Figure 1).
- Pulmonary veins are thin-walled and are easily damaged if care is not taken during dissection.

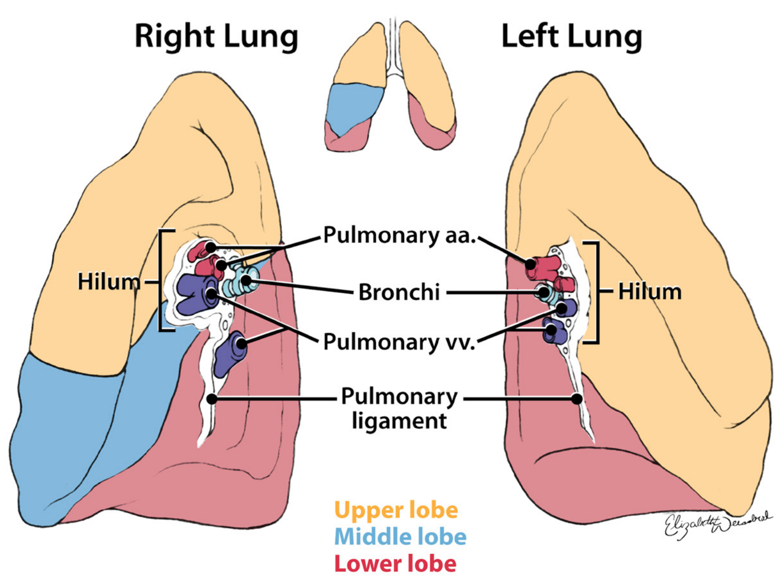


Figure 1. The anatomy of the lungs is depicted, showing the relationships of the hilar structures and the pulmonary ligament.

Positioning and Equipment

- The choice of thoracic incision is critical. The goal is to maximize exposure of the injured areas of the chest while also allowing ongoing resuscitation and access to the rest of the patient.
- Unstable trauma patients should be placed supine with the arms out, allowing access to the groin, abdomen, chest, and neck.
- If stable, the patient can be rolled slightly (roughly 20°) anteriorly using bumps, gels, or sandbags to allow greater exposure to the lateral chest and thoracic contents.
- While the formal posterolateral thoracotomy position provides good exposure for lung injuries, it should **not** be used unless (1) the patient is hemodynamically stable; (2) there are no other injuries to the abdomen, neck, or spine that may need urgent attention; and (3) the downward lung can be protected from blood by a double lumen tube or bronchial blocker.
- If a sternotomy has been done for associated cardiac injury, the right or left hemithorax can be accessed by opening the mediastinal pleura. This will provide access to the anterior portions of the lung but is inadequate for exposure of the posterior aspects. Extension with a thoracotomy incision may then be required.
- Appropriate instrumentation and equipment should be available and ready in the room at the beginning of the case and should include the following:
  - A chest or sternal retractor (Finochietto)
  - A powered sternal saw for median sternotomy
  - A Gigli saw, Lebsche knife and mallet, and rib instruments
  - Large clamps, such as DeBakey or Satinsky, as well as Duval lung clamps
  - Multiple types of stapling devices with an assortment of staple sizes and types
  - Warm lavage fluid (sterile water may improve lysis of red cells) to help remove clots and determine areas of bleeding

Exposure for Control of Lung Injuries

- The choice of incision is dictated by the stability of the patient and the suspected injuries but should be large enough to adequately visualize and control the injuries.
- In most trauma patients, the initial incision will be an resuscitative (anterolateral) thoracotomy on the side of suspected injury, with extension across the sternum (“clamshell” thoracotomy; see chapter 10) as needed.
- A chest tube should be placed on the opposite side if there has not been time to rule out concomitant injury.
- Residual blood and clots should be rapidly scooped from the chest, irrigating with warm fluid if necessary to identify sources of bleeding.
- The inferior pulmonary ligament may need to be taken down to address specific injuries.
- The use of Duval lung clamps may facilitate inspection of the lung while preserving the orientation of the lobes.
- The external opening of lung injuries that extend deep into the parenchyma with active hemorrhage should not be clamped, stapled, or oversewn, as they will continue to bleed internally. Such wounds are best treated with either tractotomy or wedge resection.
- Injuries close to the hilum may require nonanatomic resection or lobectomy.

MOBILIZATION OF THE INFERIOR PULMONARY LIGAMENT

The pulmonary ligament is not a true ligament but an extension of the parietal pleura; it surrounds the hilar structures at the lower edge of each lung and fixes them to the mediastinum (Figures 1–5).
To expose the pulmonary ligament, retract the lung superiorly and laterally. Next, use scissors to make a small cut in the inferior pulmonary ligament at the inferior edge. Then, bluntly separate the ligament from the mediastinum to the level of the inferior pulmonary vein (Figures 4 and 5).

LEFT CHEST - HEAD TO RIGHT

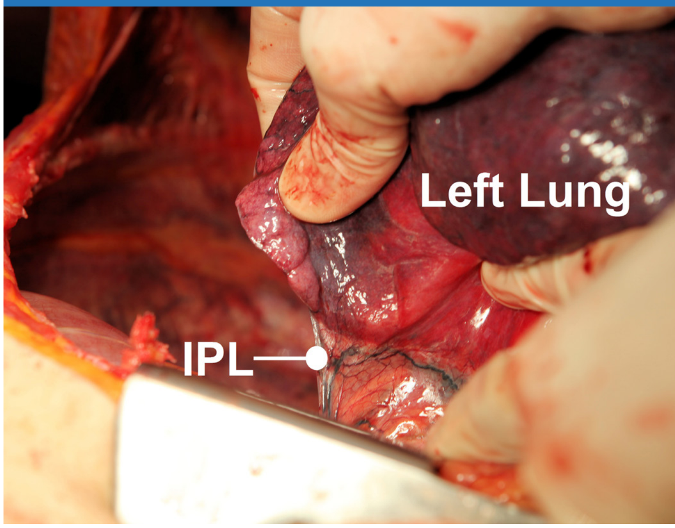


Figure 2. The inferior pulmonary ligament (IPL) in the left chest is visualized by retracting the lung.

RIGHT CHEST - HEAD TO RIGHT

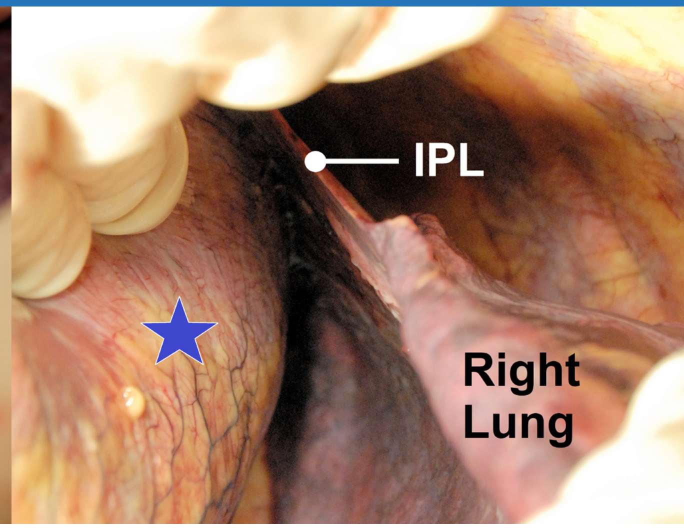


Figure 3. The inferior pulmonary ligament (IPL) in the right chest is visualized by retracting the lung. The diaphragm (blue star) is also seen.

LEFT CHEST - HEAD TO RIGHT

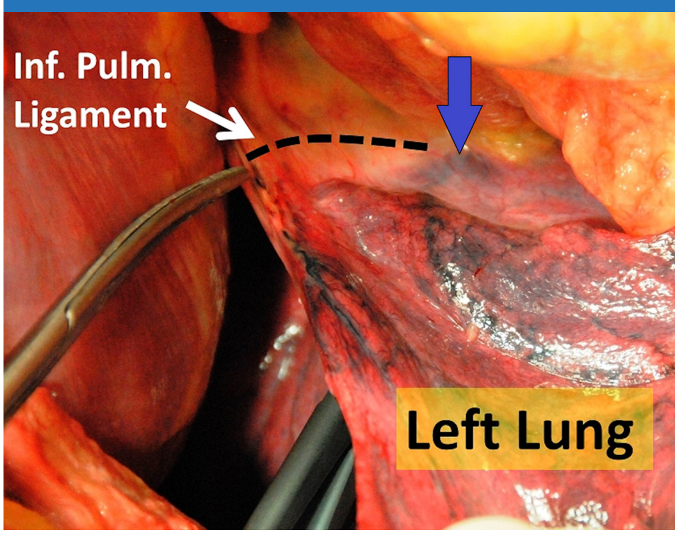


Figure 4. The inferior pulmonary ligament is carefully opened to the inferior border of the inferior pulmonary vein (arrow), taking care to avoid injury to this structure.

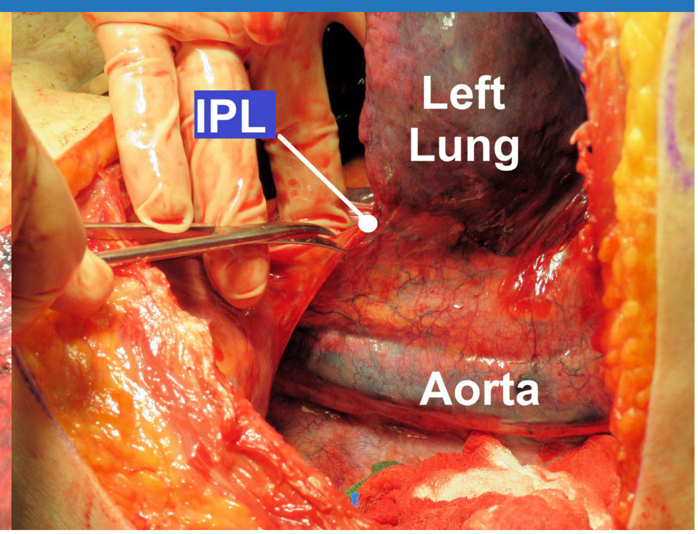


Figure 5. Taking down the inferior pulmonary ligament (IPL) in the left chest also helps visualize the thoracic aorta.

PULMONARY TRACTOTOMY

- Wounds in the peripheral half of the lung (as measured from the hilum) are usually amenable to a lung-sparing pulmonary tractotomy.
- Pulmonary tractotomy is useful in through-and-through wounds of the lung, as it allows for simultaneous exposure and control (of hemorrhage and air leak) of deep wounds.
- A linear stapler is placed through the wound in the lung parenchyma and fired (Figure 6). This maneuver will open the overlying lung and allow exposure of the wound, which can then be sutured (or further stapled) to control bleeding or air leaks.
- If a stapler is not available, the same technique may be accomplished using two clamps, manually dividing the intervening parenchyma, and placing a running horizontal mattress suture beneath the clamp, followed by oversewing.

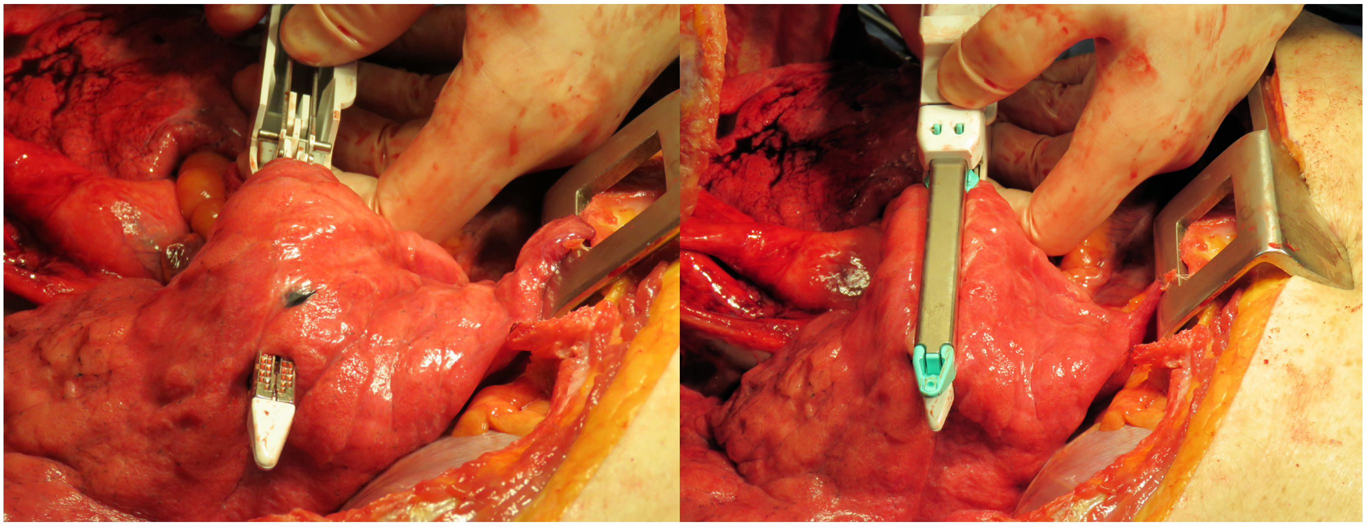


Figure 6. A linear stapler is placed across a through-and-through wound to the lung and fired, allowing for exposure of the base of the wound for subsequent management.

- Alternatively, if the through-and-through wound is relatively small, the stapler can be placed such that the tip of the device is beyond the wound, and the wound is contained within the jaws of the stapler (Figure 7). This maneuver may completely seal off the raw edges of the wound or decrease the raw surface area that will require subsequent suturing (Figure 8).

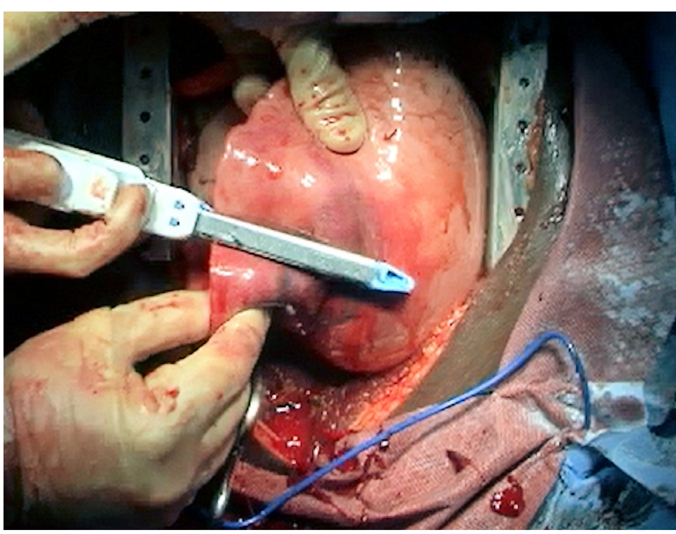


Figure 7. The linear stapler has been placed with the tip beyond and incorporating a through-and-through wound to the lung.

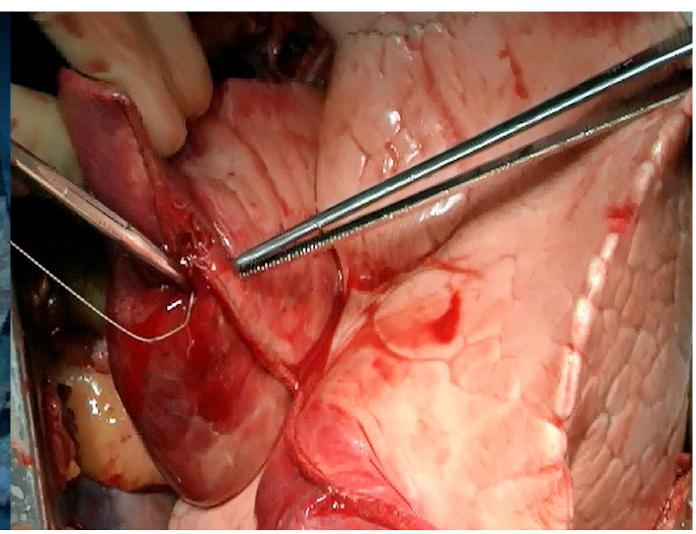


Figure 8. By incorporating the wound into and firing the stapler beyond it, the residual area requiring further suturing is minimized.

NONANATOMIC RESECTION

- The lung is extremely forgiving of nonanatomic resections due to its dual blood supply. Isolated areas near the periphery of the lung can be wedge resected with a linear stapling device, providing vascular and air leak control (Figures 9 and 10).
- Lung clamps are used to grasp the lung and manipulate it into a configuration that allows for optimal application of the stapler.
- A complete nonanatomic resection may require several sequential stepwise firings of the stapler.
- Manual compression of the lung and/or closure of the stapler for 15 seconds prior to firing may compress some of the edema fluid and allow for a more secure closure. Using staplers with a higher staple height may be needed in some cases.
- Upon removing the stapler, air leaks or bleeding at the staple line may be oversewn.
- If a nonanatomic resection is performed in the upper lobe, release of the inferior pulmonary ligament permits the lung to fully fill the pleural cavity.

HILAR CONTROL

- Active hemorrhage from the central portion of the lung often requires hilar control before complete identification and management of the injuries are possible.
- The lung is a pedicled organ, and proximal control of the pulmonary vessels can be obtained with occlusion at the hilum.
- Effective control of the pulmonary hilum may require division of the inferior pulmonary ligament, as outlined above.
- Once the hilum is identified and isolated, several techniques can be used to gain control:
  - The hilum can be grasped with the whole hand, providing temporary manual control. This may also facilitate identification of the source of bleeding.
  - A large-angled vascular clamp can be placed across the entire hilum (Figure 11). While clamping may achieve vascular control, complete occlusion may result in injury to the bronchus (Figure 11).

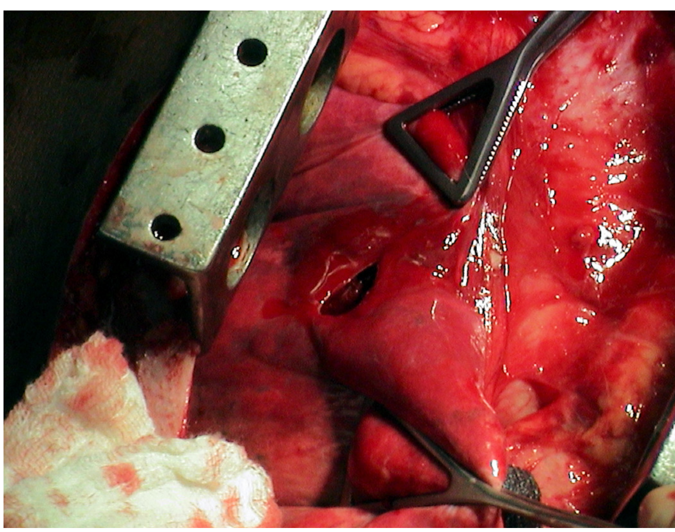


Figure 9. Duval clamps are used to evaluate and align this peripheral injury to the lung prior to a planned resection.

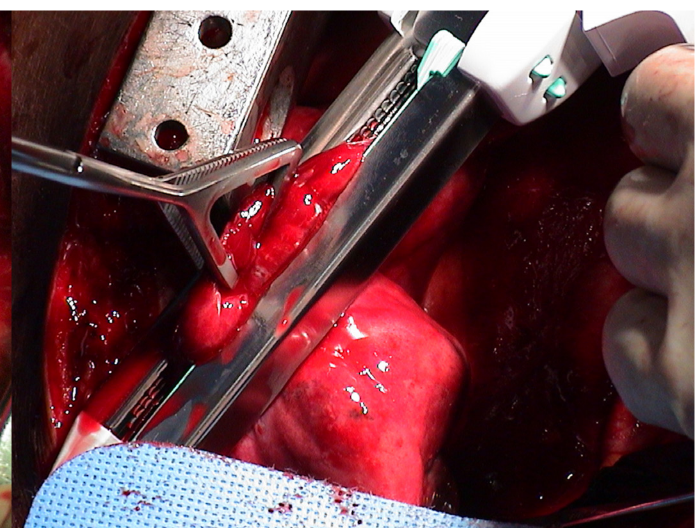


Figure 10. A nonanatomic resection of the injured lung is accomplished with a linear stapler fired below the wound.

- The hilum can be looped with an umbilical tape and snared with a tourniquet (Rumel) for hilar control. This compresses the vasculature against the bronchus. As umbilical tape is quite narrow, a second tourniquet often is needed to obtain full control.
- The hilar twist is a technique that may be useful primarily during a resuscitative thoracotomy when vascular clamps are not available. Once the inferior pulmonary ligament is divided, the lung can be gently rotated 180°, effectively twisting the vascular structures around the more rigid bronchus (Figure 12). Twisting the lung makes delineation of lung injuries more difficult.

- The downside of all of these hilar control techniques is that they will significantly increase pulmonary artery pressures and can induce right heart failure and cardiac arrest.

LOBECTOMY AND PNEUMONECTOMY

- Most pulmonary injuries can be addressed by nonanatomic stapled lobectomy.
- Injuries in the central portion of the lung may need to be managed by a major resection for rapid control of bleeding if pulmonary tractotomy fails.
- Depending upon the patient's anatomy, the fissures can simply be divided with scissors, and any air leaks and bleeding can be controlled following resection. Alternatively, the fissures can be divided using staplers. Reticulating staplers may be advantageous in open-lung resection.
- Trauma pneumonectomy has been associated with a very high mortality (> 90 percent), with two major reasons:
    - The procedure is usually performed late and as a desperate attempt to control hilar bleeding after other techniques have failed.
    - The combination of shock and clamping of the pulmonary artery results in almost irreversible right heart failure.

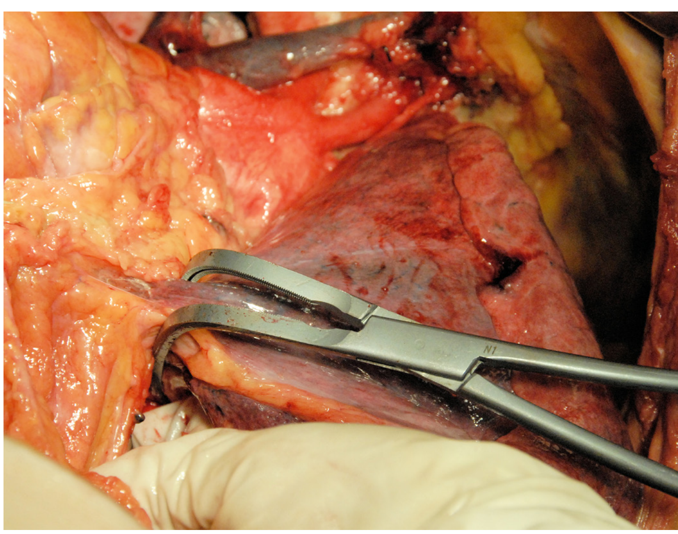


Figure 11. The hilum of the left lung has been clamped with a Satinsky clamp.

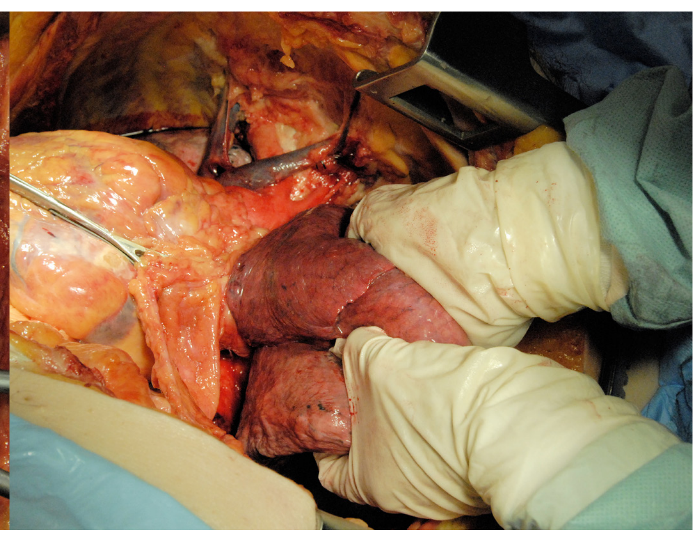
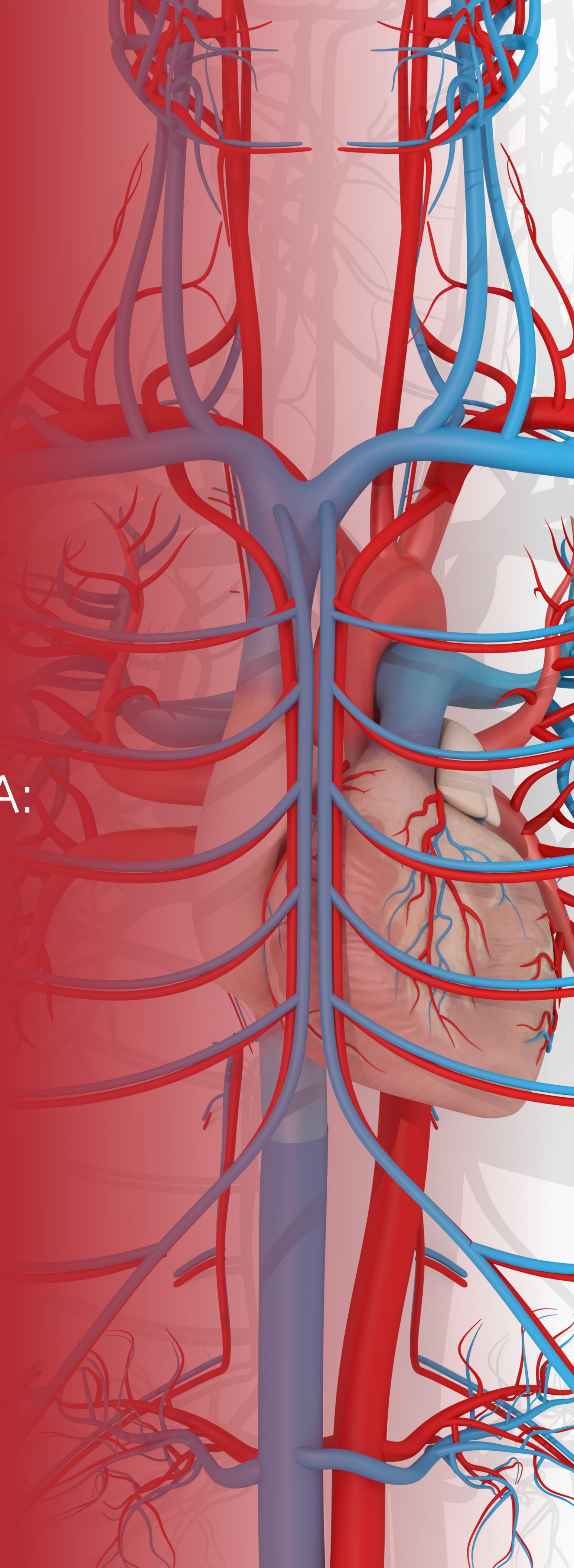


Figure 12. The lung has been "twisted" around the hilum, compressing the vessels against the bronchus.

CHAPTER 14

OPERATIVE EXPOSURE IN THORACIC TRAUMA: EXPOSURE OF THE GREAT VESSELS



Operative Exposure in Thoracic Trauma: Exposure of the Great Vessels

This chapter will present the exposure of actual or suspected injuries of the great vessels of the chest.

Learning Objectives

By the end of the ASSET course, participants should be able to do the following:

1. Describe and demonstrate appropriate positioning and incisions to expose the ascending, arch, and descending thoracic aorta.
2. Demonstrate surgical exposure of the ascending aorta, aortic arch, and descending thoracic aorta.
3. Demonstrate exposure of the innominate vessels.
4. Demonstrate surgical exposure of the carotid artery at its origin.
5. Demonstrate resection of the clavicular head.
6. Demonstrate surgical exposure of the subclavian vessels.
7. Describe damage control techniques for thoracic injuries.

Considerations

- Patients with injuries to the great vessels usually present with immediate, life-threatening hemorrhage. Prompt diagnosis and treatment by experienced practitioners is essential to the successful management of these injuries.
- When time permits, engaging the assistance of appropriate specialists (cardiothoracic or vascular surgeons and/or interventional radiologists) may be helpful.
- Successful surgical repair of major thoracic vascular injuries requires decisive action including adequate exposure, rapid vascular control, and effective repair.
- Although digital control can temporize almost any bleeding, repair requires adequate proximal and distal vascular exposure.
- Ligation and shunting are both viable options in unstable patients. The proximal subclavian artery can be ligated distal to the thoracoacromial trunk. Carotid injuries should be shunted if possible. Venous injuries can usually be ligated.
- Remember the close proximity to the vasculature of the vagus, recurrent laryngeal, and phrenic nerves, as well the thoracic duct. Grasping large amounts of adjacent tissue while focusing on vascular structures may cause injury to these nearby structures.

Incisions in General

- The surgeon should make strategic decisions on positioning, exposure, and control based on the suspected injury pattern.
- The placement and size of the incision is the foundation for success. The patient's stability will dictate the incision to be made.
- Patients in extremis from penetrating thoracic injuries must undergo immediate resuscitative thoracotomy via an anterolateral thoracotomy and, if needed, extension across the right chest as a "clamshell" incision (Figures 1 and 2), as described in chapter 10.
- If the patient is not in extremis, the most appropriate incision is dictated by the structure(s) most likely to be injured.
- Anterior wounds in a stable patient are best approached through a median sternotomy (Figure 3). The innominate (brachiocephalic) vein (Figure 3) crosses anterior to and obscures the origin of the arch vessels. This structure can be divided and ligated to facilitate exposure.
- A median sternotomy can be extended into the neck or above the clavicle (Figure 4) to expose and manage injuries to the thoracic outlet vessels. As such, it is important to place the sternal retractor with the bar toward the feet (Figure 3) to allow extension of the incision above the sternal notch.

HEAD TO LOWER RIGHT

Figure 1. The left anterolateral incision for resuscitative thoracotomy can be carried across the sternum to provide exposure of both sides of the chest.

HEAD TO TOP

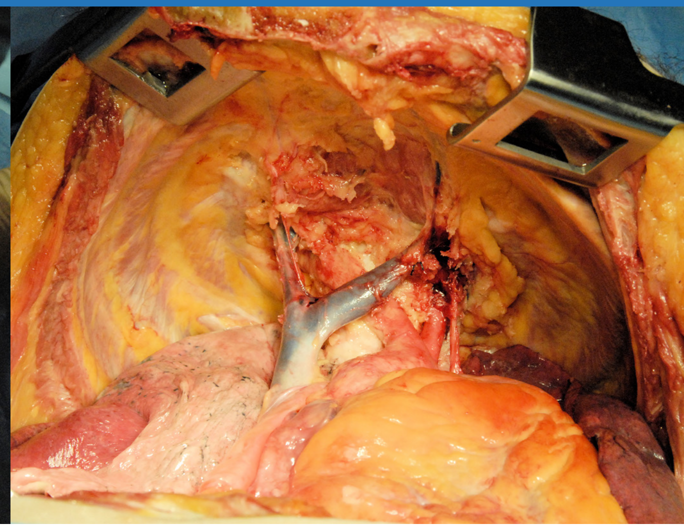


Figure 2. The clamshell incision provides unparalleled exposure of the great vessels, as seen in this cadaveric dissection.

ANTERIOR CHEST - HEAD TO LOWER RIGHT

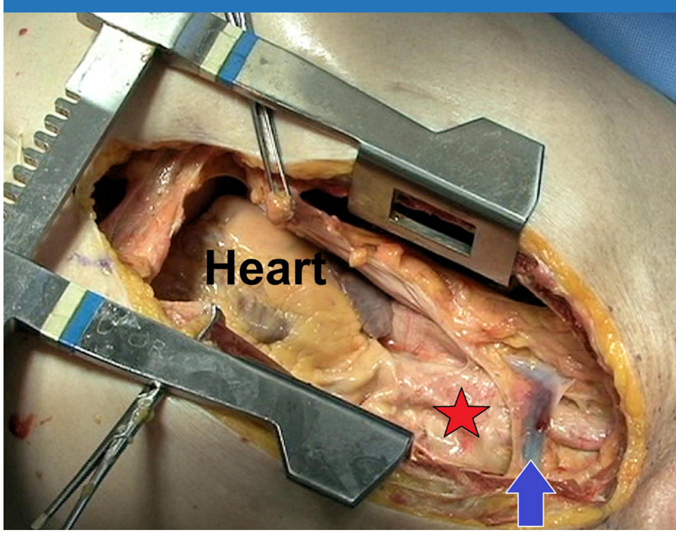


Figure 3. The median sternotomy provides exposure of the heart, aortic arch (star), and proximal arch vessels. The innominate vein (arrow) can be divided to aid exposure.

Figure 4. The median sternotomy can be extended into the neck or above the clavicle to better expose the vessels of the thoracic outlet.

- Lateral and posterior wounds may be better visualized via a posterolateral thoracotomy, but this should only be done in a stable patient in whom other life-threatening injuries in the abdomen and chest have been ruled out.
- Be flexible, and extend or create new incisions as needed. Make a decision, make an incision. If it's the wrong incision, make a bigger or another incision.

Exposure of Specific Injuries

THORACIC AORTA

- Injuries to the ascending aorta and aortic arch are usually exposed and managed through a median sternotomy with an appropriate superior extension (Figures 3 and 4). As previously discussed, in unstable patients, a "clamshell" thoracotomy may be indicated and will provide excellent exposure (Figure 2).
- The ascending aorta is largely intrapericardial, with the superior pericardial reflection occurring at the level of the innominate artery takeoff. The anterior and right lateral aspects of the ascending aorta are more readily accessible. The left lateral border of the ascending aorta is adherent to the pulmonary artery, making it prone to inadvertent injury.
- Injuries to the descending thoracic aorta in a stable patient are ideally managed via endovascular approaches or by a left posterolateral thoracotomy (Figures 5 and 6).
- After the chest has been entered during a posterolateral thoracotomy, the lung is retracted (or deflated using a double lumen tube or bronchial blocker), providing exposure of the descending thoracic aorta. The aortic arch and left subclavian artery can be exposed and controlled, taking care to avoid the vagus nerve (Figure 7).
- For injuries to the distal ascending aorta and aortic arch, the key maneuver is mobilization of the aortic arch. The pericardium is opened, and the left innominate vein is identified. The superior pericardial reflection is dissected from the aorta, and the innominate vein is divided to facilitate exposure.
- Injuries to the descending aorta can be controlled with a partial occluding clamp or between two vascular clamps.
- For through-and-through wounds, identification of both wounds is mandatory. This may require surgical extension of the injury or transection of the aorta with subsequent repair.

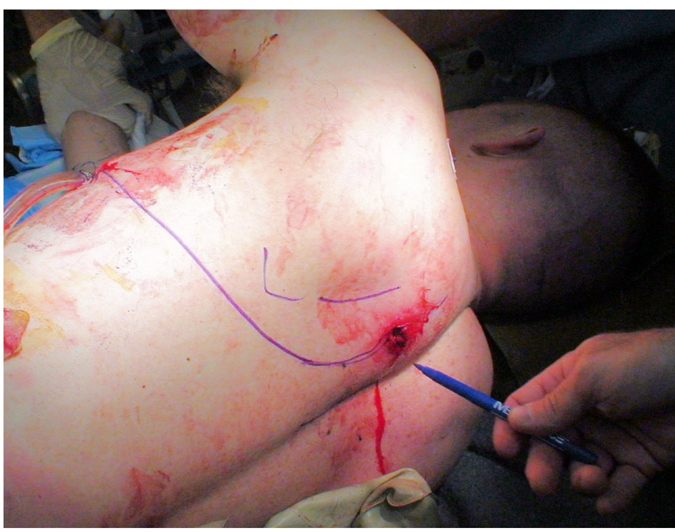


Figure 5. In stable patients, the left posterolateral thoracotomy is the ideal approach to the descending thoracic aorta.

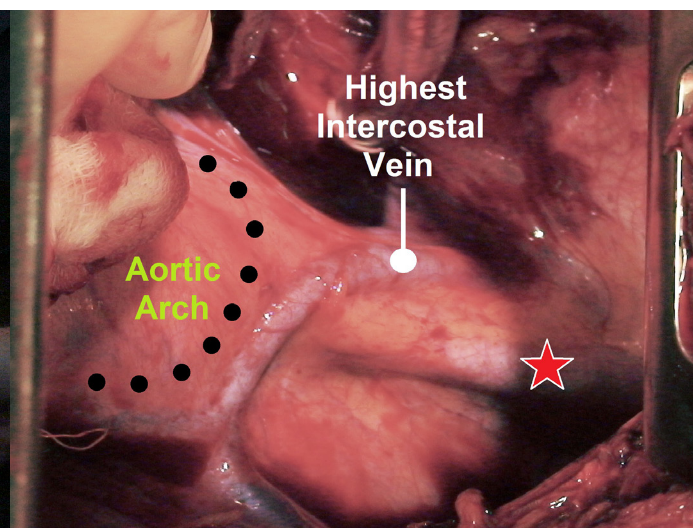


Figure 6. The view initially seen upon opening the chest during a left posterolateral thoracotomy. The arch and left subclavian (star) can be exposed via this incision.

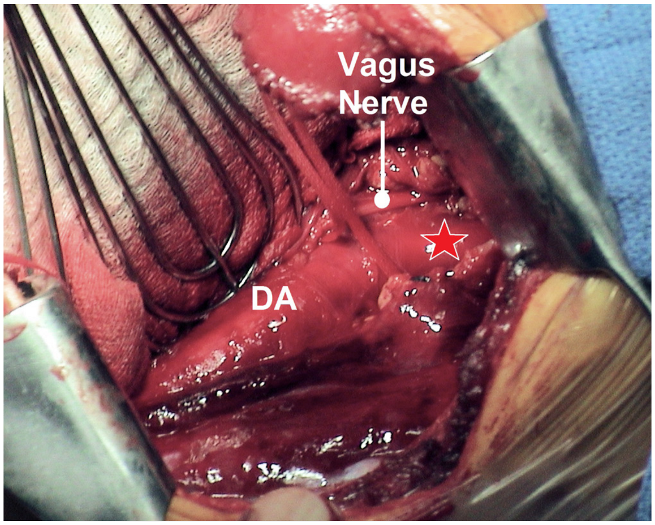


Figure 7. This approach allows exposure of the descending aorta (DA) and the subclavian artery (star), taking care to avoid injury to the vagus nerve as the lung is retracted.

INNOMINATE ARTERY AND VEIN

- Median sternotomy is usually the incision of choice, but the "clamshell" can also provide excellent exposure of this region in patients in extremis (Figure 8).
- Deliberate division of the left innominate vein provides further exposure of the arch vessels.
- Injuries at the aorto-innominate junction may require resection and bypass from the ascending aorta.
- Based upon their location and complexity, innominate artery injuries can be managed with simple repair, interposition grating, or jump grafts from the proximal aorta.

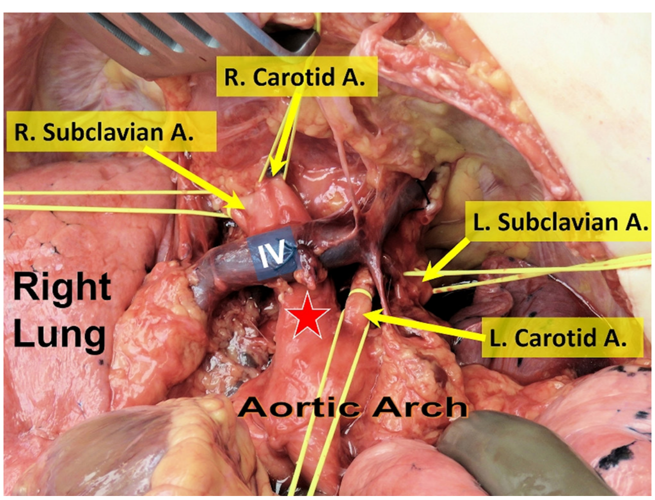


Figure 8. The relationship of the arch and great vessels to the innominate artery (star) is clearly seen in this "clamshell" thoracotomy. If needed, the left innominate vein (IV) can be divided to optimize exposure of the underlying structures.

CAROTID ARTERY

- Injuries in the neck are best approached through an incision along the sternocleidomastoid muscle. This approach is described in chapter 7.
- For injuries with obvious thoracic involvement, the proximal carotid arteries are exposed through an extension of a median sternotomy along the anterior border of the sternocleidomastoid muscle on the appropriate side of the neck (Figure 9). A partial sternotomy (division of the manubrium) may be adequate to achieve this exposure (Figures 9 and 10).

SUBCLAVIAN VESSELS

- As their name implies, the subclavian vessels are well hidden behind the clavicle. A variety of exposure techniques have been described for proximal and distal control.
- In stable patients with suspected subclavian artery injury, consideration should be given to endovascular techniques to control hemorrhage. If the patient is unstable and actively bleeding, prompt surgical exposure and control is vital.
- Proximal exposure and control needs to be obtained through the chest; the site for distal control is tailored to the site and extent of the injury.

RIGHT NECK AND UPPER CHEST - HEAD TO UPPER LEFT

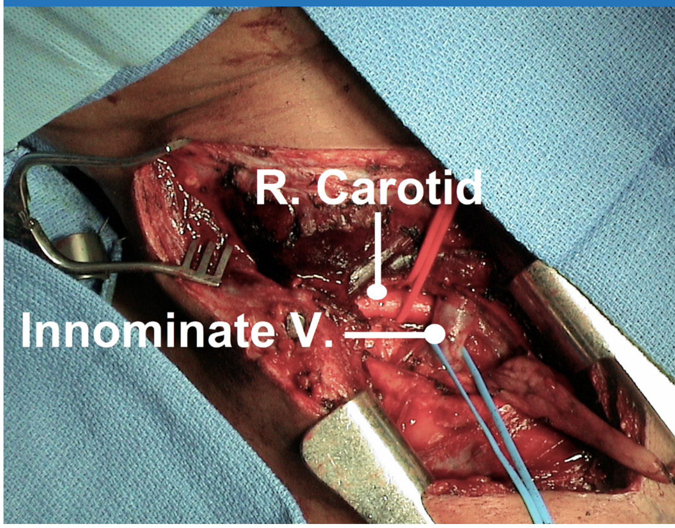


Figure 9. A partial median sternotomy with division of the manubrium and extension into the right neck allows for exposure and proximal control of the common carotid artery and the innominate (brachiocephalic) vein in Zone 1 of the neck.

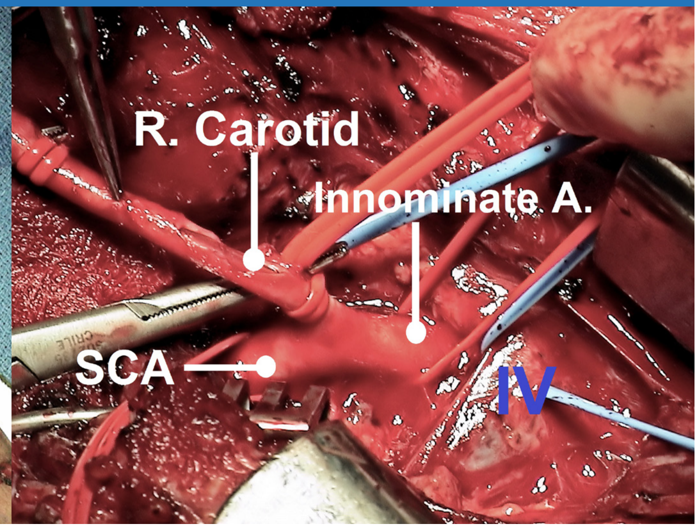


Figure 10. Further dissection allows for exposure and control of the innominate (brachiocephalic) artery and vein (IV), as well as the right subclavian artery (SCA) and the right common carotid artery.

Proximal Exposure of the Subclavian Artery

- Proximal exposure and control of the right subclavian can be achieved via a median sternotomy.
- Proximal exposure and control of the left subclavian artery is challenging due to its posterior course.
  - One well-described method of obtaining proximal control of the left subclavian is to perform an anterior thoracotomy in the left third intercostal space (Figure 11). However, in muscular individuals with a well-developed pectoralis major muscle—or in the setting of other intrathoracic injuries—this incision may be inadequate.
  - In unstable trauma patients, the initial approach may be a resuscitative thoracotomy at the fifth interspace, extended across to a "clamshell" incision; this provides excellent access to the origin of both subclavian arteries for proximal control (Figure 12).

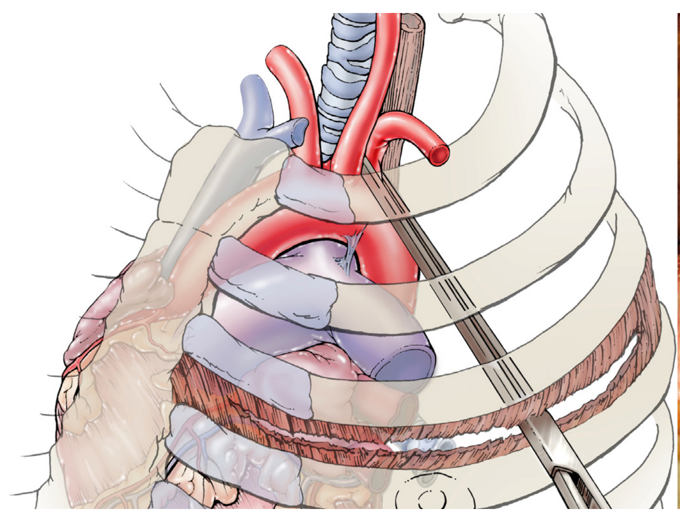


Figure 11. The left third intercostal space incision can be used to obtain proximal control of the intrathoracic portion of the left subclavian artery.

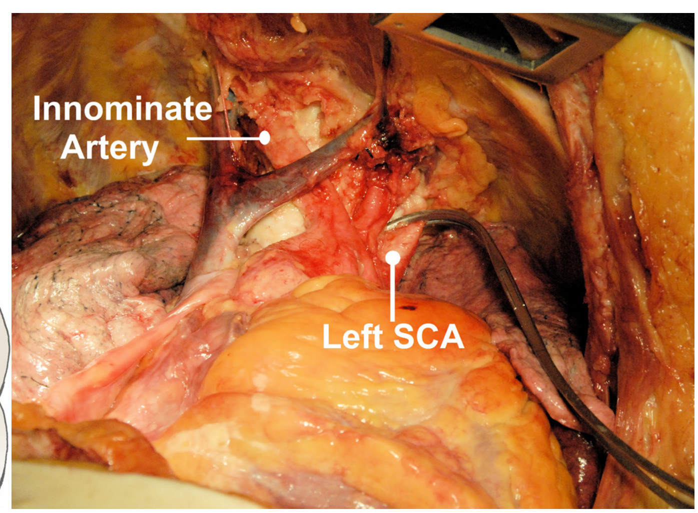


Figure 12. The left subclavian artery (SCA) has been exposed and clamped to gain proximal control through a "clamshell" incision.

Exposure of the Subclavian Artery above the Clavicle (Supraclavicular Approach)

- Distal control of both subclavian arteries (or proximal control of axillary artery injuries) can be obtained using a supraclavicular approach. The exposure is easier on the right side than the left, as the course of the subclavian artery is deeper on the left.
- To expose the subclavian artery above the clavicle, an incision is made parallel to and 1 cm above the medial half of the clavicle (Figure 13).
- This incision is carried down through the platysma, and the attachment of sternocleidomastoid to the clavicle is divided about 1 cm from the clavicle to expose the underlying internal jugular vein and the scalene fat pat (Figure 14).
- The anterior scalene muscle, which lies between the subclavian vein and the subclavian artery, is exposed. The phrenic nerve, which courses obliquely from the superior lateral to the inferior medial aspect of the muscle, is identified and preserved (Figure 15).
- The anterior scalene muscle is divided about 1 cm from the clavicle to expose the underlying subclavian artery, which can then be controlled (Figure 16).
- If the subclavian artery is followed medially, the vertebral artery can be identified, as described in chapter 9.

RIGHT NECK ABOVE CLAVICLE - HEAD TO LOWER LEFT

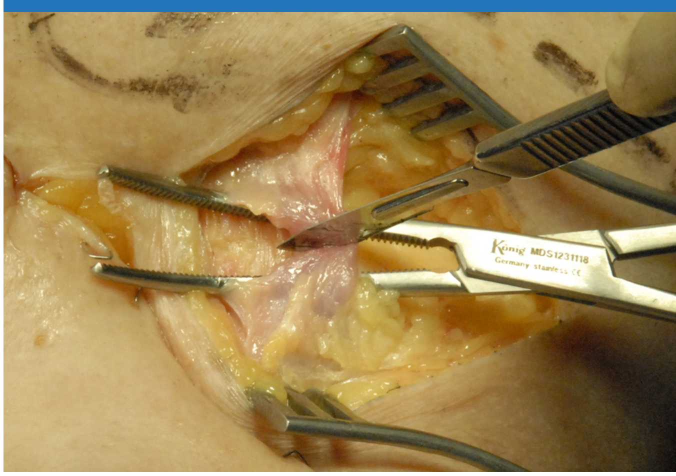


Figure 13. The subclavian artery is exposed above the clavicle (dotted line) by making an incision parallel to the clavicle and dividing the clavicular head of the sternocleidomastoid muscle.

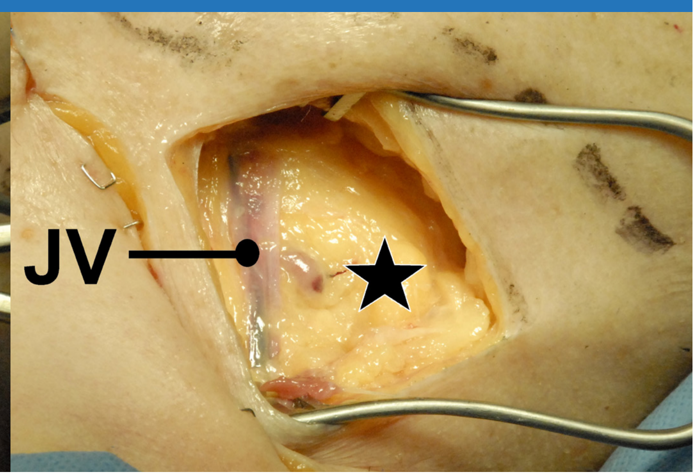


Figure 14. The internal jugular (JV) and scalene fat pad (star) are exposed above the clavicle after division of the sternocleidomastoid muscle.

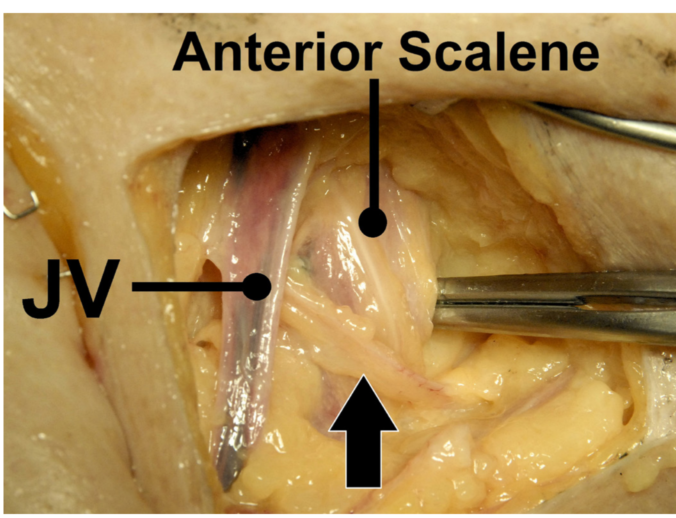


Figure 15. The anterior scalene muscle is identified lateral and deep to the internal jugular vein (JV). The phrenic nerve (arrow), which runs from lateral to medial on the muscle, is identified and preserved.

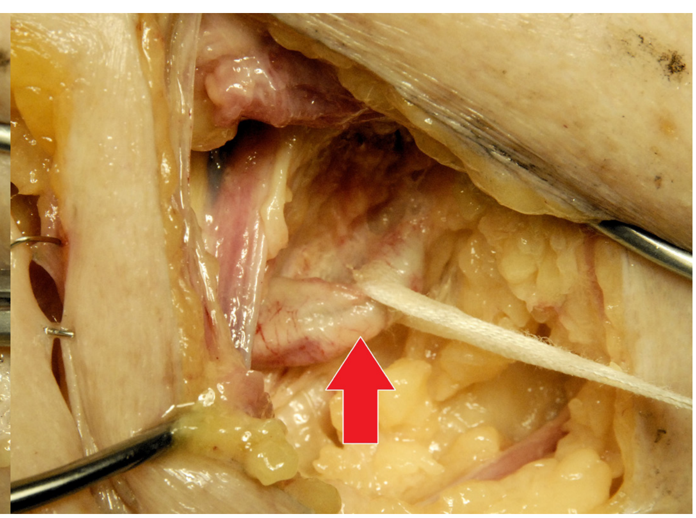


Figure 16. After division of the anterior scalene muscle, the subclavian artery (arrow) is exposed and controlled.

Resection of the Clavicle to Expose the Subclavian Artery

- If the desired exposure of the subclavian vessels is not achieved via sternotomy and extension above the clavicle or into the neck, a portion of the clavicle can be removed.
- An incision is made down onto the anterior surface of the clavicle, which is then cleared circumferentially of the surrounding tissues. A perforating towel clamp is used to grasp the clavicular head, and then a Gigli saw is used to divide the clavicle in its mid portion (Figures 17 and 18).
- The sternal head of the clavicle is dissected free, and the portion of clavicle is removed to allow exposure of the underlying structures (Figures 19–21).
- Alternatively, the clavicle can be divided near the sternum and retracted laterally.
- The clavicle can be replaced and wired once the vascular issues have been resolved, but this is not mandatory.

UPPER CHEST - HEAD TO CENTER

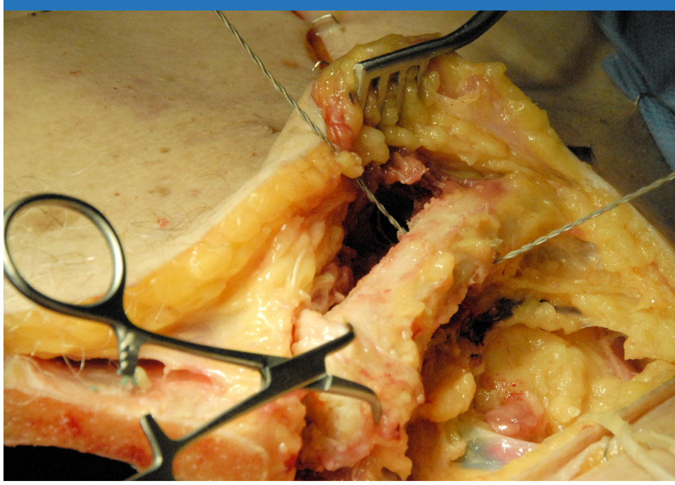


Figure 17. After circumferentially dissecting the right clavicle free of tissues, divide it in the mid portion using a Gigli saw.

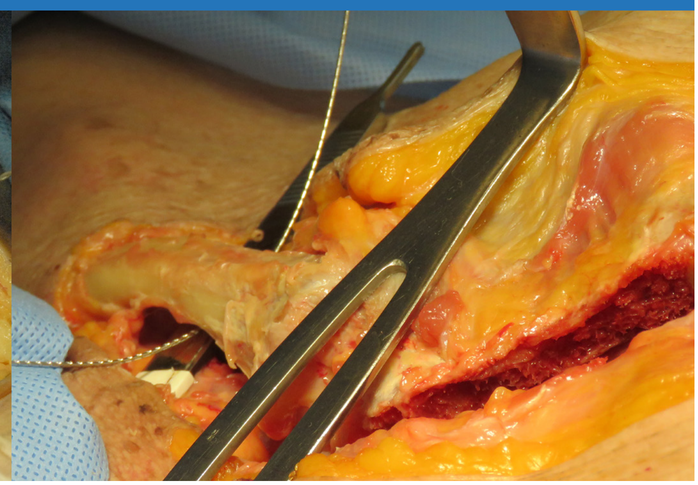


Figure 18. After circumferentially dissecting the left clavicle free of tissues, divide it in the mid portion using a Gigli saw.

RIGHT UPPER CHEST - HEAD TO RIGHT

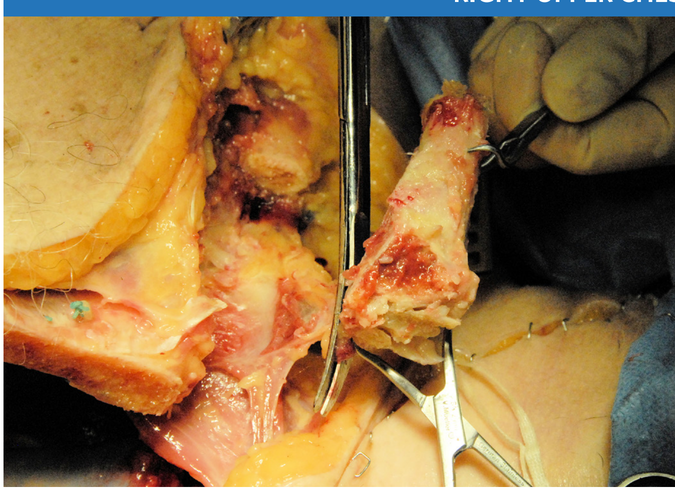


Figure 19. The sternal head of the right clavicle is dissected free and removed.

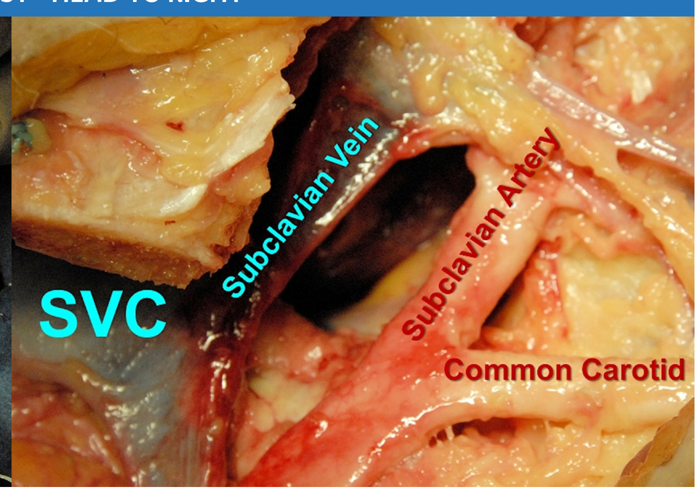


Figure 20. With the right clavicle removed in conjunction with a median sternotomy, the subclavian vessels, superior vena cava (SVC), and carotid are well visualized.

- The clavicle is generally removed as an extension of sternotomy for exposure of the proximal vessels in the chest, but if control in the chest is not needed, the subclavian vessels can also be exposed via resection of the clavicle without sternotomy (Figures 21 and 22).
- Though clavicular resection without sternotomy can provide exposure to the subclavian vessels, more proximal control is generally required with the addition of the median sternotomy providing full access to the great vessels in the chest and the root of the neck as seen in Figure 23.

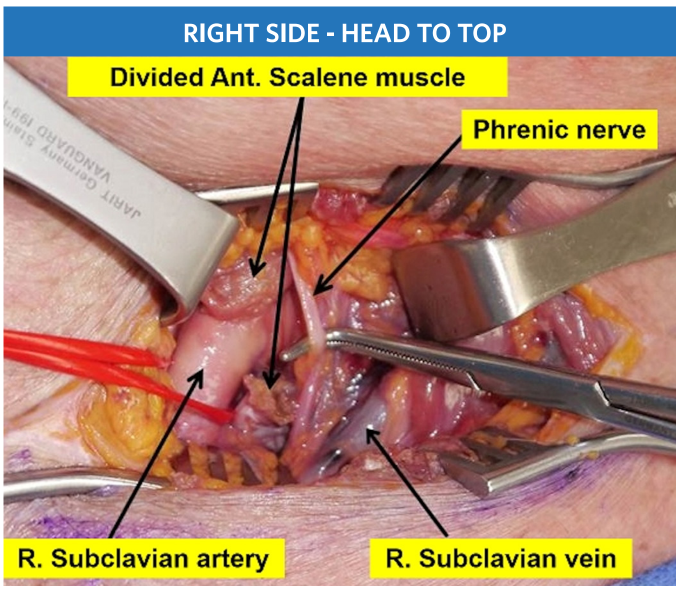


Figure 21. The right clavicle has been removed and the anterior scalene muscle divided to reveal the subclavian vessels and the phrenic nerve.

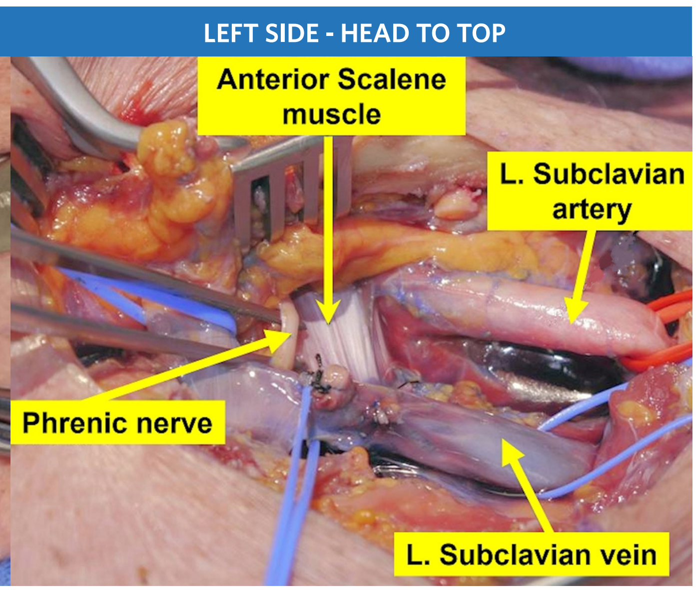


Figure 22. After circumferentially dissecting the left clavicle free of tissues, divide it in the mid portion using a Gigli saw.

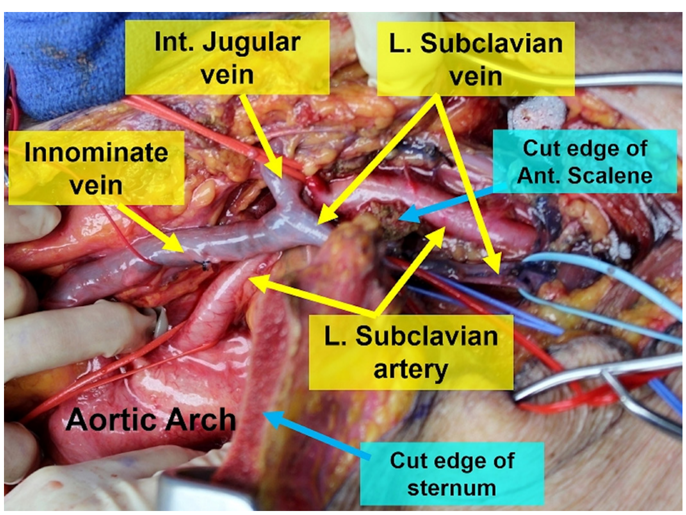
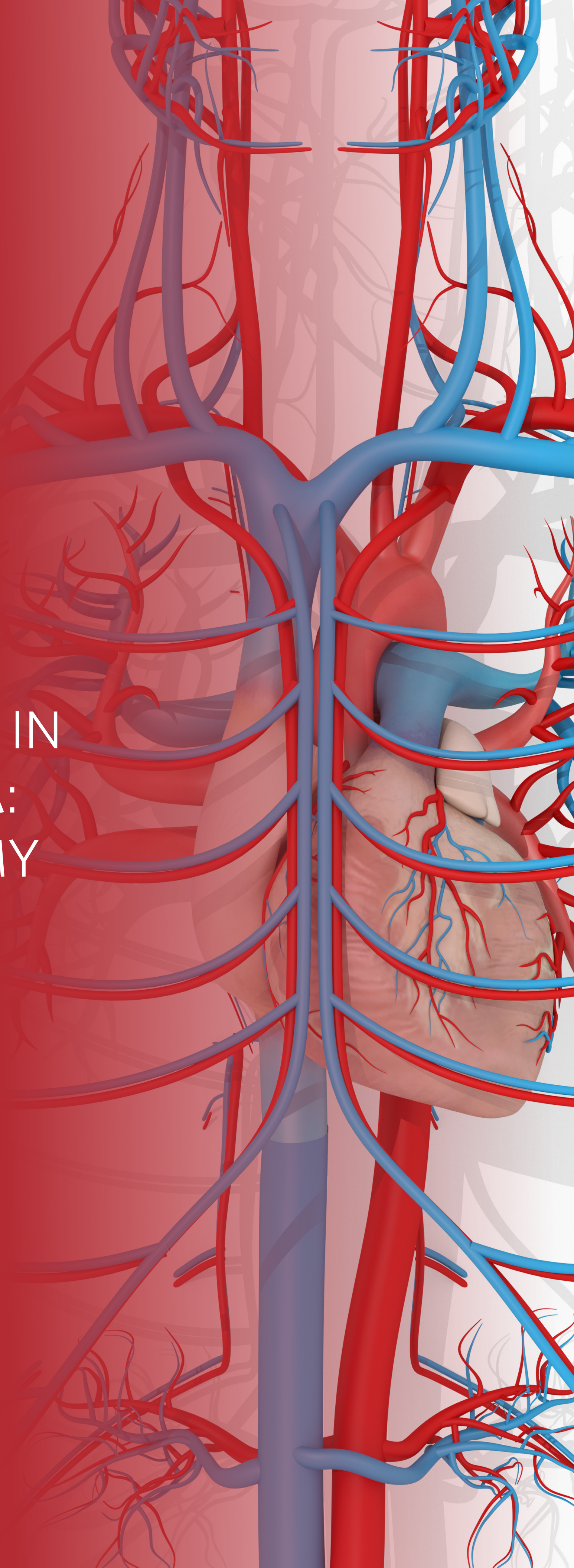


Figure 23. A median sternotomy, which has been extended to the left with resection of the clavicle, provides excellent exposure of the great vessels in the chest, thoracic outlet, and root of the neck.

CHAPTER 15

OPERATIVE EXPOSURE IN ABDOMINAL TRAUMA: TRAUMA LAPAROTOMY



Operative Exposure in Abdominal Trauma: Trauma Laparotomy

This chapter will discuss trauma laparotomy, including the incision, basic operative mobilization, and surgical exposure maneuvers.

Learning Objectives

By the end of the ASSET course, participants should be able to do the following:

1. Describe the goals of a trauma laparotomy.
2. Describe the zones and contents of the retroperitoneum.
3. Demonstrate exposure and control of the supraceliac aorta at the diaphragm.
4. Demonstrate right-to-left medial visceral rotation (Cattell-Braasch maneuver).
5. Demonstrate mobilization of duodenum (Kocher maneuver).
6. Demonstrate left-to-right medial visceral rotation (Mattox maneuver).

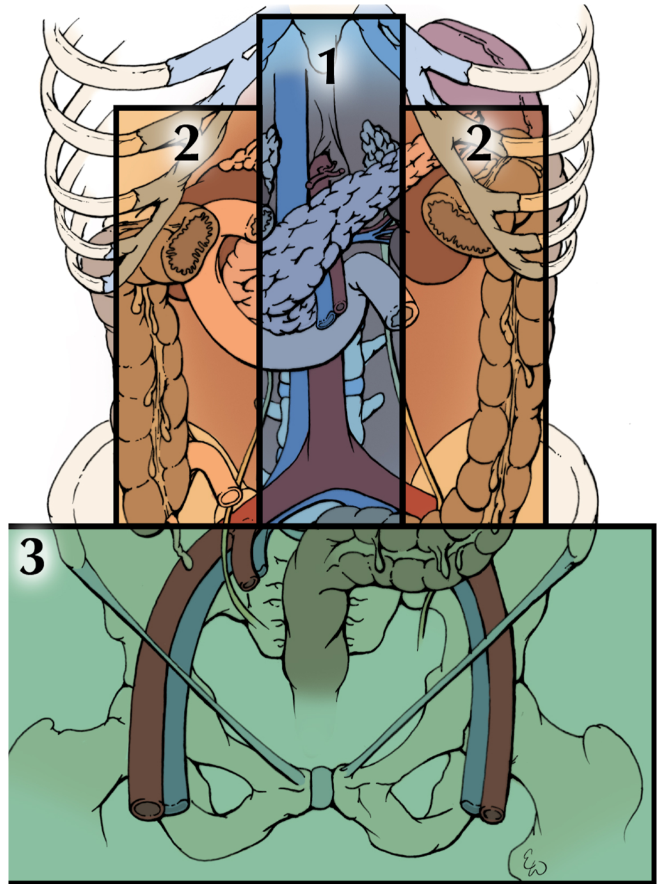


Figure 1. The zones and contents of the retroperitoneum.

General Considerations

- The vasculature of the abdomen is located in three zones (Figure 1).
- All hematomas in Zone 1, which is further subdivided into supramesocolic and inframesocolic areas, require surgical exploration.
- Zone 2 hematomas from penetrating injury are typically explored; hematomas from blunt injury are usually explored only when they are expanding.
- Zone 3 hematomas from penetrating injury require surgical exploration, while exploration of hematomas from blunt injury should be avoided if at all possible.

Goals of Trauma Laparotomy

- Control of potentially life-threatening bleeding
- Identification of injuries
- Control of contamination
- Repair of injuries when appropriate

Incision

- The patient should be placed supine and prepped from the chin to the knees and from table to table laterally. This will allow for extension into the chest and for harvest of veins from the legs for vascular repairs, if needed.
- Make sure you have appropriate equipment, such as adequate suction (two suction devices, with cell saver if available), numerous laparotomy pads, vascular and bowel instruments, retractors (e.g., Bookwalter or Omni-Tract®), appropriate staplers, and supplies for temporary abdominal closure.

- The trauma laparotomy incision runs from xiphoid process to pubic symphysis.
- This incision provides access to all intra-abdominal contents, including the retroperitoneal vascular structures.
- The entire length of the incision is opened down to the fascia prior to entry into the peritoneum.
- The peritoneum should be opened last. If a patient has significant hemoperitoneum, entering the peritoneum prematurely will obscure the field with blood and delay exposure.
- Good communication with anesthesia is important prior to opening the abdomen.

Control of Hemorrhage

- The peritoneum is rapidly opened, and any blood and clots are rapidly evacuated. If there is ongoing bleeding, the four quadrants of the abdomen are packed using two or three packs per quadrant.
- Packing is not about quantity but about quality. The small bowel should be eviscerated prior to packing, which may be inadequate if the bowel is left in place.
- Once the abdomen is packed, the packs in the quadrants that are **least** likely to be the source of bleeding should be removed first. If you go first to the quadrant that you suspect is the source, you may miss another potentially life-threatening source of bleeding in another quadrant.
- Initial control of hemorrhage may require rapid proximal control of the aorta immediately upon entering the abdomen.
- If ongoing hemorrhage involving a major vascular structure is present, additional surgical exposure maneuvers may be required, including the following:
    - Exposure and control of the supraceliac aorta at the diaphragm
    - Right-to-left medial visceral rotation (Cattell-Braasch maneuver)
    - Mobilization of the duodenum (Kocher maneuver)
    - Left-to-right medial visceral rotation (Mattox maneuver)
    - Control of the abdominal aorta at the root of the mesentery
    - Control in the chest via a resuscitative thoracotomy, as discussed in chapter 10
    - Temporary control might also be obtained in select cases using resuscitative endovascular balloon occlusion of the aorta (REBOA), as discussed in chapter 22.
- The decision to control the aorta at the hiatus or to perform a medial visceral rotation on either side should be based on the suspected injuries and which maneuver is most likely to allow adequate exposure for subsequent vascular control and repair.

Exposure and Proximal Control of the Aorta at the Diaphragm

CONSIDERATIONS

When hemorrhage or hematoma is present in the upper portion of Zone 1 (the central supramesocolic area), an injury to the aorta, celiac axis, superior mesenteric artery, or renal arteries may require proximal control of the supraceliac aorta at the diaphragm.

TECHNIQUE

- The liver is retracted to the right to expose the gastrohepatic ligament (lesser omentum), which is opened vertically (Figure 2). The distal esophagus and stomach are retracted to the patient's left.
- The aorta can be initially occluded by compression against the vertebral bodies using an assistant's fingers or an aortic occluder (a commercial device, a sponge stick, or a Richardson retractor).
- Definitive clamping of the supraceliac aorta first requires blunt dissection on either side of the aorta at the hiatus (Figures 3 and 4).

- The aorta below the diaphragm is invested in thick neurofibrous tissue, which makes application of a clamp difficult.
- Splitting or sharp division of the muscles of the right crus of the diaphragm (Figure 5) facilitates clamping of the aorta.
- The aorta is further dissected anteriorly and laterally to accommodate a vascular clamp. It is not necessary to encircle the aorta to place the clamp, as this may result in injury to posterior arterial branches.
- An atraumatic vascular clamp is placed on the aorta, using the spine and the paraspinal muscles as the posterior landmarks (Figures 6 and 7). The clamp must be placed securely, as it can easily be dislodged while working in the abdomen. It is often helpful to have an assistant hold the clamp in place.
- The clamp should be released as soon as more distal control of bleeding has been achieved.

HEAD TO TOP

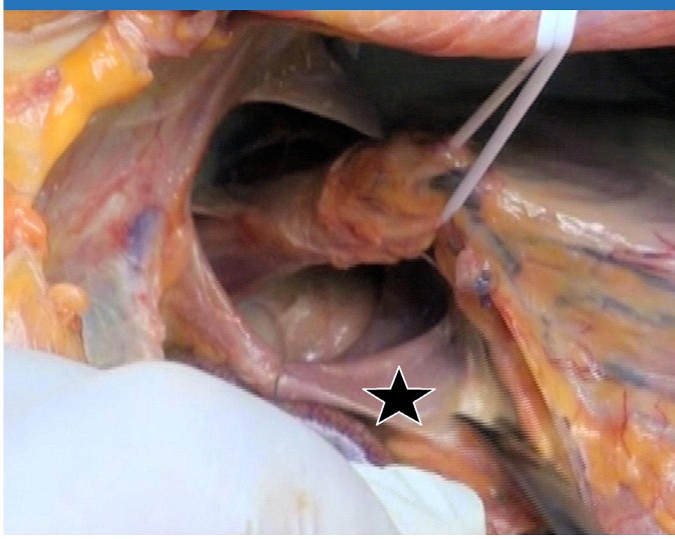


Figure 2. The lesser omentum is opened between the liver and esophagus (sling), exposing the right crus (star) of the diaphragm.

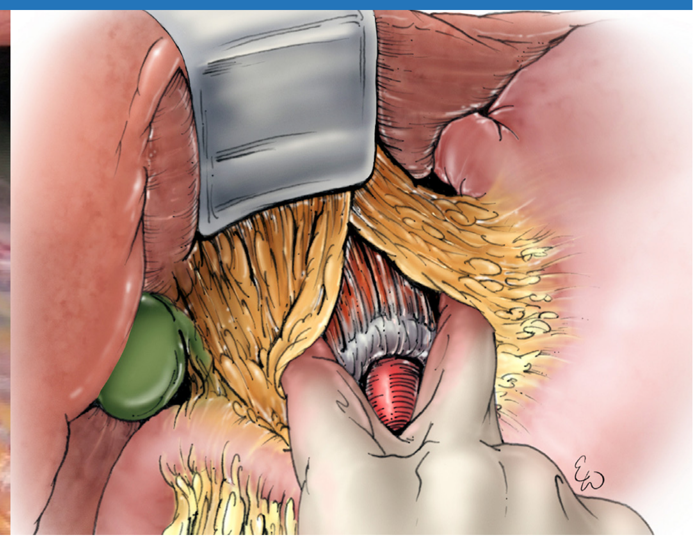


Figure 3. The lesser omentum is entered and then bluntly dissected to find the aorta.

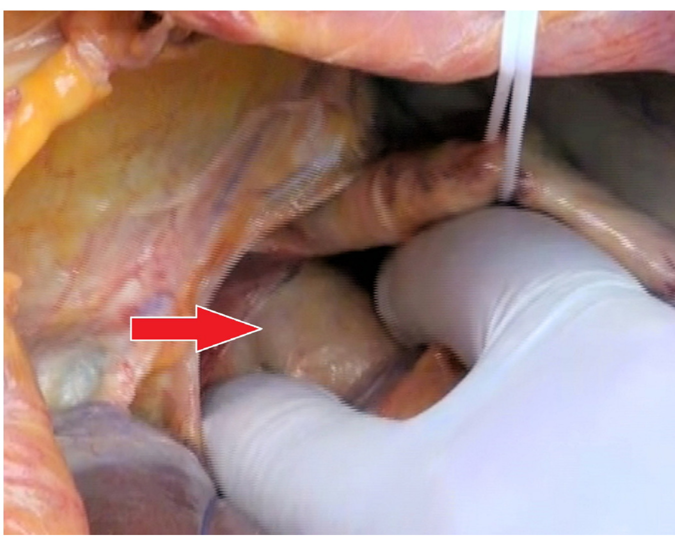


Figure 4. Fingers are used to bluntly dissect and sweep the loose tissue from around the aorta (arrow).

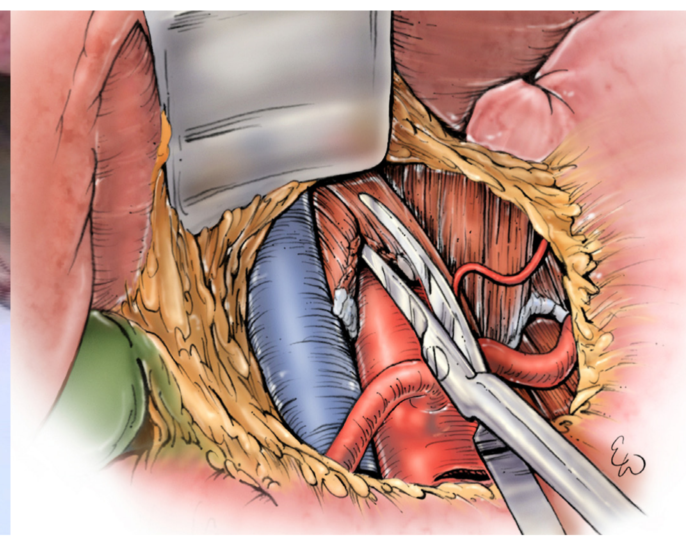


Figure 5. The right crus of the diaphragm is divided to facilitate exposure and control.

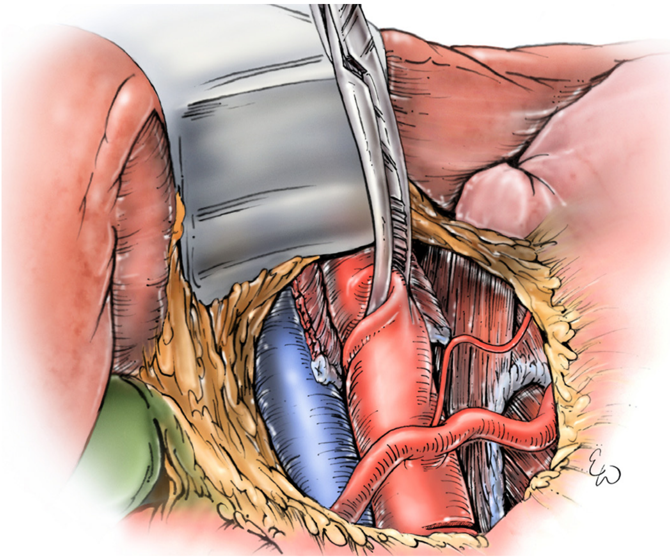


Figure 6. The aorta is clamped at the hiatus, using the paraspinal muscles and the vertebral bodies as the landmarks for the tips of the clamp.

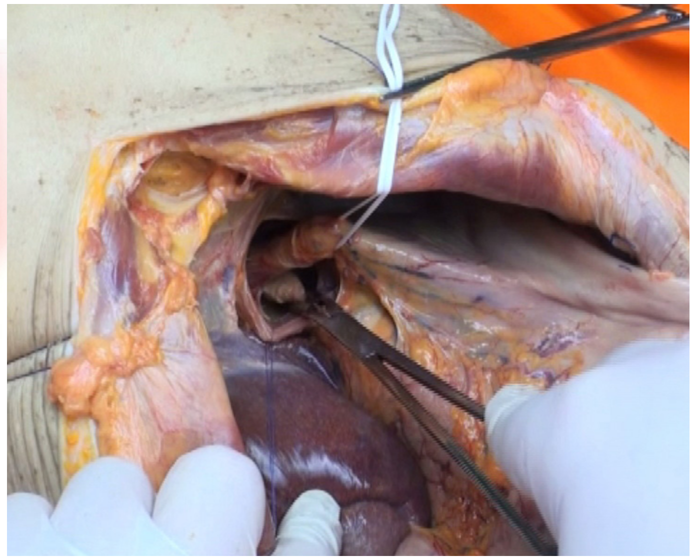


Figure 7. Clamping of the supraceliac aorta above the right crus of the diaphragm, as seen in this cadaveric specimen. The esophagus (sling) is retracted to the patient's left.

Right-to-Left Medial Visceral Rotation (Cattell-Braasch Maneuver)

CONSIDERATIONS

- Right-to-left medial visceral rotation provides excellent exposure of injuries to the structures of the right retroperitoneum, including the duodenum, head of the pancreas, right kidney and its vessels, ureter, inferior vena cava (IVC), and right iliac vessels.

TECHNIQUE

- The first step of right-to-left medial visceral rotation (Cattell-Braasch maneuver) is to incise the parietal peritoneum at the white line of Toldt, from the base of the cecum to the hepatic flexure (Figure 8). The dissection plane between the right colon and the abdominal wall is avascular and, once entered, can be extended rapidly with blunt dissection.
- If there is an IVC injury, performing a medial visceral rotation may unroof a contained hematoma with significant bleeding. One must plan for this possibility and be prepared to obtain rapid control of the IVC.
- The second step of the Cattell-Braasch maneuver is to mobilize the hepatic flexure of the colon and perform a Kocher maneuver to fully visualize the sweep of the duodenum and the head of the pancreas.
- The final step of the maneuver is to rotate the cecum and small bowel up and out of the pelvis in a right-to-left, inferior-to-superior fashion. Completion of the maneuver should enable the displacement of the patient's cecum to near the patient's left shoulder.
- The completed Cattell-Braasch maneuver (Figure 9) provides excellent visualization of the retroperitoneal structures in the right mid abdomen and pelvis.

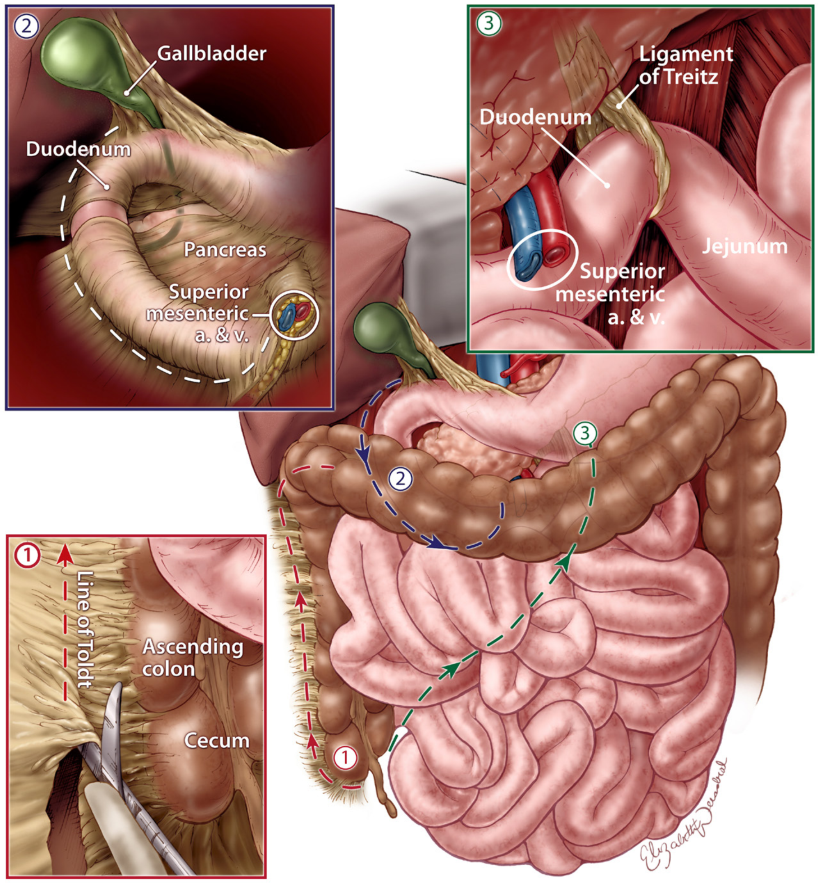


Figure 8. The Cattell-Braasch maneuver involves mobilization of the right colon (1), exposure of the duodenum and head of pancreas by an extended Kocher maneuver (2), and retraction of the colon and small bowel superior and medial (3) to provide wide exposure of the right-sided retroperitoneal structures.

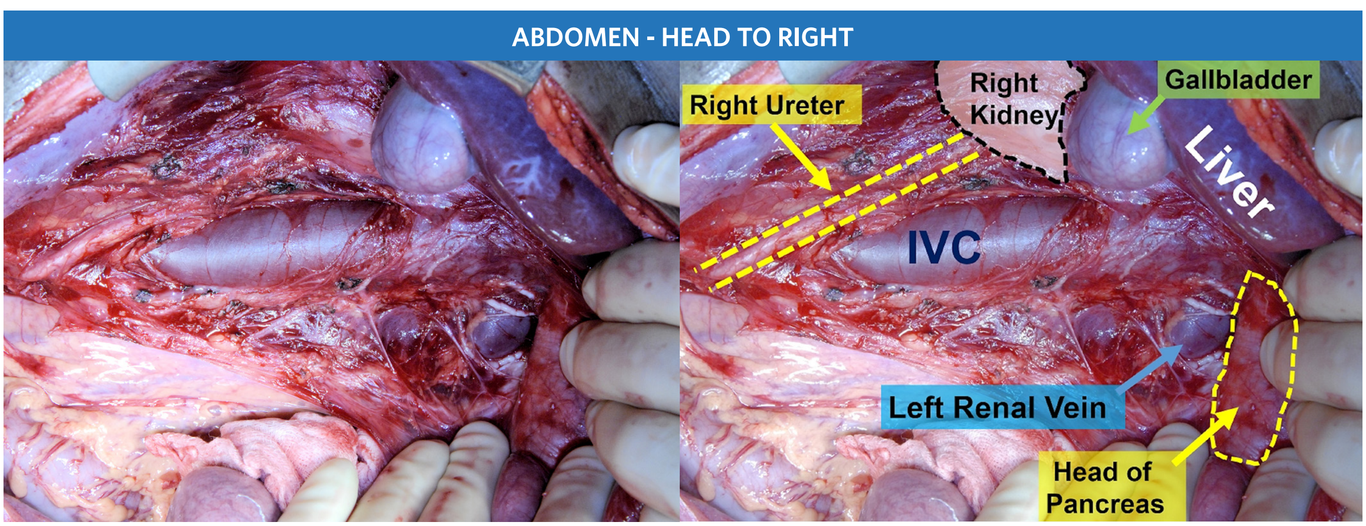


Figure 9. The completed right-to-left medial visceral rotation (Cattell-Braasch maneuver) provides excellent exposure of the head of the pancreas, the inferior vena cava (IVC), the right kidney and ureter, the renal veins, and the right iliac vessels into the pelvis.

Left-to-Right Medial Visceral Rotation (Mattox Maneuver)

CONSIDERATIONS

- The entire aorta, from the diaphragmatic hiatus to the iliac vessels, can be visualized using this maneuver.
- This maneuver is challenging in a cadaveric specimen due to the tissues being stiff and fused together. In living patients with an injury, the hematoma will do much of the dissection work (Figure 10).

TECHNIQUE

- The white line of Toldt, along the descending colon, is incised using either sharp or blunt dissection (Figure 11). In this bloodless plane, the entire left colon is mobilized and rotated up and out of the abdomen toward the midline.
- The spleen is also mobilized upward and medially, taking care to divide any lateral attachments such that the spleen and tail of the pancreas can be rotated up off the retroperitoneum. Care should be taken not to injure the spleen or the tail of the pancreas.

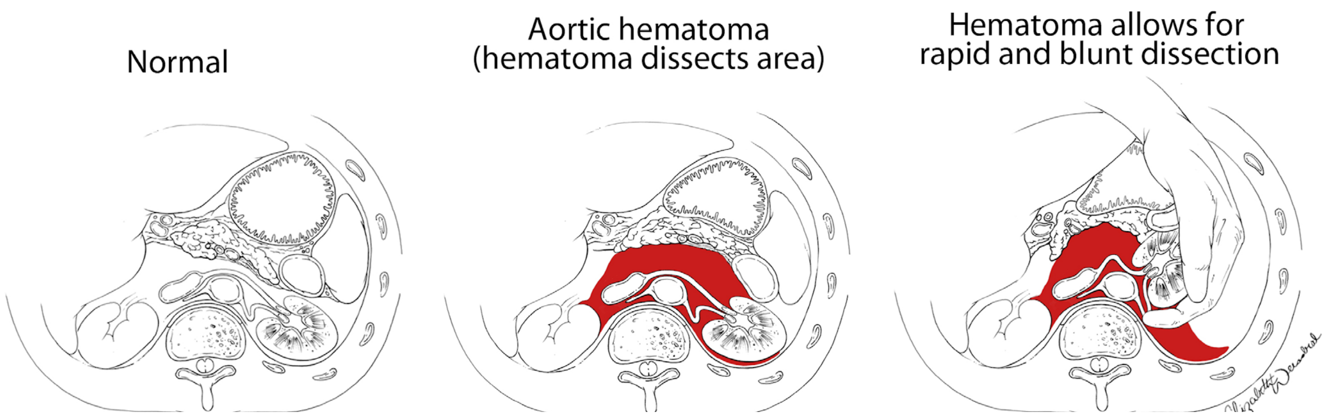


Figure 10. A Zone 1 injury to the abdominal aorta with hemorrhage will dissect many of the tissue planes, allowing for rapid blunt dissection using the left-to-right medial visceral rotation (Mattox) maneuver.

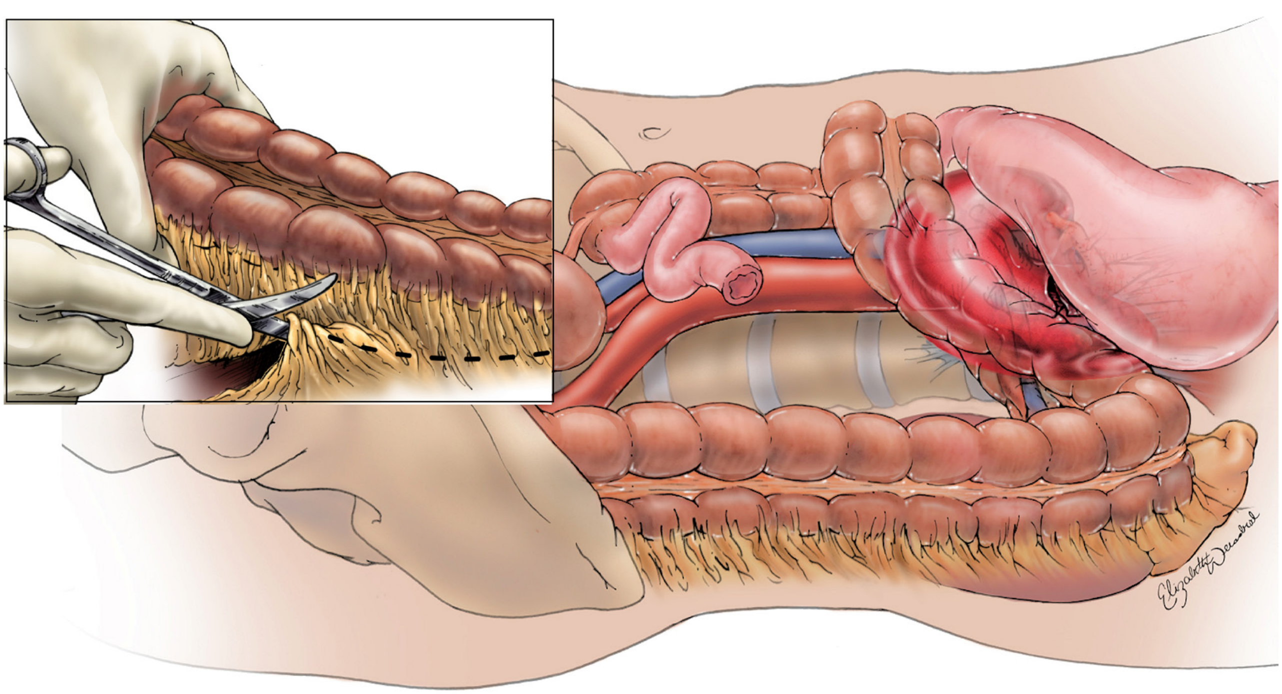


Figure 11. A Zone 1 injury to the abdominal aorta with hemorrhage will dissect many of the tissue planes, allowing for rapid blunt dissection using the left-to-right medial visceral rotation (Mattox) maneuver.

- The left colon, spleen, tail of the pancreas, and stomach are reflected medially, bringing the dissecting hand into a plane anterior to the left kidney.
- The "classic" Mattox maneuver includes mobilization of the left kidney (Figure 12) and is performed when there is an injury posterior to the kidney or to the aorta below the renal pedicle.
- More commonly performed is a modified Mattox maneuver in which the left kidney is not mobilized (Figure 13).
- The completed left-to-right medial visceral rotation (Mattox maneuver) provides exposure of the abdominal aorta from the diaphragm down, allowing access to the celiac trunk, the origin of the superior mesenteric artery, the origin of the inferior mesenteric artery, and the vascular pedicle of the left kidney (Figure 14).
- These anatomic relationships are better illustrated in Figure 15.

LEFT LATERAL ABDOMEN - HEAD TO RIGHT

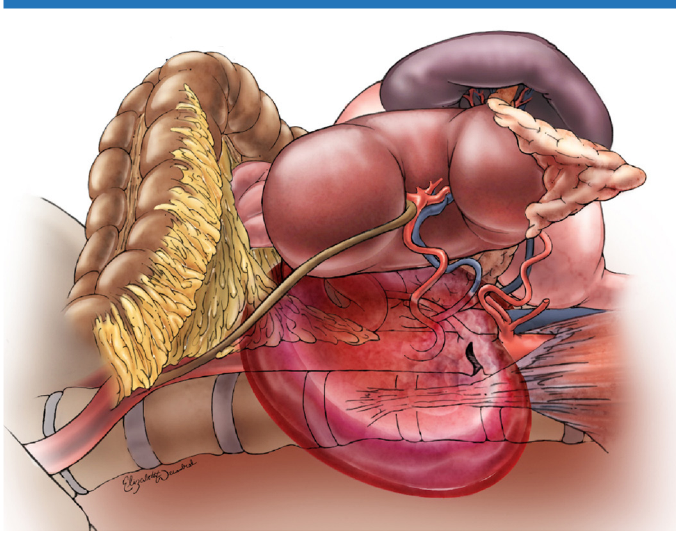


Figure 12. In the classic Mattox maneuver, the left kidney is rotated up with the left colon, spleen, and pancreas to expose the underlying hematoma.

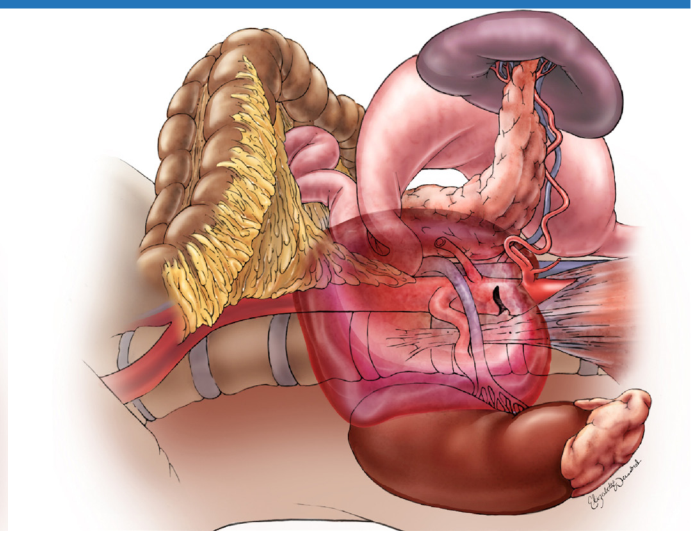


Figure 13. The left kidney is not mobilized with the modified Mattox maneuver. Most injuries can be exposed with this approach.

LEFT LATERAL ABDOMEN - HEAD TO RIGHT

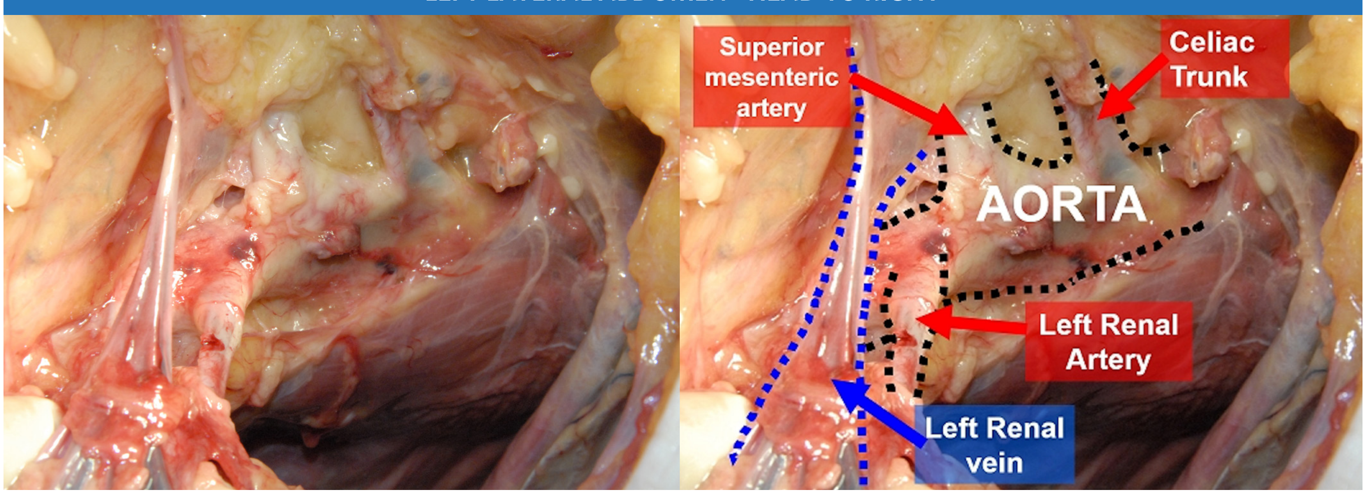


Figure 14. The completed left-to-right medial visceral rotation (modified Mattox maneuver shown here) provides exposure of the abdominal aorta from the diaphragm down, allowing access to the supraceliac aorta, the celiac trunk, the origin of the superior mesenteric artery, and the vascular pedicle of the left kidney.

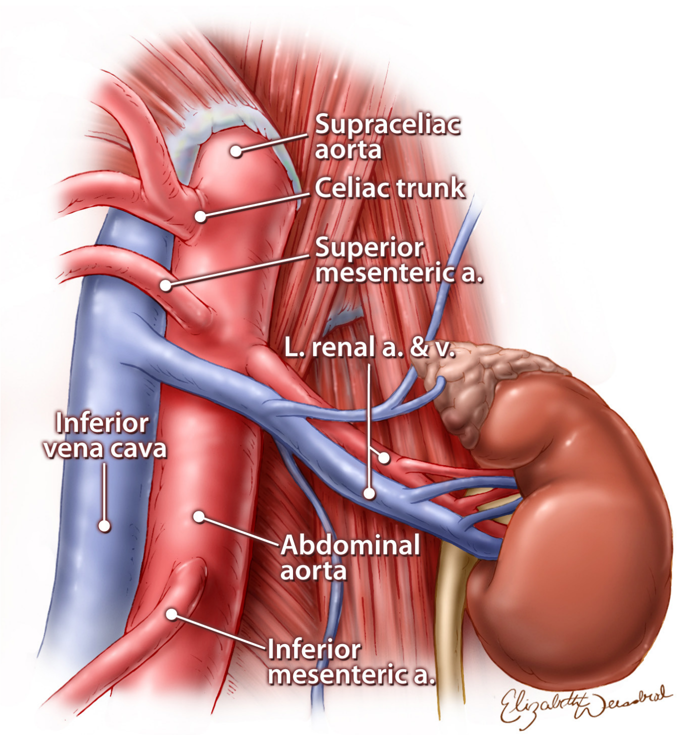


Figure 15. The aorta in the upper abdomen and its branches are well visualized with a completed left-to-right medial visceral rotation (modified Mattox maneuver depicted here).

Exposure and Control of the Infrarenal Aorta

CONSIDERATIONS

- When the hemorrhage or hematoma involves only the infrarenal aorta, an alternative to the Mattox maneuver is to directly expose and proximally control the aorta at the root of the mesentery, just below the renal vessels.

TECHNIQUE

- The small bowel is retracted superiorly to expose the root of the mesentery, and the peritoneum overlying the infrarenal aorta is opened (Figure 16).
- Further sharp and blunt dissection is used to identify the infrarenal aorta, which can be clamped to achieve proximal control (Figure 17).
- Distal vascular control is similarly achieved over the distal aorta or the iliac arteries, depending on the clinical situation, taking care to identify and avoid injury to the ureters (Figure 17).

ROOT OF THE MESENTERY, LOWER ABDOMEN - HEAD TO TOP

Figure 16. The small bowel and transverse colon are retracted superiorly to expose the root of the mesentery, and the peritoneum over the infrarenal aorta is opened.

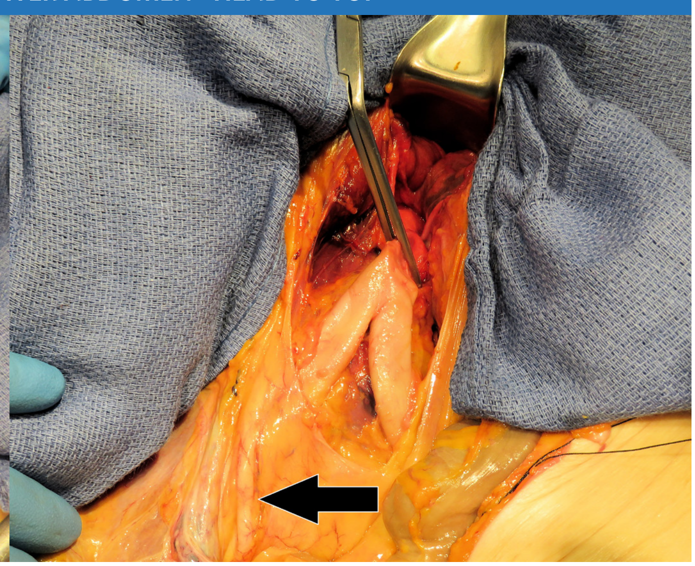
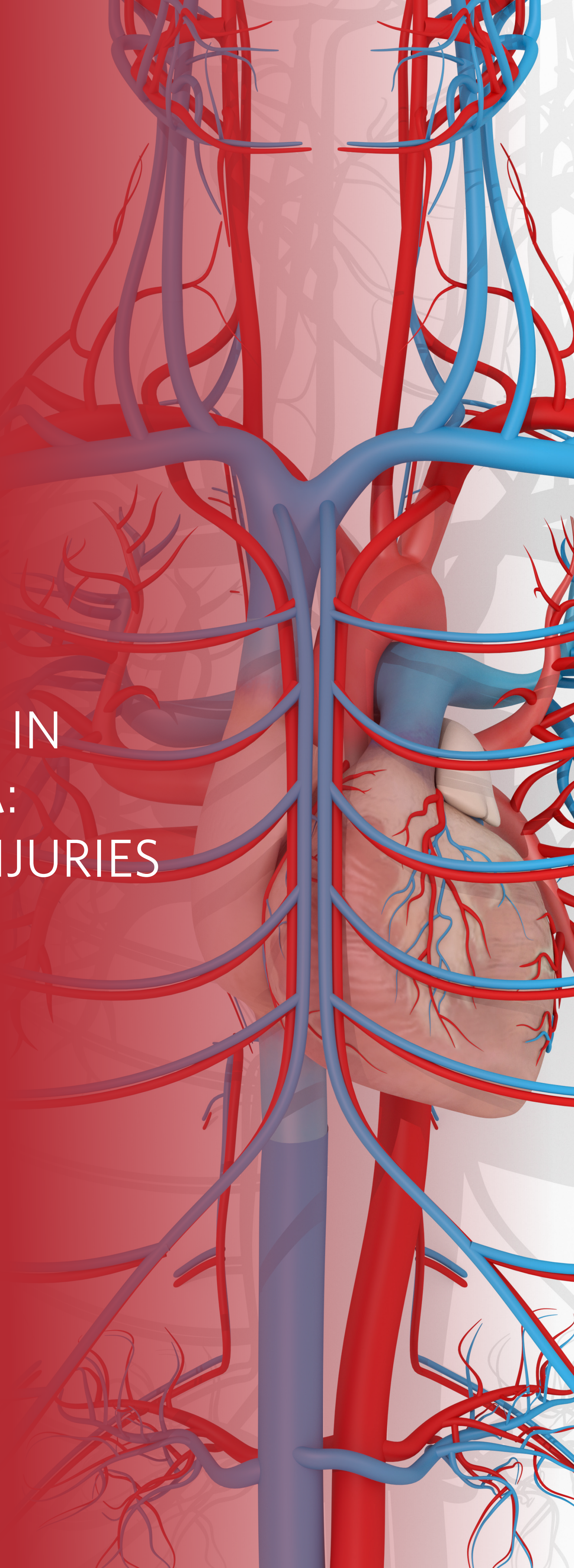


Figure 17. Further dissection exposes the infrarenal aorta, which can be clamped to provide proximal control. Distal dissection is undertaken as warranted, taking care to avoid injury to the ureters (arrow).

CHAPTER 16
OPERATIVE EXPOSURE IN ABDOMINAL TRAUMA: EXPOSURE OF LIVER INJURIES



Operative Exposure in Abdominal Trauma: Exposure of Liver Injuries

This chapter will discuss the anatomical techniques utilized to address injuries to the liver.

Learning Objectives

By the end of the ASSET course, participants should be able to do the following:

1. Describe the key anatomical features required to expose and manage trauma to the liver.
2. Describe the common patterns of liver injury resulting in life-threatening hemorrhage.
3. Describe techniques to control hemorrhage of the liver.
4. Describe a stepwise approach to management of major liver injury.
5. Demonstrate the Pringle maneuver.
6. Describe the finger-fracture technique.
7. Demonstrate the use of staplers in liver surgery.
8. Demonstrate the steps in surgical mobilization and exposure of the liver.
9. Demonstrate exposure of the hepatic veins.
10. Demonstrate exposure of the retrohepatic inferior vena cava (IVC).
11. Describe options for vascular isolation of the liver.

Considerations

- Hepatic injuries are common following both blunt and penetrating trauma.
- Most liver injuries do not require operative intervention.
- Morbidity and mortality from severe hepatic trauma is primarily related to hemorrhage from the juxtahepatic veins or, less frequently, the hepatic arteries.
    - The mortality for juxtahepatic venous injuries is reported to be between 50 and 80 percent.
    - Most deaths are caused by rapid intraoperative exsanguination, either due to failure to control initial hemorrhage or because of severe hemorrhage resulting from attempts to expose and directly control the injuries.
- Venous injuries make up the bulk of life-threatening hepatic hemorrhage. Understanding the most common patterns of these venous injuries and the underlying anatomy will help dictate the proper management.
    - The major pattern of life-threatening liver hemorrhage (Type A) is intraparenchymal disruption of the major hepatic or portal veins, associated with disruption of the liver parenchyma and capsule, with bleeding coming directly through the disrupted liver substance (Figure 1).
    - A less common pattern of liver injury (Type B) occurs with avulsion of the juxtahepatic vein(s), associated with disruption of the suspensory ligaments of the liver and resultant uncontained hemorrhage issuing from around (rather than through) the liver (Figure 2).
- Be certain to prep the patient from chin to knees in the event it is necessary to enter the chest or to gain access to the groin veins if a vascular conduit is needed.
- The initial approach to controlling hemorrhage from liver trauma is a midline incision, with a subcostal extension if necessary to gain better exposure. On rare occasions, a sternotomy or extension into the right chest may be required.
- The ultimate surgical goals of operative management of major liver injury are the following:
    - Control of hemorrhage
    - Control of bile leak
    - Debridement of devitalized liver
    - Drainage

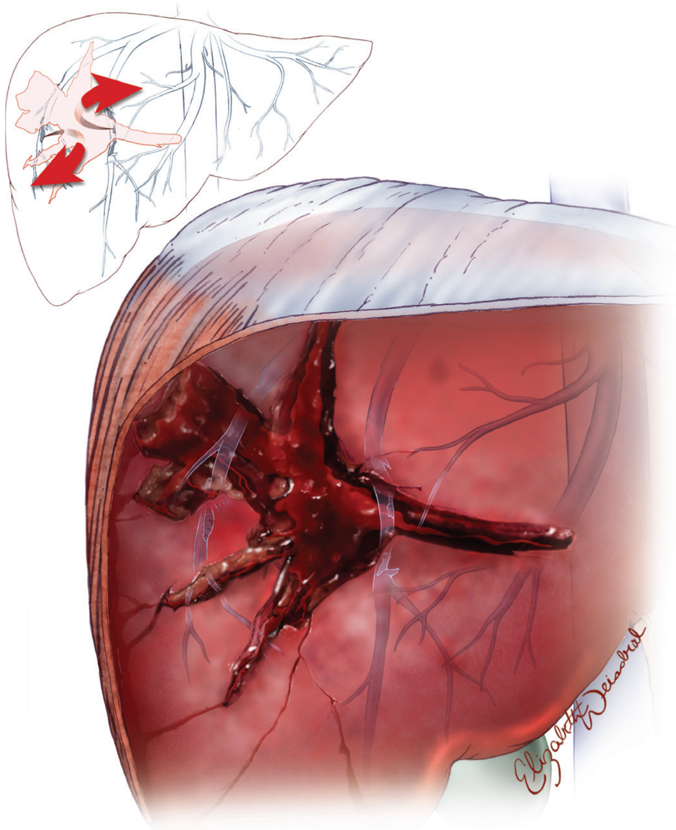


Figure 1. Type A juxtahepatic venous injury: injury to intraparenchymal portions of the hepatic vein(s), with bleeding coming directly through the disrupted surface of the liver.

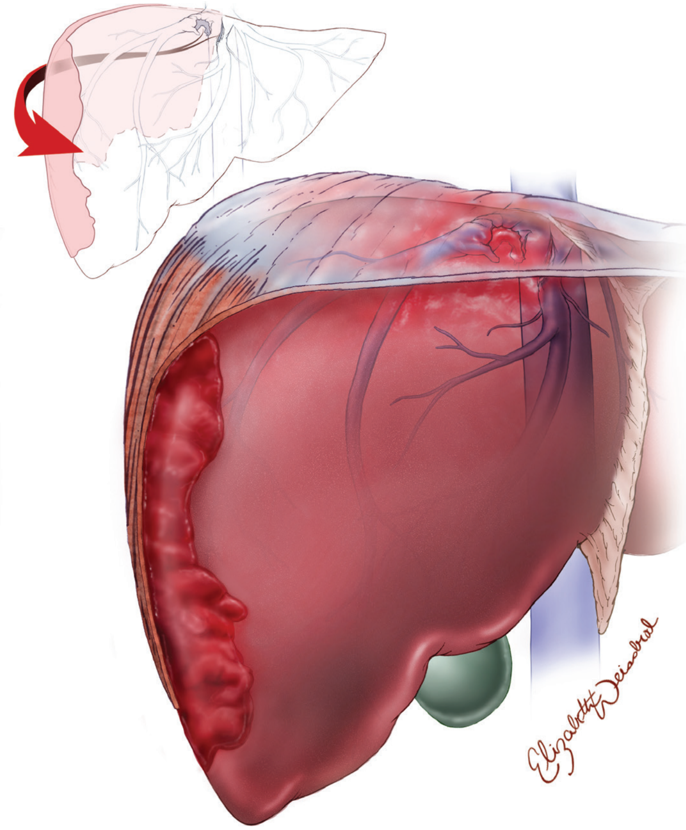


Figure 2. Type B juxtahepatic venous injury: injury to extraparenchymal hepatic vein(s), associated with disruption of the suspensory ligaments and resultant uncontained hemorrhage from around (rather than through) the liver.

- Attempts to evaluate the liver injury before adequate resuscitation may result in further blood loss and worsening hypotension.
- The first maneuver should be bimanual compression of the liver with one's hands (attempting to recreate the liver's normal three-dimensional shape) to slow bleeding, allow for temporary control of bleeding, and facilitate ongoing resuscitation.
- Perihepatic packing should be performed to return the liver to its normal three-dimensional shape. Do not pack within the liver parenchyma itself; this will divide the liver parenchyma further and may worsen bleeding.
- Be a minimalist. If packing stops the bleeding in an unstable patient, truncate the operation (damage control).
- If packing does not stop the bleeding, move to a Pringle maneuver (described later in this chapter).
- In a hemodynamically unstable patient who requires damage control for major liver injury, the primary operative goal is control of hemorrhage.
- If initial packing and the Pringle maneuver fail to control hemorrhage, mobilization of the liver, rapid exposure of the injury, and vascular control are paramount to a successful outcome.
- Angioembolization has a role in both pre- and postoperative management of hepatic trauma with hemorrhage.
- Aortic clamping is not necessary to control liver hemorrhage and may compound ischemic insult in a patient who is already decompensated.

Anatomical Considerations

- Understanding the relevant anatomy is vital to management of significant injuries to the liver.
- The retrohepatic vena cava is closely adherent to the back of the liver, lying entirely within the "bare area" of the liver (i.e., the portion lacking a capsule and completely circumscribed and contained by the hepatic suspensory ligaments).
- There is direct contact between the posterior aspect (caudate lobe) of the liver and the vena cava, and the liver parenchyma partially (approximately 90 percent) or completely (approximately 7 percent) encircles the retrohepatic vena cava, making exposure and repair challenging.
- The portal vein, which is formed by the merging of the superior mesenteric and splenic veins, supplies approximately 75 percent of the blood flow to the liver.
- The portal vein enters the liver through the porta hepatis, along with the hepatic artery and common hepatic duct, and divides into right and left branches that terminate in sinusoids. The blood from the sinusoids is collected by hepatic veins that empty into the vena cava (Figure 3).

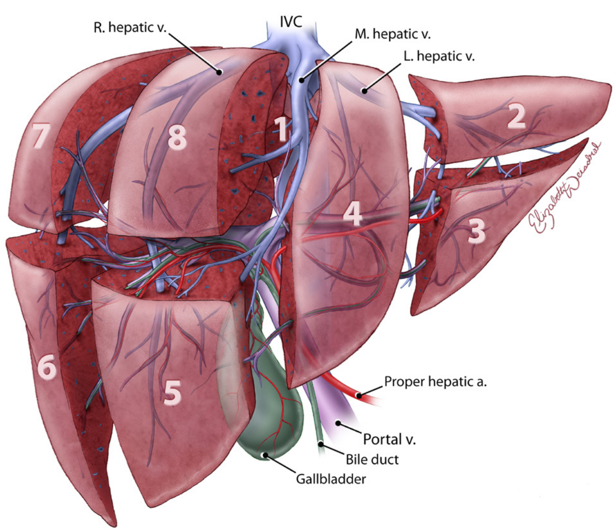


Figure 3. Anatomical and functional division of the liver into eight Couinaud segments, with the portal vein dividing the liver into upper (superior) and lower (inferior) segments. The middle hepatic vein divides the liver into right and left lobes. The right hepatic vein divides the right lobe into anterior (segments 5 and 8) and posterior (6 and 7) segments, and the falciform ligament divides the left lobe into medial (4) and lateral (2 and 3) segments.

- Venous drainage of the liver parenchyma occurs in an anterior-to-posterior and inferior-to-superior direction through the intrahepatic veins, which ultimately coalesce into three hepatic veins (right, middle, and left) that drain into the IVC superiorly (Figure 3).
- As described by Couinaud, the liver is divided into eight functionally independent segments. The center of each segment contains a branch of the portal vein, hepatic artery, and bile duct. Each segment has vascular outflow through the hepatic veins (Figure 3).
- The portal vein anatomically divides the liver into upper and lower segments (Figure 3).
- The middle hepatic vein divides the liver into right and left lobes, or hemi-livers (Figures 3 and 4). An external reference line—between the middle of the gallbladder fossa anteriorly to the IVC posteriorly (Cantlie's line)—is used to separate the right and left lobes, with the middle hepatic vein found at the base (Figures 4 and 17).

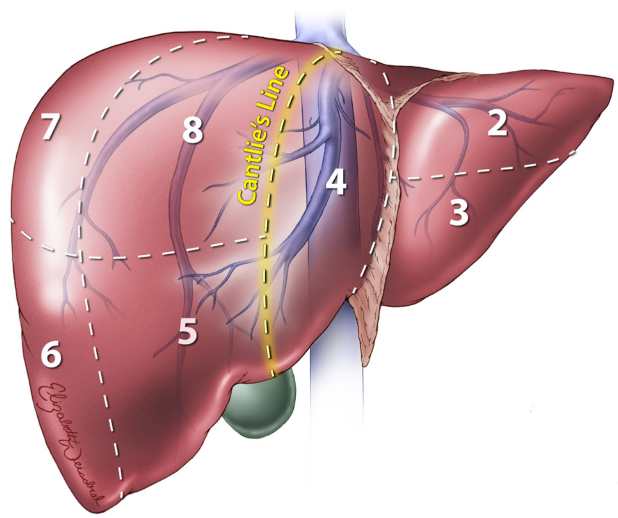


Figure 4. Cantlie's line, which runs from the middle of the gallbladder fossa anteriorly to the inferior vena cava (IVC) posteriorly, is an external reference point that anatomically separates the right and left lobes of the liver. When the liver parenchyma is opened along this line, the middle hepatic vein can be found at its base (See also Figure 17).

- The right hepatic vein divides the right lobe into anterior (segments 5 and 8) and posterior (6 and 7) segments (Figures 3 and 4).
- The falciform ligament divides the left lobe into a medial (segment 4) and lateral (2 and 3) segments. The left hepatic vein is also located in this divide (Figure 4).
- The hepatic veins are largely intraparenchymal, with the extraparenchymal portion being between 1 cm and 2 cm in length. In approximately 85 percent of cases, the left and middle hepatic veins fuse before emerging from the liver to form a single extraparenchymal trunk that enters the vena cava (Figures 3 and 4).
- The IVC joins the right atrium approximately 3 cm above the superior end of the retrohepatic section and can be exposed in the pericardial sac (Figure 5).

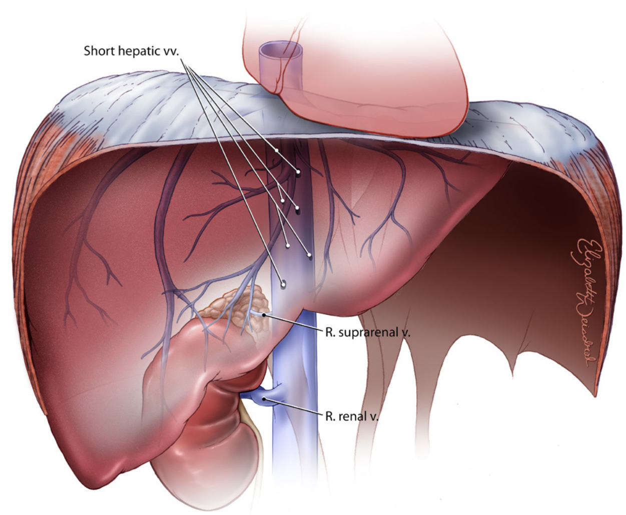


Figure 5. The retrohepatic IVC is closely approximated to the bare area of the liver and joins the right atrium approximately 3 cm above the diaphragm, within the pericardial sac. There are numerous short hepatic veins directly between the liver and the IVC.

- In addition to the main hepatic veins, there are several (an average of seven) short accessory hepatic veins directly between the liver and the IVC (Figures 5 and 6). These veins may be up to 1.5 cm in diameter and are short, thin, fragile, and prone to injury. As such, they can be a source of significant bleeding, either from the traumatic injury or from iatrogenic injury while mobilizing the liver.

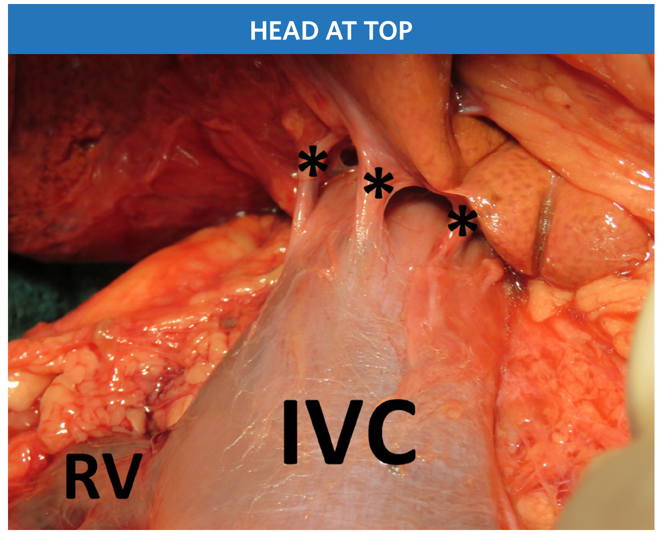


Figure 6. A view of the short hepatic veins (*), looking cephalad as the liver is mobilized from the inferior vena cava (IVC). The right renal vein (RV) is also seen in this picture.

- The suspensory ligaments of the liver include the falciform, coronary, and triangular ligaments (Figure 7). These ligaments tether the liver to the diaphragm and retroperitoneum and support the weight of the liver, preventing traction on the extraparenchymal hepatic veins. Additionally the ligaments contain the bare space of the liver, into which bleeding from the retrohepatic vena cava and extraparenchymal hepatic veins will flow.
- It is important to **not** mobilize the liver unless absolutely indicated, as this risks opening a contained hematoma with resultant massive hemorrhage.

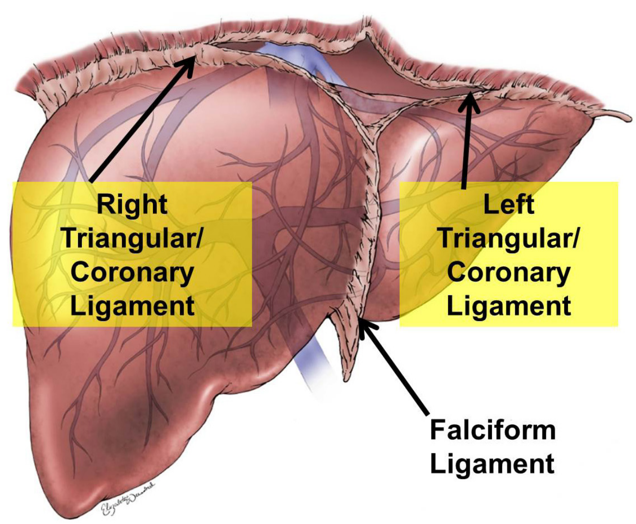


Figure 7. Suspensory ligaments of the liver.

Techniques

- Hemorrhage from the liver may be controlled with a variety of techniques, ranging from simple to complex:
  - Bimanual compression (restoring three-dimensional shape of liver)
  - Packing
  - Simple suture
  - Omental packing
  - Balloon tamponade
  - Pringle maneuver
  - Tractotomy with vascular and ductal ligation
  - Finger fracture
  - Division of liver parenchyma with a stapler
  - Hemostatic agents
  - Argon beam or electrocautery coagulation
  - Radiofrequency energy (Aquamantys)
  - Nonanatomic liver resection
  - Hepatic mobilization
  - Hepatic vascular isolation/bypass
  - Anatomic liver resection (rarely needed acutely; more common at a return to the operating room after damage control)

General Approach to Major Liver Injury

The approach to bleeding in major liver injury must follow an organized, systematic approach (Figure 8).

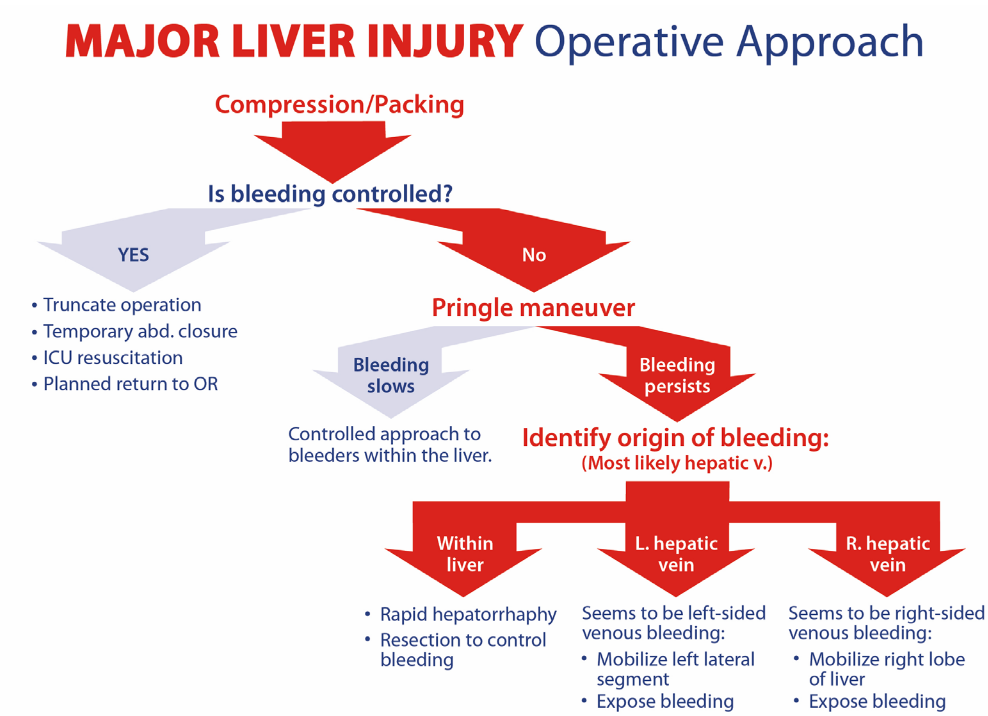


Figure 8. An algorithmic approach to the operative management of major liver injury.

Bimanual Compression and Packing

- **Bimanual liver compression:** The first maneuver when entering the abdomen for managing a major liver injury (while not knowing the precise location) is temporary control of the bleeding from the liver with bimanual compression. This will allow anesthesia some time to catch up on volume resuscitation in a hypotensive patient. Two concepts are critical in this maneuver:
    - First, compress the liver back to its normal three-dimensional shape using both hands. The right hand should grasp the left lateral segment, and the left hand should grasp the lateral right lobe. Then move the two hands toward each other, compressing the right and left hemi-livers back to restore normal anatomy (Figure 9).
    - Second, immediately after accomplishing the above, push the entire liver posteriorly and slightly cephalad. This maneuver will usually slow bleeding from the hepatic veins or retrohepatic IVC.
    - If the bleeding seems to be controlled with bimanual compression, this is a good indication that packing alone will be successful.

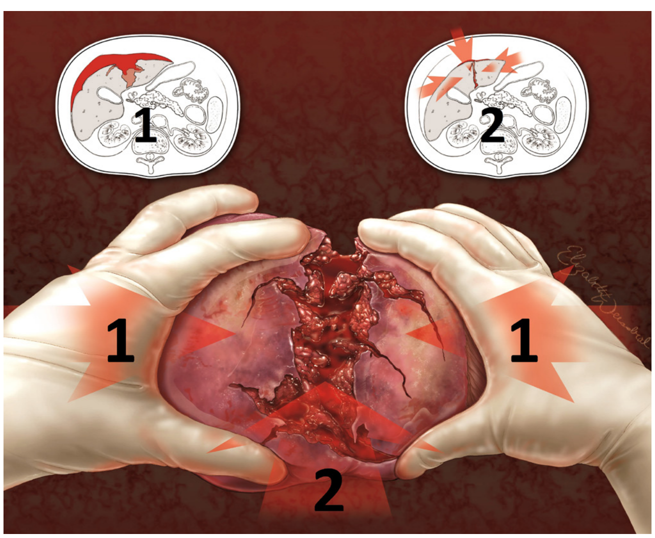


Figure 9. Bimanual compression of the liver can be achieved by pushing the liver parenchyma together to recreate the normal three-dimensional structure of the liver (1). Once the shape of the liver is restored, the entire liver is pushed posterior and slightly cephalad (2).

- **Perihepatic Packing:** Proper packing of the liver is a skill that all surgeons dealing with hepatic injury should master. The key to packing the liver is to recreate its three-dimensional anatomy using packs above, below, and to the sides. The packs are placed between the liver and the diaphragm, abdominal sidewall, and infrahepatic structures (Figure 10). Packing is about the quality, **not** the quantity.
- If bleeding stops after packing, it is best to leave the packs in place without further manipulation. Avoid the temptation to remove the packs once placed.
- Packs may be left in place while performing a damage control laparotomy or if the patient is to undergo angiographic evaluation and embolization of the liver to control hemorrhage or embolize pseudoaneurysms.
- It should be noted that packing too tightly may compress the IVC, impeding venous return.
- At subsequent operation, the packs can be carefully removed, allowing for localization and control of any residual bleeding.

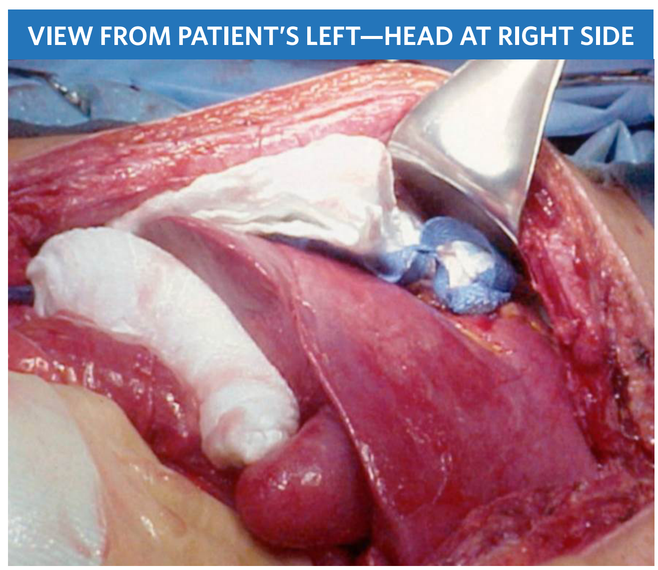


Figure 10. Packs are placed above and below the liver to recreate its normal three-dimensional shape and anatomy. Do not put packs within the liver injury.

Simple Suture of Liver Lacerations

- Most minor and many moderate liver lacerations can be treated with simple suturing. Some authors recommend using a large, blunt needle and taking large bites of the hepatic capsule and parenchyma using a mattress technique.
- While oversewing the bleeding liver with a large needle may at times be lifesaving, this technique may also leave untreated a major injury deeper within the liver parenchyma. This will ultimately cause a problem, and as such oversewing should rarely be considered in the case of major liver lacerations.

Hemostasis Using Topical Hemostatic Agents and Omental Pack

- Hemostasis can be accomplished in less severely injured livers using a variety of techniques.
- Topical hemostatic agents may be placed or sprayed on the exposed, raw hepatic parenchyma to assist with maintenance of hemostasis.
- Once surgical hemostasis has been achieved, a "tongue" of vascularized omentum may be mobilized and placed in the parenchymal wound, as shown in Figure 11.
- Large liver sutures (0-chromic sutures on blunt liver needles) may be placed to keep the omentum in place and to close dead space.

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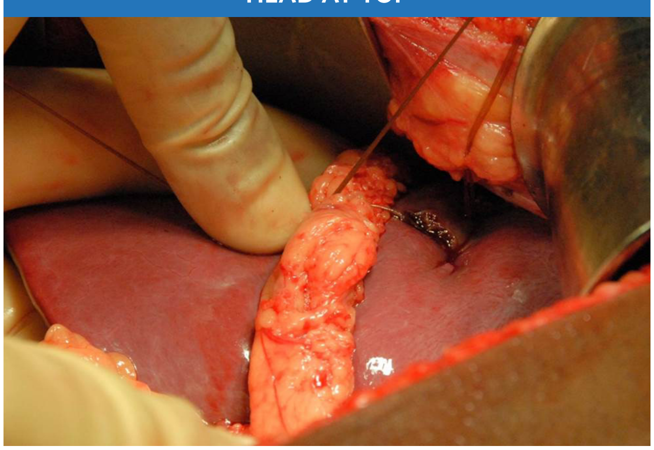

Figure 11. A "tongue" of omentum may be placed into a deep liver laceration after surgical hemostasis and secured in place with suture using a large, blunt needle (as shown here).

Balloon Tamponade of Through-and-Through Liver Injury

- Through-and-through penetrating injuries to the substance of the liver can occasionally be controlled with balloon tamponade, using a commercial device such as the esophageal portion of a Sengstaken–Blakemore tube, a Foley catheter with a 30 cc balloon, or a homemade device in which a red rubber catheter is placed inside a Penrose drain and inflated with saline (Figure 12).
- The balloon is essentially "packing" the liver from the inside of the injury tract, and subsequent removal of the device after the patient has been resuscitated can be accomplished similar to removal of perihepatic packs.
- If the balloon is deflated and bleeding continues, reinflate the balloon and send the patient for angioembolization.

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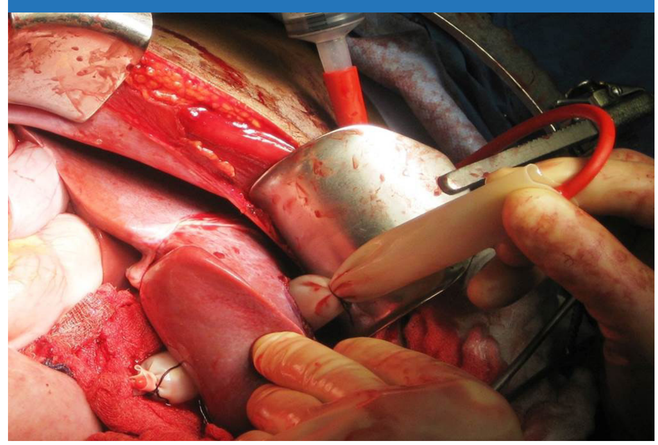

Figure 12. A balloon tamponade device constructed from a red rubber catheter inside a Penrose drain and filled with saline is used to control this through-and-through penetrating injury to the liver.

Pringle Maneuver to Control Hemorrhage

CONSIDERATIONS

- The Pringle maneuver should be considered as an early step in vascular control of an injured and massively bleeding liver (after bimanual compression and packing).
- Digital occlusion or clamping of the portal vein and hepatic artery during the Pringle maneuver interrupts the blood flow in these vessels.
- The Pringle maneuver is both diagnostic and therapeutic. If the bleeding slows, the injury is either to the hepatic artery or portal vein branches. Bleeding from these vascular structures should then be approached directly within the liver and oversewn. If the bleeding persists, you have confirmed the hepatic veins or retrohepatic IVC (or more rarely, aberrant arterial anatomy, as described below) as the source of ongoing blood loss.

TECHNIQUE

- The index finger is inserted into the inferior aspect of the foramen of Winslow, and when the thumb is pinched on top of the index finger, the structures of the portal triad are effectively controlled (Figure 13). A vascular clamp or vessel loop may be used to replace the fingers if longer-term control is needed.
- The safe duration of portal triad occlusion using the Pringle maneuver in a hypotensive trauma patient is not known. If possible, the clamp should be intermittently released to limit total warm ischemia time.
- The Pringle maneuver will be ineffective in patients with a replaced left hepatic artery, which typically arises from the left gastric artery.

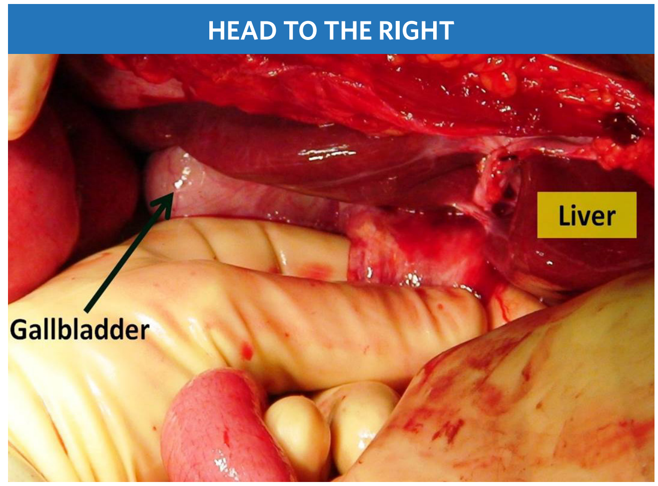

Figure 13. The Pringle maneuver is accomplished through the foramen of Winslow by pinching the portal triad between the thumb and index finger, which occludes the portal vein, hepatic artery, and common bile duct.

Direct Surgical Control of Parenchymal Injuries

TECHNIQUE

- At times, injuries in the liver must be enlarged to adequately expose and oversew bleeding vessels. With these deeper penetrating or blunt injuries, the finger-fracture technique (Figure 14) may be used to identify deep bleeding vessels, which can then be controlled with surgical clips or ties (Figure 15).
- The finger-fracture technique is a method of intrahepatic digital dissection in which the capsule of the liver is incised and a thumb and forefinger are used to gently “tear” through the liver tissue by gently squeezing and rubbing the fingers together; this exposes the intrahepatic vessels and ducts (Figure 15) so that they can be clamped and then ligated or clipped.
- Exposure of the parenchymal injury allows suturing of exposed vascular and ductal structures, as well as direct application of surgical clips, staplers, and/or tissue coagulation with Bovie cautery, argon beam coagulation, or an Aquamantys device.

RIGHT LOBE OF LIVER - HEAD TO LEFT

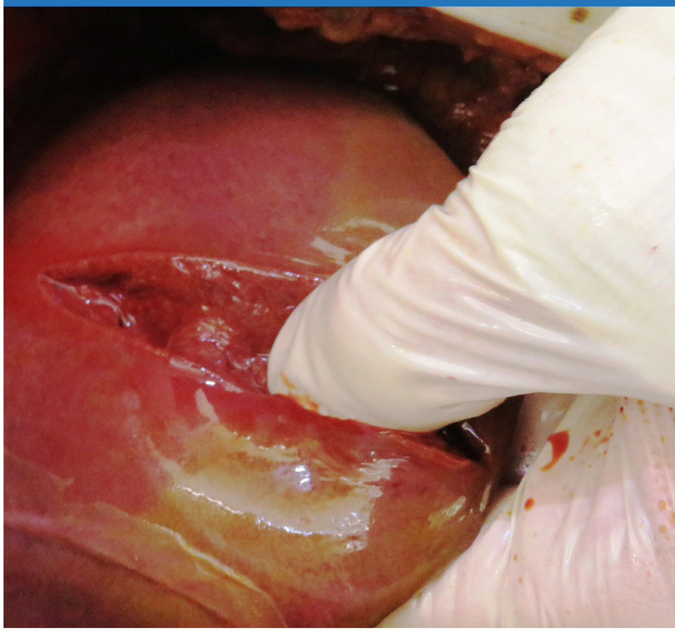

Figure 14. In the finger-fracture technique to identify deep parenchymal injuries, the thumb and forefinger are used to gently separate the liver tissue from the underlying vessels and ducts.

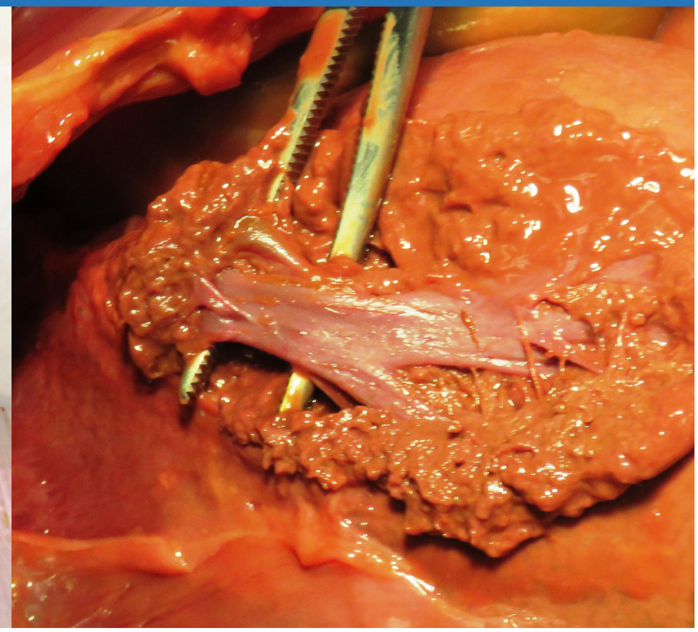

Figure 15. Underlying vessels and ducts exposed using the finger-fracture technique can then be clamped, clipped, or oversewn.

- Alternatively, a stapler with a vascular load may be used to divide the liver parenchyma (Figure 16).
- A blunt-ended clamp may be passed into the liver along the intended transection plane and used as a guide before placing the blades of the stapler.
- A stapler may be used to rapidly expose injury to the central liver, with exposure of the middle hepatic vein accomplished by firing the stapler along Cantlie's line (Figure 17).
- The stapler may also be used to perform a nonanatomic resection.
- If there is still significant bleeding after the aforementioned maneuvers, there is likely an injury to one of the other hepatic veins or the retrohepatic vena cava, and the liver will need to be fully mobilized with control of the IVC above and below the liver.

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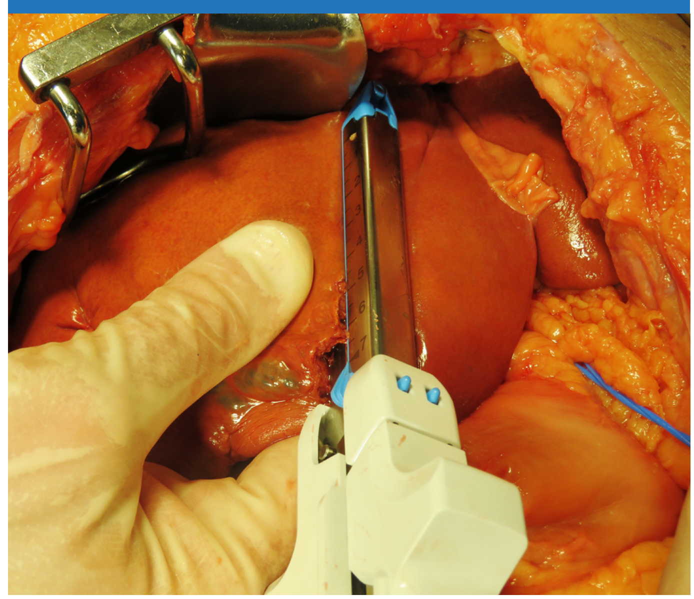

Figure 16. A stapler may be used to rapidly divide or resect the liver.

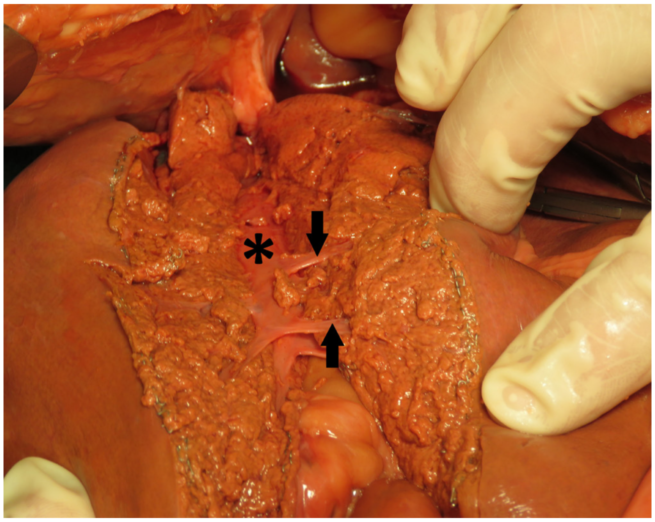

Figure 17. The middle hepatic vein is often a source of major hemorrhage with complex liver injury. Using a stapler (Figure 16), the liver has been bisected down Cantlie's line to demonstrate the entire course of the middle hepatic vein (*) and its branches (arrows).

Surgical Mobilization and Exposure of the Liver

CONSIDERATIONS

- The decision to mobilize the liver should be made only after careful consideration of the consequences. Injuries to the retrohepatic vena cava and the hepatic veins may be contained by the liver and its attachments. Mobilization of the liver in these circumstances may convert a controlled situation into one of uncontrolled hemorrhage, with potentially dire consequences.

TECHNIQUE

- Self-retaining retractors are essential for management of major liver injury. The goal is to lift the subcostal margins both cephalad and anteriorly (away from the table).
- For severe right lobe injury or retrohepatic injury, a right subcostal extension off the midline incision may facilitate exposure and access.
- Mobilization of the liver requires bringing it to the midline. This requires division of the hepatic ligaments.
- The liver is retracted caudally and medially to divide and ligate the falciform ligament (Figure 18).
- Further mobilization of the liver requires division of the right coronary and triangular ligaments (Figures 19 and 20) to expose the bare area of the liver and allow rotation of the right lobe of the liver toward the midline (Figures 20 and 21). Avoid damaging the diaphragm as you perform this mobilization.

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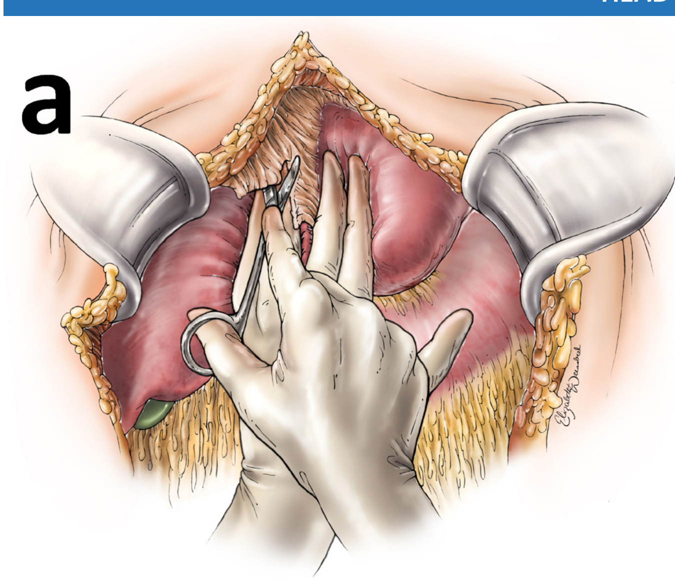

Figure 18a. Mobilization of the liver requires division of the falciform ligament.

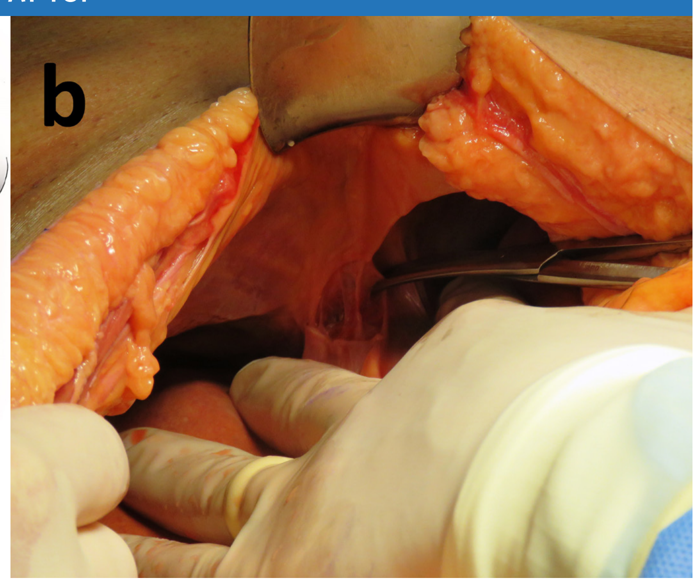

Figure 18b. Dissection of the leaflets of the falciform ligament is continued posteriorly, being careful to avoid injury to the major hepatic veins.

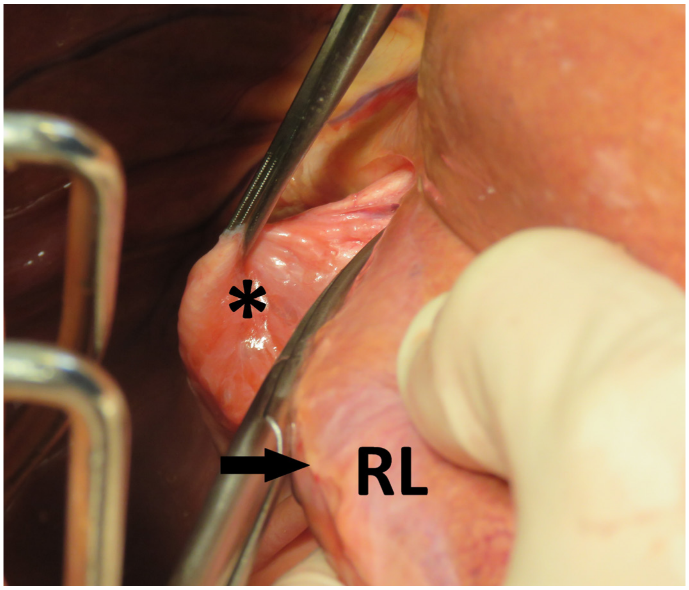

Figure 19. The right lobe (RL) of the liver is mobilized by taking down the right triangular ligament (arrow) from the diaphragm (*), being careful to avoid injury.

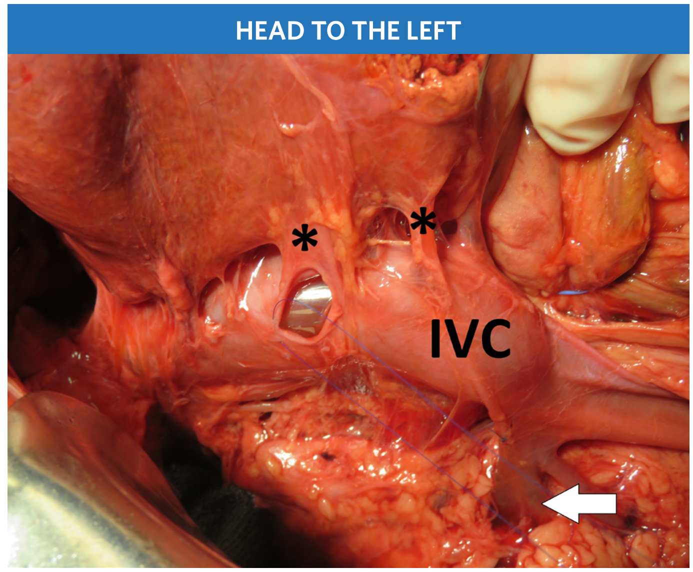

Figure 21. The right lobe of the liver has been mobilized medially, revealing the inferior vena cava (IVC), the short hepatic veins (*), and the right renal vein (arrow). A percutaneous venous balloon (a Spectranetics Bridge™ Occlusion Balloon is used in this case) is occluding the IVC, allowing for repair of a partial avulsion injury to a large short hepatic vein.

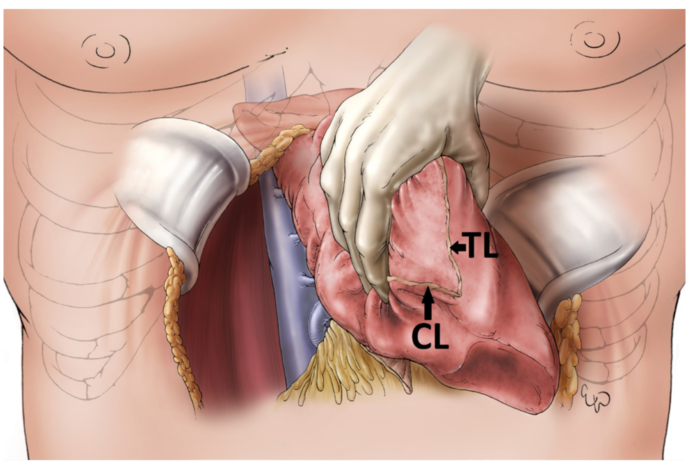

Figure 20. The right lobe of the liver has been further mobilized medially by taking down the right triangular (TL) and coronary (CL) ligaments to expose the IVC and the short hepatic veins.

- The left lobe of the liver can be mobilized by taking down the left triangular, falciform, and the left coronary ligaments.
- Division of the hepatoduodenal and gastrohepatic ligaments will give access to the lesser sac, the portal vein, the medial aspect of the IVC, and the caudate lobe of the liver, if required (Figure 22).

POSSIBLE PITFALLS OF LIVER MOBILIZATION

- Mobilization of the liver must be performed with care, as the retrohepatic vascular structures are more anterior than one might expect and can be easily injured by traction or errant dissection.
- Success in controlling suspected retrohepatic caval bleeding with initial packing should preclude liver mobilization in the acute setting. If the liver is mobilized in this setting, uncontrolled bleeding may be unleashed, requiring the much more drastic (and often lethal) maneuvers described in this chapter.

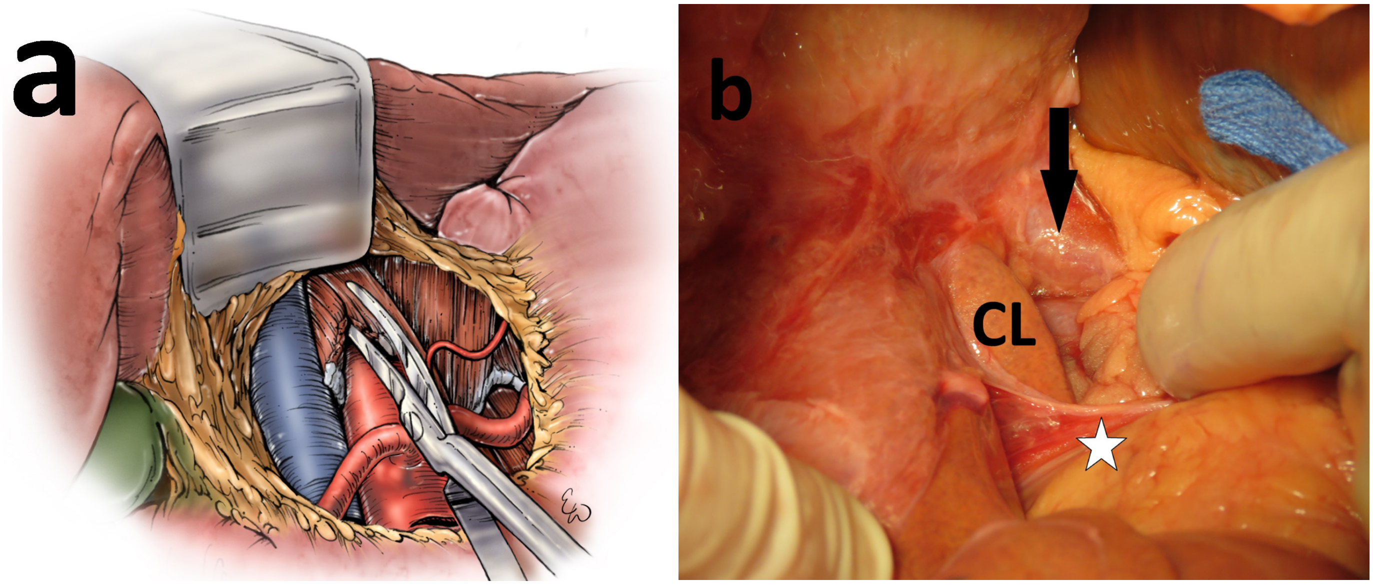

Figure 22. Taking down the ligament (star) allows entry into the gastrohepatic space for identification of the diaphragmatic crus (arrow) and the caudate lobe (CL) of the liver, as well as exposure of the medial aspect of the IVC.

- Major liver injuries are usually accompanied by significant bleeding, making repairs technically challenging.
- Complete knowledge of hepatic anatomy and maneuvers to rapidly obtain exposure—and the confidence to do so—are essential for salvage of patients with juxtahepatic venous injury.
- Hemorrhage control of complex injuries may require hepatic isolation with proximal control of the suprahepatic IVC, distal control of the infrahepatic IVC, and the Pringle maneuver.
- The most commonly used technique for hepatic vascular isolation is the Heaney maneuver (described below).
- On rare occasions and if available, venovenous bypass may be needed if the patient does not tolerate hepatic vascular isolation. In select centers, this has been used as an adjunct to primary injury repair or as a bridge to potential liver transplant.
- Other described hepatic vascular isolation techniques, such as the atrial caval (Schrock) shunt, have had few reported survivors and are mostly of historic interest only.

The Heaney Maneuver

- This maneuver of hepatic vascular isolation involves clamping the suprahepatic and infrahepatic IVC in addition to application of the Pringle maneuver. This technique results in severe acute decrease in venous return to the heart, with sudden cardiac arrest as a possible outcome. Attention to aggressive volume infusion, including the use of large-bore infusion catheters into the large veins of the neck, should be considered to preserve venous return and maintain cardiac output.
- The original Heaney maneuver described opening the pericardium from the abdomen, as one would do for a pericardial window, and controlling the suprahepatic IVC within the pericardial sac (Figure 23).
- In the majority of cases, the suprahepatic IVC can usually be clamped in the abdomen, between the diaphragm and the top of the liver, by mobilizing and retracting the liver caudally and anteriorly.

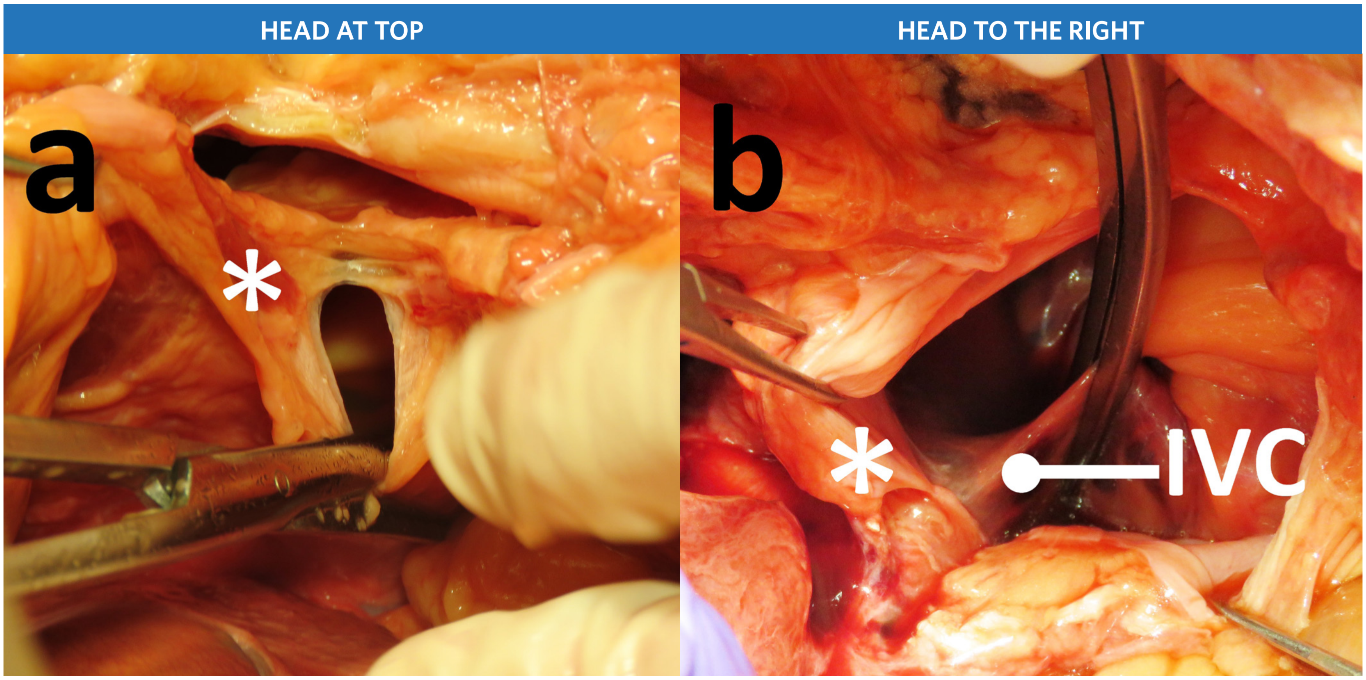

Figure 23. The pericardium is opened from the abdominal side just to the right of central diaphragm (a) to expose and control the suprahepatic IVC in the pericardial sac (b).

- Suprahepatic intra-abdominal control of the IVC requires mobilization of the suspensory ligaments of the liver and entry into the gastrohepatic ligament, as previously described, in order to expose the segment of IVC above the top of the liver and below the diaphragm for control (Figure 24).
- Aggressive dissection of the suprahepatic IVC should be avoided, with just enough dissection to enable placement of an occluding clamp (Figure 25).
- Control of the infrahepatic IVC may be challenging, particularly if active hemorrhage is ongoing.
- The segment of the IVC below the liver edge and cephalad to the renal veins can be quite short, and the renal veins may be injured if one fails to recognize this anatomy (Figure 26).
- The hepatoduodenal window is opened and the lower portion of the liver is retracted up off the IVC in a cephalad direction to allow for visualization of and clamping of the infrahepatic IVC between the lower surface of the liver and the renal veins. With the clamp angled in a cephalad direction to avoid injury to the renal veins the vein is carefully closed (Figure 27).

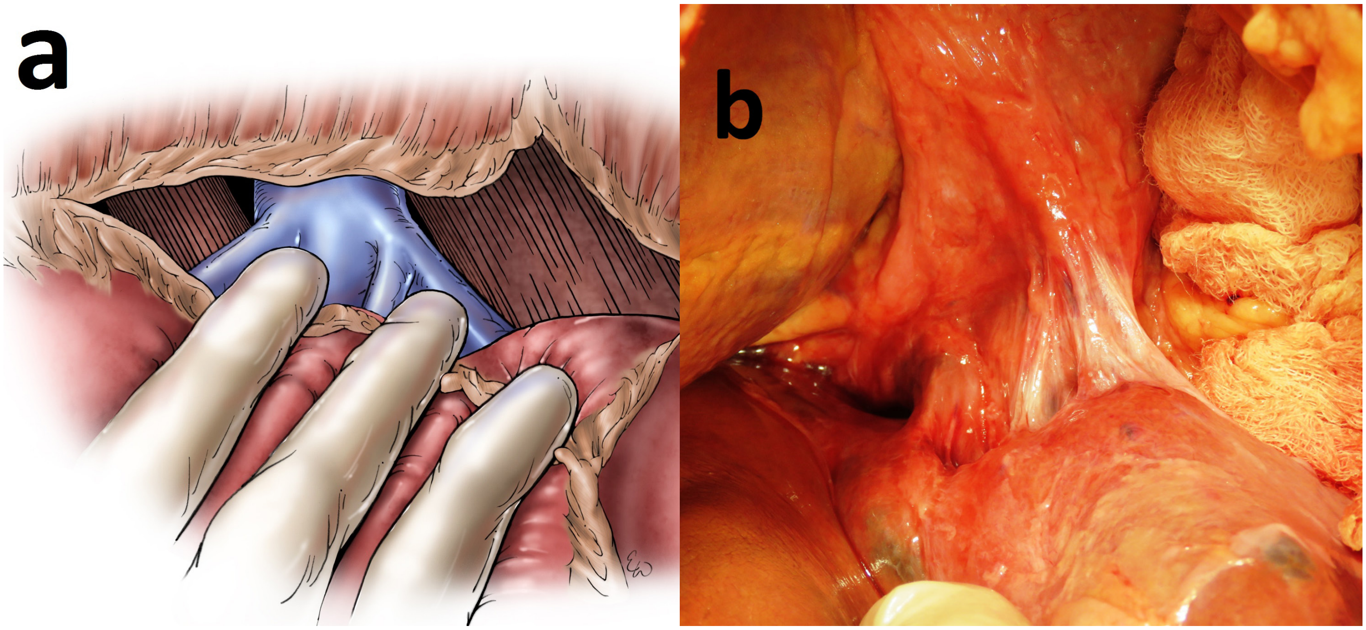

Figure 24. Exposure of the suprahepatic IVC below the diaphragm is accomplished with mobilization of the suspensory ligaments. This allows a careful dissection of the IVC between the liver and diaphragm.

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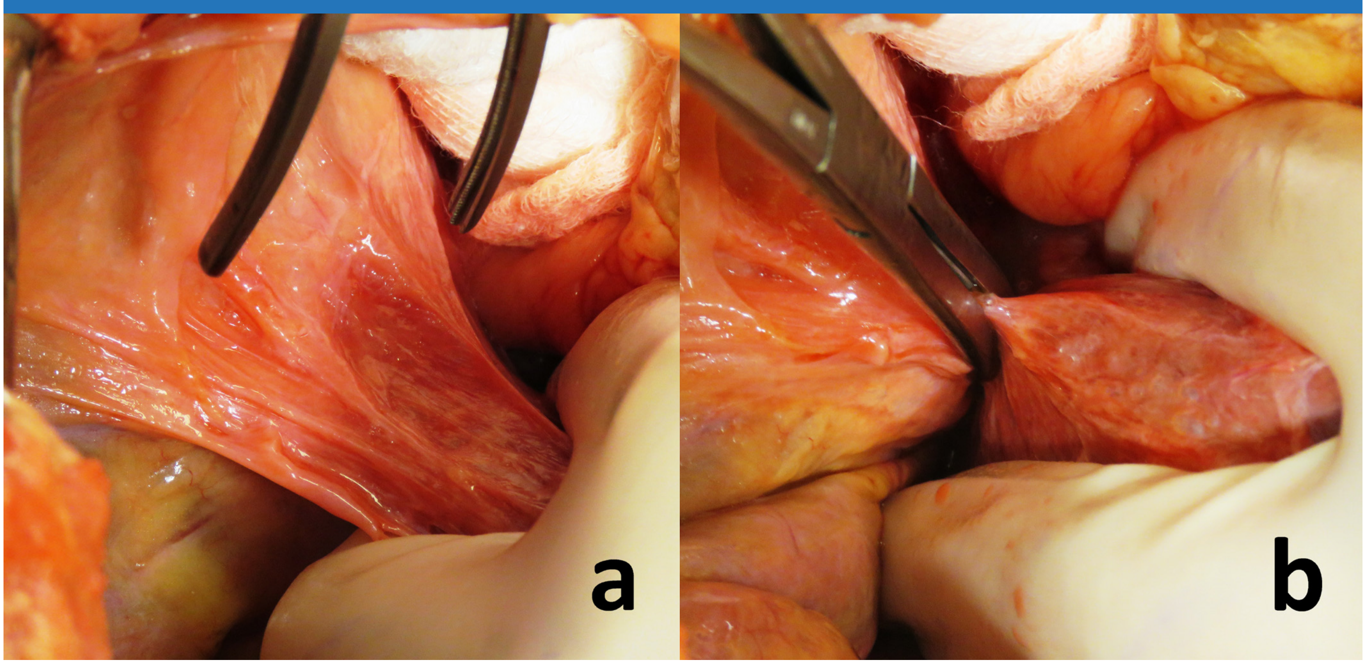


Figure 25. The liver is retracted caudally and anteriorly, with the suprahepatic IVC grasped between fingers such that a vascular clamp, which is directed posteriorly until both jaws touch the spine, can be used to gain occlusion.

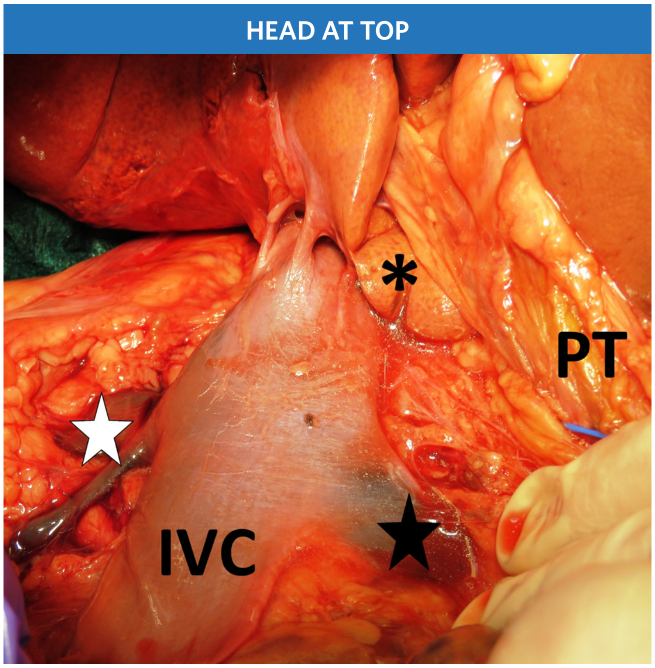


Figure 26. The liver is elevated cephalad, and the hepatoduodenal window is dissected. Sweeping the duodenum medially allows for visualization of the short segment of the infrahepatic IVC between the caudate lobe (*) of the liver, the right (white star) and left (black star) renal veins, and the nearby portal triad (PT).

Alternative Technique: Hepatic Venovenous Bypass

- Venovenous bypass involves returning blood from the lower body to the heart.
- This technique is unlikely to be used outside of specialized centers, as it requires the time, pump, and technician to set up the bypass following vascular isolation.
- On occasion, if the patient is hemodynamically stable enough and a very complex liver or retrohepatic injury is documented by computed tomography, placement of shunts for venovenous bypass and readiness of the team prior to entering the abdomen may be advisable.

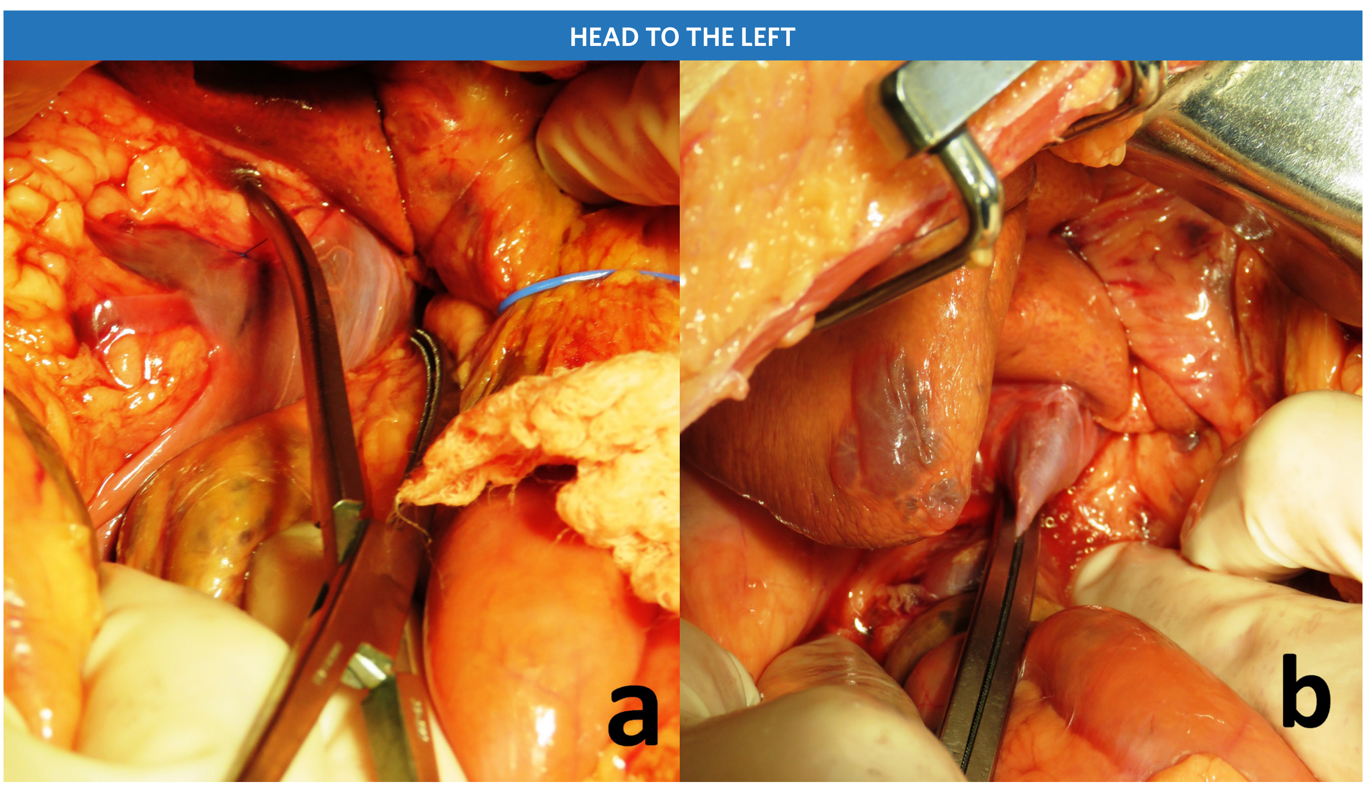


Figure 27. The liver is retracted caudally and anteriorly, with the suprahepatic IVC grasped between fingers such that a vascular clamp, which is directed posteriorly until both jaws touch the spine, can be used to gain occlusion.

CHAPTER 17
OPERATIVE EXPOSURE IN ABDOMINAL TRAUMA: EXPOSURE OF THE SPLEEN AND SPLENIC INJURIES

Operative Exposure in Abdominal Trauma: Exposure of the Spleen and Splenic Injuries

This chapter will discuss exposure and mobilization of the spleen.

Learning Objectives

By the end of the ASSET course, participants should be able to do the following:

- Demonstrate the steps to mobilize the spleen.
- Demonstrate isolation of splenic hilar vessels and splenectomy.

Considerations

- While nonoperative management (NOM) of splenic injuries is common, splenic surgery remains an important technique in patients who are not candidates for or fail NOM.
- Guidelines for NOM of spleen injuries are available on the EAST website, *www.east.org.*
- Patients requiring splenic surgery are often actively bleeding and hemodynamically unstable, making it very important that the surgeon is capable of rapid, effective surgical exposure in order to control hemorrhage.
- In a resource-limited setting without (or with limited) access to blood products or interventional radiology, consideration should be given to early splenectomy in lieu of NOM. Additionally, if the patient requires lengthy transport to a higher level of care and if close observation and frequent reevaluation are not possible, early splenectomy may be warranted.
- Patients requiring operative intervention should undergo a trauma laparotomy, as described in chapter 15.

Technique: Emergent Exposure for Splenectomy

- Make a generous midline incision, with the operating surgeon on the right side of the patient.
- It is important to remember the anatomical relationship of the spleen to the kidney and the tail of the pancreas (Figure 1).

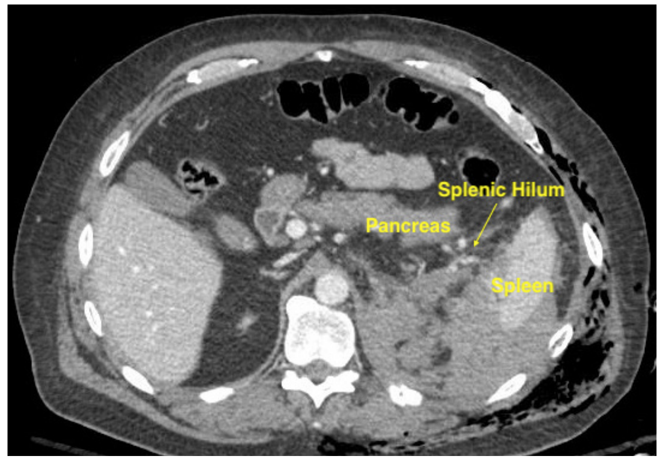


Figure 1. This CT of the abdomen shows the posterior location of the lacerated spleen and its relationship to the tail of the pancreas.

- The spleen is a posterolateral structure and must be mobilized to the midline for evaluation and management.
- Mobilization of the spleen requires division of the attachments (splenophrenic, splenorenal, splenocolic, and splenogastric) that connect it to surrounding structures (Figure 2).
- The spleen is grasped with the surgeon's nondominant hand and pulled medially while carefully dividing the ligaments, using long scissors or electrocautery (Figure 3).
- In the setting of trauma, the ligaments may have already been partially or completely disrupted, and rapid blunt dissection may be possible.
- Placing laparotomy pads behind the spleen may assist in elevating it medially and anteriorly.
- Once the spleen is mobilized, the hilum can be controlled with digital occlusion.

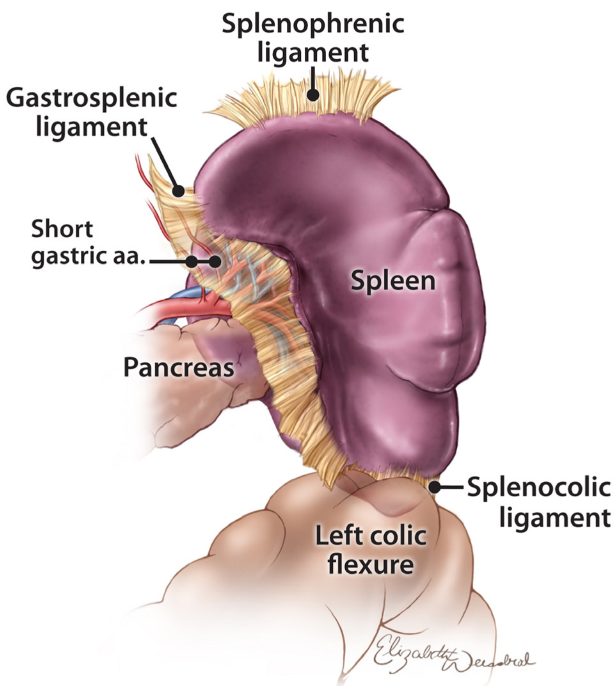


Figure 2. The attachments of the spleen to surrounding structures must be divided to mobilize the spleen for removal or repair.

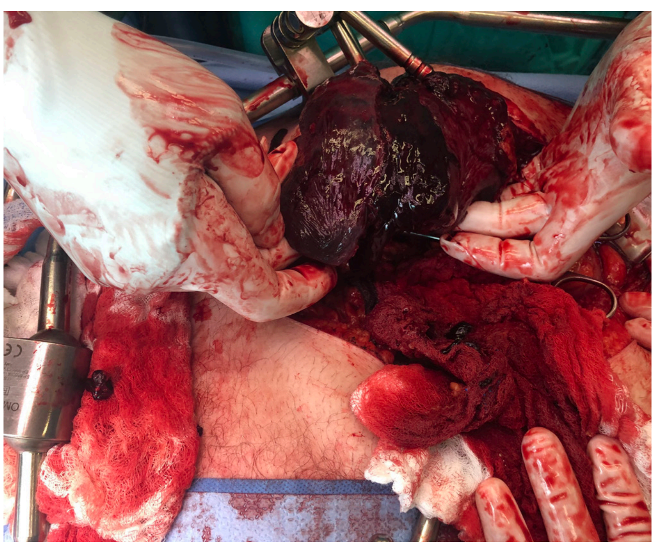


Figure 3. The spleen is grasped and mobilized anteromedially to the midline by taking down the ligamentous attachments.

- The short gastric vessels in the gastrosplenic ligament are divided and ligated, taking care to avoid injury to the stomach. This maneuver exposes the splenic hilum.
- The decision to salvage the spleen or perform a splenectomy requires consideration of the total complexity of the patient's injuries and potential for future blood loss. In general, if a patient has other injuries or physiologic perturbations, **splenectomy is the default**.
- The vessels of the splenic hilum can be dissected out (individually or en bloc) and ligated (Figure 4).
- Alternatively, the hilar vessels can be divided with a stapling device (Figure 5).
- Care must be taken not to injure the tail of the pancreas when clamping or dividing the splenic hilum.
- In hypotensive patients, it is important to examine the splenic bed once blood pressure has been restored and prior to closing the abdomen. Uncontrolled short gastric vessels that were not initially bleeding can bleed profusely once perfusion is restored.
- Sponges placed in the left upper quadrant (LUQ) should be removed systematically by having the operating surgeon roll them anteromedially to evaluate the splenic bed. The assistant can then easily see and control any further bleeding.
- If splenectomy has been performed, remember to provide appropriate immunizations to prevent subsequent infection with encapsulated organisms.

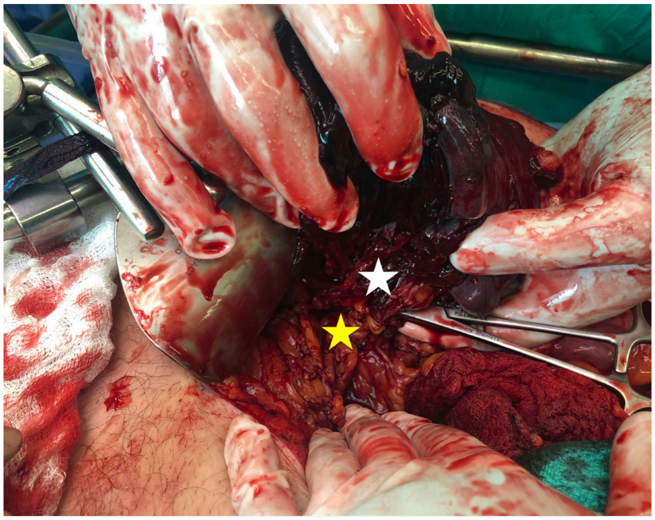


Figure 4. The splenic hilum (white star) has been isolated distal to the tail of the pancreas (yellow star). The vessels can be ligated and divided.

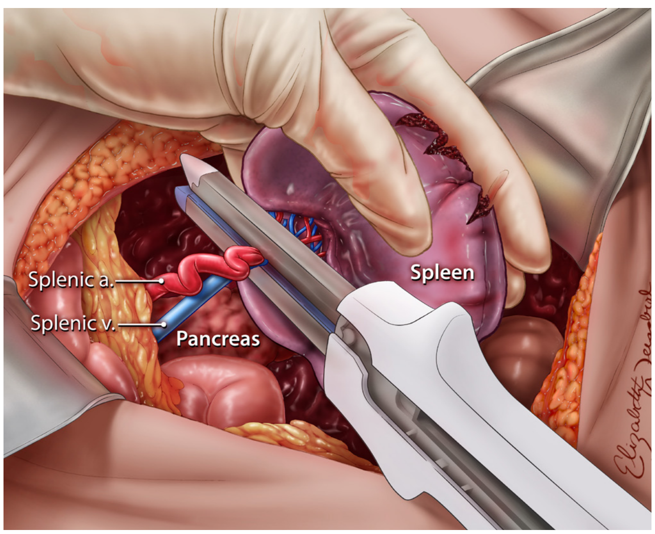
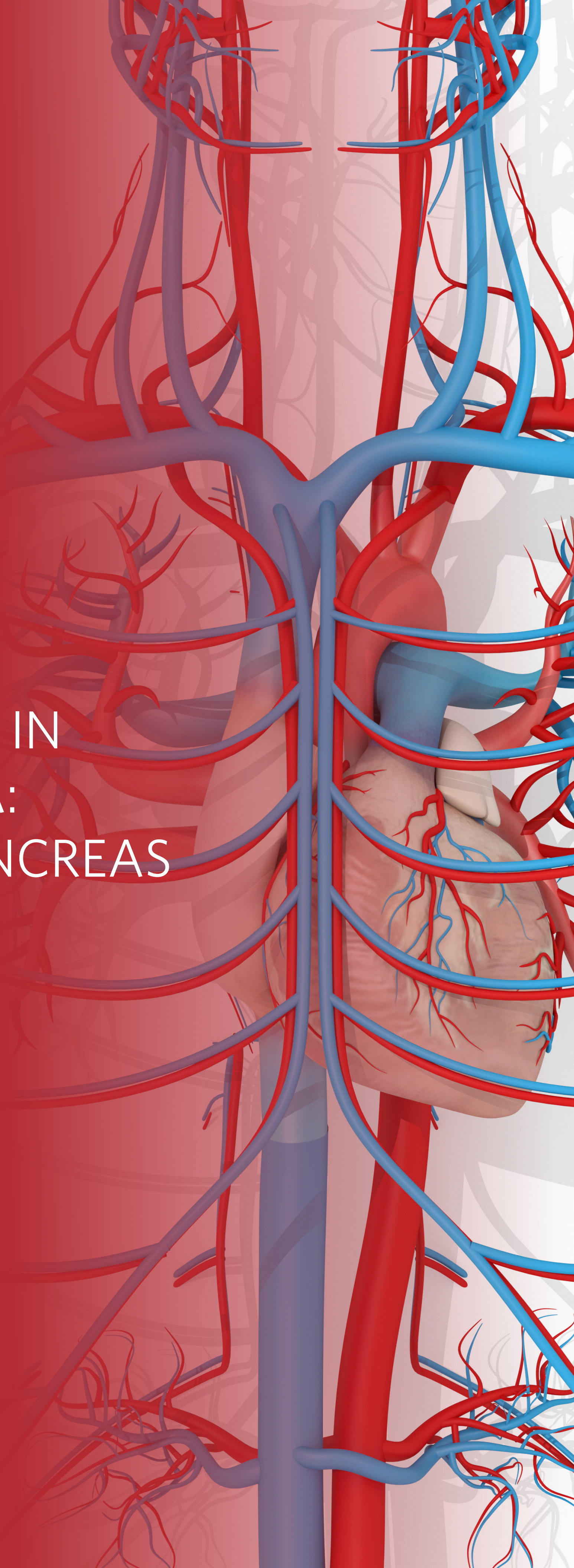


Figure 5. The splenic hilum is crossed with a vascular stapling device.

CHAPTER 18
OPERATIVE EXPOSURE IN ABDOMINAL TRAUMA: EXPOSURE OF THE PANCREAS AND DUODENUM



Operative Exposure in Abdominal Trauma: Exposure of the Pancreas and Duodenum

This chapter will discuss surgical exposure of the duodenum, pancreas, and nearby vascular structures.

Learning Objectives

By the end of the ASSET course, participants should be able to do the following:

1. Demonstrate operative exposure of the head of the pancreas and the second and third portions of the duodenum with the Kocher maneuver.
2. Demonstrate operative exposure of the body of the pancreas in the lesser sac.
3. Demonstrate exposure of the fourth portion of the duodenum and the inferior border of the pancreas by mobilizing the ligament of Treitz.
4. Demonstrate exposure of the distal pancreas using the Aird maneuver.
5. Discuss the management of injuries to body of the pancreas.
6. Identify the anatomic relationships of the duodenum, pancreas, and surrounding structures.

Considerations

- The duodenum is nestled among a number of vital structures, including the aorta, inferior vena cava (IVC), hepatic portal structures, renal arteries and veins, pancreas, and superior mesenteric artery and vein (Figure 1).
- Injuries to the pancreas and duodenum are often accompanied by life-threatening vascular injuries.
- Complex repairs to the duodenum or pancreas should rarely be undertaken at the initial operation if the patient has multiple concurrent injuries and is physiologically compromised. In these circumstances, it is best to use damage control techniques (hemorrhage and contamination control) with wide drainage of the pancreas.

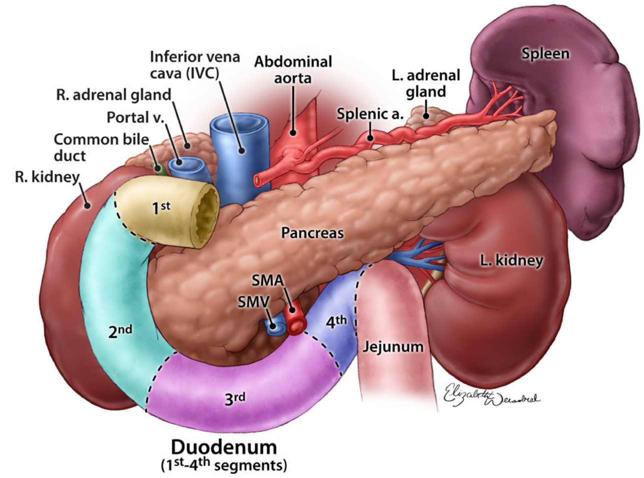


Figure 1. The complex anatomic relationships of the pancreas, duodenum, and surrounding structures, including the superior mesenteric artery and vein (SMA and SMV).

- Definitive surgical intervention is best accomplished with the involvement of surgeons with appropriate expertise in these rare injuries.
- Complete assessment of the pancreas and duodenum requires several different operative maneuvers.
- A generous midline incision as part of a trauma laparotomy is used to access these structures. As with all trauma laparotomies, the patient should be prepped to the knees in case a segment of saphenous vein needs to be harvested for interposition arterial grafting.

Operative Technique to Expose the Anterior Pancreas

- The anterior segment of the pancreas is best accessed by entry into the lesser sac via division of the gastrocolic ligament.
- This tissue is divided inferior to the gastroepiploic vessels, between the stomach and the transverse colon, with cautery and/or division between clamps with ligation.
- As this dissection is carried to the patient's right, care must be taken to avoid injury to the gastroepiploic arcade, as the gastrocolic connection may be foreshortened.

- With the stomach retracted cephalad, the anterior surface of the pancreas is identified at the base of the lesser sac (Figure 2).
- If a hematoma overlies the pancreas, it may be contained by the posterior peritoneum, which should be entered to fully explore the extent of the injury (Figure 3).

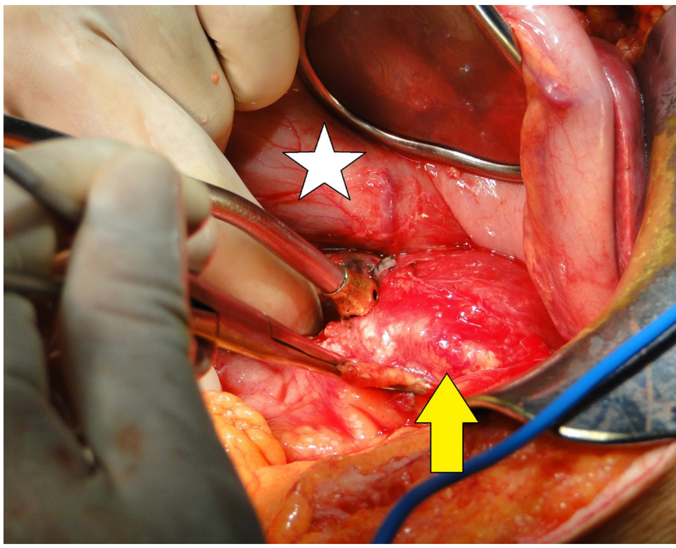


Figure 2. The lesser sac has been entered by taking down the gastrocolic ligament. The stomach (star) is retracted to expose the anterior body of the pancreas (arrow).

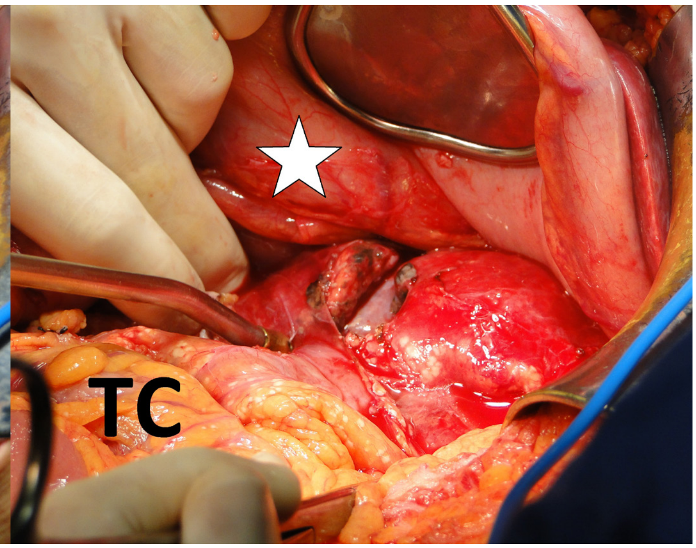


Figure 3. The posterior peritoneum overlying the body of the pancreas, found between the stomach (star) and transverse colon (TC), has been opened to reveal a traumatic pancreatic transection.

Operative Technique to Expose the Head of the Pancreas and Segments Two and Three of the Duodenum

- The anterior and medial surfaces of the duodenum are inspected by following the anterior surface of the stomach to the pylorus and tracing it around the second and third portions of the duodenum.
- The Kocher maneuver, with or without formal medial visceral rotation (chapter 15), exposes the lateral and posterior aspects of segments two and three of the duodenum (Figures 4 and 5), the head of the pancreas, the uncinate process, and the right renal pedicle.
- A right-to-left medial visceral rotation (chapter 15), which includes an extended Kocher maneuver, allows for inspection of the head and uncinate process of the pancreas, the entire duodenum, the IVC down to the pelvic brim, and the right kidney. With medial and superior rotation of the ascending colon and hepatic flexure, care must be taken to identify and avoid injury to the middle colic and superior mesenteric vessels (Figure 6).

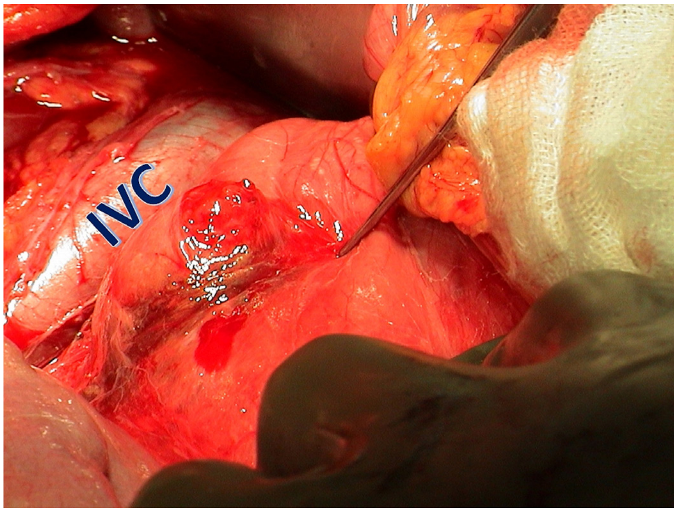


Figure 4. A penetrating wound to the posterolateral wall of the second portion of the duodenum adjacent to the IVC, as seen after a Kocher maneuver.

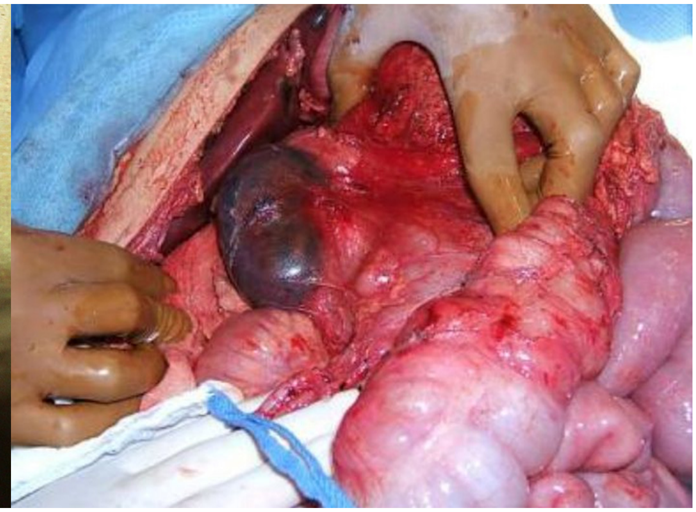


Figure 5. A blunt injury to the second portion of the duodenum, as seen after a medial visceral rotation.

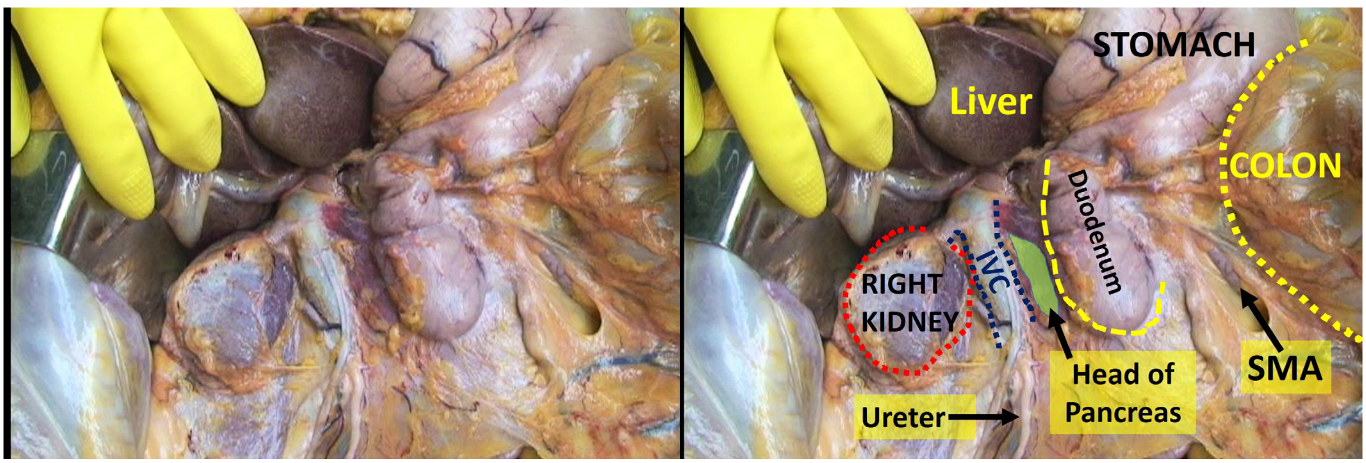


Figure 6. The right-to-left medial visceral rotation with an extended Kocher maneuver provides excellent exposure of the duodenum, head of the pancreas, right kidney, and IVC, as well as an initial view of the superior mesenteric artery (SMA).

Operative Technique to Expose the Posterior Pancreas and Fourth Portion of the Duodenum

- The fourth portion of the duodenum is inspected at the ligament of Treitz to the right of the inferior mesenteric vein at the base of the transverse mesocolon. The ligament may be taken down, as shown in Figure 7.
- The inferior border of the pancreas and posterior portion of the fourth segment should be carefully inspected by dividing the posterior peritoneum along the inferior aspect of the body of the pancreas and by dividing the ligament of Treitz.
- Mobilizing the duodenojejunal flexure allows exposure of the inferior aspect of the pancreas, as well as the aorta and the left renal pedicle (Figure 8). During mobilization, care must be taken to avoid injury to the inferior mesenteric vein.
- Again, the posterior aspects of the second and third duodenal segments can be visualized with the Kocher maneuver.

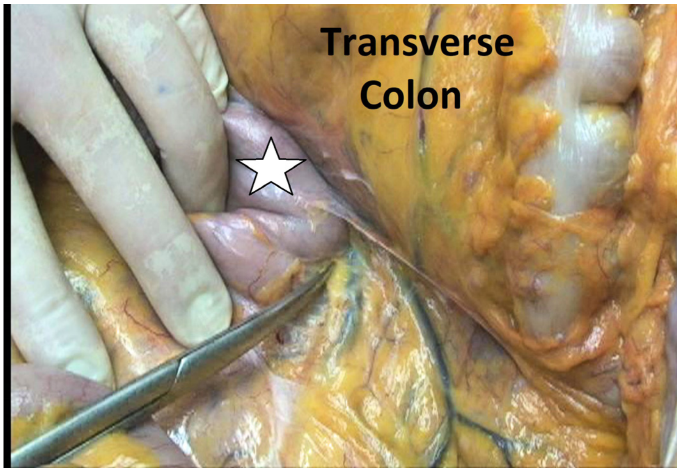


Figure 7. The ligament of Treitz is taken down at the base of the transverse colon and the duodenojejunal flexure (star) mobilized.

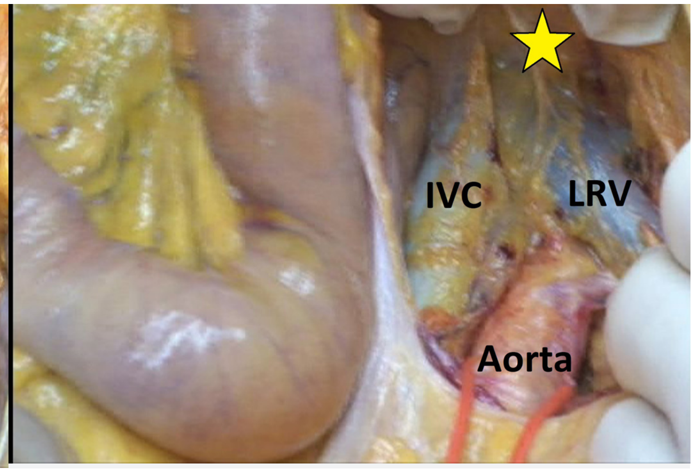


Figure 8. Further dissection will allow for exposure of the inferior border of the pancreas (star), the aorta, inferior vena cava (IVC) and left renal vein (LRV).

Operative Technique to Expose the Distal Pancreas (Aird Maneuver)

- The Aird maneuver involves dividing all peritoneal attachments to the spleen to allow medial mobilization of the spleen and tail of the pancreas (Figure 9).
- Lateral and inferior attachments of the pancreas should be divided sharply to the level of the inferior mesenteric vein to allow full medial rotation and improved exposure. The retroperitoneal attachments can be sharply dissected superiorly via the lesser sac.
- Mobilization of the spleen and tail of the pancreas allows inspection of the posterior tail of the pancreas and identification of the splenic vein and artery (Figure 10).
- Further exposure of the posterior pancreas is accomplished by dividing the retroperitoneal attachments along the inferior border, with retraction of the pancreas cephalad (Figure 11).
- With the spleen and tail of the pancreas mobilized, they can be rotated medially to completely inspect the body and tail of the pancreas (Figure 12).

Operative Technique to Expose the Portal Vein, SMV, and SMA

- The duodenum is exposed via a Kocher maneuver, and the lesser sac is entered to inspect the anterior portion of the pancreas.
- If active hemorrhage is present in the region of the neck of pancreas, there may be an injury to the portal vein, SMV, and/or SMA. After blunt dissection anterior to the SMV/portal vein and behind the neck of pancreas, a stapler may then be used to divide the neck. This allows for rapid exposure of injured vessel(s) and will help control any hemorrhage from the pancreas itself.
- The origin of the SMA can also be identified with a left-to-right medial visceral rotation (as described in chapter 15) or through the root of the small bowel mesentery.

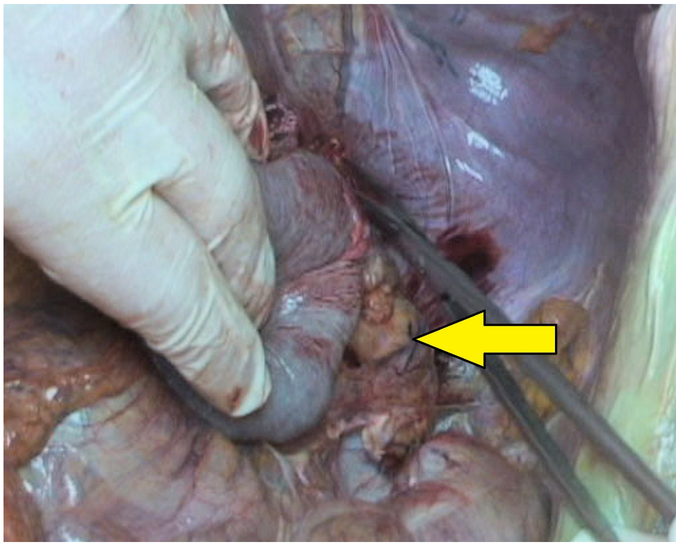


Figure 9. The Aird maneuver mobilizes the spleen and tail of the pancreas (arrow) by taking down the peritoneal attachments.

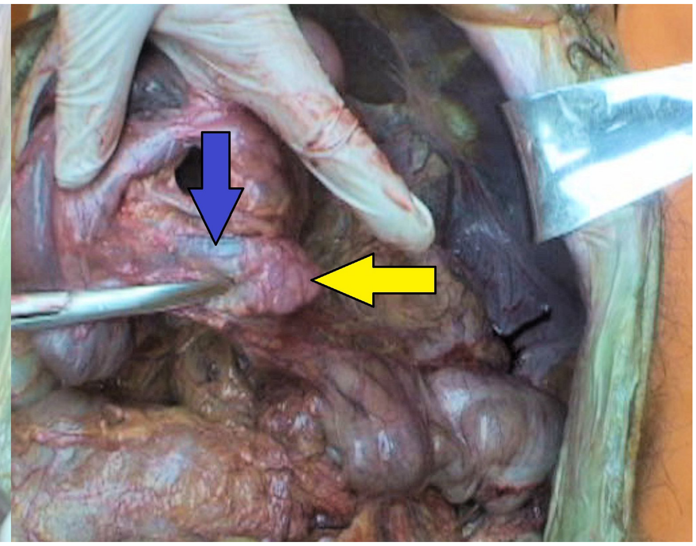


Figure 10. The pancreatic body (yellow arrow) is further mobilized to expose the splenic vein (blue arrow) and artery (tip of scissors).

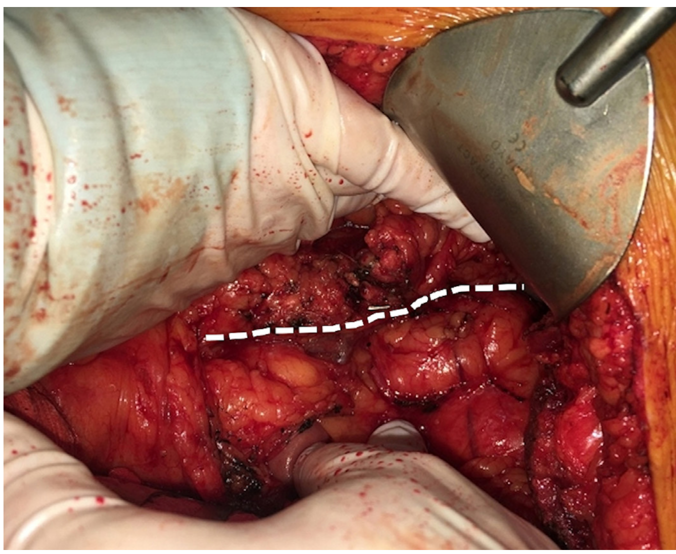


Figure 11. Mobilization of the inferior border of the pancreas.

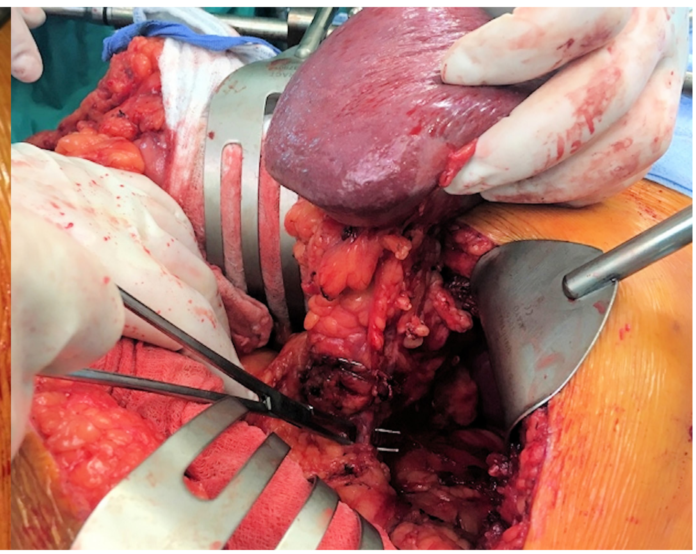


Figure 12. Completion of the Aird maneuver, with identification of the inferior mesenteric vein (on top of right-angle clamp).

Considerations for Pancreatic Resection

- Resection proximal to the injury should occur if there is a definite (or strong suspicion of) pancreatic ductal injury.
- If the pancreas is disrupted to the left of the SMA/SMV, a distal pancreatectomy should be performed, with or without splenectomy (Figures 13 and 14).
- Splenic preservation is contraindicated if the patient has multiple injuries, is physiologically deranged (e.g., coagulopathic, hypothermic, acidotic), or has other time-sensitive injuries.
- If the injury is to the right of the SMA/SMV complex, a distal pancreatectomy may be required but will sacrifice the majority of the pancreatic mass (Figure 15). In the acute setting, it may be preferable to perform damage control drainage with delay of definitive resection.
- If there is massive injury to the head of the pancreas, the patient should be widely drained and resuscitated. Consideration should be given to performing one of several variations of the Whipple procedure once the patient is physiologically resuscitated.

Pearls and Pitfalls

The first priority is to control bleeding. Concurrent injuries may be managed with damage control techniques, with delayed reconstruction if necessary. External drainage, external drainage, external drainage ....

- The key for the majority of pancreatic injuries is to identify if there is a ductal injury; strong indicators include a more than 50 percent transected gland, a central injury, and massive tissue destruction.
- Consider options for early administration of postoperative enteral nutrition; intraoperative placement of feeding tubes is encouraged.

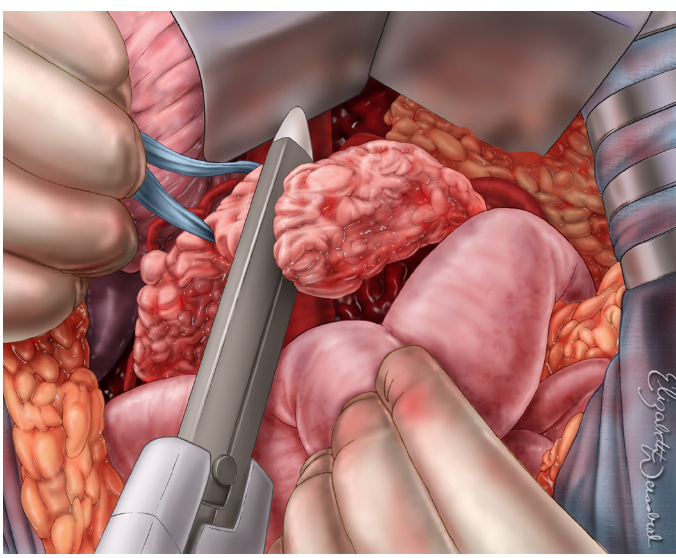


Figure 13. Distal pancreatectomy (and splenectomy) using a gastrointestinal anastomosis (GIA) stapling device. (Patient's head is to the right.)

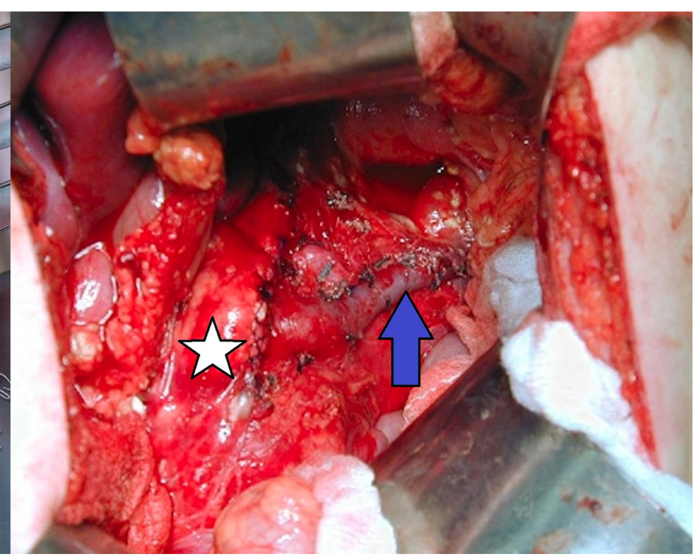
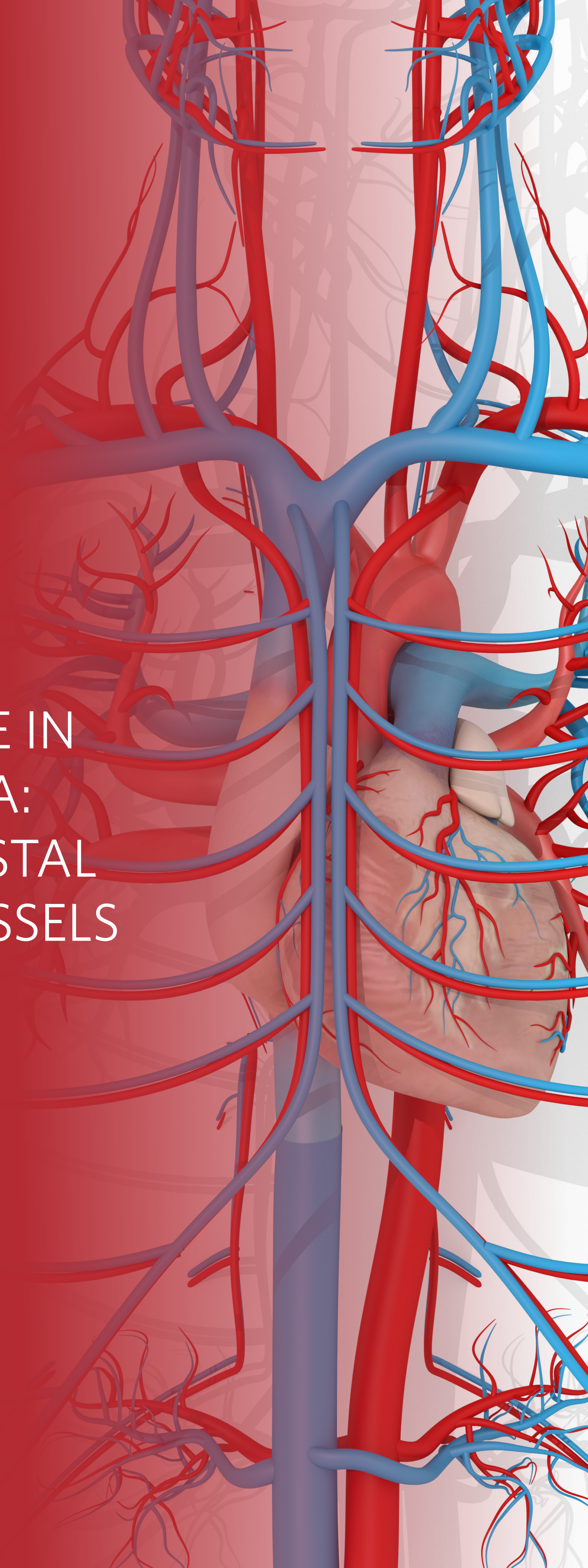


Figure 14. A spleen-preserving distal pancreatectomy. The remnant of the pancreas (star) is seen medial to the splenic vein (arrow).

CHAPTER 19
OPERATIVE EXPOSURE IN ABDOMINAL TRAUMA: EXPOSURE OF THE DISTAL AORTA AND ILIAC VESSELS



Operative Exposure in Abdominal Trauma: Exposure of the Distal Aorta and Iliac Vessels

This chapter will discuss the key vascular exposures that will be potentially lifesaving for patients with injury to or rupture of their distal aorta or iliac artery or vein.

Learning Objectives

By the end of the ASSET course, participants should be able to do the following:

1. Describe and demonstrate the steps to obtain vascular control of the distal aorta.
2. Describe and demonstrate the steps to obtain exposure of the right and left iliac arteries and veins.

Considerations

- The distal aorta and the iliac vessels are located in retroperitoneal Zones 1 and 3 (chapter 15), respectively. When injured, they can present life-threatening hemorrhage, with an associated high mortality rate.
- Penetrating wounds to the pelvis are the most common causes of distal aorta and iliac vessel injuries.
- Iliac vein injuries result in significant blood loss, and operative exposure is difficult. These veins may be ligated if necessary. Ligation of the external iliac vein distal to the bifurcation will place the patient at risk of developing lower extremity edema and/or deep venous thrombosis.
- The first priority is hemorrhage control.
- Ureteral injuries are commonly associated with iliac vessel injuries, and therefore the ureter should be evaluated after the vascular injuries have been addressed.

Operative Exposure

- Distal aorta and iliac vessel injuries are typically exposed through a midline incision as part of a trauma laparotomy.
- Understanding the anatomic relationships of the distal aorta and iliac vessels is critical to obtaining safe and rapid control. Remember that the iliac arteries are **anterior** to their corresponding veins.
- As outlined in chapter 15, right-to-left medial visceral rotation (Cattell-Braasch maneuver) can be performed rapidly and allows for the colon and small bowel to be mobilized up and off the distal aorta, inferior vena cava, and iliac vessels (Figures 1 and 2).
- The common iliac veins are intimately adherent to the back wall of the common iliac arteries. If not careful, mobilization of the artery may result in venous injury and profuse bleeding. The right common iliac vein and bifurcation are particularly difficult to expose.
- Occasionally, it may be necessary to transect the right common iliac artery to gain adequate exposure of the right common iliac vein, as depicted in Figures 3 and 4. Transection and ligation of the internal iliac artery can also improve exposure of the ipsilateral common iliac vein.
  - Excessive retraction of the external iliac artery to obtain better exposure of this vein may damage the artery.

HEAD TO TOP

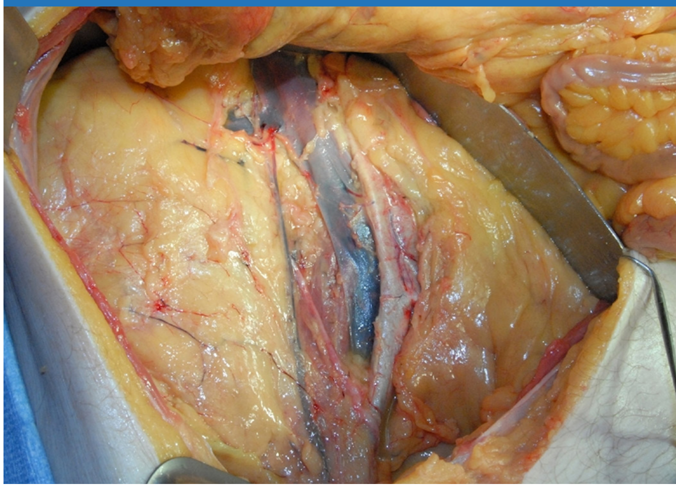


Figure 1. Right-to-left medial visceral rotation provides excellent exposure of the distal aorta, the inferior vena cava, and their branches.

HEAD TO RIGHT

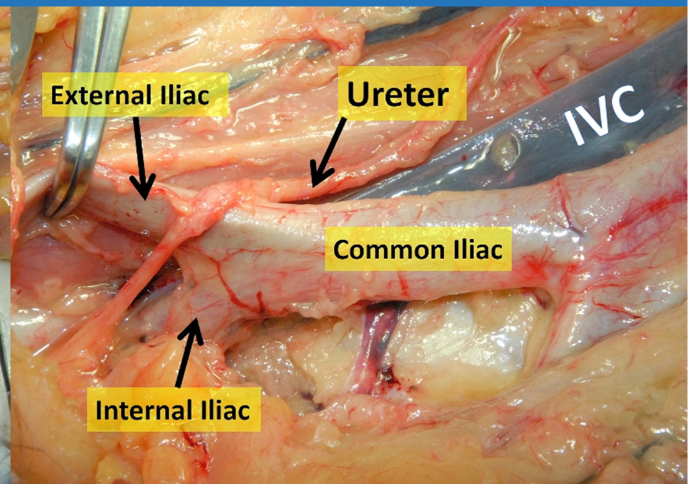


Figure 2. Further dissection nicely exposes the distal aorta, the inferior vena cava (IVC), the right iliac vessels, and the right ureter.

RIGHT PELVIS - HEAD TO RIGHT

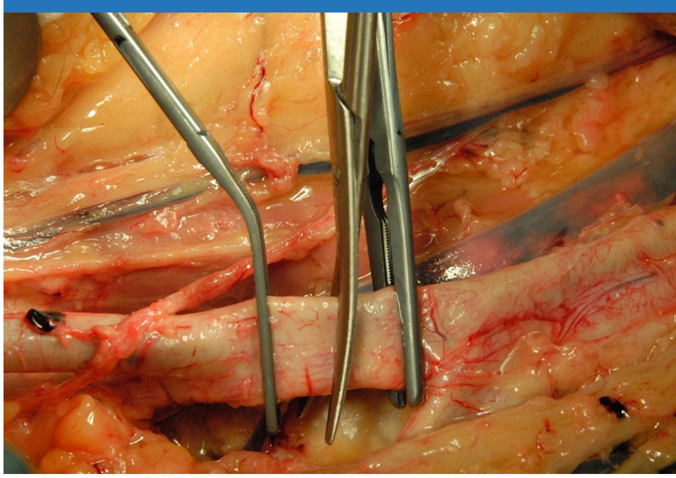


Figure 3. The right common iliac artery has been clamped and will be divided to expose the iliac vein below.

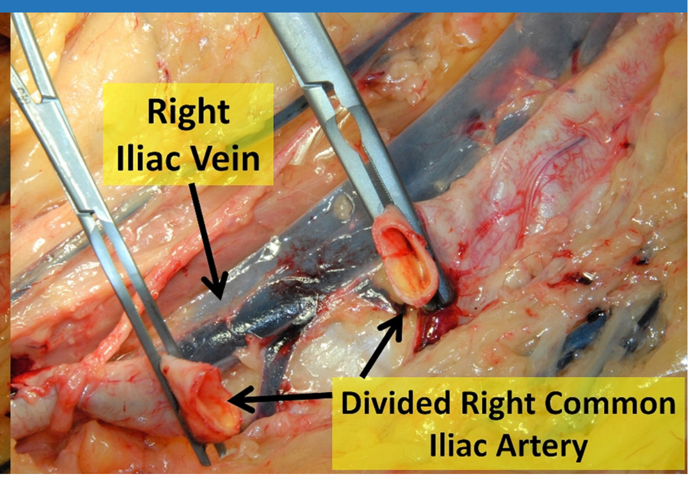


Figure 4. Once the iliac artery is divided, it can be dissected up and off the underlying iliac vein to address the injury. The artery is then anastomosed.

Vascular Control of the Distal Aorta

- Injuries to the distal aorta and bifurcation may be temporarily controlled by local manual compression with a laparotomy pad, sponge stick, or fingers until proximal and distal vessel control can be achieved.
- REBOA, as described in chapter 22, can also provide temporary hemorrhage control.
- It is important to remember that the aorta proximal to the injury should be isolated with vessel loops and clamped, taking care to avoid injury to lumbar vessels. Additionally, both common iliac vessels distal to the injury need to be isolated.
- For suspected injuries to the distal aorta and its bifurcation, exposure can also be accomplished by entering the midline retroperitoneum at the root of the mesentery below the renal vessels, with the small bowel retracted upward to the right and the colon to the left (Figure 5).

Vascular Control of the Iliac Vessels

- Injury to the iliac artery or vein that results in an expanding hematoma or significant bleeding may necessitate manual compression until proximal and distal control can be obtained. Again, sponge sticks can be very helpful.
- Vessel loops can be passed around the common iliac artery for proximal control and around the external and internal iliac arteries (Figure 6).
- Bilateral iliac injury may be exposed using total pelvic vascular isolation, which consists of cross-clamping the distal abdominal aorta and inferior vena cava, as well as clamping both external iliac arteries and veins.
- A temporary arterial or venous shunt may be used to control hemorrhage and provide temporary restoration of distal blood flow in damage control situations.

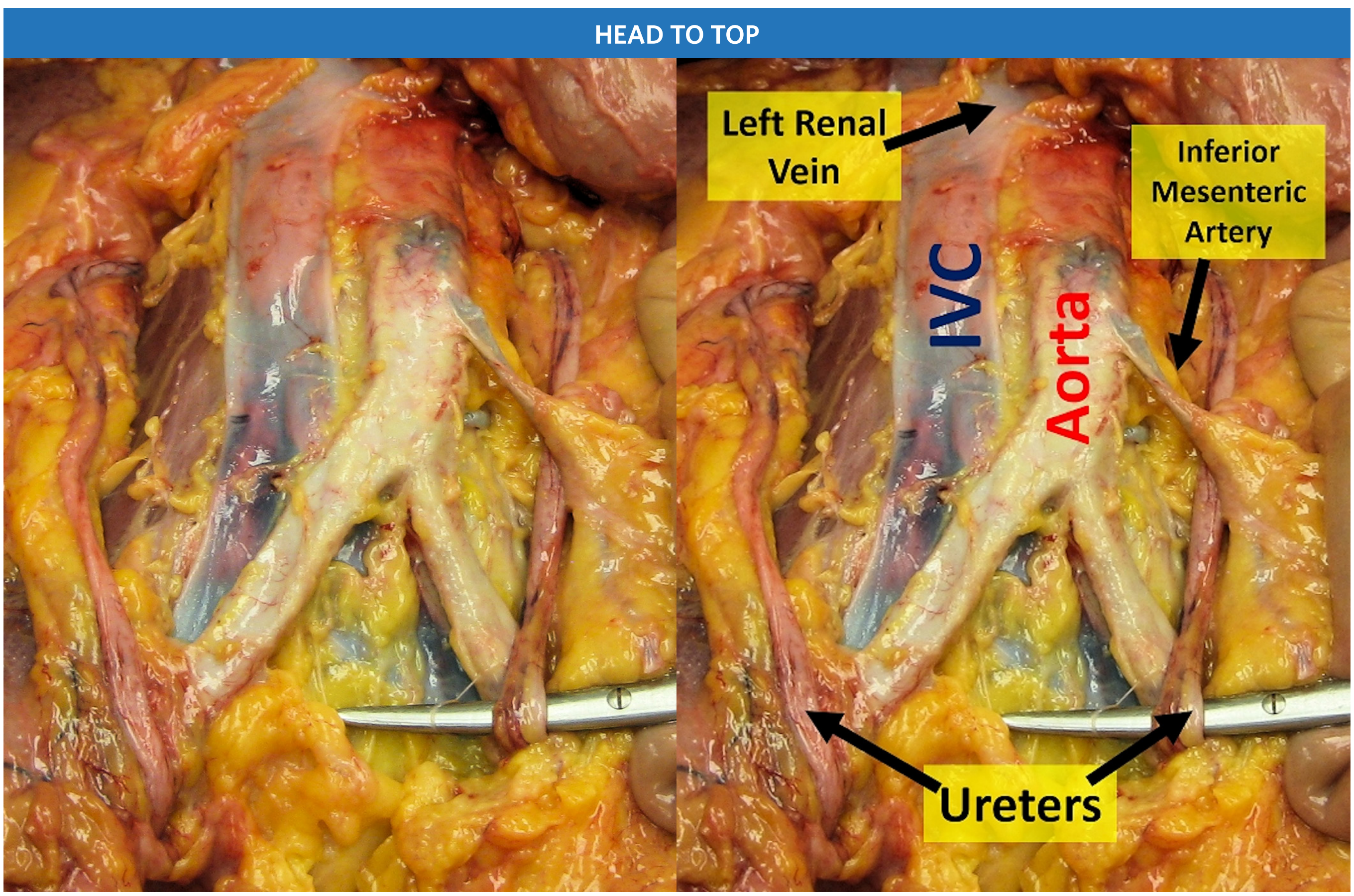


Figure 5. Exposure of the distal aorta and bifurcation can be accomplished by entering the midline retroperitoneum below the renal vessels, moving the small bowel up and to the right, and moving the colon to the left. The ureters should be identified and preserved.

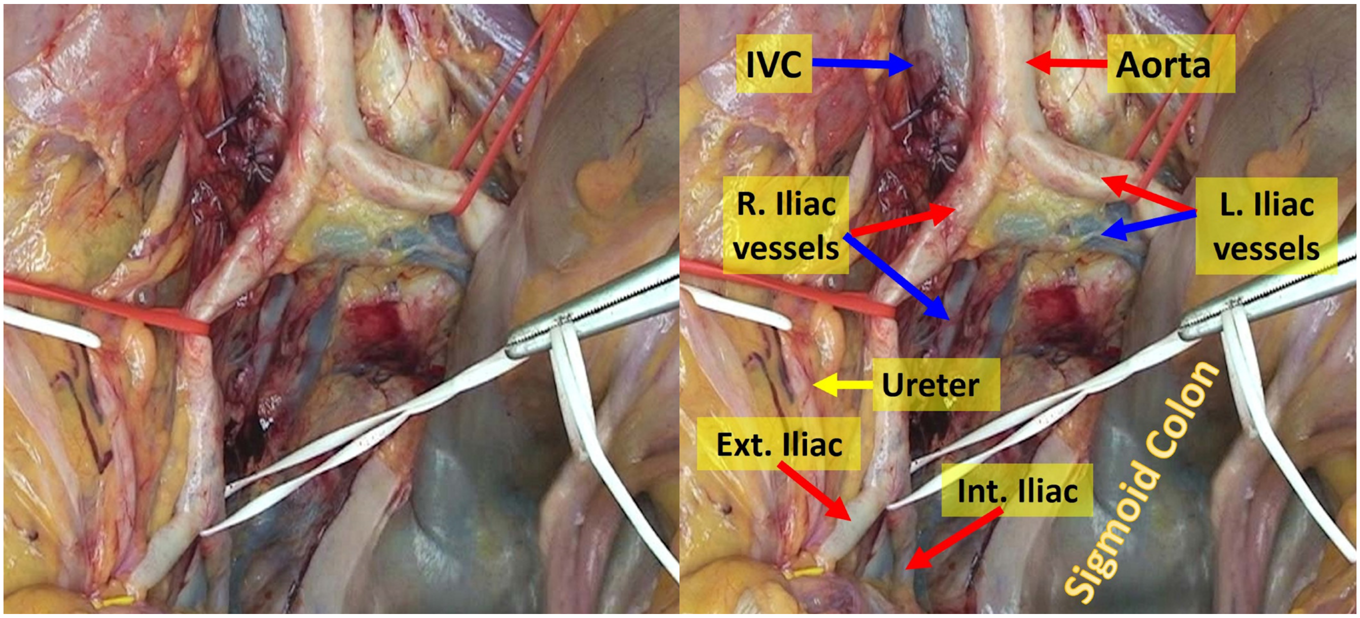
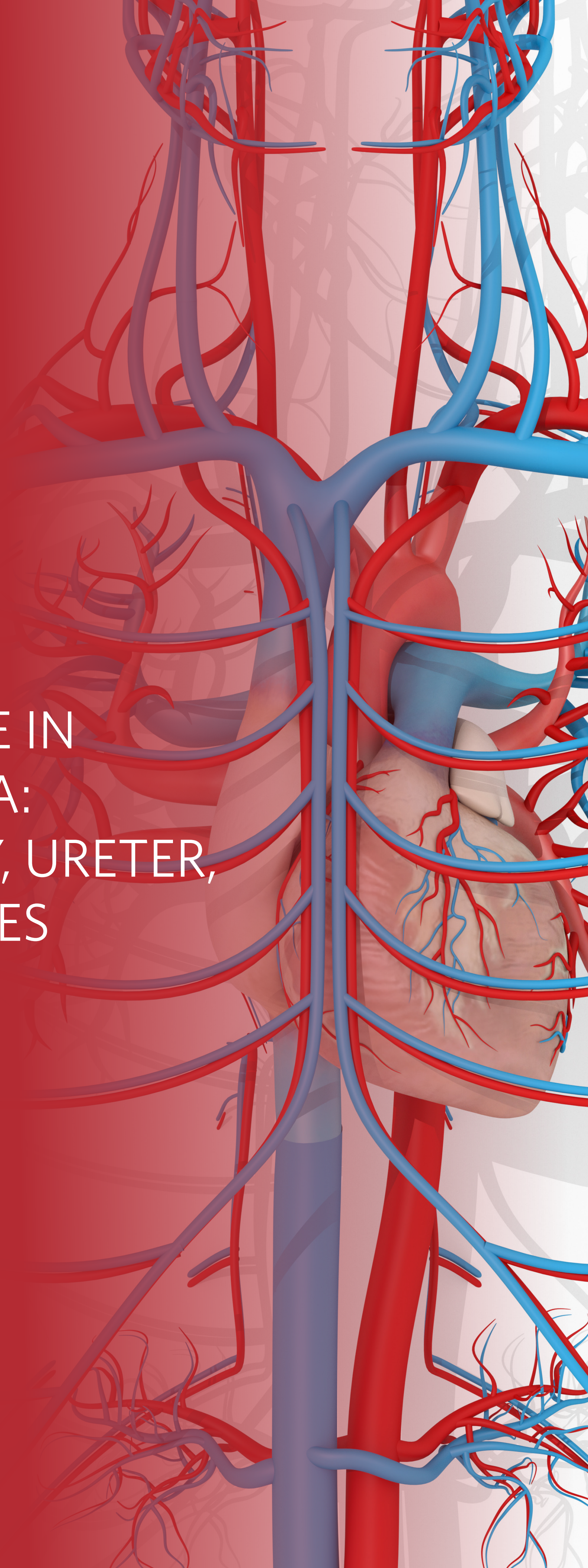


Figure 6. Further distal dissection allows for identification and control of the retroperitoneal vessels in the lower abdomen and pelvis.

CHAPTER 20
OPERATIVE EXPOSURE IN ABDOMINAL TRAUMA: EXPOSURE OF KIDNEY, URETER, AND BLADDER INJURIES



Operative Exposure in Abdominal Trauma: Exposure of Kidney, Ureter, and Bladder Injuries

This chapter will discuss surgical exposure of both kidneys, with a focus on how the different anatomic relationships and vasculature impact surgical exposure in emergent situations. In addition, surgical exposure of ureters and the urinary bladder will also be discussed.

Learning Objectives

By the end of the ASSET course, participants should be able to do the following:

1. Demonstrate the steps to obtain surgical exposure of the kidneys.
2. Demonstrate vascular isolation of the kidneys.
3. Demonstrate exposure of the ureter.
4. Demonstrate bladder exposure by opening the anterior wall/dome of the bladder.

Kidney—Considerations and Investigations

- The kidney is the most commonly injured genitourinary organ.
- Indications for operative intervention include hemodynamic instability, expanding or pulsatile hematoma discovered during trauma laparotomy, active bleeding into the peritoneal cavity, or an injury to the extrarenal urinary collecting system.
- In a stable patient, injury is usually diagnosed by CT scan with IV contrast (Figure 1).
- The presence of a vascular blush on CT scan (Figure 2) indicates active bleeding. This can be managed by angiographic embolization in a hemodynamically stable patient, or as part of a trauma laparotomy in an unstable patient.
- While historically emphasized, the use of a single-shot intravenous pyelogram (IVP) has fallen out of favor and should be discouraged.
- The presence of a unilateral nonperfused kidney may indicate a blunt vascular injury with occlusion of the renal artery. Whether an urgent renal exploration or angiographic intervention is warranted depends on whether the other kidney is perfused, the time elapsed since injury (warm ischemia time), the prioritization of other injuries, and the ability of the patient to tolerate a revascularization procedure.
- When discovered at laparotomy, penetrating wounds that extend into the retroperitoneum may require exploration for possible injury to the kidney, ureter, and vascular structures, unless preoperative CT injury assessment indicates that observation is appropriate.

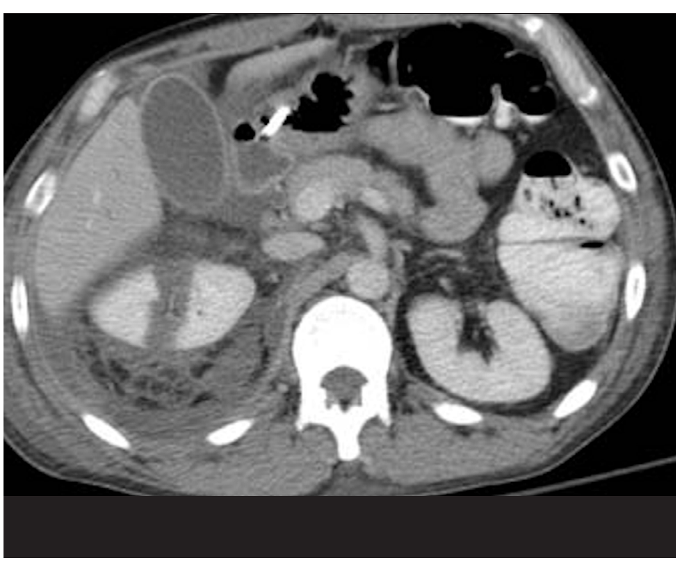


Figure 1. CT scan showing laceration to the right kidney.

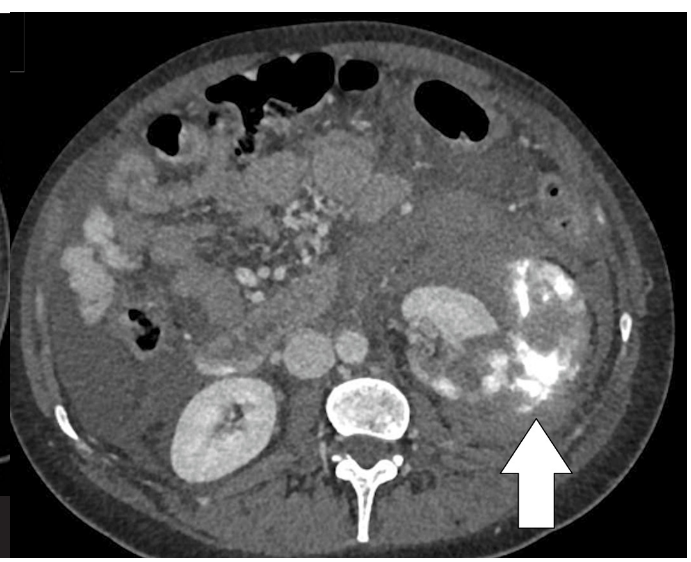


Figure 2. Contrast extravasation (arrow) indicating active bleeding in the left kidney.

Operative Exposure

- Renal injuries are explored through a generous midline incision.
- Though the kidneys are bilateral organs, each has quite different anatomic considerations, which must be kept in mind while exposing the vasculature.
- Before proceeding with nephrectomy, it is important to confirm the presence of a normal-sized contralateral kidney by palpation.

RIGHT KIDNEY

- Exposure of the right kidney requires mobilization as follows:
    - Right-to-left medial visceral rotation (Figure 3), as described in chapter 15
    - Kocher maneuver (chapter 15) to mobilize the duodenum off the right kidney

LEFT KIDNEY

- Exposure of the left kidney begins with left-to-right medial visceral rotation (modified Mattox maneuver) of the descending colon, splenic flexure, spleen, and distal pancreas (Figure 4), as described in chapter 15.

Vascular Control

- Proximal control of the renal vasculature should be obtained before entering Gerota's fascia in the presence of a significant renal hematoma. There are two main ways to obtain renal vascular control: midline and lateral-to-medial.

MIDLINE APPROACH

- Vascular control can be obtained by entering the retroperitoneum at the base of the mesocolon, medial to the inferior mesenteric vein, as shown in Figure 5. It is important to open the retroperitoneum from the ligament of Treitz to the aortic bifurcation.
- This exposure allows control of the renal arteries at their origin from the aorta prior to entering significant perinephric hematomas.
- Once the retroperitoneum is opened, the renal vessels can be isolated and controlled near the midline, as depicted in Figures 5 and 6.
- **Left renal vascular control:** Vessel loops are placed around the left renal vein first, as it is typically anterior, and then around the left renal artery.

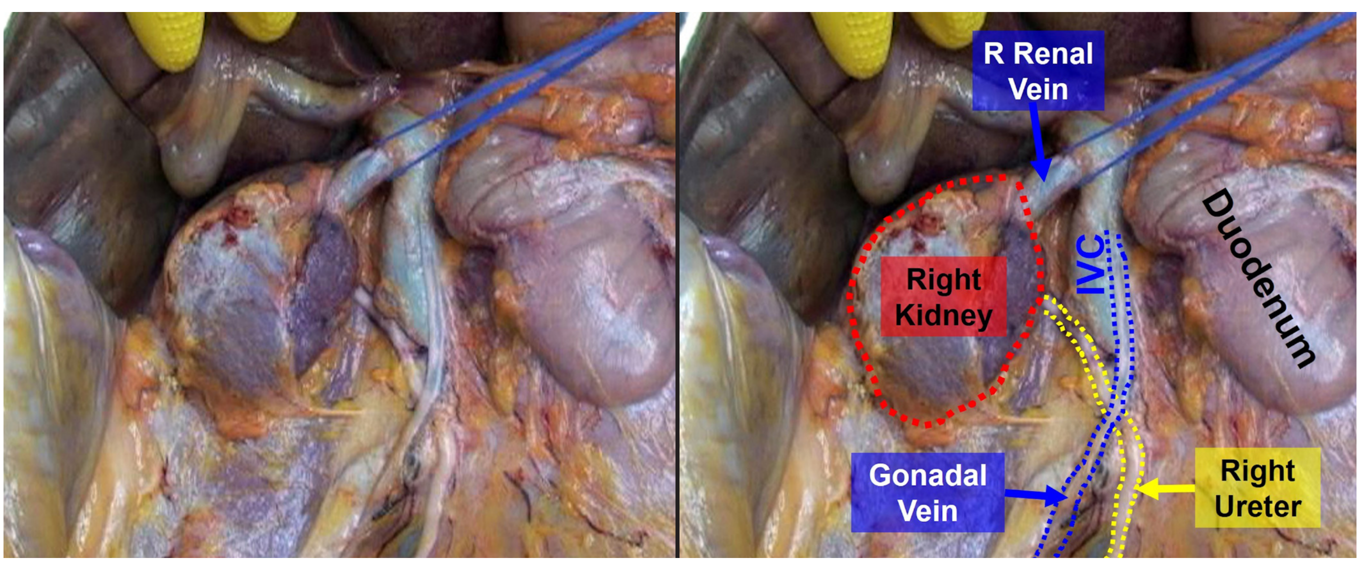


Figure 3. The right kidney, its vascular pedicle, the ureter, and the inferior vena cava (IVC) are exposed using right-to-left medial visceral rotation and Kocher maneuver of the duodenum. The right renal artery will be found just behind and inferior to the renal vein.

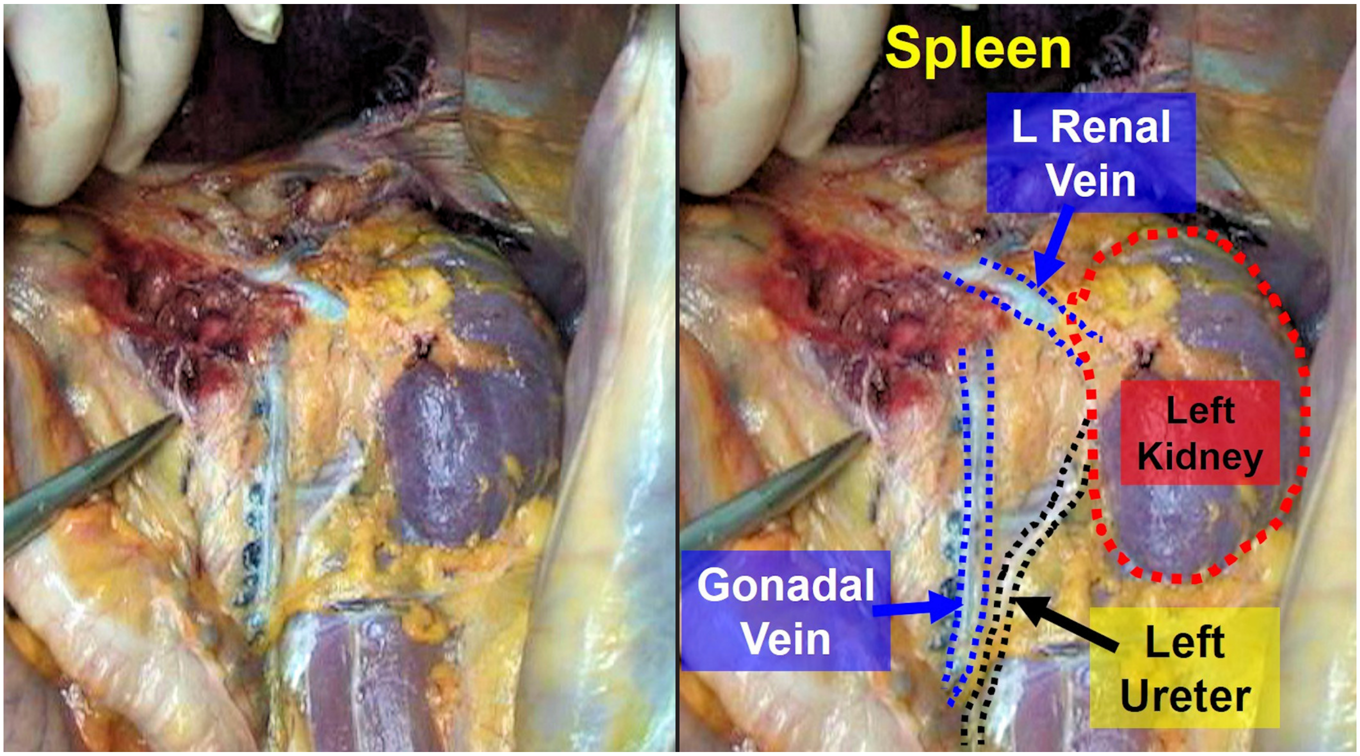


Figure 4. The left kidney, its vascular pedicle, the ureter, and the aorta are exposed using left-to-right medial visceral rotation (modified Mattox maneuver). The left renal artery will be found just behind and inferior to the renal vein. The left renal artery will be found just behind and inferior to the left renal vein.

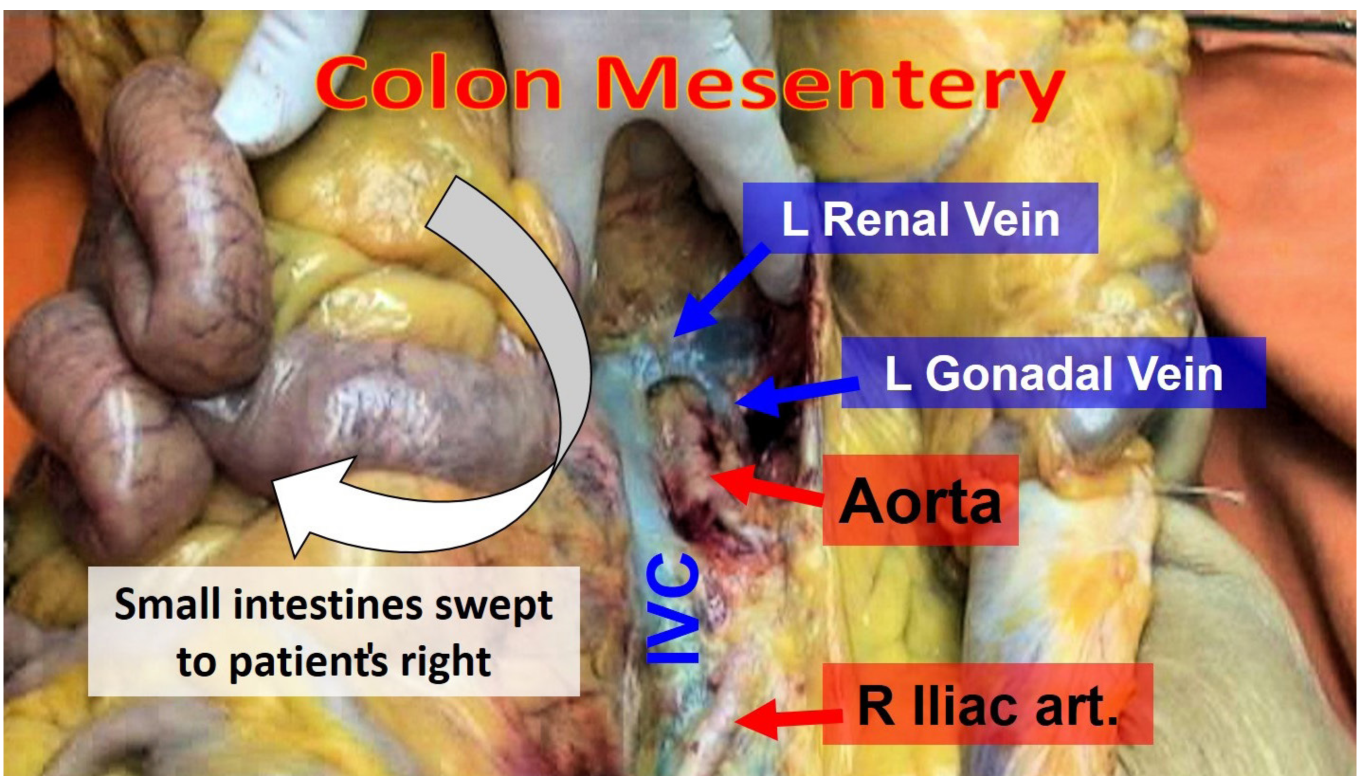


Figure 5. The renal arteries can be approached centrally at their aortic origin by widely opening the retroperitoneum at the root of the mesentery. Access is facilitated by retracting the transverse colon upwards, with exposure of the ligament of Treitz.

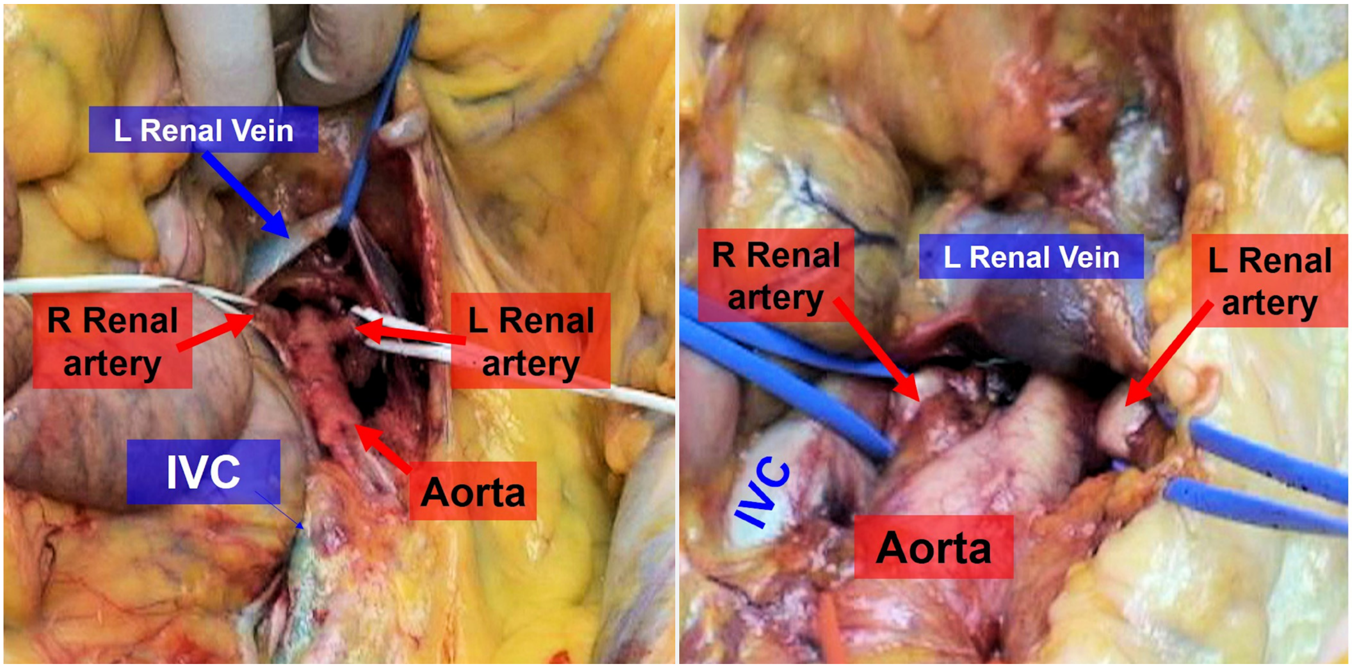


Figure 6. The left renal vein crosses the aorta, and retracting it upwards allows for exposure, identification, dissection, and control of both renal arteries close to their origin.

- **Right renal vascular control:** The right renal artery is isolated at its origin by slightly retracting the medial portion of the left renal vein cephalad, as shown in Figure 6. After a vessel loop is placed around the right renal artery, the right renal vein is isolated at its junction with the inferior vena cava (IVC).
- It is important to remember that the adrenal vein usually drains directly into the IVC on the right and into the renal vein on the left.
- The left renal vein may be ligated if necessary, as there is sufficient collateral venous flow through gonadal and adrenal veins.

LATERAL-TO-MEDIAL APPROACH

- Either kidney can be rapidly accessed from lateral to medial if the patient is in extremis. This is easier and quicker, with less blood loss in patients with large central hematomas.
- After mobilization of the colon, the retroperitoneum and Gerota's fascia are entered, and the surgeon's hand is placed around the kidney from lateral to posterior.
- With the hand in that position, the vascular pedicle can be easily controlled with the thumb and forefinger. The kidney can then be rotated medially and brought up into the surgical field.
- The vascular pedicle can be controlled with a vascular clamp (or a crushing clamp, if nephrectomy is to be performed) while the ureter is isolated.

Ureter—Considerations and Investigations

- Most ureteral injuries are penetrating and are often associated with vascular injury. These are most often diagnosed at laparotomy. Preoperative contrast imaging may not be feasible or appropriate in unstable patients prior to laparotomy.
- Blunt injury to the ureter is rare, but when it occurs is often associated with disruption of the ureteropelvic junction. Blunt avulsion injuries of the ureter are more common in pediatric patients.

- The longitudinal blood supply to the ureter runs between the muscularis and the adventitia; dissection outside the adventitial layer avoids devascularization, which otherwise may result in stricture or leak.
- If the patient is being treated in a damage control fashion, ureteral repair should be delayed until the patient's physiology will permit. In this setting, an appropriately sized tube (feeding tube or red rubber) can be placed into the proximal end of the ureter and exteriorized to provide urinary drainage. In cases of extremis, simple drainage of the ureteral bed may also be employed.
- Repair of complex ureteral injuries is beyond the scope of this manual and is best accomplished by surgeons experienced in such repairs, if and when the patient's physiology permits.

Operative Exposure of Ureters

- Exposure of the ureters can be accomplished by right-to-left or left-to-right medial visceral rotation, or through the root of the mesentery (Figure 7), depending on the area of injury.
- The ureters lie directly over the psoas muscle and will cross the pelvic brim over the top of the iliac arteries (Figure 7).
- In order to differentiate the ureter from the gonadal vessels, it may be helpful to observe for peristalsis or lightly compress the ureter with vascular forceps to stimulate peristalsis (Kelly's sign).
- Exposure near a hematoma may be difficult, and it is easier to identify the ureter in an area slightly removed from discernable trauma.
- If the ureter is in a hematoma, small injuries can be difficult to identify, and injecting methylene blue or indigo carmine intravenously (both are excreted in the urine) may be helpful in ensuring that no injuries are missed. Place a dry white sponge over the site of possible injury, and examine it 10 to 15 minutes after the dye is injected.

Figure 7. The ureters can be reliably found where they cross anterior to the iliac vessels. They can then be followed into any hematoma that may exist, taking care not to jeopardize the blood supply.

Operative Repair of Ureteral Injuries

- While exposure is the primary focus of this manual and course, repair of a transected ureter is certainly within the skill set of surgeons caring for the traumatically injured, if the patient's physiology permits and subspecialty expertise is not readily available.
- The steps of ureteral repair are detailed in Figures 8 and 9 and are as follows:
    - Identify the injury, and mobilize the transected ends (Figure 9). Mobilization should be minimized to prevent devascularization.
    - The ends of the transected ureter are debrided and spatulated using Potts scissors, with the spatulation on opposite surfaces (i.e., anterior on one and posterior on the other).

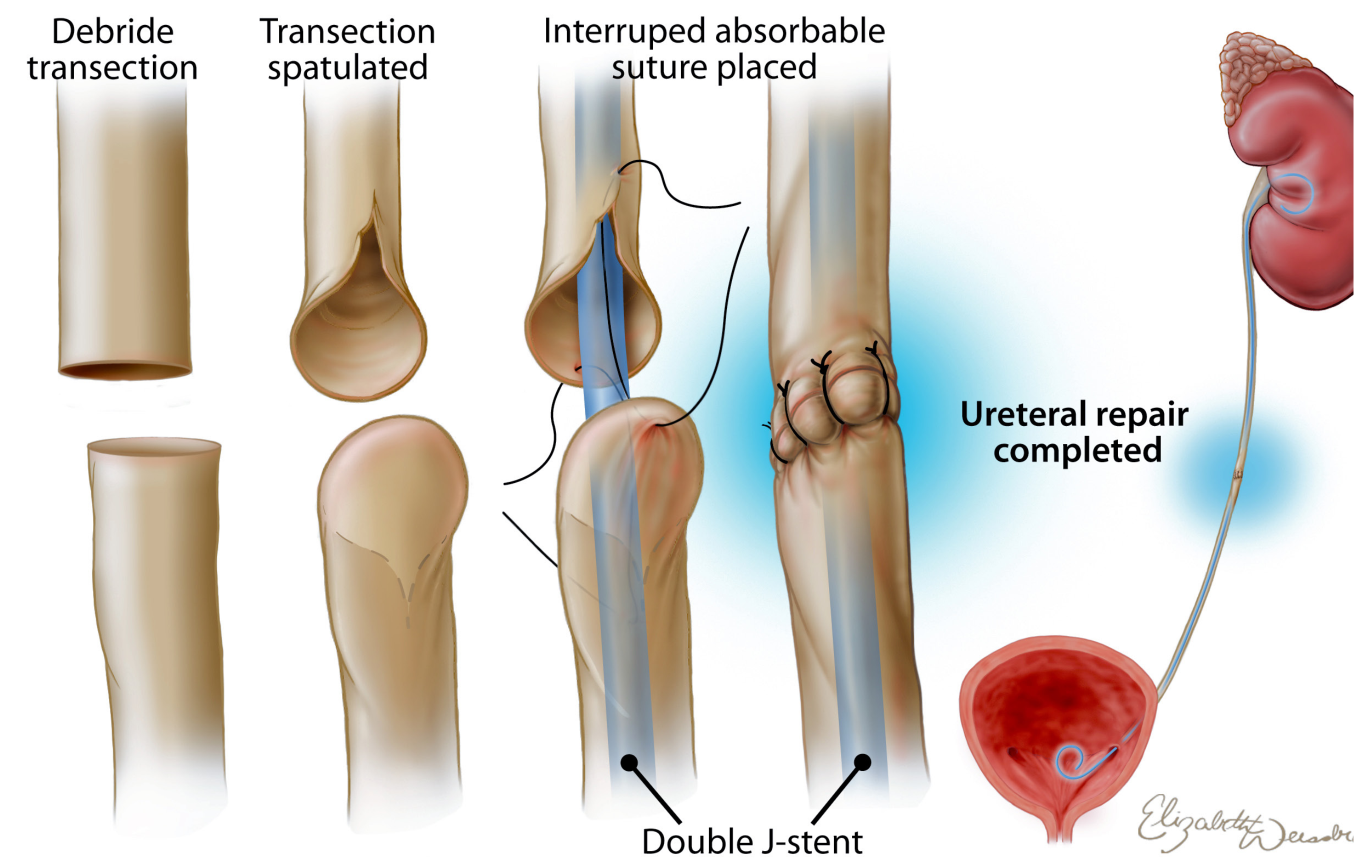


Figure 8. The key steps of repairing a simple ureteral transection are detailed in this illustration.

- A double-J stent is placed into each end of the transected ureter. The distal end of the stent is placed into the bladder and the proximal end into the calyx of the kidney. This will allow for cystoscopic retrieval of the stent following healing.
- The ureteral ends are then sewn together over the stent using interrupted absorbable sutures, as permanent sutures are lithogenic.

- Complex ureteral injuries and injuries involving significant portions of damaged or missing ureter will require repairs best left to urology colleagues. As mentioned, in the damage control setting, the proximal ureter can be intubated with any small tube that can then be brought out through the skin.

Urinary Bladder—Considerations

- Bladder injuries can be diagnosed using conventional or CT cystography (Figure 10).
- Blunt extraperitoneal injuries usually accompany pelvic fractures and usually do not require operative exploration. Such injuries can usually be managed with transurethral catheter drainage alone.
- Penetrating bladder injuries typically will require surgical exploration and repair.
- Intraperitoneal injuries (blunt and penetrating) require surgical repair. Blunt injuries usually result from direct impact to the anterior lower abdominal wall in the setting of a full bladder, causing a large laceration of the dome of the bladder.

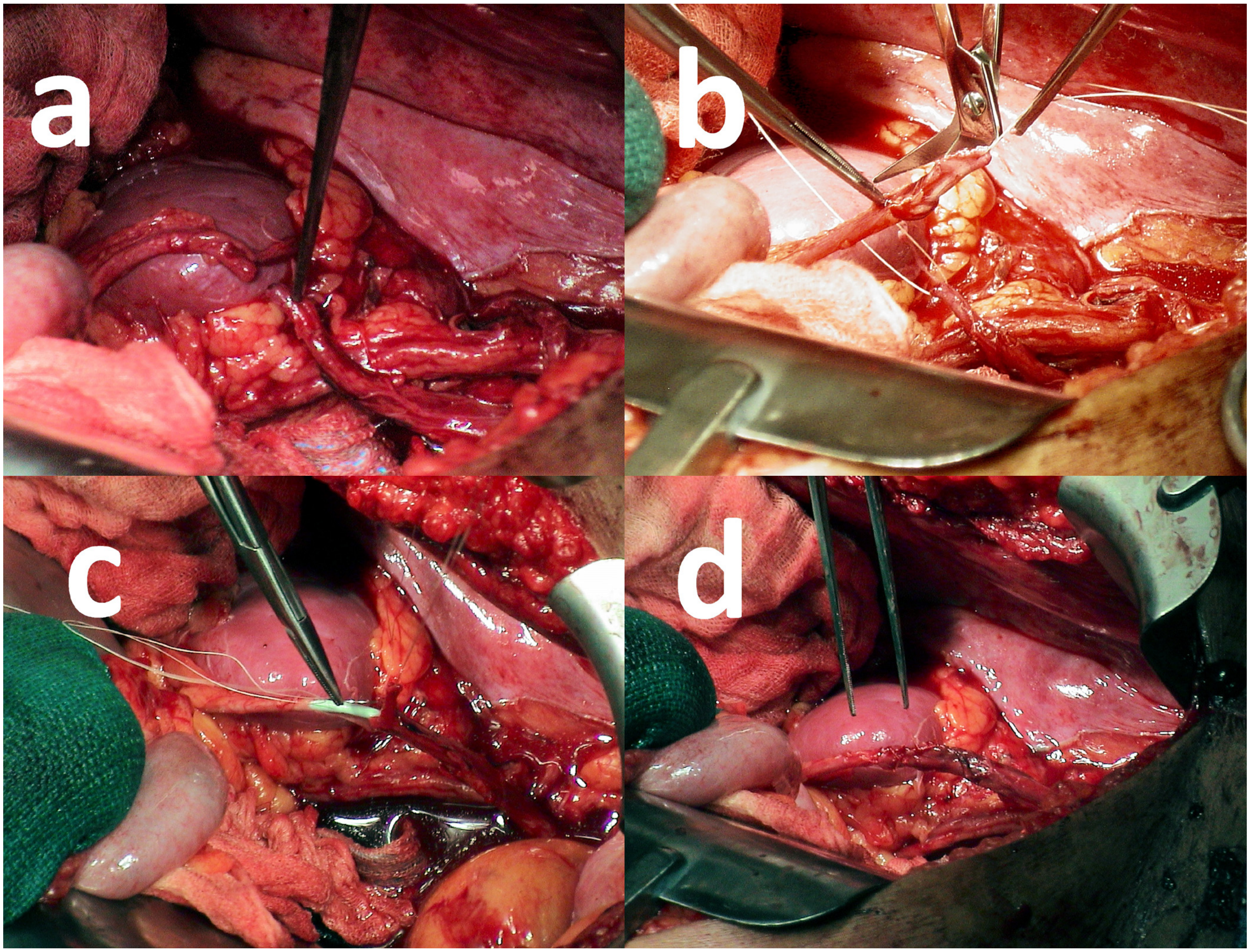


Figure 9. In this patient with a transected left ureter, the injury is identified (distal end in forceps) and the ureter mobilized (a). The ureteral ends have been tagged with absorbable suture and spatulated using Potts scissors (b). A double-J stent has been placed with the distal end into the bladder and the proximal end into the kidney. The ureter is approximated with interrupted absorbable sutures (c). The final repair is made over the stent (d).

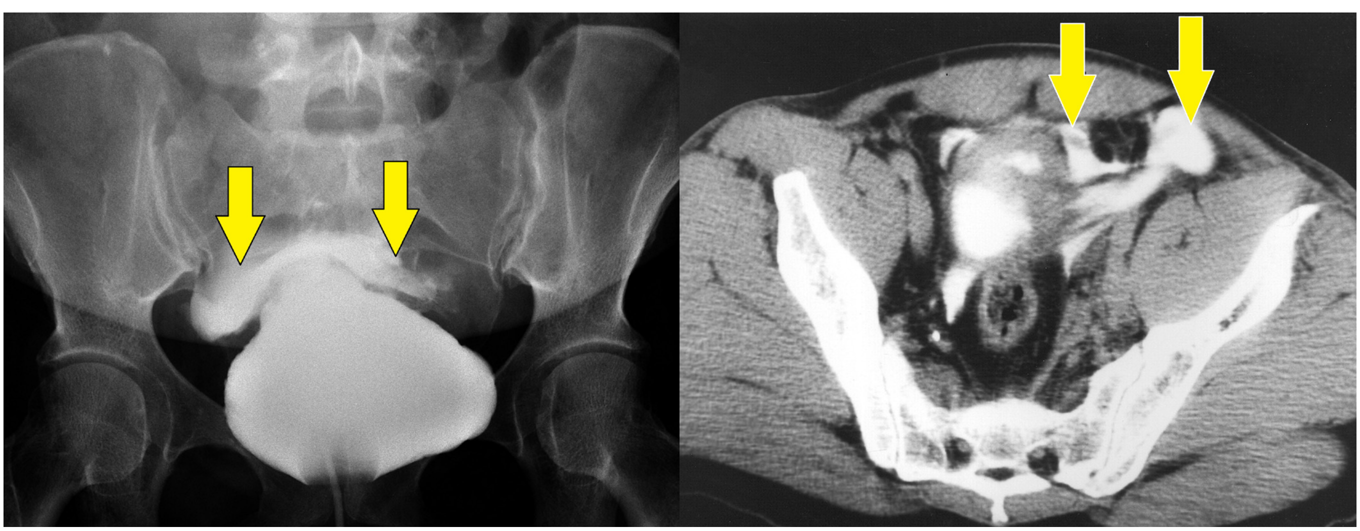


Figure 10. Conventional (left) and CT (right) cystograms showing intraperitoneal leakage of contrast material (arrows).

Operative Exposure of the Bladder

- The bladder should be explored during trauma laparotomy and will be decompressed if a Foley catheter has been inserted. The Foley can be clamped or filled retrograde to assist evaluation of the bladder.
- Bladder injury discovered at laparotomy mandates exploration of the inside of the bladder (Figure 11). This can generally be done through the injury or by extension of the injury.
- Exploration of the interior portion of the bladder requires inspecting the wall of the bladder, looking for other wounds, and inspecting the trigone of the bladder.
- The trigone is the smooth triangular region of the internal urinary bladder formed by the two ureteral orifices and the internal urethral orifice.
- The ureteral orifices should be visualized bilaterally and efflux of clear urine seen. If this is not observed (and the injury is in proximity), ureteral injury may be present, and insertion of a stent (Figure 11) or further exploration is warranted.
- Repairs to the bladder are made with two layers of absorbable suture.
- A suprapubic catheter is typically **not** required, but it is necessary to have a large-bore Foley catheter inserted until a cystogram demonstrates no leak postoperatively.
- A suprapubic catheter may be valuable or necessary when there is a concomitant posterior urethral injury that precludes safe placement of a urethral catheter, or when the bladder is severely injured and the repair is tenuous or incomplete.

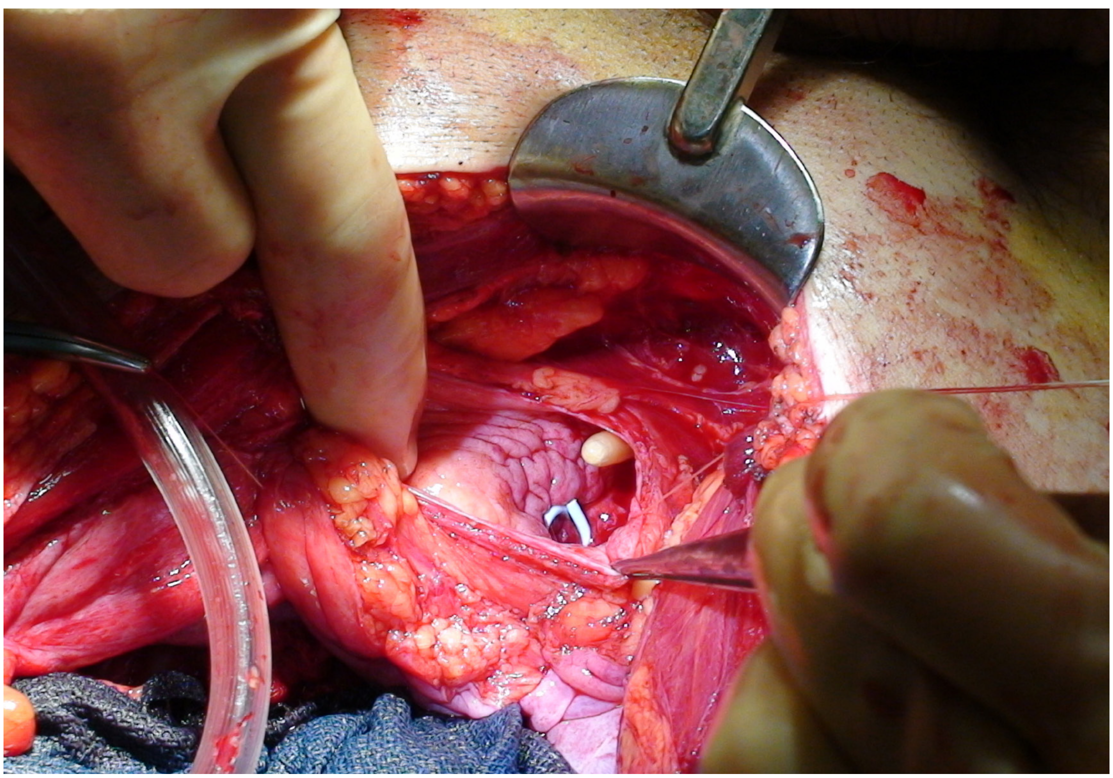
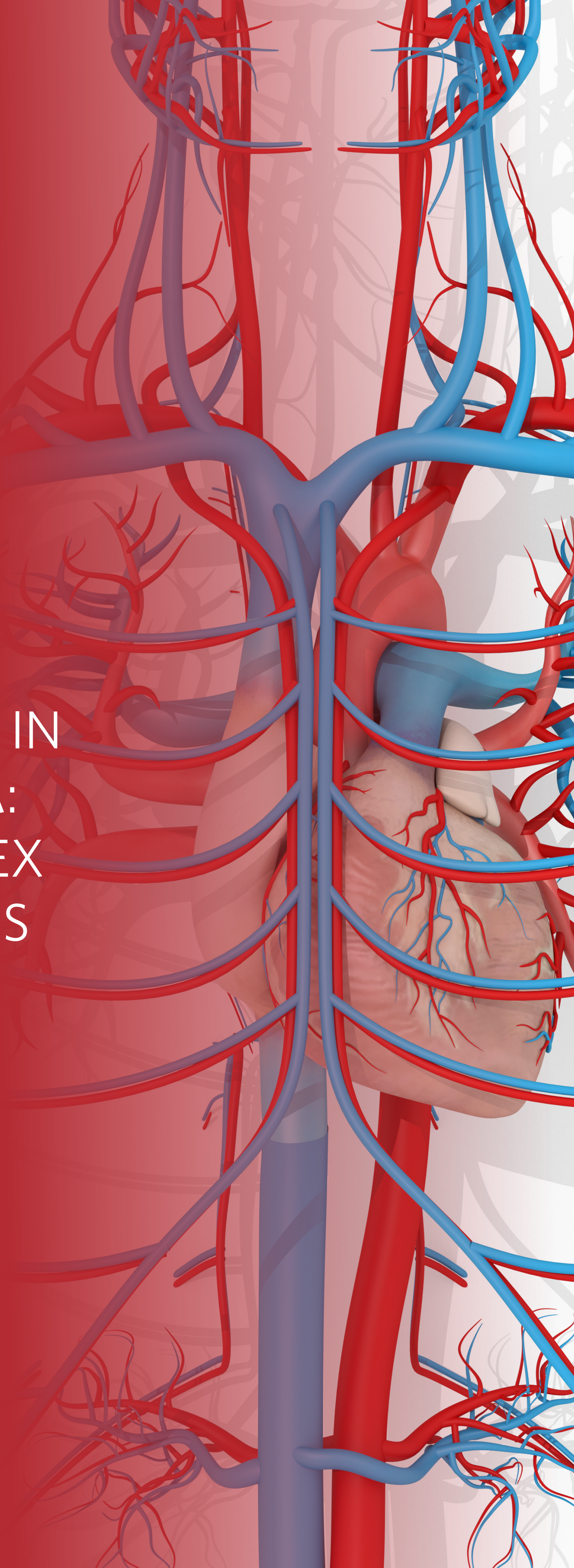


Figure 11. The urinary bladder is being inspected through an extension of the injury to the intraperitoneal dome of the bladder. Note the tip of the Foley catheter and the end of a double-J stent that has been inserted into the right ureter. The bladder dome will be closed with two layers of running absorbable suture.

CHAPTER 21

OPERATIVE EXPOSURE IN ABDOMINAL TRAUMA: EXPOSURE OF COMPLEX INJURIES TO THE PELVIS AND PERINEUM



Operative Exposure in Abdominal Trauma: Exposure of Complex Injuries to the Pelvis and Perineum

This chapter will discuss complex pelvic and perineal injuries and their surgical exposure.

Learning Objectives

By the end of the ASSET course, participants should be able to do the following:

1. Describe the approach to complex injuries of the pelvis and perineum.
2. Describe the role of angiography and angioembolization to control pelvic hemorrhage.
3. Demonstrate preperitoneal packing.

Considerations

- Traumatic pelvic injuries result from very high-energy mechanisms, placing the patient at risk of associated life-threatening and devastating injuries.
- The combination of potential vascular, genitourinary, rectal, nerve, soft tissue, and bony injuries requires a multispecialty care team typically found in a trauma center (Figures 1 and 2).

Initial Management

- Hemodynamically unstable pelvic fractures are very challenging to treat. Patients can easily exsanguinate from a pelvic fracture.
- Patients with suspected or proven severe pelvic fractures are likely to require initiation of massive transfusion protocol for optimal outcomes. A low threshold for resuscitation with blood products should be maintained.
- If the pelvic fracture is unstable, particularly in the case of an open-book fracture, the pelvic ring should be closed to assist with hemorrhage control. This can be accomplished with minimal equipment, such as wrapping a sheet snugly around the pelvis at the level of the greater trochanters (Figure 3).
- Several commercial devices, such as the T-pod (Figure 4), are also available and are generally more effective when used properly (centered over the greater trochanters) than using a sheet to wrap the pelvis.
- Field-expedient and commercial pelvic binders help control hemorrhage from the pelvis by decreasing the pelvic volume (Figure 5). An open-book fracture with separation of the pubic symphysis can increase the pelvic volume with potential for significant blood loss into the resultant space.

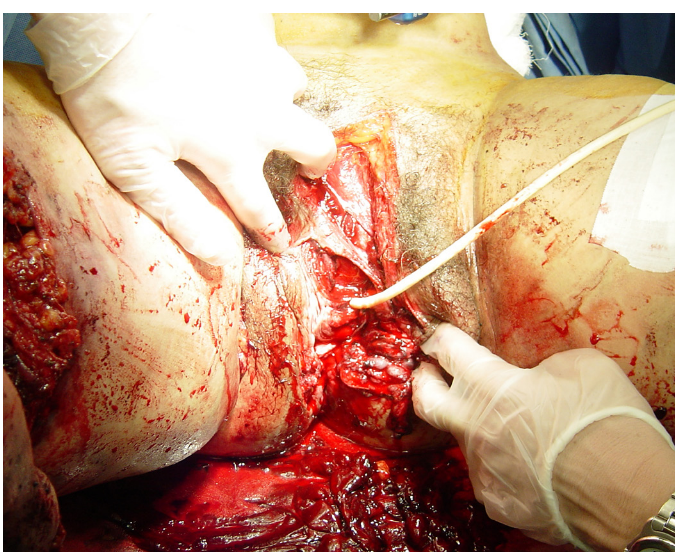


Figure 1. Open pelvic fracture in a middle aged female with associated injury to the rectum, vagina, and urethra.

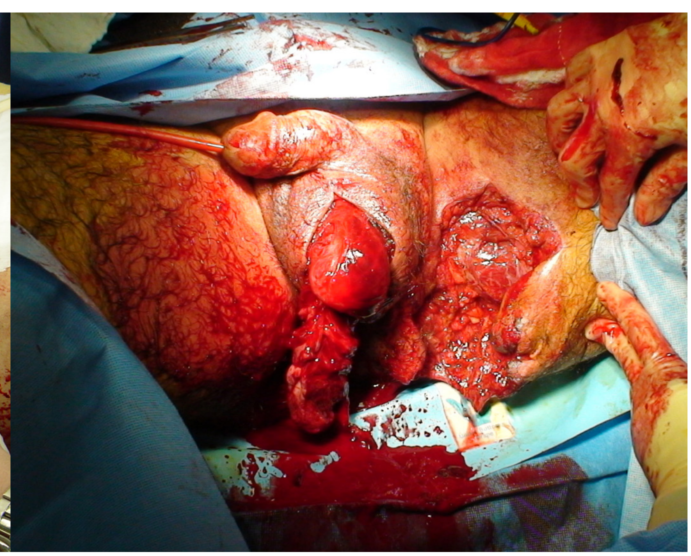


Figure 2. Open pelvic fracture in a young male with associated injury to the rectum and scrotum.

Figure 3. A sheet has been used to bind the pelvis at the level of the greater trochanters in this young male with a pelvic fracture, using a stick to tighten the wrap.

Figure 4. This commercially available pelvic binder (T-pod) has been placed on this female with a pelvic fracture and is centered over the greater trochanters.

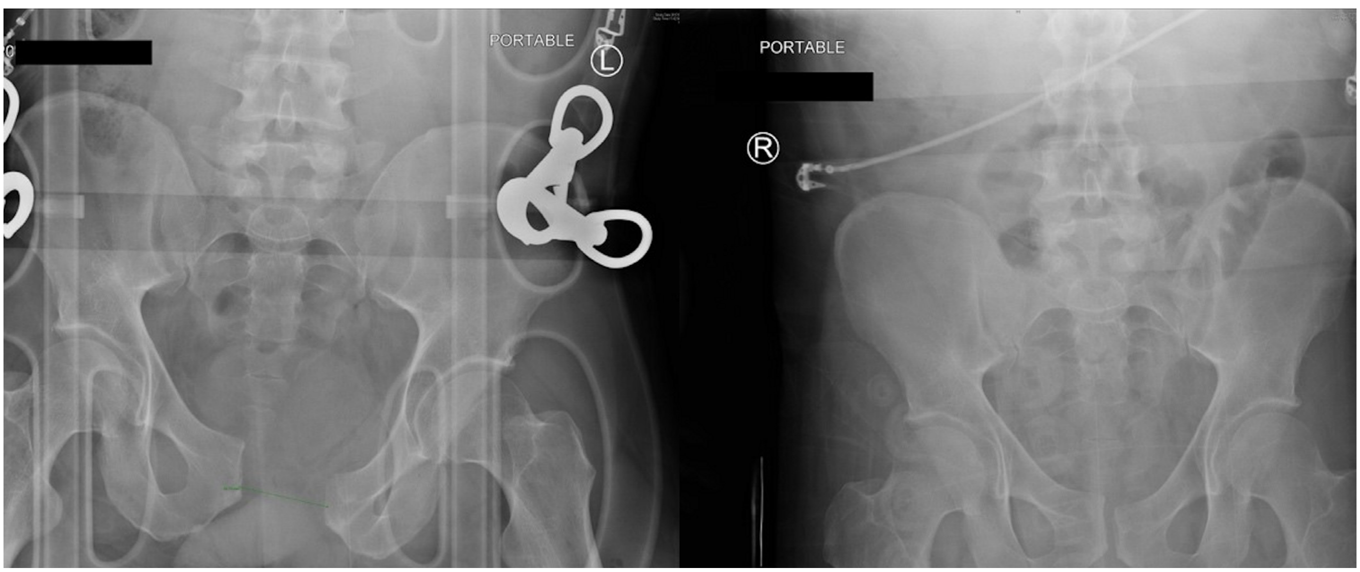


Figure 5. The X rays above show an open-book pelvic fracture before (left) and after (right) a pelvic binder was placed, showing the utility of such devices to decrease pelvic volume.

- Following initial stabilization and closure of the pelvic ring with a binder, several paths for the further management of these injuries are available and will be dictated by the presence of other life-threatening injuries, the patient's hemodynamic and physiologic stability, and access to specialty services such as interventional radiology and orthopaedics.
- The management of hemodynamically unstable high-energy pelvic injuries remains controversial, and there are a number of proposed modalities.
- Alternatives for temporizing and/or definitive management of hemorrhage from pelvic fractures are as follows:
  - Pelvic binding, as described above, is a temporizing measure.
  - Pelvic packing can be either temporizing or definitive, depending on the source of hemorrhage.
  - Resuscitative endovascular balloon occlusion of the aorta (REBOA), as described in Chapter 22, is a temporizing measure that will allow for subsequent definitive management.

- Intravascular embolization of hemorrhage using coils or gelfoam is done either in an interventional radiology suite or, preferably, in a hybrid operating room. This allows for definitive control of hemorrhage and is strongly supported by available literature (Level 1 recommendation) and 2011 EAST guidelines (*east.org/education/practice-management-guidelines/pelvic-fracture-hemorrhageupdate-and-systematic-review*).
- Ligation of bilateral internal iliac arteries.
- External (or delayed internal) fixation of the pelvic fracture is described in Chapter 28. Early fixation of the pelvic ring may assist with bleeding control and will help subsequent patient care and mobilization. In patients with hypotension, pelvic fixation should not delay the implementation of the other procedures described above.

PELVIC PACKING

Considerations

- Timing and sequence of intervention for patients with hemorrhage from pelvic fractures is very dependent on local institutional practice, but hemodynamically unstable patients are best managed in the operating room (ideally a hybrid room). There, external fixation, preperitoneal packing, and angiographic embolization can be performed. If interventional radiology is not available or will be delayed, patients who are hemodynamically unstable should be considered for pelvic (retroperitoneal) packing.
- Classically, pelvic packing is performed through a dedicated incision in the lower abdomen. However, it must be remembered that patients who have significant pelvic trauma also have a high likelihood (roughly 35 percent) of associated intra-abdominal injuries, necessitating a laparotomy.
- Pelvic packing can serve as a temporizing measure, but in small series it has been shown to be definitive in up to 83 percent of patients.

Technique

- In patients in whom a concomitant trauma laparotomy is not indicated (ruled out by CT scan or other means), a midline incision is made between the umbilicus and the pubis (Figure 6).
- The rectus sheath is divided and the space of Retzius (preperitoneal space) is entered, taking care **not** to enter the peritoneum, which is displaced posteriorly along with the bladder (Figure 7).

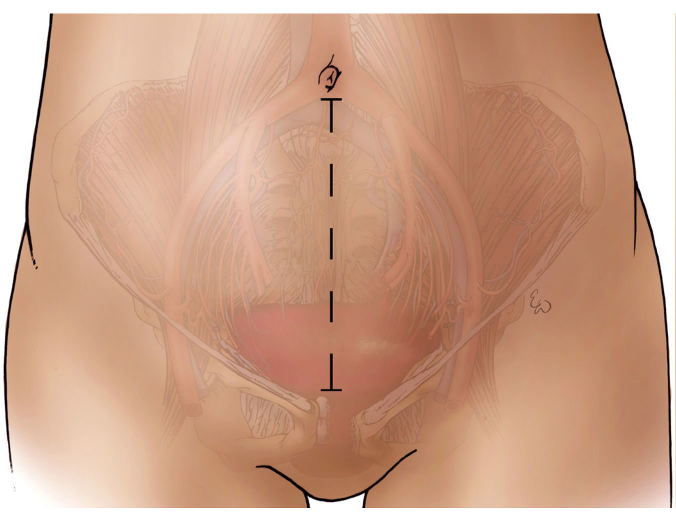


Figure 6. Pelvic packing is accomplished via a lower midline incision between the umbilicus and pubis.

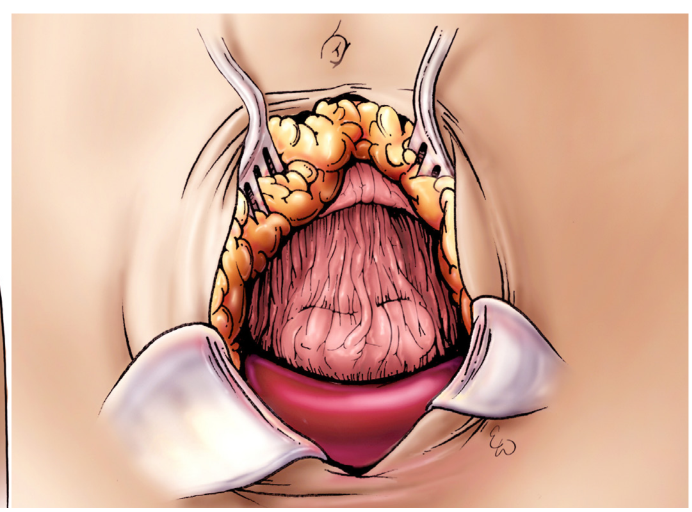


Figure 7. The space of Retzius, which is anterior to the bladder and peritoneum, is entered after division of the rectus sheath. Hematoma in this space is then evacuated.

- In the presence of a large pelvic hematoma, dissection of the retroperitoneal space will have been accomplished by the hematoma. The hematoma is evacuated by hand, and packs are placed on either side (usually three or four per side) as far posteriorly as possible to tamponade bleeding (Figure 8). Be mindful of bony shards when placing the packs.
- The fascia is then closed over the packs (Figure 9), which will be removed once the patient's physiology has been corrected and any bleeding controlled.
- If the patient has intra-abdominal injuries that require a laparotomy as well as an unstable pelvic fracture, pelvic packing can still be performed. This requires that the lower portion of the peritoneum be left intact. This can be accomplished by stopping the laparotomy incision just below the umbilicus and making a second incision inferiorly along the midline (Figure 10).
- Alternatively, the pelvis can be packed through a standard single-incision trauma laparotomy in which the lower portion of the peritoneum is left intact and the space of Retzius is entered above the peritoneum to allow placement of packs (Figures 11 and 12).

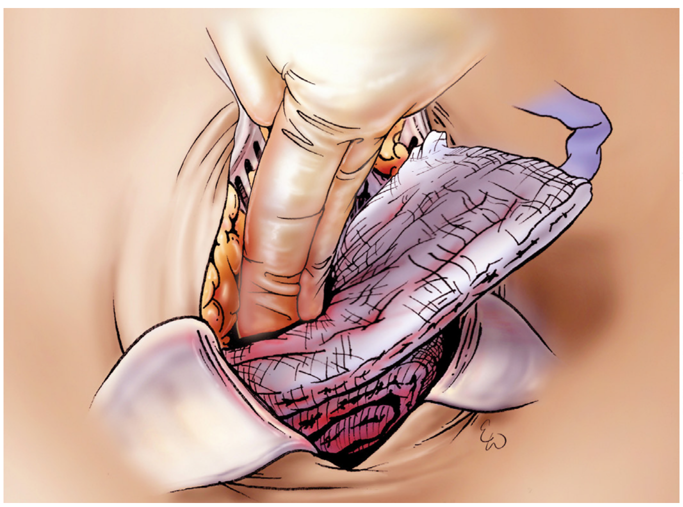


Figure 8. Pelvic packs are placed into the retroperitonel space as far posteriorly as possible and along the pelvic sidewalls.

Figure 9. Typically, three packs are placed on either side of the pelvis, and the fascia is closed over them to effect hemostasis.

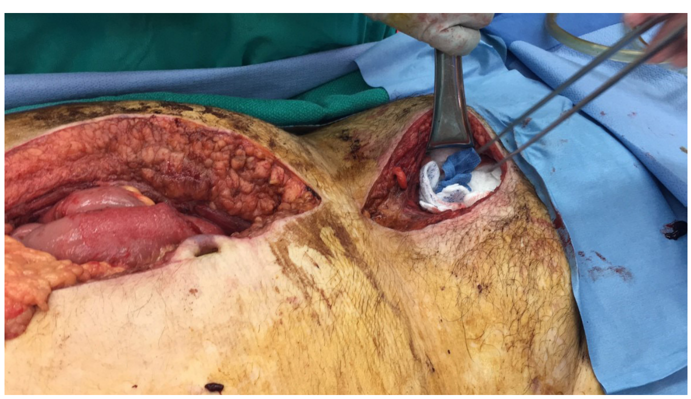


Figure 10. The laparotomy incision has been terminated just below the umbilicus, and a second incision has been made caudally to enter the space of Retzius for placement of packs to control bleeding from a pelvic fracture.

LOWER ABDOMEN/PELVIS - HEAD TO BOTTOM

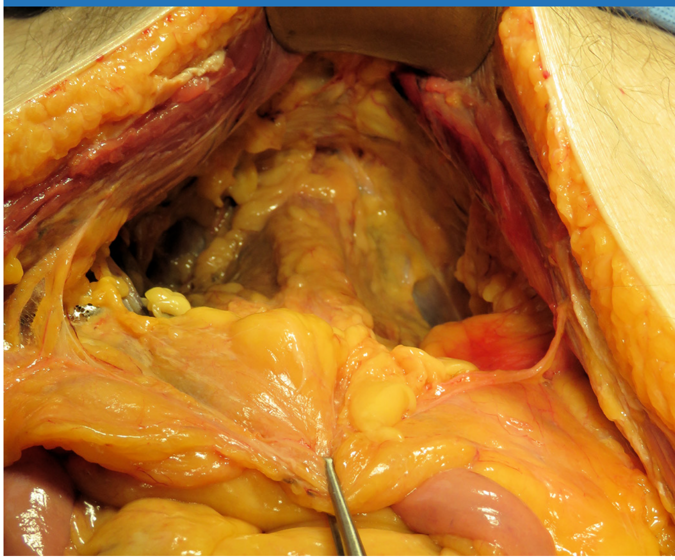


Figure 11. The lower portion of the peritoneum (clamp) has been preserved and the space of Retzius developed from a standard laparotomy incision.

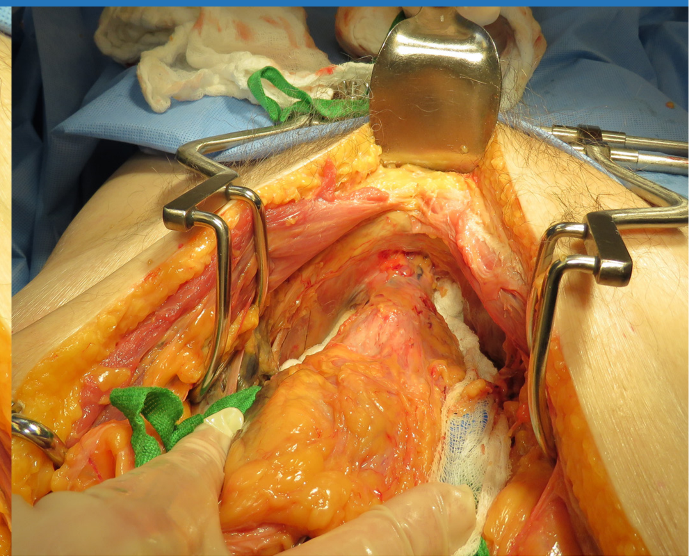
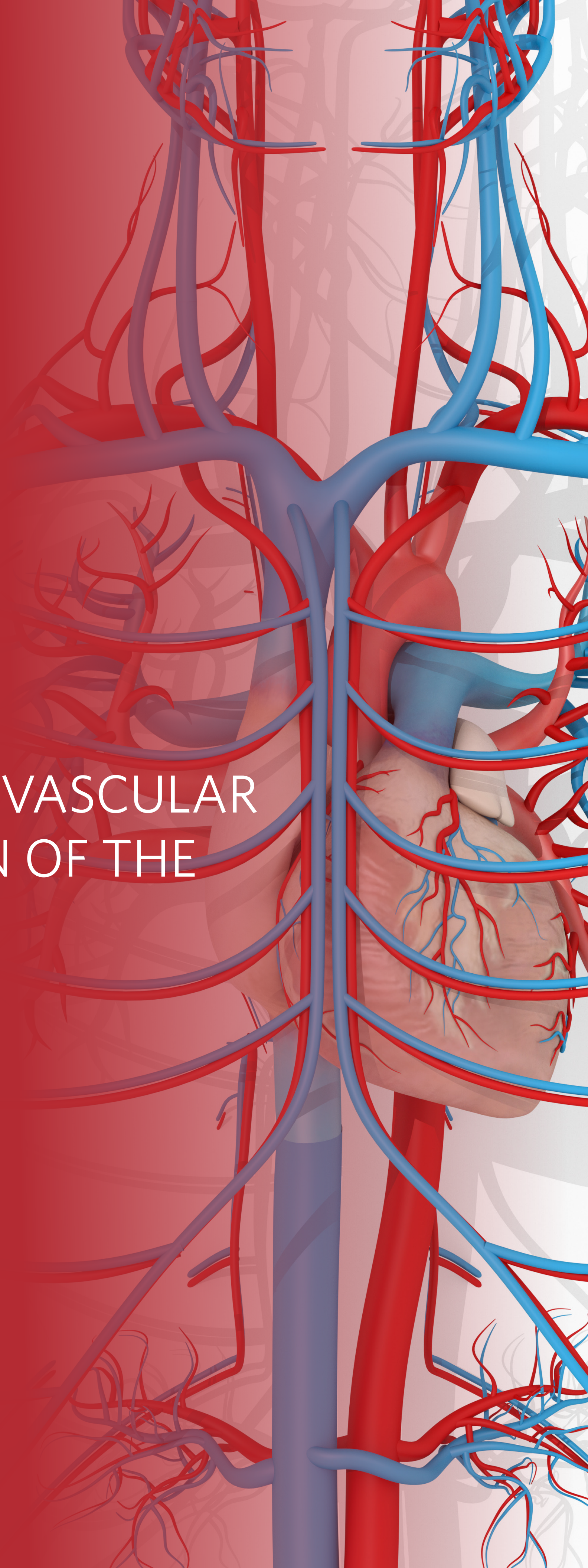


Figure 12. Packs are placed on either side of the bladder down along the pelvic sidewalls to control bleeding from a pelvic fracture via this single incision laparotomy.

Evaluation of Injuries to the Perineum

- After abdominal sources of bleeding have been controlled, the next step is a detailed examination for injuries of the perineum, genitalia, and rectum. A speculum and rigid sigmoidoscopy should be used to evaluate for injury of the vagina and rectum, respectively. The patient may also require evaluation with retrograde urethrogram.
- Removal of debris and foreign bodies, as well as debridement of devitalized tissue followed by copious irrigation, can be helpful in delineating the extent of injury. Complex injuries such as those seen in Figures 1 and 2 are examples of complex soft-tissue injuries of the perineum that require careful evaluation, irrigation, debridement, and packing.
- If the injury involves the anorectal region, or if the injury is so extensive that there will be possibility of significant ongoing contamination during defecation, a diverting-loop colostomy may be needed to divert fecal flow from the injury site. This does not always have to be done at the initial operation.
- Reconstruction of extensive soft-tissue injuries should be delayed due to the risk of ongoing contamination, necrotizing infection, and sepsis. Involvement of subspecialty expertise is advisable for the reconstruction of these difficult injuries.
- All fractures should be immobilized as soon as possible.

CHAPTER 22
INTRODUCTION TO RESUSCITATIVE ENDOVASCULAR BALLOON OCCLUSION OF THE AORTA (REBOA)



Introduction to Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA)

This chapter will review the indications for and technical steps of performing resuscitative endovascular balloon occlusion of the aorta (REBOA). The major emphasis of this module will be to review options for obtaining access to the common femoral artery (CFA), as well as the use of the two most common REBOA catheter systems in North America. This module is designed to be an introduction and is not intended to replace formal REBOA training courses such as the Basic Endovascular Surgery for Trauma (BEST®) course administered by the American College of Surgeons Committee on Trauma.

Learning Objectives

By the end of this module, participants should be able to do the following:

1. Discuss indications for the use of REBOA.
2. Identify external landmarks for common femoral artery (CFA) access.
3. Describe options available to access the CFA.
4. Demonstrate surgical exposure of the CFA and the basic steps of REBOA insertion.
5. Describe the external landmarks for the aortic occlusion zones.
6. List the technical differences of the two REBOA catheters most commonly used in North America.
7. Describe the potential complications of REBOA.

General Considerations and Indications

- Noncompressible torso hemorrhage (NCTH) is a leading cause of potentially preventable death in both civilian and military trauma settings.
- NCTH resulting in profound hypotension or shock requires proximal control of blood flow while increasing cardiac afterload and central aortic pressure until direct hemostasis can be achieved.
- Proximal control in such circumstances is typically obtained by resuscitative thoracotomy (RT), as discussed in chapter 10, or less commonly via intra-abdominal control of the aorta, as described in chapter 15.
- REBOA is an alternative approach to proximal aortic control in patients at risk of imminent cardiovascular collapse or in traumatic arrest. It can be performed through a CFA approach without the need for thoracotomy. During arrest, it can be performed concurrently with closed chest compressions (CPR).
- REBOA is most useful when the site of hemorrhage is below the diaphragm and open thoracic vascular intervention is not required.
- RT remains the procedure of choice for patients with significant thoracic or cardiac injury, and REBOA is contraindicated in these conditions, as the procedure will likely increase thoracic bleeding. Additionally, RT remains the gold standard for aortic occlusion in traumatic arrest.
- Patients exsanguinating from abdominal, pelvic, or junctional lower extremity trauma may be candidates for REBOA.
- Early recognition of hemorrhagic shock will facilitate identification of patients who may benefit from REBOA. Mechanisms of injury likely to benefit include penetrating injuries to abdomen or pelvis, blast or blunt mechanism with a positive FAST, suspected pelvic fracture, or massive proximal lower extremity trauma.

- REBOA has also been used successfully for proximal aortic occlusion in ruptured abdominal aortic aneurysms, elective oncologic resections, orthopaedic procedures, gastrointestinal bleeds, and hemorrhage from obstetric and gynecologic conditions.
- In patients with risk factors for impending cardiovascular collapse, consider placing an arterial line in the CFA, as this will facilitate subsequent placement of a REBOA catheter if needed.
- Ideally, REBOA should be performed prior to cardiac arrest.
- Exsanguinating hemorrhage in the chest must be ruled out (by chest X ray, ultrasound, or chest tube placement) **prior** to placing a REBOA catheter, as endovascular occlusion of the aorta may fatally increase such bleeding.
- Practitioners wishing to perform REBOA should be experienced in obtaining surgical exposure of the CFA, as up to 50 percent of patients in need of REBOA will require cut-down on the CFA to insert the sheath.
- REBOA is a temporary, minimally invasive bridge to definitive surgical or endovascular hemorrhage control.

REBOA Catheters

- A number of catheters that can be used for REBOA are available internationally, but in North America, two are commonly used: the Coda® Balloon Catheter (Cook Medical) and the ER-REBOA™ Catheter (Prytime Medical).
- The Coda Balloon Catheter is a 9 French device with a 32 mm balloon that is 120 cm in length. It requires a 12 French introducer sheath and a 260 cm guide wire. Placement requires a significant length of sterile field (Figure 1).
- Due to the size of the introducer sheath of the Coda Balloon Catheter, insertion into the CFA will require cut-down and repair of the vessel.
- The ER-REBOA Catheter is a 6 French catheter with a 32 mm balloon that is 72 cm in length and can be inserted via a 7 French introducer sheath. It does not require a guide wire. Additionally, this catheter has centimeter markings along the length, a secondary lumen allowing for monitoring of arterial blood pressure above the balloon, an atraumatic tip, and a compliant balloon with radiopaque markers on either end allowing for confirmation of placement with plain radiography (Figure 2).
- The smaller size of the ER-REBOA makes the need for repair of the artery much less likely upon removal of the required 7 French introducer sheath.

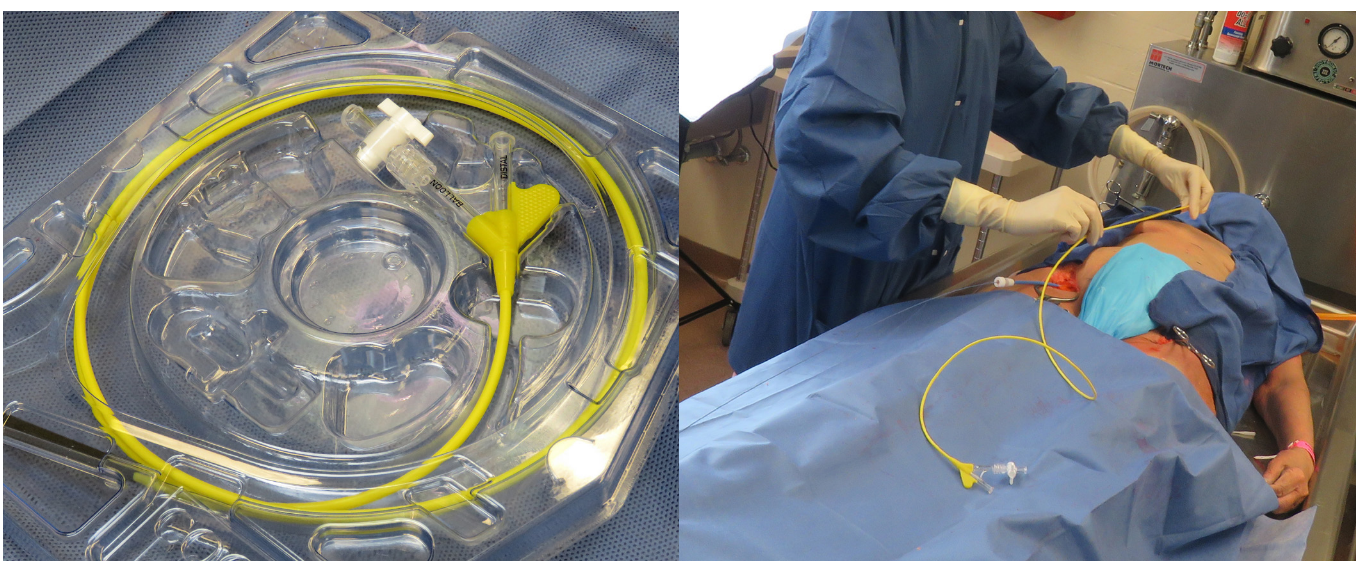


Figure 1. The Coda Balloon Catheter is a 120 cm long 9 French catheter that requires a 260 cm guide wire and a long sterile field (note the wire extending over the feet).

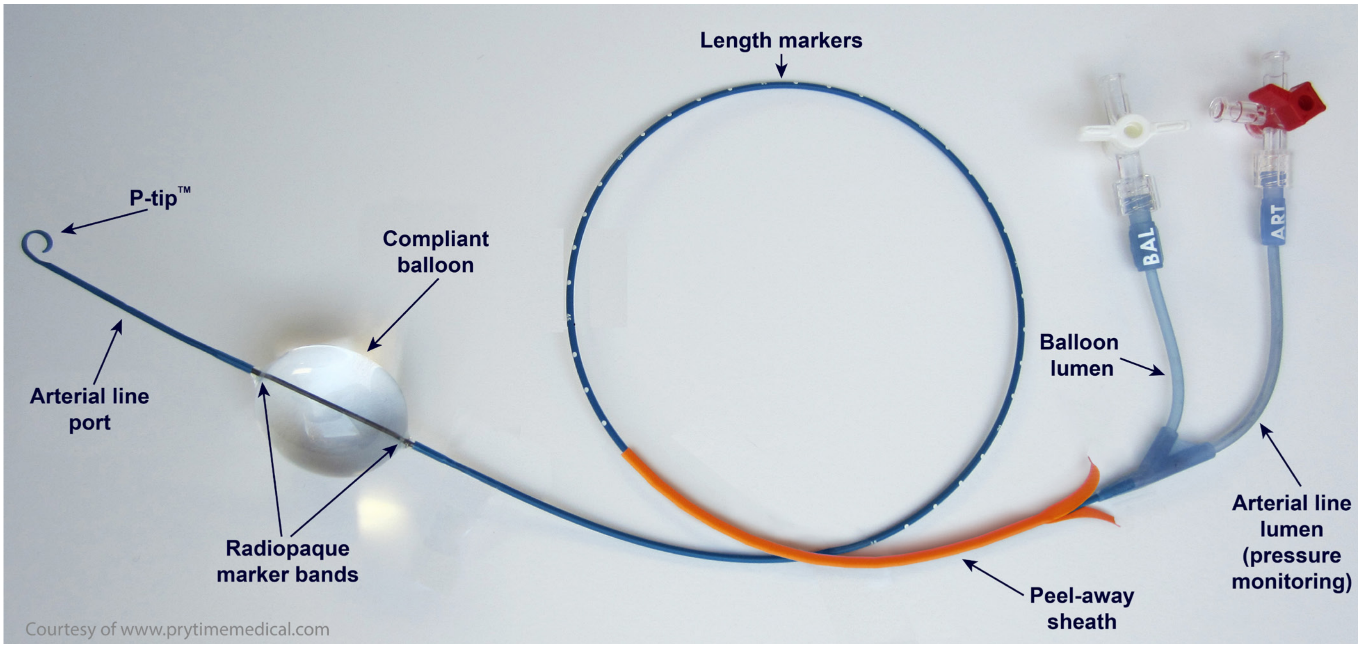


Figure 2. The ER-REBOA Catheter. Image courtesy of Prytime Medical

Positioning and Arterial Access

- The patient should be in the supine position with wide prep of the groin. Pertinent anatomical landmarks should be visible, including the anterosuperior iliac crest and the pubic bone. A line drawn from the anterosuperior iliac crest to the pubic bone represents the inguinal ligament (Figure 3).
- The CFA is the preferred site of insertion of the sheath required to place the REBOA catheter. Cannulation of the superficial femoral artery (SFA) should be avoided as its diameter is smaller than that of the CFA, leading to possible arterial injury and hemorrhage, ischemia, thrombosis, and/or amputation.
- Percutaneous, ultrasound-guided (if available) cannulation (Figure 3) is the preferred method for accessing the CFA. After the CFA has been entered with a needle, the Seldinger technique is used to place an introducer sheath into the artery for REBOA placement (Figures 4 and 5).
- Percutaneous cannulation of the CFA in the setting of cardiac arrest can be technically challenging. In these situations, ultrasound guidance should be used or open access via a femoral artery cut down should be pursued (Figure 6). Regardless of the size of introducer sheath used for REBOA, approximately half of the patients require an open groin cut-down for access (as described in chapter 3).
- The inguinal ligament is a crucial anatomic landmark for accessing the CFA. The inguinal crease is often incorrectly assumed to correlate with the inguinal ligament. However, the relationship between the inguinal crease and inguinal ligament is highly variable, with the inguinal crease often lying well below the inguinal ligament.

Figure 3. The inguinal ligament (marked line) on this patient's left side (head to right) is used as a landmark to percutaneously cannulate the CFA just below the ligament.

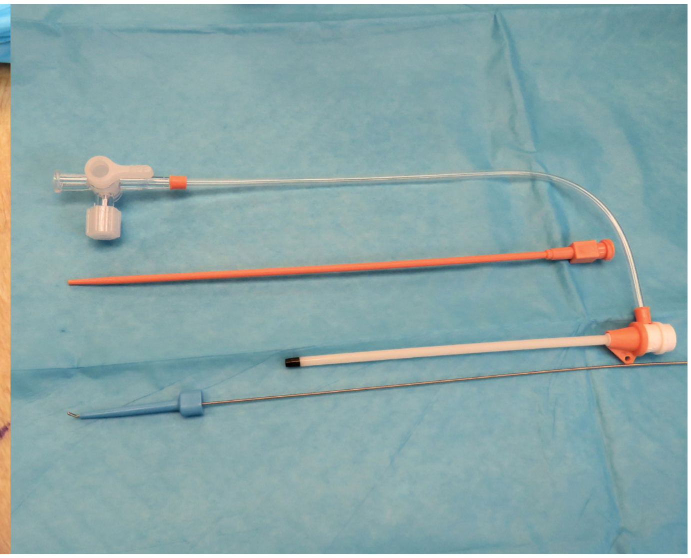


Figure 4. A 7 French introducer sheath will be placed using the Seldinger technique in preparation for insertion of the ER-REBOA Catheter.

Figure 5. A 7 French introducer sheath in place in the left CFA. The wire and dilator are still in the sheath and will be removed prior to catheter placement.

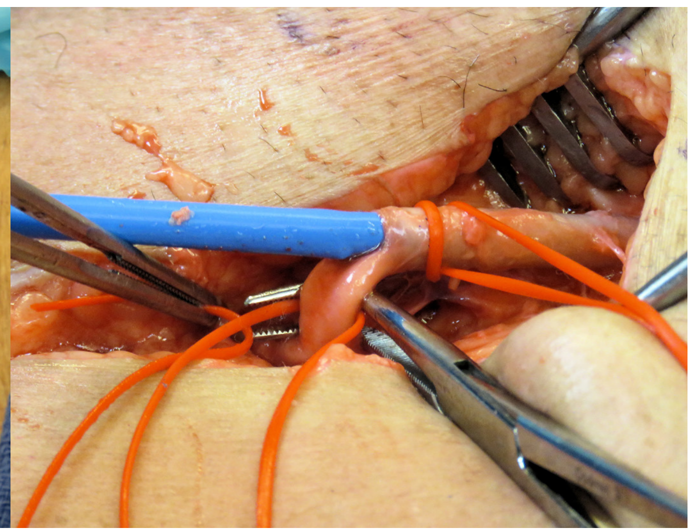


Figure 6. A 12 French introducer sheath has been placed via cut-down into this patient's right CFA to enable subsequent placement of a Coda Balloon Catheter.

Catheter Insertion

- The catheter for REBOA is placed in either Aortic Zone I or Aortic Zone III, which are illustrated in Figure 7. Aortic Zone I is the area from the distal aortic arch down to the celiac artery. Aortic Zone III is the area from just below the renal arteries down to the aortic bifurcation. Aortic Zone II is the area between Zones I and III and includes the mesenteric and renal arteries.
- The depth of insertion of the balloon catheter is determined by the most likely source of the bleeding to be temporarily controlled.
- The REBOA catheter is placed and inflated in Aortic Zone I when the source of exsanguination is believed to be intra-abdominal or retroperitoneal hemorrhage. Aortic Zone I is also used in patients with traumatic arrest in lieu of performing a resuscitative thoracotomy, keeping in mind that REBOA should not be performed if the etiology of the shock or arrest is secondary to injury in the chest.

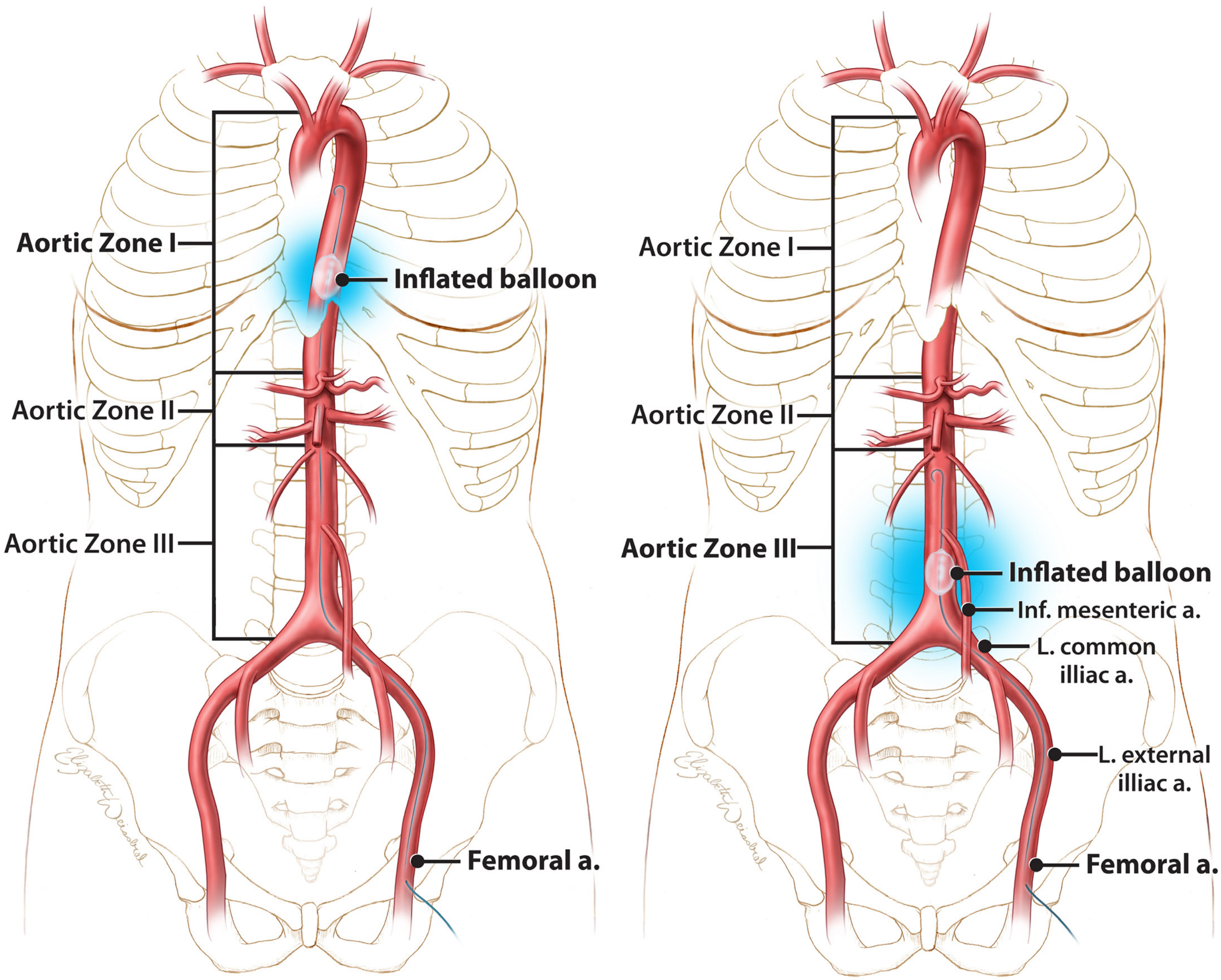


Figure 7. The aortic zones of occlusion, with balloons inflated in Zone I on the left and Zone III on the right.

- Aortic Zone III is occluded with the REBOA catheter when the suspected source of exsanguination is pelvic, junctional, or proximal lower extremity hemorrhage.
- The radiographs seen in Figures 8 and 9 demonstrate balloon inflation in Aortic Zones I and III, respectively.
- Proper positioning of the balloon can be achieved by the use of external landmarks on the patient followed by confirmatory radiography prior to balloon inflation.
- Different external landmarks are used for the Coda Balloon Catheter and the ER-REBOA Catheter, as detailed below.

Figure 8. An aortic occlusion balloon inflated in Aortic Zone I.

Figure 9. An aortic occlusion balloon inflated in Aortic Zone III.

INSERTION OF THE CODA BALLOON CATHETER

- The Coda Balloon Catheter has no external length markers. Therefore, an external indicator must be placed on the actual catheter prior to placement to indicate the depth of insertion required to reach either Aortic Zone I or III. A marking pen or sterile tape can be employed for this task.
- The external landmark for Aortic Zone I occlusion when using the Coda catheter is the xiphoid process; proper placement requires orienting the bottom of the balloon about 2 cm above the xiphoid process (Figure 10).
- The external landmark for Aortic Zone III occlusion when using the Coda catheter is the umbilicus; proper placement involves orienting the bottom of the balloon about 2 cm above this landmark (Figure 11).
- Radiographic confirmation of placement should be obtained prior to balloon inflation. This step can be omitted if the patient is in arrest with ongoing CPR, but radiographic confirmation should be obtained if and when return of spontaneous circulation occurs.

HEAD TO THE RIGHT

Figure 10. The xiphoid process is used to estimate the depth of insertion of the Coda Balloon Catheter to occlude Aortic Zone I.

Figure 11. The umbilicus is used to estimate the depth of insertion of the Coda Balloon Catheter to occlude Aortic Zone III.

INSERTION OF THE ER-REBOA BALLOON CATHETER

- The ER-REBOA Catheter has external distance markers printed on the catheter, which helps estimate depth of insertion at the hub of the CTA introducer sheath.
- The external landmark for Aortic Zone I occlusion is the suprasternal (jugular) notch, orienting the tip of the catheter just below the notch (Figure 12).
- The external landmark for Aortic Zone III occlusion is the xiphoid process, placing the tip of the catheter just below this landmark (Figure 13).
- Radiographic confirmation of placement is obtained prior to balloon inflation, if possible (Figure 14).
- The arterial port is flushed and then attached to monitoring tubing in order to provide pre- and post-inflation systolic blood pressures.

Balloon Inflation

- Once the position of the balloon has been confirmed with radiographic imaging, the catheter should be secured to the introducer sheath **before, during, and after inflation**. Failure to secure the catheter to the sheath may result in distal migration, possible aortic intimal injury, and loss of hemorrhage control.
- The balloon should be inflated cautiously, as overinflation could result in injury to the aorta.
- Watch for hemodynamic changes during inflation, remembering that a vasoconstricted distal abdominal aorta can be less than 1 cm in diameter. With low-profile systems such as the ER-REBOA Catheter, resistance to inflation is largely from the shaft lumen, with little feedback from the balloon itself.
- The maximum inflation volume of the aortic balloon differs based upon the REBOA catheter being used. Users are obligated to be familiar with the system being utilized and the maximum inflation volumes for the specific catheter being used, as well as the estimated aortic diameter of the patient.

HEAD TO LEFT

Figure 12. The suprasternal (jugular) notch is used to estimate the depth of insertion of the ER-REBOA Catheter to occlude Aortic Zone I.

Figure 13. The xiphoid process is used to estimate the depth of insertion of the ER-REBOA Catheter to occlude Aortic Zone III.

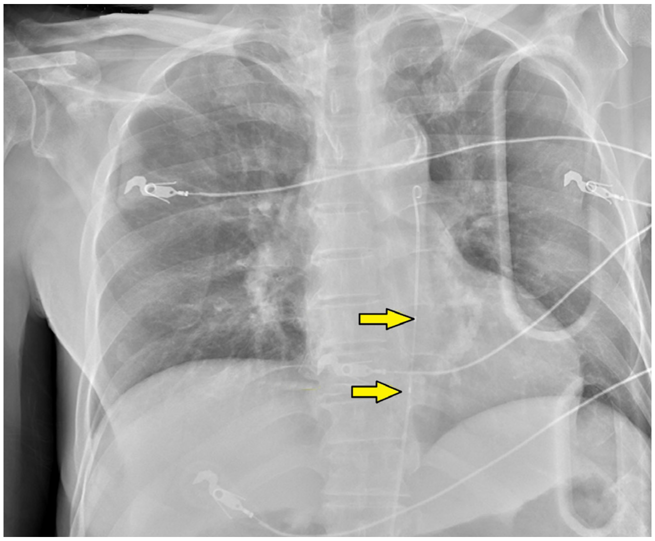


Figure 14. Radiograph confirming appropriate placement of the balloon of an ER-REBOA Catheter in Aortic Zone I. Radiopaque markers (arrows) mark the proximal and distal extent of the balloon.

- The recommended **initial** inflation of the ER-REBOA Catheter balloon is 8 cc for Aortic Zone I and 3 cc for Aortic Zone III ("3 to 8, don't overinflate").
- If hemostasis is not obtained after inflation in Aortic Zone III, then the balloon should be deflated, advanced, and inflated in Aortic Zone I.
- Once the balloon has been inflated, the time of inflation should be recorded in the medical record, and the patient should undergo emergent surgical or catheter-based control of bleeding.
- The exact duration of safe occlusion of the aorta using REBOA is not well defined, but longer is definitely worse. Current clinical experience and published guidelines recommend limiting occlusion of Aortic Zone I to 15 to 30 minutes (with 60 minutes as the extreme).
- The occlusion time tolerated by Aortic Zone III is longer than Aortic Zone I but is also not well established. Published series show a survival advantage for shorter occlusion times in both zones.
- Partial balloon inflation has been proposed as a way to extend safe occlusion times but cannot currently be supported as standard practice.

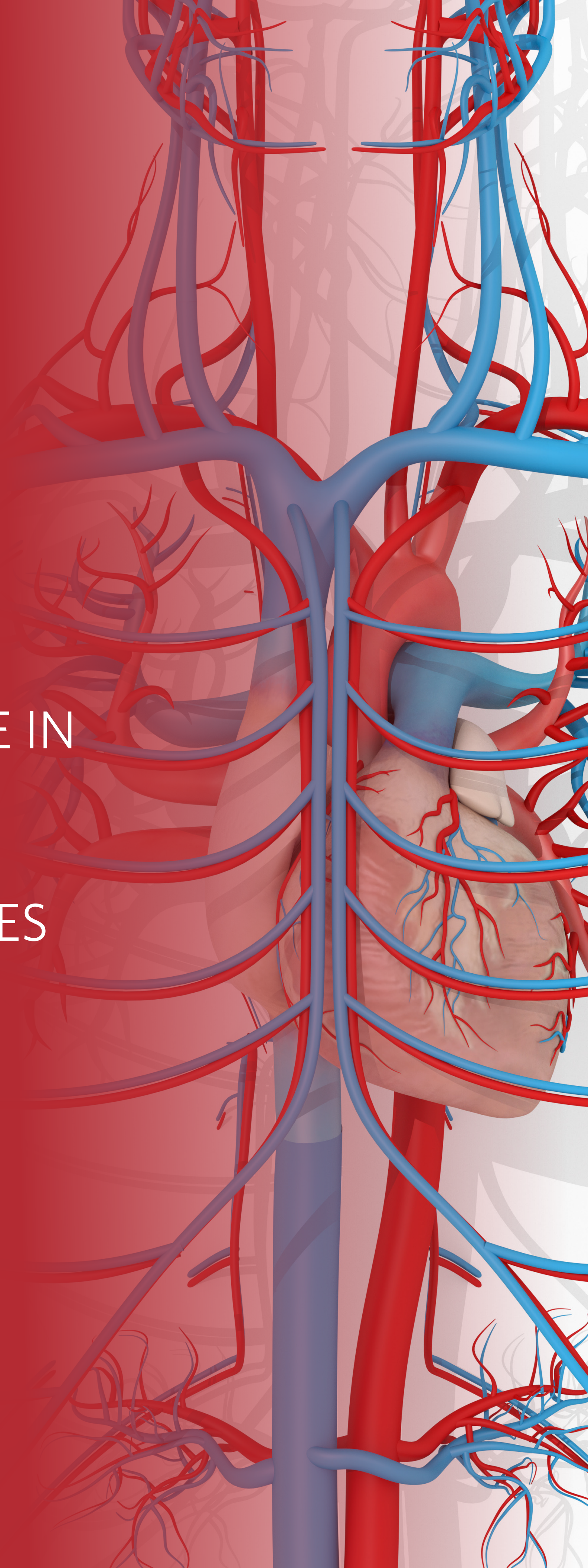
Balloon Deflation and Aftercare

- Once definitive hemorrhage control has been obtained, the REBOA balloon should be slowly deflated and removed from the sheath.
- Be prepared to treat rebound hypotension and to reinflate the balloon if necessary.
- Reperfusion injury should be anticipated and can lead to cardiac arrest upon balloon deflation.
- The technique for sheath removal is dependent upon the size of the sheath utilized. If a 12 or 14 Fr system is used, or if the 7 Fr sheath was placed via open cut-down (Figure 6), exploration of the CFA **must** be performed, with open repair of the arteriotomy.
- If a 7 Fr or smaller system is used percutaneously, the sheath can be pulled once the patient has stabilized and coagulopathy has reversed. Thirty minutes of correctly applied manual compression is recommended and has not been found to be inferior to any available arterial closure device.
- Following sheath removal, the extremity must be assessed for adequate perfusion. The color and temperature should be compared with the opposite side. Pulses should be examined digitally; if not palpable, the use of Doppler ultrasound can be helpful in characterizing symmetry. Inadequate perfusion must be acted upon promptly, either by further imaging or by surgical exploration of the accessed groin.
- In the setting of percutaneous access, patients should undergo a duplex ultrasound examination at 24 to 72 hours to assess for pseudoaneurysm formation.
- Early involvement of vascular surgeons for any suspected or proven REBOA-related complication provides optimal outcomes.

Pitfalls

- Failure to recognize the clinical indications for REBOA.
- Performing REBOA when the capability of surgically controlling hemorrhage is not immediately available.
- Difficulty locating and accessing the CFA in the groin—Patients who are obese or in profound shock will likely require open cut-down on the groin to access the CFA.
- Failure to recognize or address chest pathology—Placing a REBOA catheter in the setting of uncontrolled bleeding in the chest will likely increase bleeding and be fatal.
- Overinflation of the occlusion balloon may cause balloon rupture and may also damage the vessel.
- Leaving the balloon inflated too long—Actively bleeding sites should be controlled with temporizing measures (clamping or packing) to allow for the earliest deflation of the REBOA balloon, with most suturing, ligating, solid organ removing, and vascular shunting deferred until after the balloon is deflated.
- Failure to work with a sense of urgency once the balloon is inflated—Prolonged aortic occlusion may lead to fatal complications or spinal cord injury due to prolonged ischemia.
- Failure to adequately secure the catheter before balloon inflation, with resultant migration.
- Deflating the balloon too quickly before adequate volume resuscitation of the patient.
- Removal of arterial sheath too soon—These patients are likely to be coagulopathic, and this should be corrected prior to sheath removal. Additionally, leaving the sheath in place may allow for subsequent angiographic evaluation and treatment of other bleeding sites.
- Injury to the artery, with possible re-bleeding, thrombosis, intimal injury, arterial disruption, dissection, pseudoaneurysms, and limb-threatening ischemia.
- Aortoiliac injuries are possible, and unintended inflation of the balloon in the iliac vessels may lead to rupture or thrombosis.

CHAPTER 23
OPERATIVE EXPOSURE IN CRANIAL TRAUMA: DAMAGE CONTROL SURGICAL TECHNIQUES



Operative Exposure in Cranial Trauma: Damage Control Surgical Techniques

This chapter will discuss techniques for damage control during cranial trauma. The major emphasis of this lab experience is on indications, as well as technique for intracranial pressure (ICP) monitoring and decompressive hemicraniectomy (DHC).

Learning Objectives

By the end of this ASSET course module, participants should be able to do the following:

1. Understand the anatomical layers of the scalp, as well as its blood supply.
2. Describe the indications for intracranial pressure (ICP) monitoring.
3. Demonstrate proper placement of ICP monitors.
4. Describe the indications for decompressive hemicraniectomy (DHC).
5. Demonstrate proper surgical technique for DHC.

Considerations

- It must be kept in mind that the standard of care for treatment of severe traumatic brain injury includes direct evaluation and treatment by a trained neurosurgeon. This course module is not designed to replace care by a qualified neurosurgeon.
- The intent of this module is to outline basic, potentially lifesaving damage control neurosurgical skills that providers might employ in military, humanitarian, or rural settings when timely (more than four hours) specialist care is not available.
- If feasible, communication with a neurosurgeon is advised.

Anatomy

- The scalp has five anatomical layers (Figure 1) that can be remembered by the mnemonic *SCALP*, with structures progressing from superficial to deep, as follows:
  - Skin
  - Cutaneous tissue (dense)
  - Aponeurosis (galea)
  - Loose areolar tissue (AT)
  - Pericranium
- The scalp has a rich vascular supply from branches of the external carotid artery, with the main blood supply coming from the superficial temporal, posterior auricular, and occipital arteries.
- Bleeding from the scalp can be extensive and must be considered in the setting of unexplained hypotension.
- The brain is drained by superficial cortical "bridging" veins into larger dural venous sinuses. The main sinuses are the superior sagittal sinus and the transverse sinuses (Figure 1). Injury to these sinuses must be avoided during any cranial intervention.
- If injury to the dural venous sinus is present, operative intervention can result in catastrophic blood loss and should not be attempted without experience.
- The main muscle encountered is the temporalis muscle, which runs from the superior temporal line to the coronoid process of the mandible.

Pathophysiology

- Damage control neurosurgical techniques are most commonly required in the setting of traumatic head injury in which there is hemorrhage within the skull or brain swelling resulting in increased ICP and concern for brain herniation.
- Epidural and subdural hematomas are common indications for emergent neurosurgical intervention.

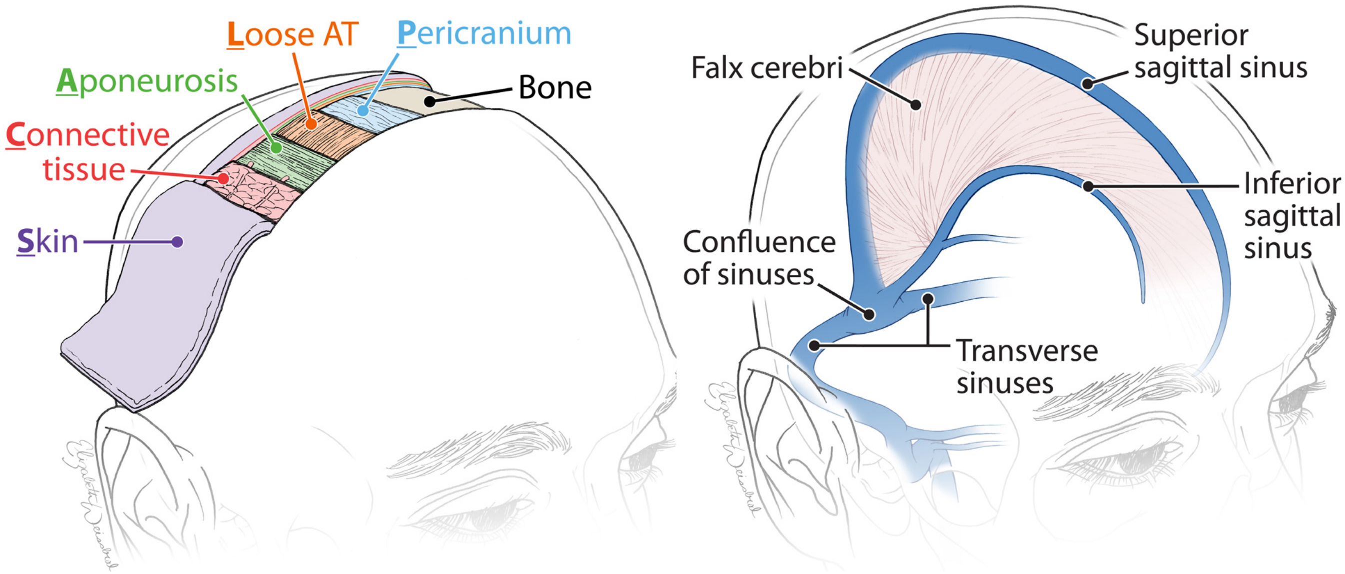


Figure 1. The layers of the scalp and venous drainage of the brain.

Epidural Hematoma

- An epidural hematoma is most commonly caused from a blow to the temporal skull and disruption of the middle meningeal artery (Figure 2).
- The hematoma forms between the inner table of the skull and the dural membrane.
- The classic finding on CT scan is of a convex, lens-shaped hematoma (Figure 2).
- The classic presentation of an epidural hematoma is a lucid interval following head trauma with rapid deterioration of Glasgow Coma Scale (GCS) as the hematoma expands and causes compression of the brain, with resultant herniation if not promptly relieved.

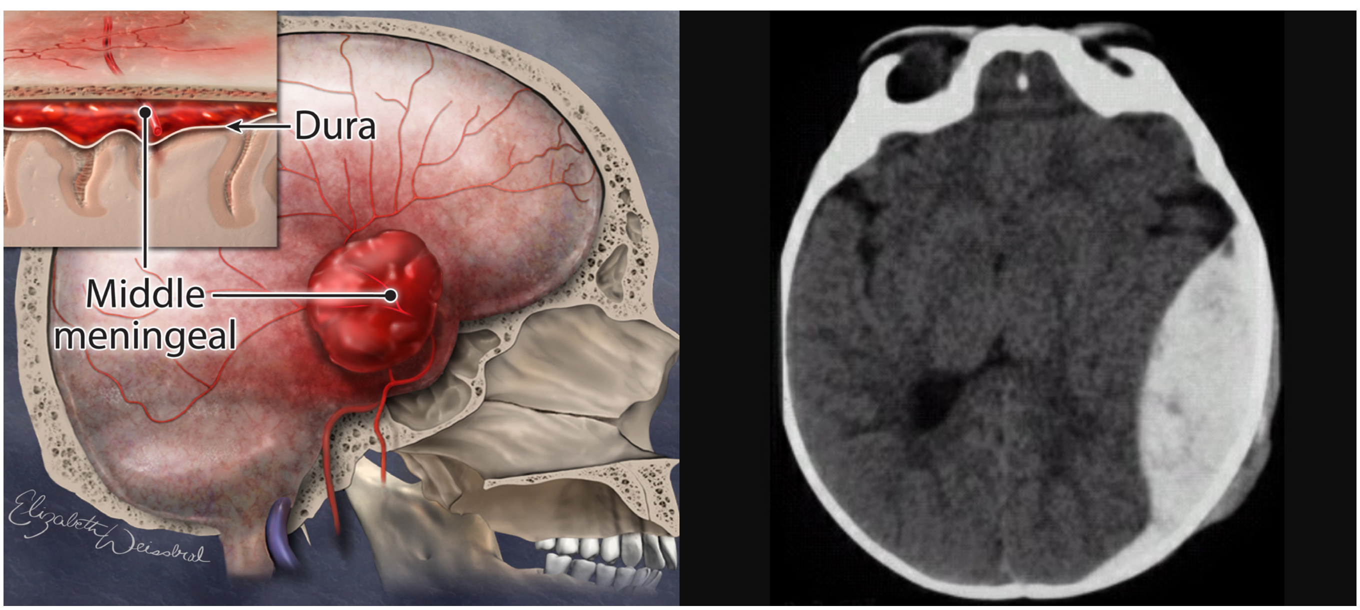


Figure 2. Anatomy and classic CT finding of epidural hematoma.

Subdural Hematoma

- Subdural hematomas result from the disruption of bridging veins where they penetrate the dura, leading to accumulation of blood between the dura and the subarachnoid covering of the brain (Figure 3).
- The classic finding on CT scan for a subdural hematoma is a crescent-shaped, concave hyperdensity (hematoma) (Figure 3).
- Subdural hematomas can be chronic or acute and can be associated with brain compression and eventual herniation if large and untreated.

Intracranial Pressure (ICP) Monitoring

CONSIDERATIONS

- ICP monitoring should be considered for patients with severe traumatic brain injury (post-resuscitation GCS < 8).
- There are two types of ICP monitors:
  - External ventricular drain (EVD)—Placed in frontal horn of lateral ventricle
  - Parenchymal monitors (bolt)—Placed a few centimeters into brain parenchyma
- While technically more difficult, an EVD offers an advantage in that it allows for both ICP monitoring and controlled drainage of cerebrospinal fluid (CSF) when ICP is elevated.
- ICP monitors should be placed in a portion of the brain that does not have eloquent function (typically the right side).
- ICP monitors are placed through a burr hole at Kocher's point, which is 10–12 cm posterior to the nasion and 2–3 cm lateral to the midline (Figure 4).
- If a right-sided craniotomy is required, the ICP monitor should be placed on the left.

PREPARATION AND POSITIONING

- Check for and reverse any coagulopathy.
- Administer prophylactic antibiotics.
- Position the patient supine in slight reverse Trendelenburg position, with the head midline and resting on a doughnut.
- The head should be stabilized (with tape or by assistant) while drilling to prevent skiving.
- Mark the midline and Kocher's point (Figure 4).
- Shave the incision area and prep the entire head.

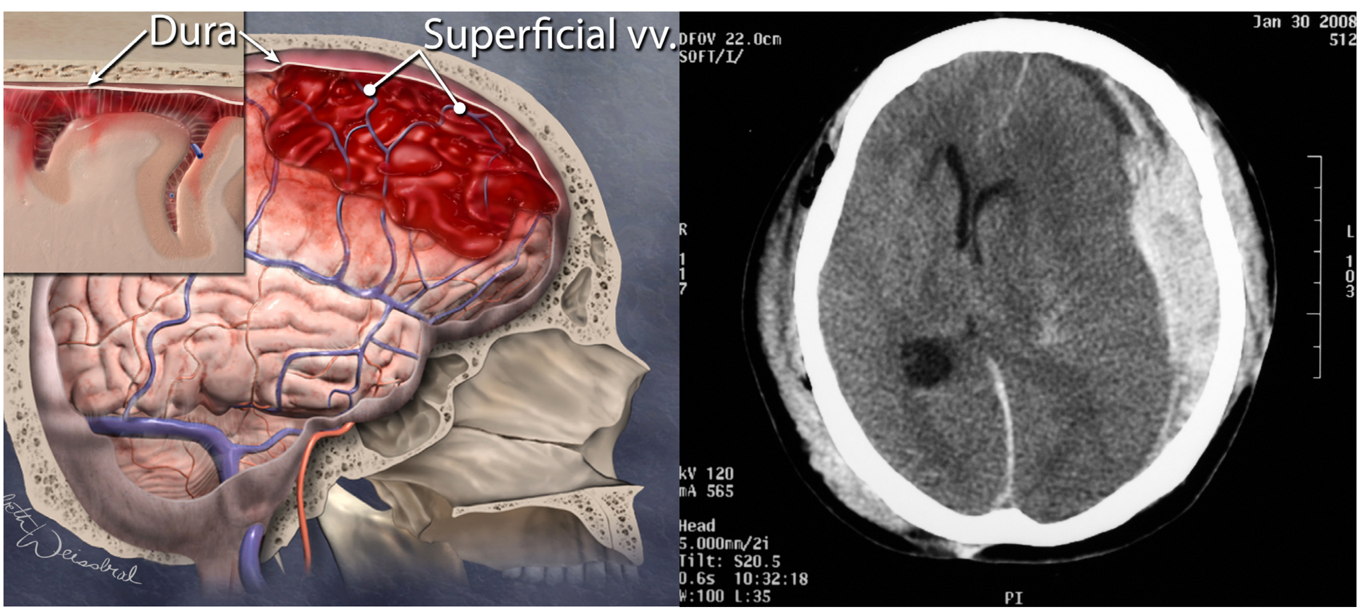


Figure 3. Anatomy and classic CT finding of subdural hematoma.

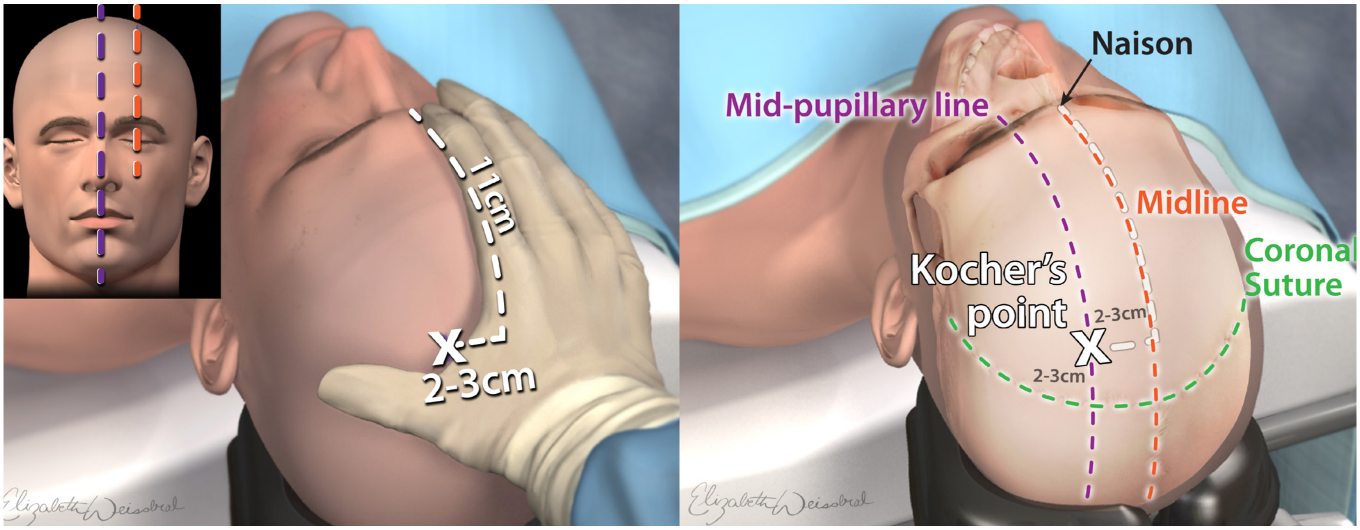


Figure 4. Intracranial pressure monitoring involves inserting a monitoring device through a twist-drill hole made at Kocher's point (X), which is located about 11 cm from the nasion, 2–3 cm from the midline, and 2–3 cm from the coronal suture on the mid-pupillary line, as depicted above.

INSERTION OF EXTERNAL VENTRICULAR DRAIN (EVD)

- A 2.5 cm linear incision (in the sagittal plane) is made centered over Kocher's point (Figure 4).
- The hand drill in the cranial access kit is used to drill a hole with the bit locked at 1 cm (Figures 5a and 5b).
  - The drill bit will pass through the outer cortex, the cancellous bone, and then the inner cortex.
  - Don't plunge into the brain. When the inner cortex has been breached, you will feel a sensation of the drill bit starting to be "pulled in."
- The trocar is then inserted through the drill hole.
- The monitoring catheter is directed toward the medial canthus and advanced for about 5–7 cm until the lateral horn of the ventricle is cannulated (Figure 5c). Do not go any further. The catheter tip should be in the foramen of Monro.
- A popping is often felt when the ependymal of the ventricle is punctured.
- If the ventricle cannot be cannulated after three attempts, abort and proceed to inserting a bolt.
- Brisk flow of CSF confirms placement of the catheter tip in the ventricle.
- The catheter is stabilized at the skin and tunneled laterally from the incision (Figure 5d), taking care not to move the catheter either in or out.
- The trocar is removed from the distal catheter, and the catheter is attached to the connector and end cap.
- The scalp incision is closed with a running 3-0 nylon, and the catheter is secured to the skin (Figure 5e).
- Tip placement is confirmed with CT scan, if available (Figure 5f).
- The EVD collection system is primed with sterile saline. The catheter is attached, with the collection system leveled at the tragus of the ear.
- A standard arterial line pressure transducer is attached to continuously measure ICP.
- The height of the EVD is set at 0–20 cm H_2O, depending on the clinical scenario.
- The EVD can be clamped shut or opened to drain, with lower heights resulting in more CSF drained.

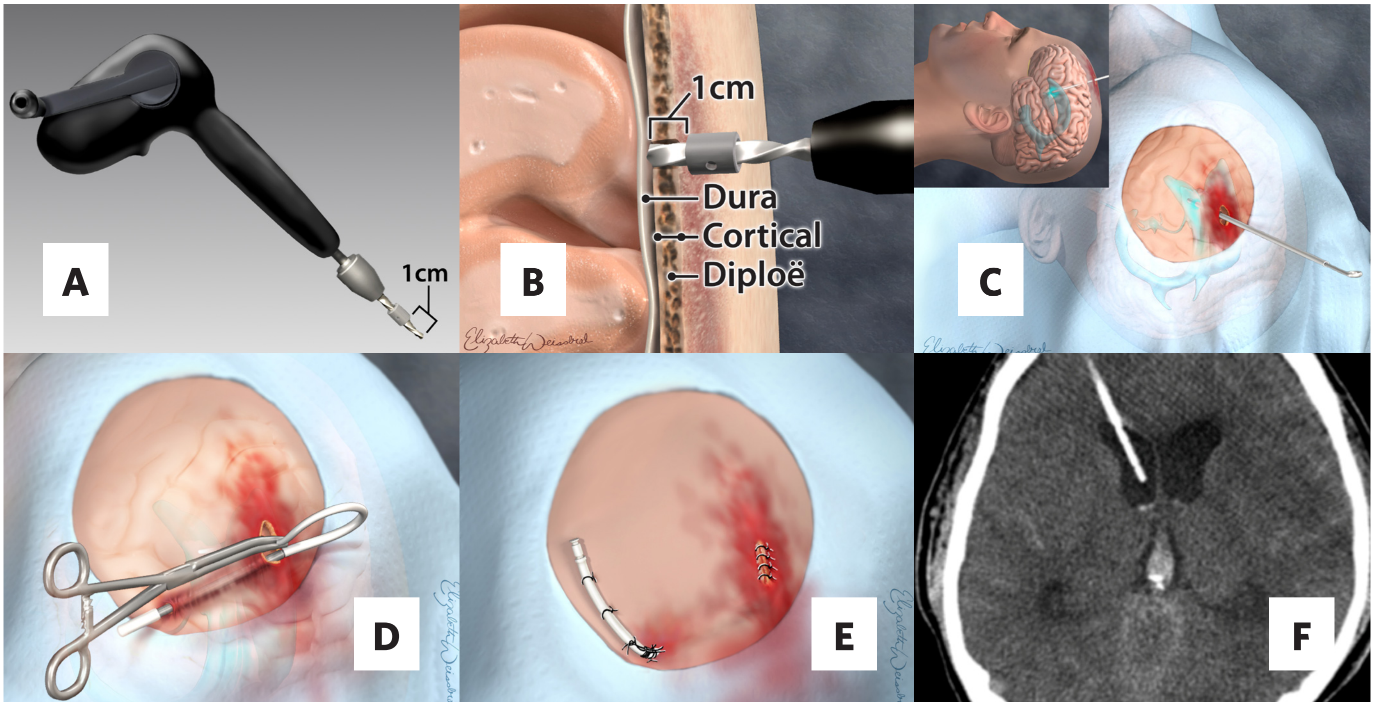


Figure 5. Insertion of an external ventricular drain is accomplished by using a hand drill with the bit locked at 1 cm of depth (A) to make a hole at Kocher's point (B). The monitoring catheter is directed towards the medial canthus and advanced for about 5-7 cm until the lateral horn of the ventricle is cannulated (C). The catheter is stabilized at the skin and then tunneled laterally (D) and secured in place with closure of the wound (E). The CT image (F) shows that the tip of the catheter is ideally placed in the ipsilateral lateral ventricle.

INSERTION OF PARENCHYMAL MONITOR (BOLT)

- A standard twist-drill hole is made at Kocher's point, as above (Figure 4).
- The bolt is threaded into the burr hole (Figures 6a and 6b).
- The pressure transducer is inserted 1–2 cm into the brain parenchyma, taking care not to pass beyond the indicated mark on the catheter (Figure 6c).
- The catheter is secured and then attached to a monitor, allowing for continuous measurement of ICP (Figure 6d).

Exploratory Burr Holes

- Exploratory burr holes have limited practical utility. They should only be performed after consultation with a neurosurgeon (if possible) and only when CT scanning is not available to better guide management.

Decompressive Hemicraniectomy

CONSIDERATIONS

- Decompressive hemicraniectomy (DHC) is a surgical procedure used to relieve increased ICP in the setting of a large cerebral hemisphere mass or space-occupying lesion.
  - The term *craniotomy* is used when the bone flap is returned to its original location.
  - *Craniectomy* is used when the bone flap is not returned.
- The aim of DHC is to reduce ICP, improve blood flow, reduce damage to surrounding tissue, and reduce secondary brain injury.
- Evidence supporting emergent DHC in trauma is controversial. However, it does help control ICP and will allow evacuation to a higher level of care.

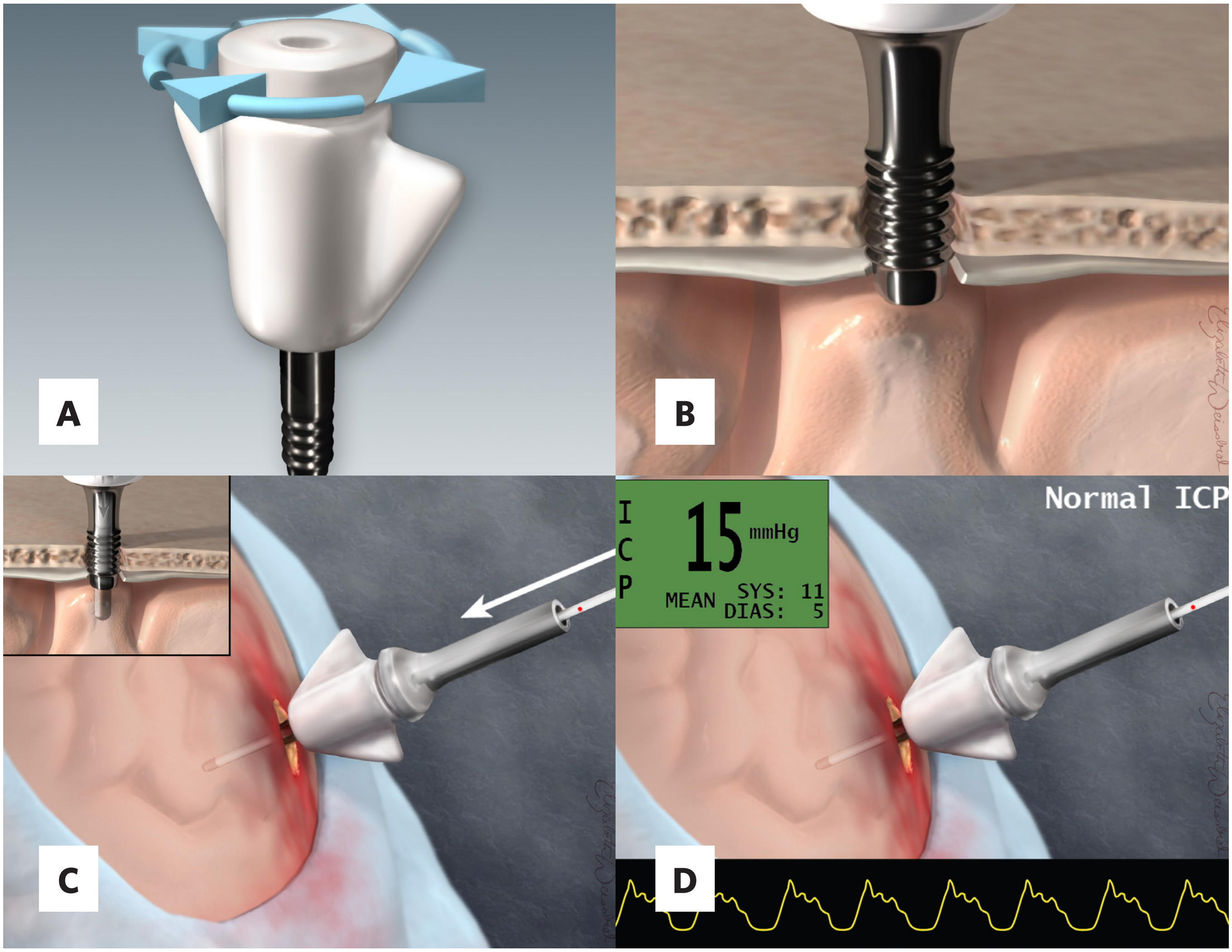


Figure 6. Insertion of a parenchymal intracranial pressure monitor, or bolt (A), is accomplished by making a standard twist-drill hole at Kocher's point. The bolt is then threaded into the burr hole (B). The pressure transducer is inserted 1–2 cm into the parenchyma, not passing beyond the red mark on the catheter (C). The catheter is secured and hooked up to a monitor, allowing for continuous measurement of intracranial pressure (D).

INDICATIONS FOR DECOMPRESSIVE HEMICRANIECTOMY

- The classic indications for DHC are as follows:
  - Evacuation of mass lesions (primary hemicraniectomy)
    - Epidural hematoma (> 15 mm in thickness or > 30 ml in volume)
    - Subdural hematoma (> 10 mm in thickness)
      - For lesions < 10 mm, if there is decrease in GCS of 2, worsening pupillary exam, and/or ICP > 20 mm Hg
    - Middle fossa/temporal lobe hematomas with brainstem compression
      - Mass lesion with > 5 mm of midline shift on CT
  - Control of ICP (secondary hemicraniectomy)
  - Treatment of depressed or open skull fractures
- If CT scanning and prompt neurosurgical care are not available, one might consider performing DHC for damage control in patients with traumatic brain injury who have a life-threatening condition, deteriorating neurological status, or localizing neurologic signs (unilateral blown pupil).
- In the military setting, without neurosurgical specialty care available, DHC is recommended by current clinical practice guidelines for the following:

- Patients presenting with severe closed or penetrating supratentorial brain injury, GCS of 8 or less, lateralizing cortical dysfunction to include unilateral mydriasis (blown pupil), hemiparesis accompanied by hemodynamic dysfunction manifested by hypertension, bradycardia, and respiratory variation (Cushing reflex)
- Cases where maximal critical care management—including the administration of 3 percent saline, mannitol, sedation, HOB elevation to 30 degrees, drainage of CSF via EVD, etc.—fails to stabilize the patient. This may manifest as a new lateralizing cortical finding (hemiparesis, rapidly expanding pupil) and/or further decline in GCS when off sedation.

PREOPERATIVE CARE AND POSITIONING

- Maximize critical care management.
- Correct laboratory abnormalities as indicated.
- Correct coagulopathies.
- Give appropriate preoperative prophylactic antibiotics within one hour before skin incision.
- Position the patient supine with a shoulder roll under the ipsilateral shoulder.
- Tuck the arm on the operative side with the other left free for vascular access.
- Place a “doughnut” roll (or equivalent) under the patient’s head, which is then turned to expose the operative hemicranium (Figure 7).
- Shave, prep, and mark the incision site on the operative side.

DECOMPRESSIVE HEMICRANIECTOMY: SURGICAL PROCEDURE

- The most commonly used skin incision for DHC is a “reverse question mark” incision.
- This incision begins 1 cm anterior to the tragus of the ear at the level of the zygomatic arch and is curved superiorly and posteriorly around the ear, continuing posteriorly around the parietal eminence, or “parietal boss,” to just lateral to the midline and carried anteriorly to the hairline (Figure 8).
  - Do not cut below the zygomatic arch, as this risks injury to the facial nerve.
  - Avoid injury to the superficial temporal artery, which should lie anterior to the incision.
- The skin is incised down to bone, with division of the galea.
- If available, monopolar electrocautery should be used down to bone to minimize bleeding.
- Hemostatic (Raney) clips should be used on the skin edges, if available (Figure 9).

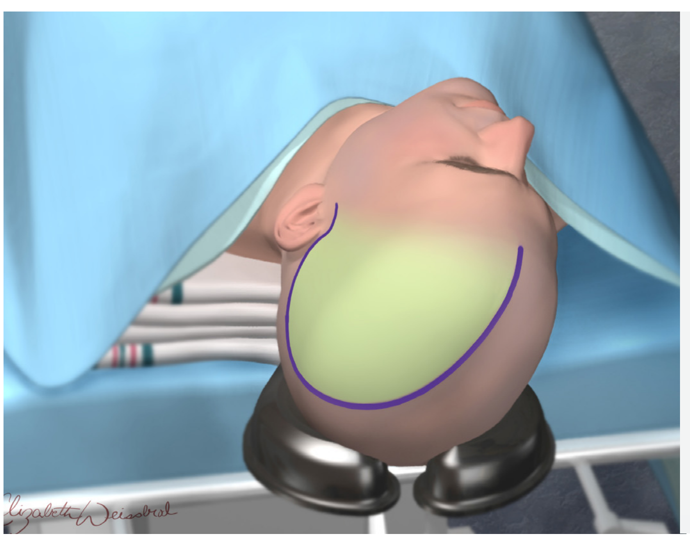


Figure 7. The patient is positioned supine, with towels under the shoulders and the head placed on a “doughnut” headrest and turned with the operative side up.

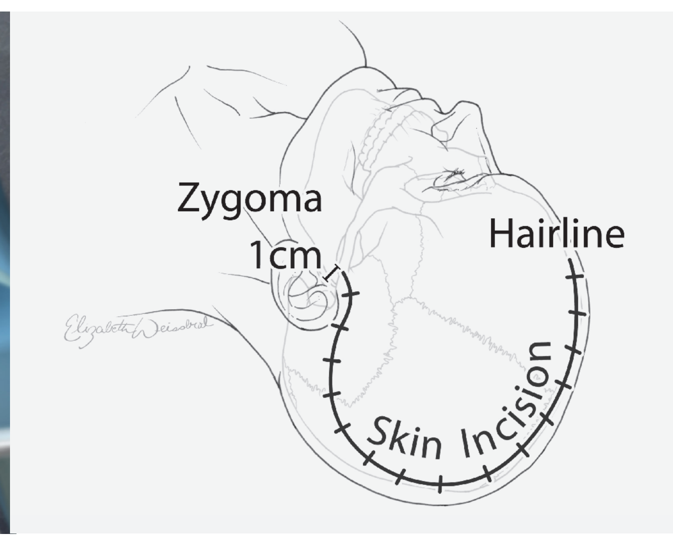


Figure 8. The “reverse question mark” incision is made 1 cm in front of the tragus, extended superior and posterior to the ear, and then curved around just lateral to the midline and to the hairline anteriorly.

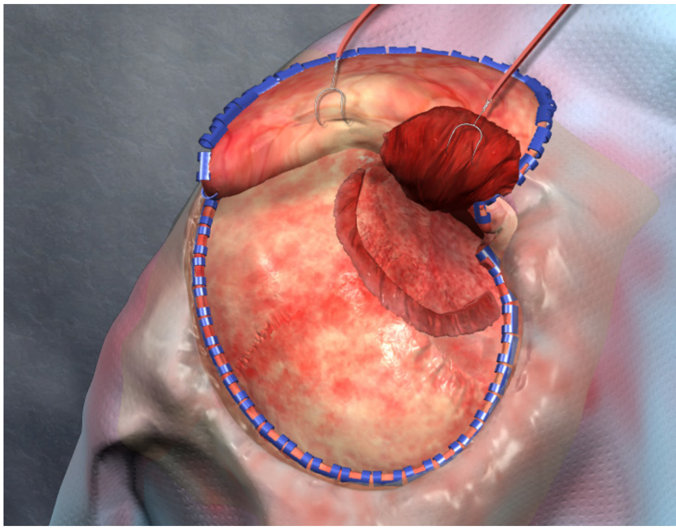


Figure 9. Hemostatic Raney clips have been placed on the skin edges to minimize blood loss from the scalp, which is reflected anteriorly as a myocutaneous flap and secured out of the operative field with hooks.

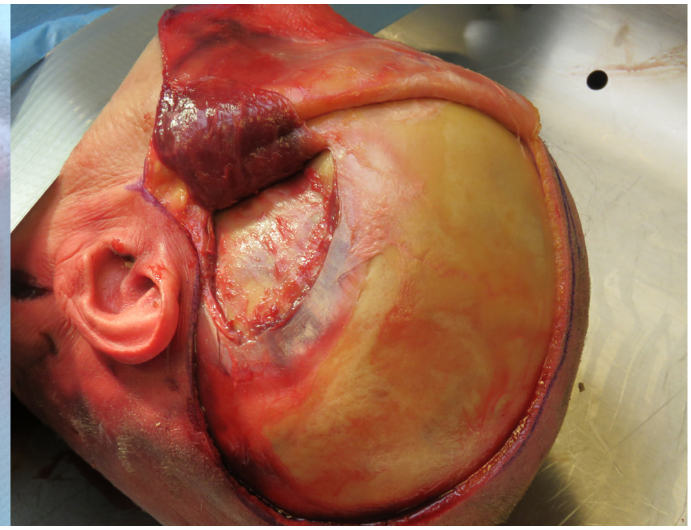
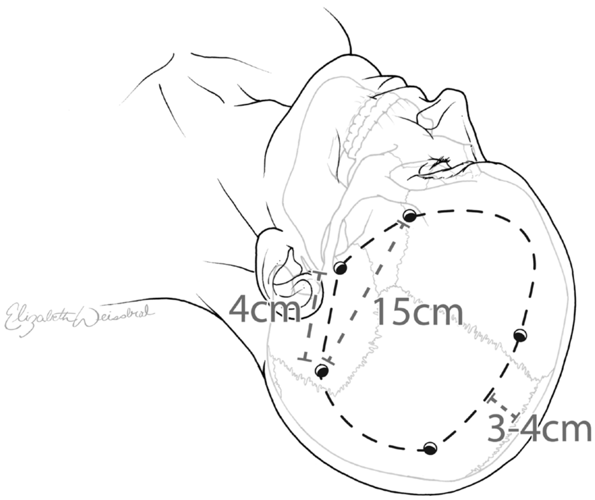


Figure 10. The myocutaneous flap has been reflected. The temporalis muscle has been divided a couple of centimeters from its insertion on the skull and has been reflected with the flap. This exposes the cranial bone to enable subsequent craniectomy.

- The scalp and underlying muscle are reflected anteriorly as a myocutaneous flap, which is secured with hooks or towel clamps (Figure 9).
- The temporalis muscle is divided a couple of centimeters from its insertion on the cranium and is reflected with the myocutaneous flap (Figures 9 and 10).
- Burr holes are then drilled into the skull. The classically described DHC entails drilling five burr holes, as follows (Figure 11):
  - Burr hole 1 is drilled slightly superior to where the zygomatic process joins with the temporal squamous bone, just anterior to the tragus.
  - Burr hole 2 is drilled in the frontal bone just superior to where the sphenoid, zygomatic, and frontal bones converge, approximately 6 cm from burr hole 1. Care must be taken to angle the drill away from the orbit so as not to enter it with this hole.
  - Burr hole 3 is drilled in the posteromedial aspect of the parietal bone, with a minimum of 15 cm between this hole and burr hole 2. Care must be taken not to go too far inferior to avoid the transverse and sigmoid sinuses.
  - Burr hole 4 is drilled above and slightly anterior to hole 3 staying 3–4 cm from the midline of the skull to avoid entry into the sagittal sinus.
  - Burr hole 5 is drilled above and slightly lateral to hole 2, staying 3–4 cm from the midline of the skull to avoid entry into the sagittal sinus.
  - Additional burr holes may be required depending on the circumstances and are usually necessary if using a Gigli saw instead of a power saw.
- The bone flap should be a **minimum** of 12 × 15 cm in size, and the burr holes should be placed with this in mind.
- When creating burr holes, care should also be taken to avoid the frontal sinus.
- Burr holes are most easily made with a power drill (Figures 12 and 13). Most such drills have an automatic clutch that allows drilling to continue until the inner table is breached, at which point the drill will automatically stop.
- Saline is usually dripped with a syringe onto the skull at the site of the burr hole as it is drilled to minimize bone dust and prevent overheating of the drill bit.



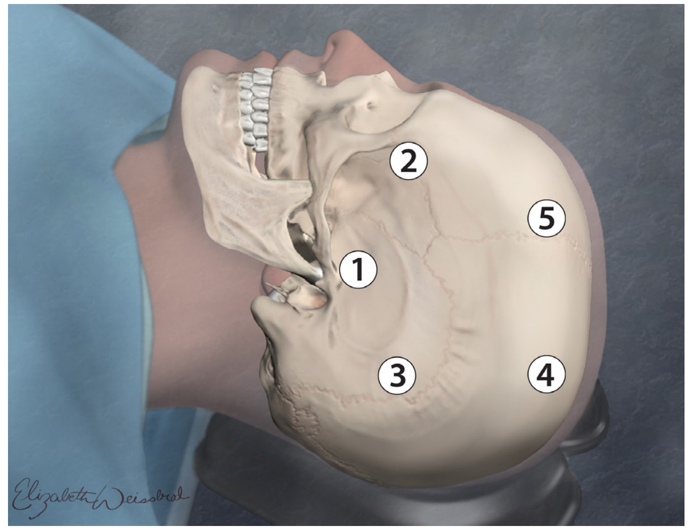


Figure 11. The classic placement of five burr holes for a decompressive hemicraniectomy.

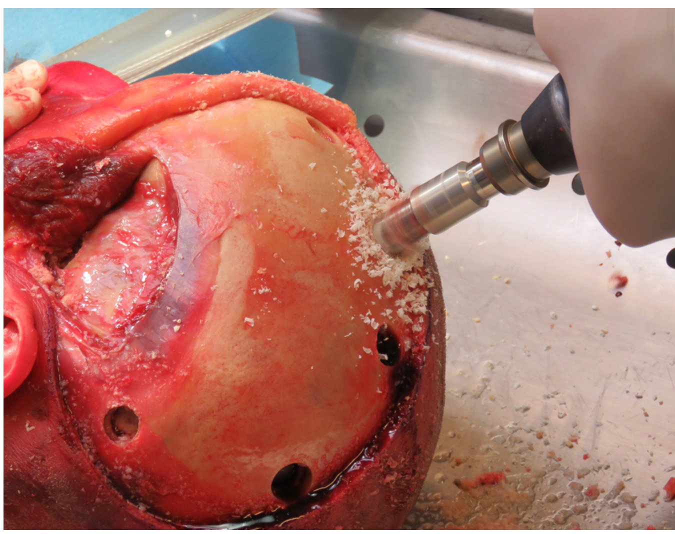


Figure 12. A power drill being used to create a burr hole.

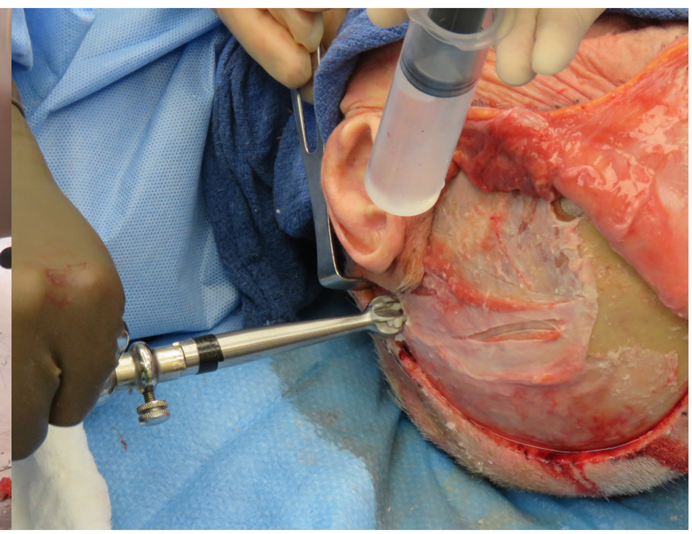


Figure 13. When power tools or power are not available, a Hudson brace drill can be used to manually create the burr holes.

- If adequate power (or equipment) is not available, a manual drill (Hudson brace type) can be used to make the burr holes (Figure 13).
- The manual drill requires significant effort on the part of the user, and its use should be practiced. Great care should be taken not to go too deep with the drill bit. Progress should be checked frequently, with the goal being to drill through the inner table until the dura is seen but not perforated.
- Once the dura is visualized, bone-cutting rongeurs and curettes can be used to expand the burr holes if needed.
- Once the burr holes have been created, the dura is carefully separated from the overlying bone through the burr holes using a Penfield dissector.
- The burr holes are connected using an electric bone saw or Duraguard router, sawing through the skull and taking care to leave the dura intact (Figure 14).
- If power or a power saw is not available, a Gigli saw (Figure 15) can be used to connect the burr holes as follows:

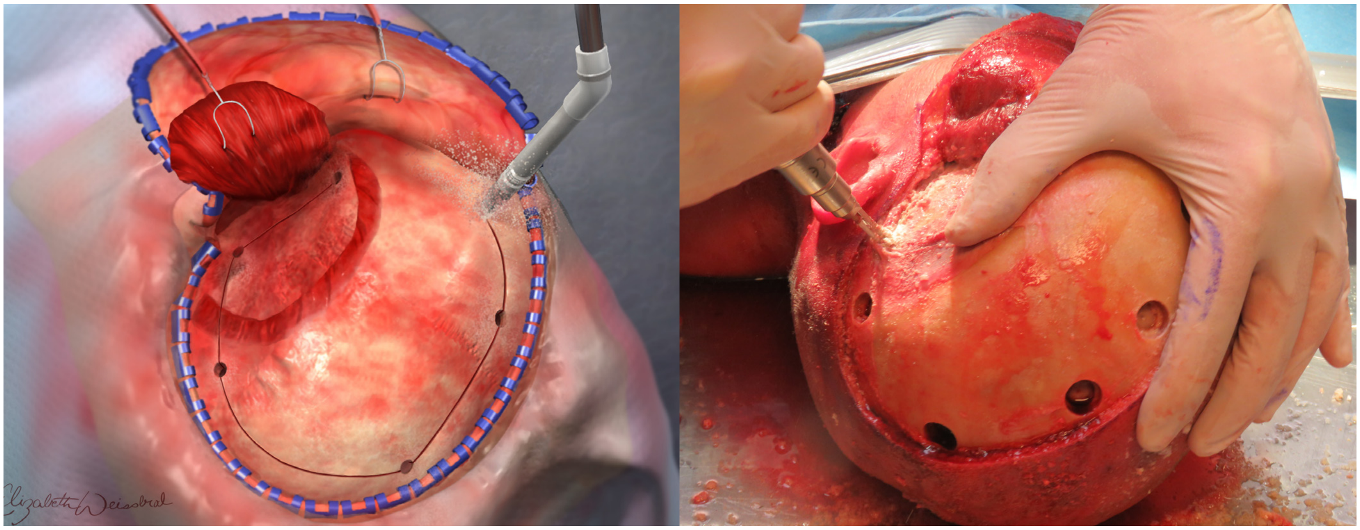


Figure 14. A Duraguard router is used to connect the burr holes in a curvilinear fashion to maximize the size of the bone flap, as seen on the right hemicranium (illustration on left) and on the left hemicranium of a cadaveric specimen (photograph on right).

- Additional burr holes may need to be created between the five standard ones to facilitate passage of the Gigli saw guard or conductor (a thin metal strip with a hook for the eyelet of the saw) between burr holes.
- The dura is carefully separated from the interior skull with a Penfield dissector, enlarging the burr holes as needed with a rongeur to accommodate the end of the Gigli saw guard.
- The Gigli saw guard is carefully threaded from one hole to another, sliding between dura mater and skull, with the small hook on the guard facing outward (Figure 16).
- The eyelet of the Gigli saw is threaded onto the hook, and the guard is passed from one hole to the other, conducting the blade under the skull (Figure 16).
- The Gigli guard is left in place, providing additional protection to the underlying soft tissues.
- The Gigli handles are attached to each end of the saw, and the bone is cut by moving the handles back and forth. This is best accomplished with the saw held at a greater than 90° angle and not stopping until the cut is complete.

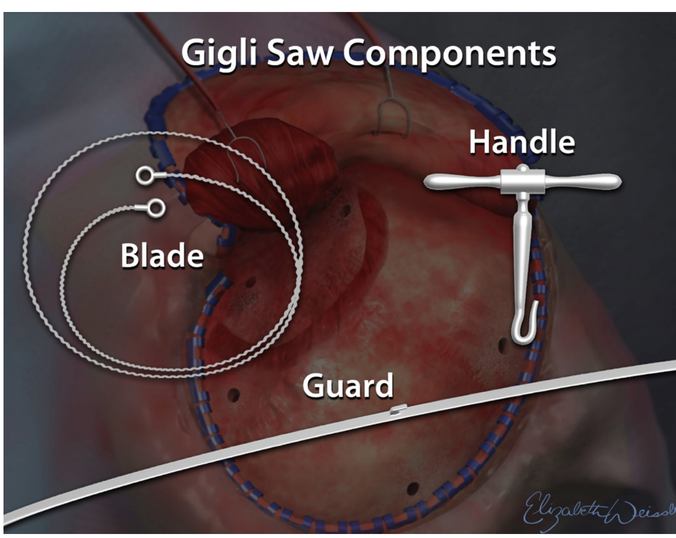


Figure 15. The Gigli saw components include a blade with eyelets on the ends, two handles, and a guard with a small hook to which one of the eyelets is attached.

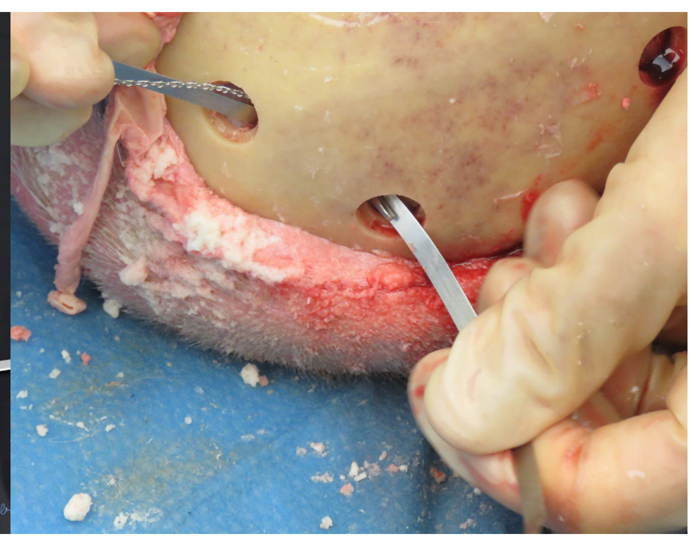


Figure 16. With the saw attached to the hook of the Gigli guard, it is passed from one burr hole to the next, with the hook facing outward.

    - The steps are repeated until all of the burr holes are connected and the bone flap is free.
- Once the bone flap is cut, it is gently lifted and slowly dissected from the underlying dura (Figure 17). This should be done slowly in a circumferential fashion, as lifting the bone flap at an angle will compress and increase pressure in the temporal lobe.
- Once the bone flap has been completely separated from the underlying dura, it is carefully lifted away.
- If the bone flap is to be saved, it is soaked in Betadine, rinsed with saline, wrapped in a soaked lap pad, and set aside until the end of the procedure, when it will be placed in the patient's abdominal wall (extraperitoneally). Alternatively, the bone flap can be cryopreserved for future reimplantation.
- A rongeur is used to remove additional temporal bone (as needed) down to the floor of the middle cranial fossa, allowing for full decompression of the temporal lobe, which takes pressure off the brainstem.
- If the DHC was performed for an epidural hematoma, clot will be found on top of the dura after lifting off the bone flap (Figure 18a).
- The clot is gently removed from the dura (Figures 18b and 18c), and the bleeding from the superficial temporal artery is controlled, leaving the dura intact but separated from the surrounding edges of the skull (Figure 18d).
- Any residual oozing or minor bleeding is controlled with hemostatic agents such as gel foam.
- Though not universally practiced, it is recommended that the dura be tacked up to the skull via sutures placed through small holes drilled between burr holes 1 and 3, 3 and 4, 4 and 5, and 5 and 1—but not between 1 and 2 (Figure 19) or to the galea or periosteum of the skull.
- Take care not to place tack-up sutures into the dural sinus.
- These tack-up sutures are placed to close the epidural space to minimize the formation of a postoperative extradural hematoma.
- The dura can be opened using several different techniques, including cruciate, parallel-strip, or curvilinear (with or without radial "wheel spoke slits") incisions (Figure 20).
- Whichever technique is used, it is advisable to place a 4-0 stitch in the dura to elevate it off the underlying brain tissue and then use a scalpel to make a small opening, which is then extended with Metzenbaum scissors.
- If there is significant ICP, opening the dura slowly can result in further damage and brain herniation through the incomplete incision, so the dura must be opened quickly once the incision is started.

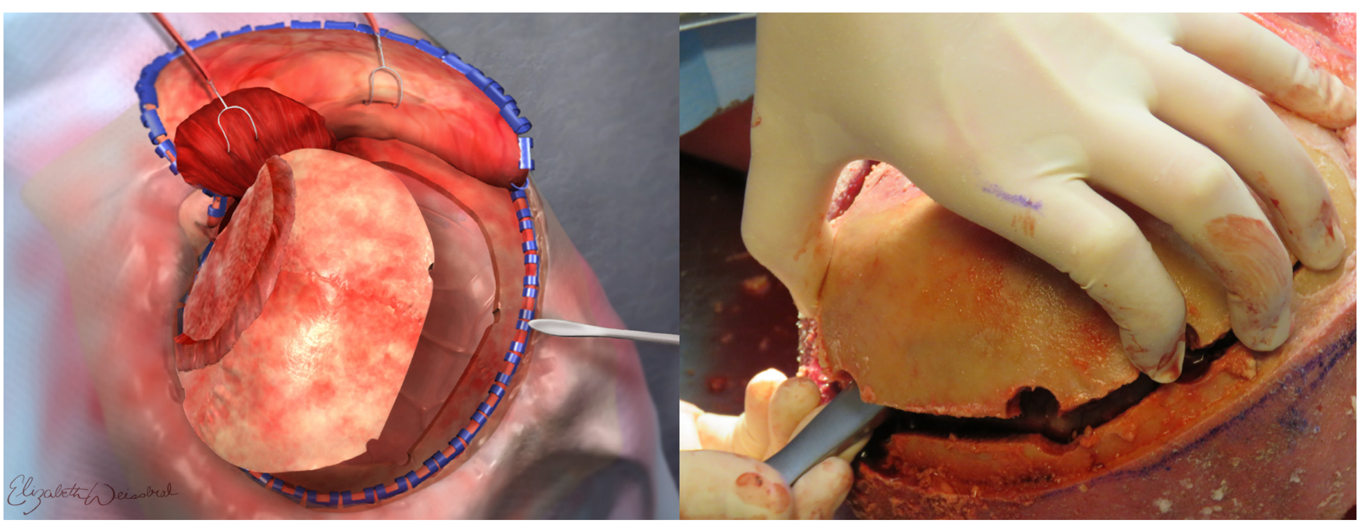


Figure 17. The bone flap is circumferentially dissected off of the underlying dura, taking care not to angle the flap and cause increased pressure on the brain.

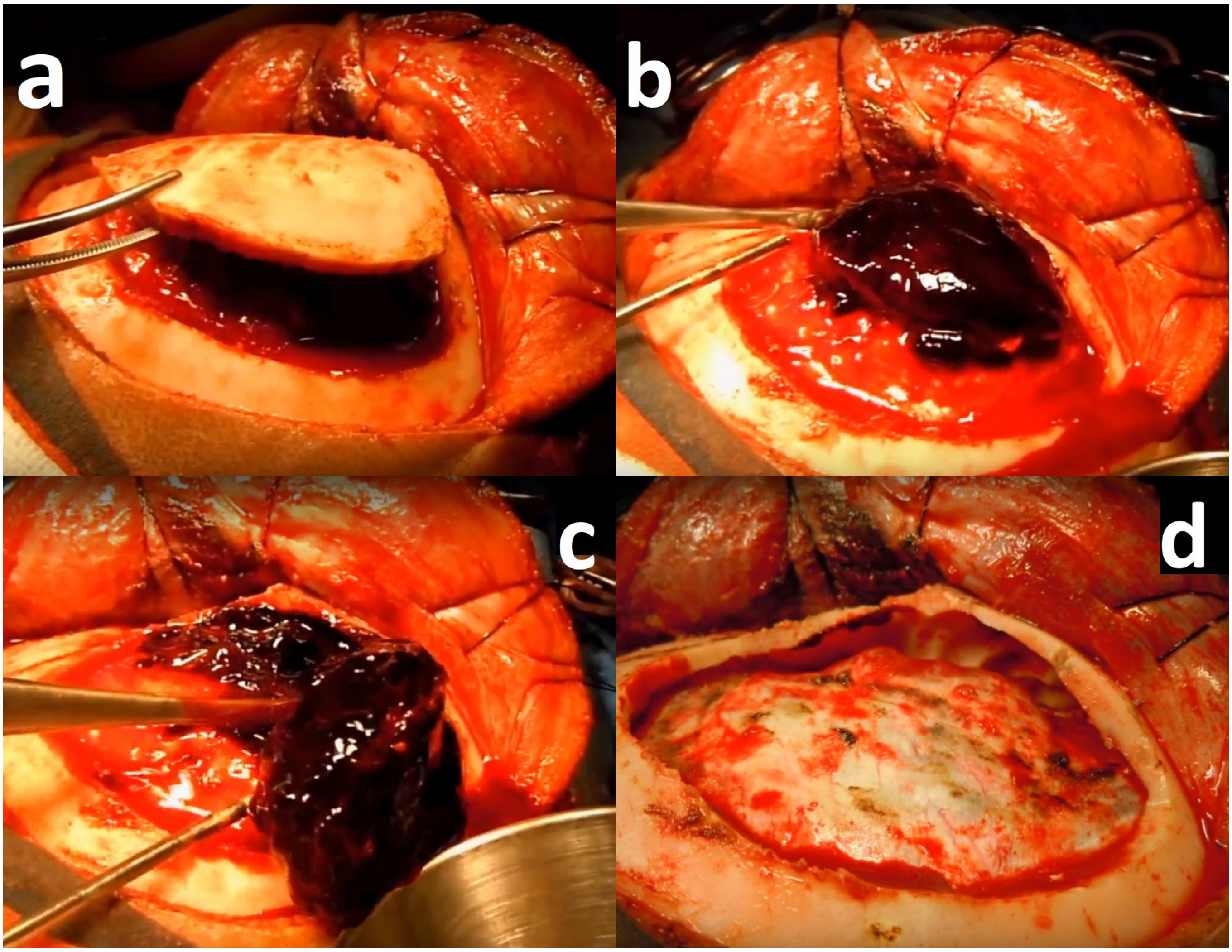


Figure 18. In this patient with an epidural hematoma, the bone flap is lifted (A) to reveal the clot on top of the dura (B). The clot is gently removed from the surface of the dura (C), and the bleeding source is controlled with bipolar electrocautery. After removal of clot and hemorrhage, the intact dura is separated from the edge of the skull (D), leaving a potential space.

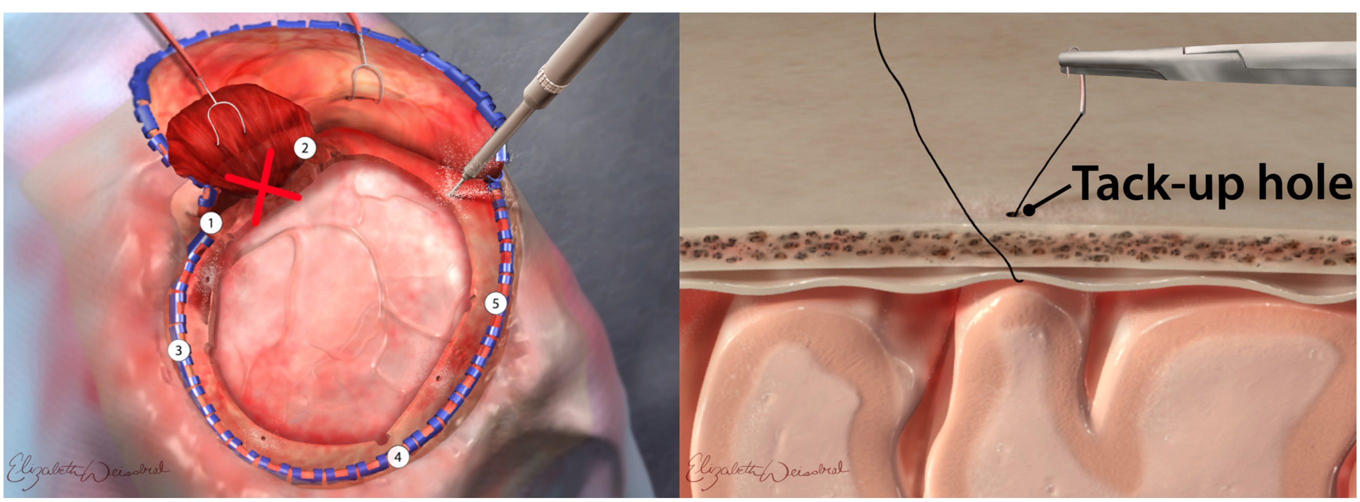


Figure 19. Four small holes are drilled in the skull between each adjacent pair of burr holes (except between 1 and 2), as seen on the left. These small holes are used to suture the dura to the skull, as seen on the right, to help minimize the occurrence of postoperative epidural hematoma.

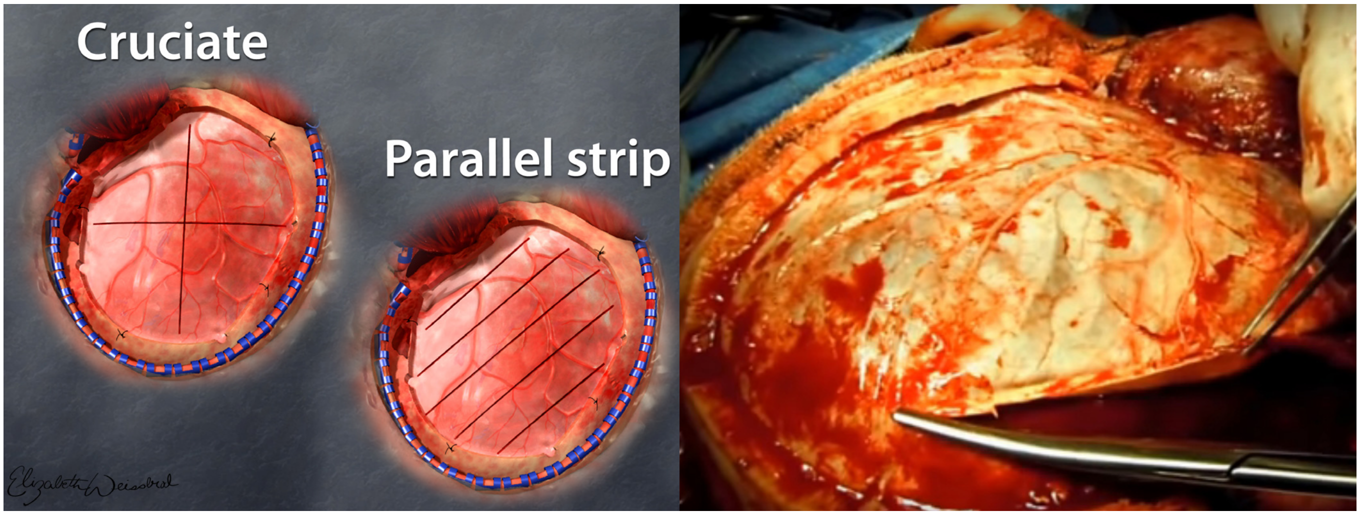


Figure 20. The dura can be opened with cruciate or parallel-strip incisions, as seen on the left. Alternatively, the dura can be opened with a curvilinear incision around the superior margin of the craniotomy incision, as seen on the right.

- If the DHC was performed for a subdural hematoma, clot will be found on the surface of the brain when the dura is opened (Figure 21).
- The subdural clot should be gently swept/scraped away from the surface of the brain using saline irrigation and gentle pressure (Figure 21).
- Once the subdural clot is removed, bleeding from the bridging veins and surface of the brain is controlled with bipolar cautery and hemostatic agents (Figure 22).
- Closure of DHC is accomplished as follows:
  - The dura is **not** closed. A dural substitute (such as DuraGen) is placed over the surface of the brain and under the cut dura.
  - A subgaleal Jackson-Pratt drain is placed and secured to the skin.
  - The galea is closed with interrupted sutures (2-0 VICRYL) spaced about 1 cm apart.
  - The skin is closed with staples after removal of the Raney clips.
  - Surgical dressing is applied.
- The head should not be wrapped, as this is compressive in nature and counteracts the goals of the surgery.

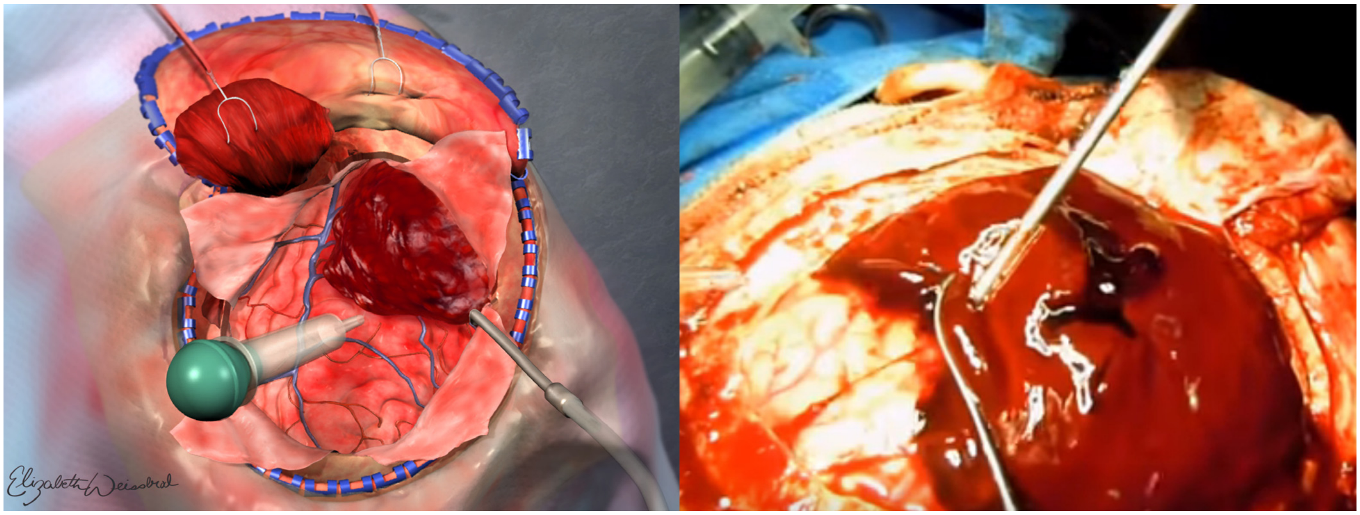


Figure 21. The clot found in a patient with a subdural hematoma lies on the surface of the brain and should be gently irrigated and, if necessary, scraped from the brain surface.

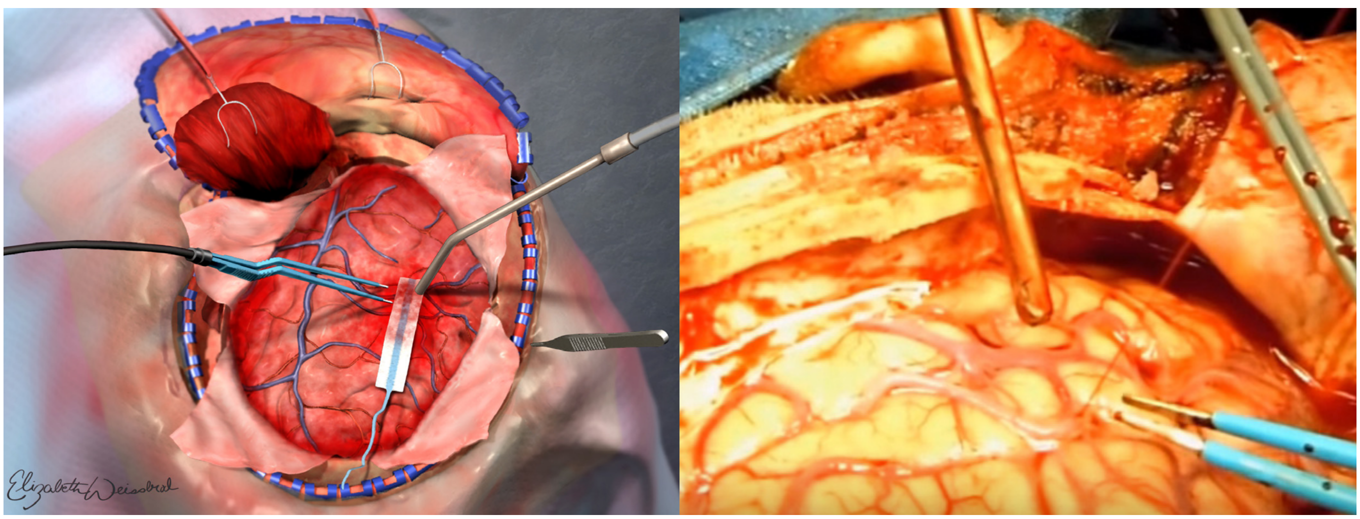
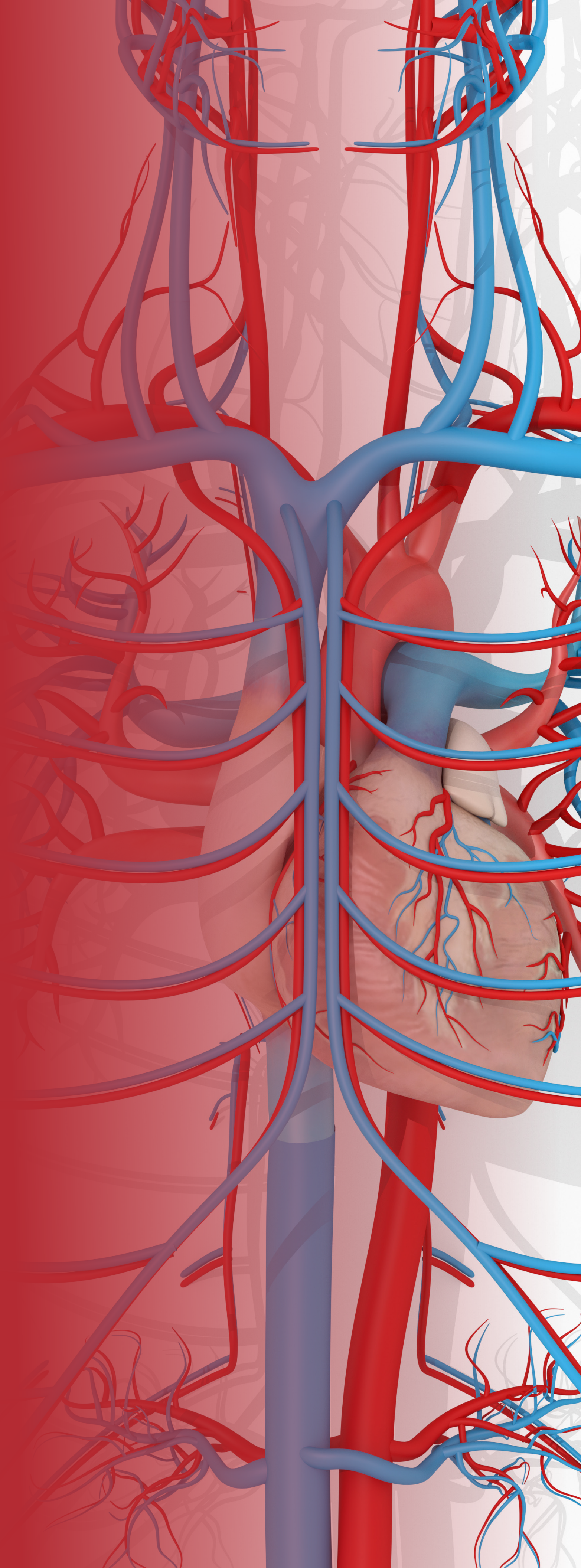


Figure 22. Bleeding in the subdural space is controlled with bipolar cautery and hemostatic agents.

CHAPTER 24
DAMAGE CONTROL MANAGEMENT OF EYE INJURIES



Damage Control Management of Eye Injuries

Priorities in the care of an injured patient are life, limb, and then eyesight. Eye injuries are usually evaluated in the secondary survey. This chapter will review a rapid approach to assessment for eye injury, essential interventions to protect the injured eye, and pitfalls in the management of eye injury.

Learning Objectives

By the end of the ASSET course, participants should be able to do the following:

1. Describe the rapid assessment and management of eye injuries.
2. Describe the common findings and symptoms of orbital compartment syndrome and retrobulbar hematoma.
3. Discuss indications for performing eye irrigation, eye shielding, and lateral canthotomy and cantholysis (LCC).
4. Demonstrate the steps required for performing LCC.
5. Explain potential pitfalls in the management of eye injuries.

General Considerations

- Vision is the vital sign of the eye in conscious patients and is the best indicator of eventual visual prognosis after injury. It also gives an indication of urgency; the worse the vision, the more urgent the condition. Vision is evaluated by simple initial assessment of each eye (with the contralateral eye closed or blocked):
  - Can you read any print or type? Identify any images?
  - How many fingers do you see? (counts fingers, CF)
  - Do you see a hand moving? (hand motion, HM)
  - Do you see light? (light perception, LP; no light perception, NLP)
- The vision of the uninjured eye can provide a useful comparison for vision assessment. A pocket Snellen chart is not necessary for accurate vision assessment in the trauma bay. Readily available and simple alternatives, such as typeface of name badges and newspapers are acceptable substitutes for documenting this important information.
- The periorbital soft tissues, upper and lower eyelids, and bony orbit protect the globe. The medial and lateral canthi serve as attachment points for the upper and lower eyelids. Regardless of consciousness, all protective structures should be inspected for lacerations and swelling as indicators of potential open globe injury.
- In a conscious patient without contralateral eye injury, eye movement can be assessed quickly for evidence of extraocular muscle entrapment from orbital floor fractures. With muscle entrapment, elevation of the eye(s) is usually restricted, and the patient will often complain of double vision with both eyes open.
- The globe is briefly evaluated for redness, foreign bodies, and lacerations. An irregular pupil, externalized iris tissue, or gelatinous eminence from the eye indicates a possible globe rupture or other penetrating globe injury. Other findings of globe injury are hyphema, bullous subconjunctival hemorrhage, enophthalmos, and/or conjunctival tear.
- Ocular proptosis (protrusion of the eye from its socket) with diffuse subconjunctival hemorrhage and swelling (hemorrhagic chemosis) suggests increased retro-orbital pressure with possible retrobulbar hemorrhage and is an eye emergency.
- There are two true eye injury emergencies requiring immediate intervention: orbital compartment syndrome (OCS, usually from retrobulbar or retro-orbital hematoma) and acid/alkali splash burns to the eye. In both conditions, minutes matter and treatment cannot be delayed for the arrival of an opthalmologist.

- OCS typically results from hemorrhage in the orbit (Figure 1). This can compress the globe, vessels, and optic nerve, putting the nerve on tension compromising blood flow to the retina. The resultant retinal and optic nerve ischemia may result in blindness within 60-90 minutes if not addressed.
- OCS is not always associated with an orbital fracture, as the fracture permits decompression of hemorrhage into the adjacent sinuses. The retro-orbital space must be decompressed rapidly with urgent LCC.
- Acid/alkali splash burns to the eye are managed immediately with copious water directly on the eye for at least 30 minutes. There is no need for further testing—history alone guides the need for immediate irrigation. Alkali exposure can cause corneal melting and ocular ischemia and is more serious than acid exposure.
- Open globe injuries are best managed initially with placement of a rigid periorbital eye (Fox) shield (convex shape) over the socket (Figure 2).
- It is vital to avoid any pressure on the eye if an open globe injury is suspected. Avoid maneuvers that might induce nausea, vomiting, or retching, and administer antiemetics and analgesics.
- In adults, intravenous antibiotics (4th generation fluoroquinolone or Cefazolin) should be administered as soon as possible and urgent ophthalmological consultation obtained.
- If a retrobulbar hematoma is present in the setting of a ruptured globe, the injury should be managed with a Fox shield and immediate ophthalmological consultation.
- Almost all eye injuries are best managed initially with placement of a Fox shield (not a patch) including corneal, conjunctival, intraocular foreign bodies, hyphema, lid lacerations, and severe corneal abrasions.
- Other than the two true surgical emergencies listed above, most eye injuries are best left to the care of an eye specialist and can be addressed in a more delayed fashion. General principles for the initial management of such nonemergency injuries are as follows:
  - Perform a rapid check of visual acuity
  - Limit manipulation of the eye to a minimum
  - Leave foreign bodies in place
  - Do not suture wounds unless evacuation is delayed
  - Do not employ topical treatment
  - Correctly apply an eye shield (Figure 2)
  - Administer antibiotics, antiemetics, and analgesics

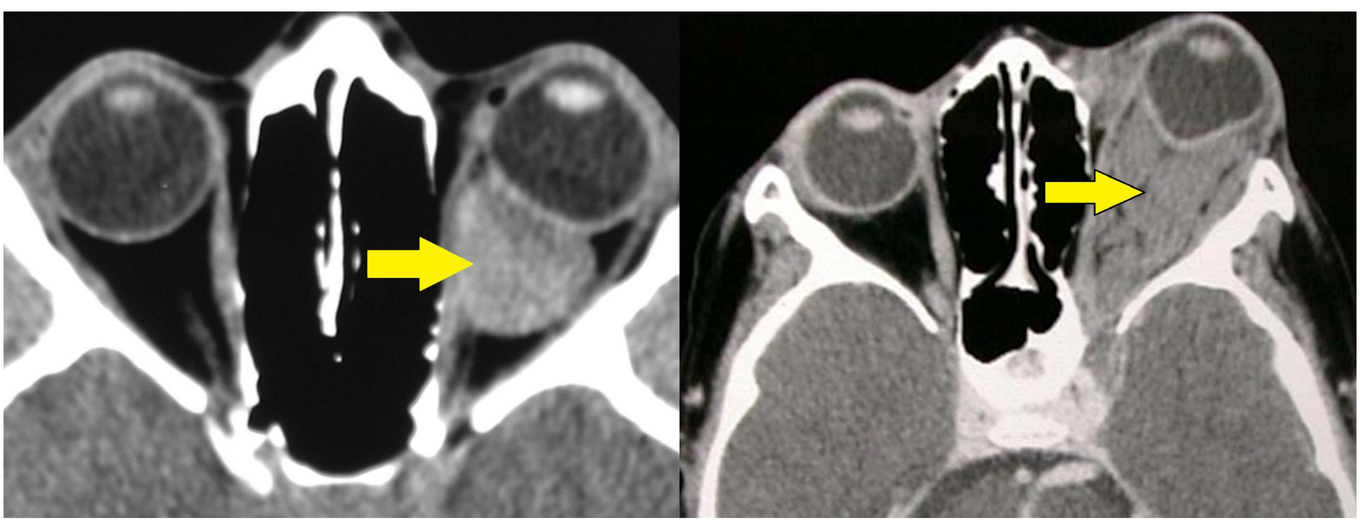


Figure 1. CT scans showing traumatic retrobulbar (retro-orbital) hemorrhage (arrows). As the hematoma gets larger, proptosis can be pronounced (right image), with compartment syndrome of the orbit leading to blindness if not emergently treated.

Figure 2. Correct application of a Fox shield (left) covers the entire orbit in an oblique orientation, with contact points on the brow/forehead and cheek, with minimal tape over the porous potion of the shield. The image on the right shows incorrect placement, with the shield in a horizontal orientation and the superior margin of the shield within the orbit, causing compression of the eyelids and globe.

Orbital Compartment Syndrome (Retrobulbar Hematoma)

- OCS, commonly caused by a retrobulbar hematoma, is an eyesight-threatening condition that requires prompt recognition and treatment.
- Irreversible vision loss can occur in as little as 60–90 minutes; therefore, expedient diagnosis and treatment are needed to prevent blindness.
- The keys to recognition of OCS are severe eye pain, tense proptosis, vision loss, afferent pupillary defect, and decreased eye movement.

Anatomy of the Lateral Eyelid Margin

- Proper performance of a lateral canthotomy and inferior cantholysis depends on identification of the lateral canthus and underlying lateral canthal tendon (Figure 3).
- The lateral canthal tendon is a web-like band of connective tissue that originates from the lateral margins of the upper and lower tarsal plates in each eyelid and inserts on the superficial lateral orbital wall. The tendon is formed from the coalescence of the superior and inferior crura.

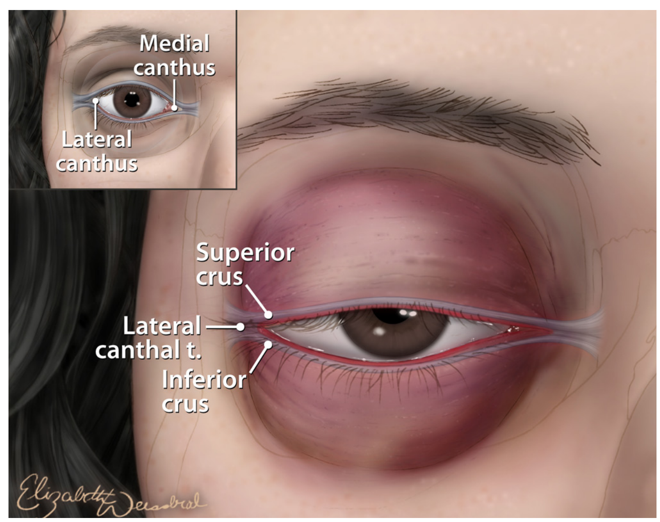


Figure 3. The anatomical features key to the proper performance of a lateral canthotomy are the lateral canthus and the lateral canthal tendon, which divides into superior and inferior crura, as seen on this depiction of an injured right eye.

- The orbit contains the globe, optic nerve, extraocular muscles, blood vessels, nerves, and posterior fat.

Lateral Canthotomy and Cantholysis (LCC)

INDICATIONS

- Emergent orbital decompression in tense orbital hemorrhage with compromised ophthalmic blood flow may be achieved with lateral canthotomy, defined as incision of the lateral canthal tendon, and inferior cantholysis, defined as canthotomy combined with release of the inferior crus of the lateral canthal tendon.
- LCC should be performed for retrobulbar hemorrhage with acute loss of visual acuity, afferent pupillary defect, increased intraocular pressure (IOP), and proptosis.
- The relative afferent pupillary defect is also known as the "Marcus Gunn pupil." The test is positive when pupils constrict less (therefore, appearing to dilate) when a light is shined from the unaffected eye to the affected eye. In the absence of this defect, both pupils constrict the same amount regardless which one is exposed to light.
- In an unconscious or uncooperative patient, a tense orbit with an IOP > 40 mmHg is an indication for a lateral canthotomy (normal IOP is 10–21 mmHg).
- LCC should also be considered in patients with retrobulbar hemorrhage along with any of the following: ophthalmoplegia, cherry-red macula, optic nerve head pallor, and severe eye pain.

CONTRAINDICATIONS

- The main contraindication to performing LCC is an actual or potential globe rupture.
- Findings suggestive of a globe rupture include hyphema, irregularly shaped pupil, bullous subconjunctival hemorrhage, enophthalmos, and/or conjunctival tear.

TECHNIQUE

- All members of the team should use standard precautions to protect against blood and body fluid exposure.
- The instruments required to perform LCC are a straight hemostat, toothed forceps, and small straight or curved blunt-tip scissors (Figure 4).
- The patient should be placed in a supine position. The eye socket should be prepped with standard povidone iodine solution/paint (not detergent/scrub).
- If the patient is conscious, inject 1–2 percent lidocaine (with or without epinephrine) into the lateral canthus, taking care not to injure the globe (Figure 5).

Figure 4. The minimum equipment needed to perform lateral canthotomy and cantholysis includes scissors, a straight hemostat, and toothed forceps.

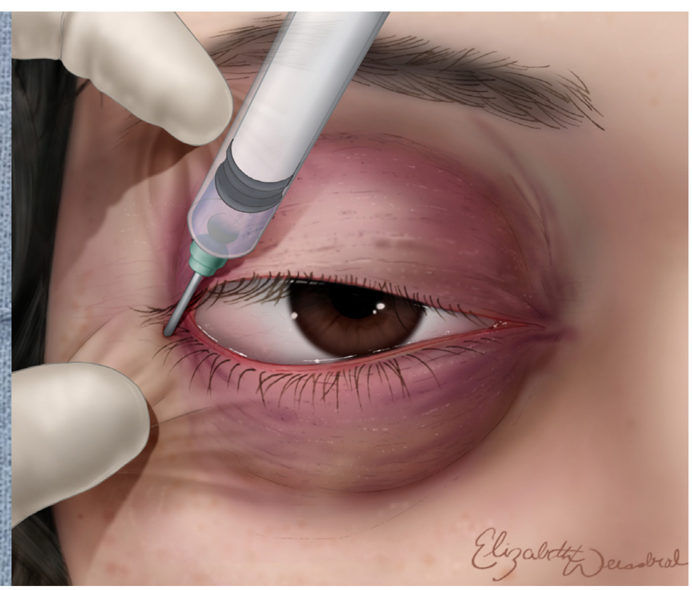


Figure 5. If the patient is conscious, inject local anesthetic into the lateral canthus.

- The lateral canthus is crushed with a straight hemostat, advancing the jaws to the lateral fornix at the orbital rim. Occluding these tissues for one minute facilitates hemostasis and marks the location where the incision is to be made (Figure 6).
- Using straight (or curved) blunt-tip scissors, make a 1 cm long full-thickness horizontal incision of the lateral canthus in the middle of the crush mark.
- Pull the lateral lower eyelid away from the face with toothed forceps to reveal the lateral canthal tendon.
- While maintaining lid traction, sever the inferior portion of the lateral canthal tendon and lateral septum with scissors by keeping the scissors in the sagittal plane of the face, with the tips directed caudally and posteriorly (Figure 7). The inner blade is just anterior to the conjunctiva, and the outer blade is just deep to the skin. When complete, the lower eyelid should pull freely away from the face, decompressing the compartment and releasing pressure on the globe. If the lid does not swing freely, continue dissection until all restricting bands are released.
- If release of the inferior tendon is insufficient (IOP remains > 40 mmHg), the superior portion of the lateral tendon may also be cut. This must be done with great care due to the proximity of the lacrimal gland, and is best deferred to the ophthalmologist.
- Hyperosmotics, such as 3 percent saline, acetazolamide, and mannitol may be used to help decongest the orbit.
- The essential component of this procedure is the cantholysis, not the canthotomy.
- A successful procedure is marked by improvement in visual acuity, softening of the orbit, resolution of a previously described afferent pupillary defect, and decrease in IOP to < 40 mmHg.
- If the intact cornea is exposed (i.e., uncovered by eyelids), apply erythromycin ophthalmic ointment or ophthalmic lubricant ointment to protect the cornea and prevent corneal desiccation or infection.
- Urgent ophthalmic consultation is required.

Figure 6. A straight clamp is used to crush the skin at the lateral canthus to provide hemostasis.

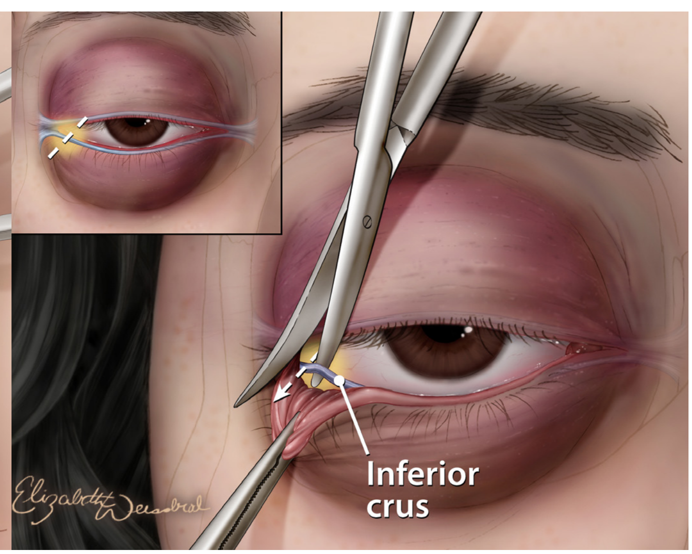
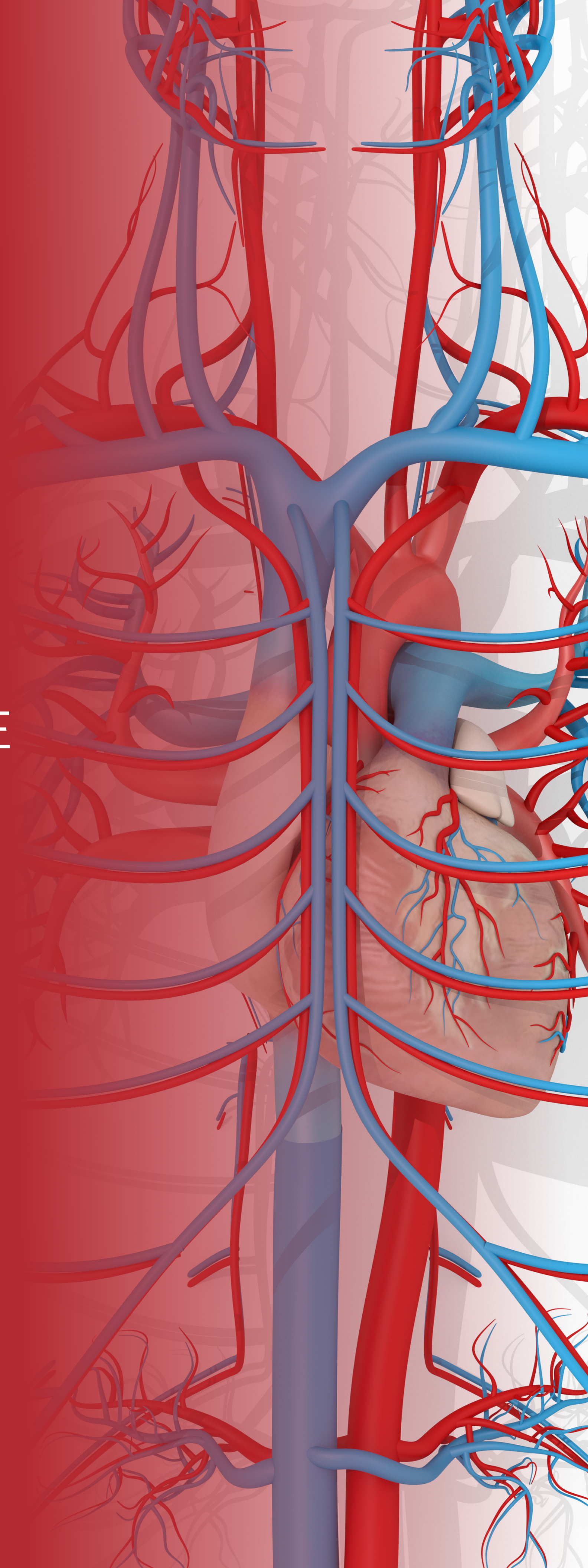


Figure 7. The skin contained in the crushed tissue is divided, and the canthal tendon is divided in a vertical fashion.

Pitfalls and Complications

- Not documenting initial vision
- Failure to assess the eye and pupil in an unconscious patient or in the setting of periorbital swelling
- Placing a flat eye patch or dressing rather than a convex rigid shield to protect the eye
- Placing the Fox shield horizontally within the orbit, rather than obliquely to cover all orbital margins
- Placing a dressing under the shield
- Manipulation of the globe when a rupture or penetrating injury is present
- Neglecting antibiotics, antiemetics, or analgesics
- Delaying irrigation of the eye in cases of acid/alkali splash burns
- Incomplete division of the lateral canthal tendon for decompression of OCS
- Iatrogenic injury to the globe
- Injury to the lacrimal gland and lacrimal artery, which lie superior

CHAPTER 25
OPERATIVE EXPOSURE IN THERMAL INJURY



Operative Exposure in Thermal Injury

This chapter will discuss basic management of thermal injury. Though the major emphasis of this lab experience is operative exposure, a brief review of the principles of diagnosis and management will also be presented.

Learning Objectives

By the end of the ASSET course, participants should be able to do the following:

1. Discuss the classification of thermal injuries.
2. Describe the ways to determine total body surface area of thermal injuries.
3. Discuss the initial management of thermally injured patients.
4. Describe the tools available for the surgical management of thermal injury.
5. Understand the indications for escharotomy.
6. Demonstrate the locations of incisions for escharotomies, when indicated.
7. Describe the steps of basic burn excision and grafting techniques.

Considerations

- Burns covering more than 20 percent of total body surface area (TBSA), or those with symptomatic inhalation injury, are life-threatening.
- Standard of care for the management of life-threatening burns is early consultation with and, if possible, prompt transfer to a burn specialist/center.
- Hypothermia risk is high in burn patients, and immediate efforts should be made to preserve body heat.
- Historically, burns have been described by degree (first, second, and third) of injury, with second degree further divided into superficial and deep, and burns to deep muscle and bone described as "fourth" degree.
- Contemporary burn surgeons more commonly use an anatomic description based on the thickness or depth of the injury (Figure 1).
    - **Superficial-thickness (first degree) burns** (Figure 2) impact only the epidermal layer. These burns look like a mild or moderate sunburn, appear red, blanch easily, do not blister, and are painful to the touch. These wounds are not included in the TBSA estimation when calculating fluid resuscitation.

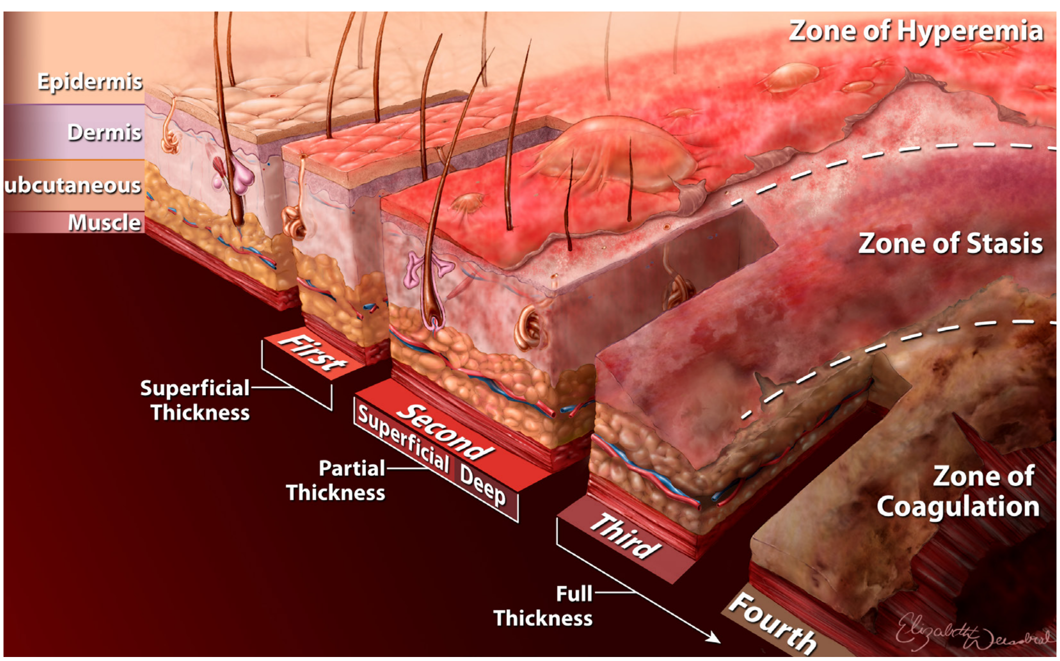


Figure 1. The anatomical classification of thermal injuries based on depth or thickness of injury. Also shown on the right is the three-zone concept of burn wound progression, as described by Jackson in 1953.

- **Partial-thickness (second degree) burns** can be superficial—involving only the papillary dermis (Figures 2 and 3a)—or deep—involving both the papillary and reticular dermis (Figure 3b). These burns are moist, blistered, painful, and can blanche.

Figure 2. Superficial-thickness burns proximal, with an early blister forming distally (partial thickness).

- **Full-thickness (third degree) burns** involve all epidermal and dermal layers and can include muscle and bone. These burns appear leathery and dry, are nonblanching, do not hurt, and often contain visible thrombosed vessels (Figure 4).

- The reticular dermis plays an important role in burn healing, and healing without surgical intervention (excision and grafting) is proportional to the amount of uninjured reticular dermis.
- A thorough history and physical examination is an important foundation for the management of thermal injuries. Knowing the mechanism (flame, scald, chemical, electrical, etc.) and the duration of contact will help guide management.
- Physical findings such as color, texture, and sensory changes are important parts of the exam and assist in determining burn depth.
- The initial assessment of burn thickness may not be the same as the final level of injury.
- Burn wounds evolve over time (Figure 5), with the ultimate depth of injury dependent on numerous factors that include adequacy of resuscitation, infection, and nutrition. As such, wounds must be frequently reassessed and care adjusted accordingly.
- Management planning can start with initial assessment of a burn injury but will often change as the wound progresses.

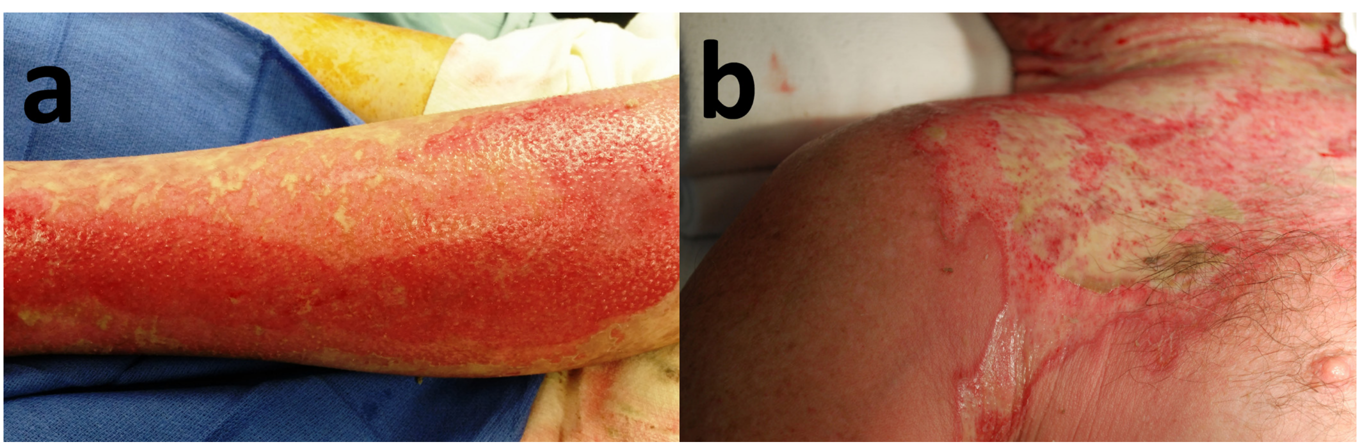


Figure 3. Superficial partial-thickness burn (a) with visible papillary dermis remaining; deep partial-thickness burn (b).

Figure 4. Full-thickness burns to the torso (dermal) on the left and to the extremities (subdermal) on the right.

Figure 5. Burn wound progression at initial presentation (left) and 48 hours later (right), despite aggressive burn resuscitation for burn shock.

- In addition to wound depth, it is important to calculate the TBSA of the burn injury.
- A rough estimate of TBSA can be calculated using the "rule of nines," as seen in Figure 6. TBSA assessments for children differ from adults, as children have proportionately larger heads and smaller extremities.
  - Significant over- or underestimation of burn wound size (by more than 10 percentage points) may lead to significant morbidity.
  - Underestimation may lead to under-resuscitation and organ failure.
  - Overestimation may lead to resuscitation morbidity, such as pulmonary failure and compartment syndromes.
  - When wounds have been cleaned and debrided, the TBSA should be recalculated using the Lund-Browder burn chart, which allows for a more precise calculation.
- Another practical way to estimate TBSA is to use the patient's hand (palm plus fingers) as one percent of TBSA (Figure 7).
- Once depth assessment is complete, wounds should be dressed as soon as possible with clean dry dressings, and the patient should be transferred to a burn care facility if they meet transfer criteria.
- If burn care facility transfer is delayed (more than 24 hours) or is not possible, consider coverage of the wound with a topical antimicrobial agent.
- If the TBSA is greater than 15–20 percent, initial care of thermal injury should be focused on the management of shock.
- The goal of burn-shock resuscitation is to replace burn-related fluid losses while avoiding over-resuscitation.

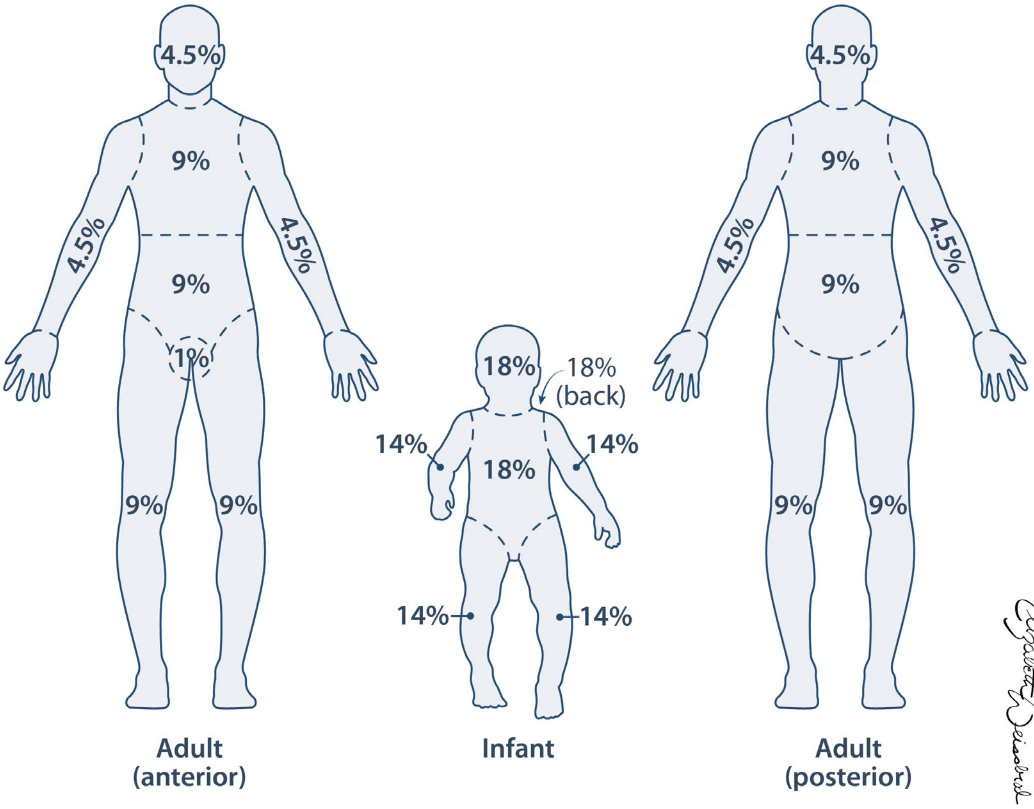


Figure 6. The "rule of nines" is used to obtain a rough estimate of TBSA burned during the initial evaluation of patients with thermal injuries.

Figure 7. Palmar equivalence of 1 percent total body surface area burn.

- Fluid resuscitation should start immediately via intravenous (IV) or intraosseous (IO) lines, which can be placed through burned skin if necessary.
- Current burn guidelines (U.S. Army Institute of Surgical Research) recommend resuscitation with IV isotonic crystalloids such as lactated Ringers or Plasma-Lyte, with volume and rate as follows:
  - Boluses should not be given unless a patient is hypotensive.
  - There is no role for "permissive hypotension" in a burned patient.
  - IV infusion rate should be started at 500 mL/hr while completing the initial assessment.
  - Measure TBSA (partial and full-thickness burns only) and multiply by 10. This will determine the ongoing IV fluid rate. For example, if the patient has 40 percent TBSA burn, the rate will be 400 mL/hr.

- For patients greater than 80 kg, add an extra 100 mL/hr for each additional 10 kg.
- If resuscitation is delayed, do not try to "catch up" by giving extra fluids.
- For children, 3 × % TBSA × body weight (in kg) gives the volume (mL) to be given in the first 24 hours, with half to be given in first 8 hours.
- Place a Foley catheter for assessment of resuscitation.
- Urine output is the main indicator of resuscitation adequacy in burn shock. Fluid intake should be adjusted to maintain urine output at a rate of 30–50 mL/hr in adults and 0.5–1.0 mL/kg/hr in children (note that the child rate is given **per kilogram** per hour).

- Local wound care to prevent wound infection and treatment of pain are important in the initial management of thermal injuries.
- Escharotomies should be considered if a patient has circumferential (or near circumferential) full-thickness burns of an extremity or neck, or full-thickness burns of the anterior torso from midaxillary line to midaxillary line.
- Once burn shock has been resolved, excision of the burn wound should be performed using one of three techniques:
  - Simple excision and primary reepithelialization (for small burn wounds)
  - Tangential excision and split-thickness skin grafting
  - Polytrauma patients who are unstable may require fascial excision to minimize operative time and blood loss.

Position and Preparation

- The area for excision should be positioned for best exposure while also providing ample visualization of normal surrounding tissues.
- Wound preparation should be performed using chlorhexidine or Betadine solution.
- Escharotomies often have to be performed without the luxury of an available operating room.
- Temperature regulation is paramount in burn patients. OR temperatures should be as high as possible, and areas not undergoing excision should be covered in plastic underneath cloth drapes to preserve body heat.
- Hemostasis during burn excision requires a multipronged approach:
  - Tourniquets should be used for extremity excisions whenever possible.
  - Epinephrine should be added to warm saline solution at a concentration of 2 ampules per liter normal saline. Laparotomy pads soaked in this solution are liberally applied throughout the process for hemostasis.
  - Topical thrombin should be available for application after excision of burn tissue.
  - Electrocautery should be used sparingly for areas of bleeding that do not stop after three or four rounds of epinephrine/thrombin/pressure wrapping.

Equipment

- A scalpel or Bovie electrocautery can be used for excisions with primary closure, fascial excisions, and escharotomies.
- The equipment seen in Figure 8 includes dermatomes for tangential excision and harvesting of donor skin. Noticeable differences between dermatome types include the width of a single pass and the depth of tissue excised. Note that all dermatomes can be used both for harvesting donor skin and for excising injured tissue.

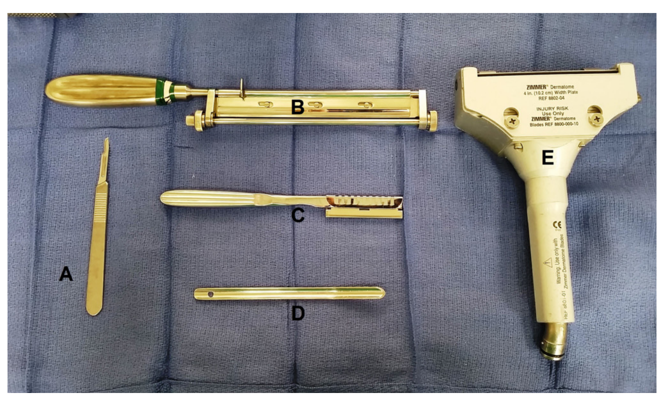


Figure 8. Instruments for excision and primary closure, tangential excision, and harvesting of skin include the scalpel (A), Humby knife (B), Goulian-Weck knife (C), Norsen debrider (D), and powered (air or electric) dermatome (E).

Surgical Exposure

ESCHAROTOMY ASSESSMENT

- Full-thickness circumferential and near-circumferential skin burns result in the formation of eschar.
- Eschar can lead to significant compromise of chest wall excursion in the case of thoracic burns and impairment of underlying tissue perfusion with accumulation of burn-associated extracellular and extravascular fluid within confined anatomic spaces.
- Escharotomy is surgical division of nonviable eschar, which allows the cutaneous envelope to become more compliant. This allows underlying tissue to expand and thereby prevent further tissue injury or functional compromise.
- Escharotomy is considered an emergent procedure in the treatment of burned patients, but it rarely needs to be performed in the emergency department at the time of initial presentation.
- Indications for emergency escharotomy are the presence of a circumferential (or near-circumferential) eschar with one of the following:
  - Impending or established vascular compromise of the extremities or digits
  - Impending or established respiratory compromise due to circumferential torso burns
  - Impending or established abdominal compartment syndrome associated with abdominal burns
- Severely burned extremities should be immediately elevated at or above the level of the heart.
- Frequent range-of-motion exercises, as tolerated by the patient, can help minimize tissue edema and elevated tissue pressure.
- Any change in capillary refill time, decrease in Doppler signal, or change in sensation should lead to reevaluation of compartment pressures, with low threshold to perform immediate decompression via escharotomy and fasciotomy, if needed.
  - Markers of physiologic distress in a burned extremity parallel those of compartment syndromes developing for other reasons. Skin pallor as a sign is unreliable in thermal injury, as the color of burned skin may not change with vascular compromise.
  - Neurologic changes such as numbness, tingling, and paresthesia are more reliable than changes in skin color.
  - Markers of physiologic distress in the chest include increasing peak airway pressures or lower delivered tidal volumes for a set pressure.
  - Many patients who require escharotomy will not be able to interact for a complete physical exam. Therefore, a high index of suspicion for compromise and a low threshold for intervention should be maintained.
- It is important to realize that a subset of burn patients will need fasciotomies as their primary intervention for true compartment syndromes (see chapter 5 on extremity compartment syndromes).

ESCHAROTOMY TECHNIQUE

- Escharotomies should be performed in as clean an environment as possible. Required equipment includes a scalpel, hemostats, ties, and electrocautery if available.
- Classic lines for escharotomy incisions are seen in Figure 9. It is helpful to mark them out on the patient beforehand, especially over the arm, to avoid inadvertent involvement of a joint.
  - Avoid exposing major neurovascular structures.
  - Never place escharotomy incisions on the palmar surfaces of the hands or the soles of the feet.
  - Escharotomies to address increased chest wall resistance and pulmonary problems should include abdominal wall escharotomies (Figure 10) if the abdomen is affected.
  - Escharotomies of the extremities should be placed in a manner that will facilitate fasciotomy (if needed) and extend beyond the areas of full-thickness injury (Figure 11).

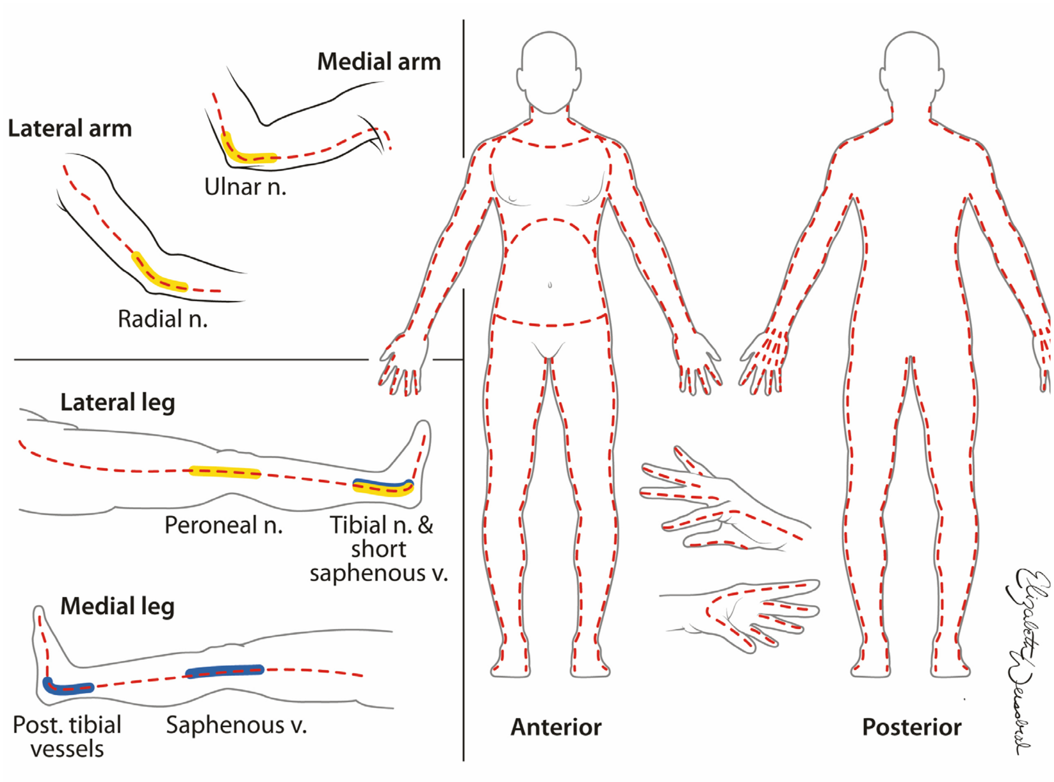


Figure 9. The incisions used for escharotomy for all areas of the body. Areas of caution (nerves and vessels) are highlighted on the left.

Figure 10. Chest wall escharotomies include the upper abdomen for a patient with respiratory compromise from circumferential burns of the thorax.

Figure 11. Escharotomy of the medial lower extremity, placed to facilitate fasciotomy if needed.

- Escharotomies for the hand should start with radial and ulnar releases along the thenar and hypothenar eminences (similar to the skin incisions performed for compartment syndrome of the hand), as seen in Figure 12. If these are insufficient, dorsal incisions between the metacarpal bones can also be performed.
- If needed, foot escharotomy is also performed with skin incisions similar to those used for fasciotomy, as described in chapter 5.

Figure 12. Hand escharotomies.

- Incision into the eschar should result in a significant split of the involved tissue; this is similar to the bulging of tissue from a fasciotomy incision (Figure 13).
  - It is important to fully divide the eschar, including the hypodermis, to allow for full expansion of the tissue.
  - It is also important to extend the escharotomy incisions beyond the edges of the eschar to prevent a tight constricting band and subsequent failure to decompress the underlying tissues.

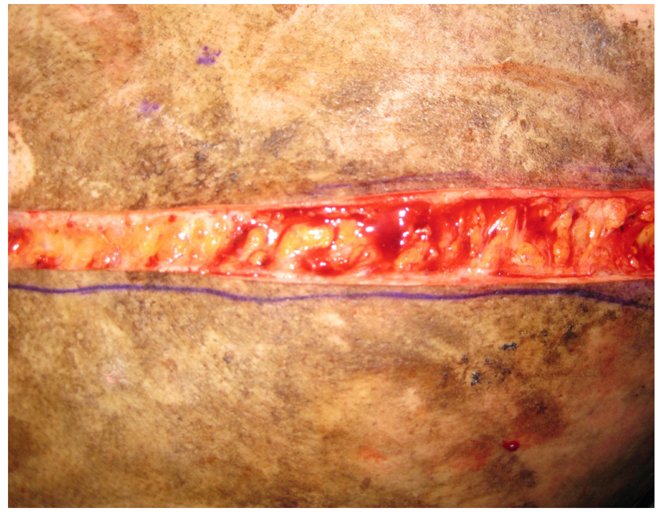


Figure 13. Separation of eschar after a complete release.

FASCIAL EXCISION

- Fascial excision removes all levels of eschar and underlying tissues down to the level of the fascia but **does not** include excision of the fascia itself.
- Fascial excision is recommended when subcutaneous fat is burned and in select large burns that have a high risk for infection, significant blood loss, or loss of skin graft.
- A plane can be developed along the fascia of the anatomic area, using electrocautery or suture ligation to control perforating vessels (Figure 14).
- Once the excision is complete, redress the wound using standard antimicrobial dressings.

Figure 14. Fascial excision of the lower legs, with removal of overlying damaged skin, subcutaneous tissue, and fat.

TANGENTIAL EXCISION AND GRAFTING

- Excision of burn tissue and replacement with autologous skin (autograft) is a cornerstone of burn reconstruction.
  - Fundamental principles include:
    - Excision of all dead tissue
    - Adequate hemostasis
    - Prevention of shear injury through fixation of the graft
  - Significant blood loss can be expected and can challenge a resource-poor environment.
  - Burn excision is typically not recommended for patients who can be transferred to a burn center within one to two weeks of their injury.
- Positioning and preparation are discussed in the previous section.
- Adequate counter-tension is necessary to achieve optimal depth of excision:
  - Areas that are not amenable to counter-tension (torso, large thighs) can be excised by picking up a small segment to bring it into the path of the blade or by having assistants apply local pressure sequentially around the borders of the excision (Figure 15).
- A Weck or Humby knife (Figure 8) is held in the dominant hand (handle in the palm, loosely held by the fingers, with the index finger and thumb at the most proximal portion of the handle) and engages with the area of burn to be excised at approximate a 45° angle. Gentle, back and forth movements while progressing along the length of the wound result in excision of a uniform layer of tissue.
- Once an area is completely excised, the wound bed should bleed uniformly if dermis is still present; if fat is visible, there should be no evidence of hemorrhage.
  - Note that if vessels underlying the dermis can be visualized and do not blanch (i.e., are clotted), the overlying dermis has been irreparably damaged and must be removed.
  - Bleeding can be quite extensive during a large excision. Segmental excision with application of thrombin followed by wrapping with epinephrine-soaked gauze pads to provide pressure is advised.
- Once hemostasis is complete, skin grafts can be applied to the region requiring coverage.
  - Split-thickness skin grafts are taken at a depth of 0.008 to 0.012 inches (approximately to the thickness of the beveled end of a 10 scalpel blade).
  - Harvesting of skin can be done with any dermatome (Figure 16). Subdermal clysis of dilute epinephrine solution can make harvesting easier in some regions (the scalp in particular) but is not necessary.

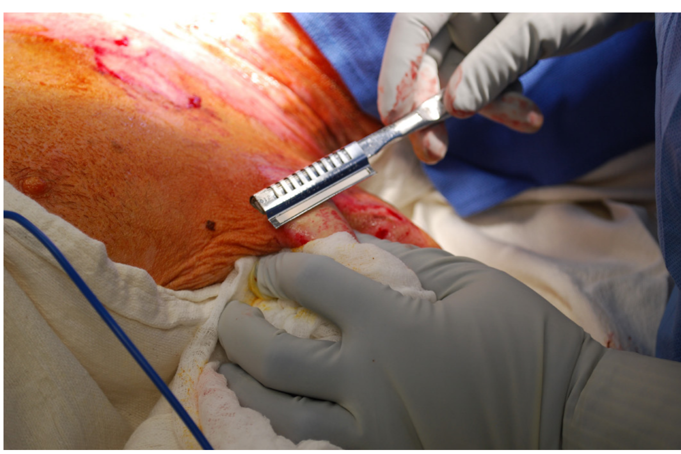


Figure 15. Tangential excision. Here, the nondominant hand is used to elevate a section of burn tissue for a smooth pass of a Weck knife.

Figure 16. Harvesting of skin with a powered dermatome.

- Once harvested, grafts can be applied directly (sheet graft) or meshed at ratios of 1.5:1 up to 6:1 (Figure 17). Smaller-meshed grafts are applied to areas of function (Figure 18), while broader-meshed grafts are useful for covering large areas (Figure 19).

- After application, it is important to fixate the graft to prevent shear injury (Figures 18–21).
  - Absorbable sutures or staples can be used to decrease movement of the graft, but true fixation comes from a compressive dressing.
  - Initially, nonadherent dressing layers are placed over the skin graft.
  - A tie-over bolster dressing can be constructed by placing sutures at one inch intervals around the outer edge of the graft and using them to firmly tie down fluffed cotton that is laid over the top of the nonadherent dressing (Figures 19 and 20).
  - Alternatively, negative-pressure wound devices can be used for graft stabilization (Figure 20) and are especially helpful for areas where movement is hard to prevent.

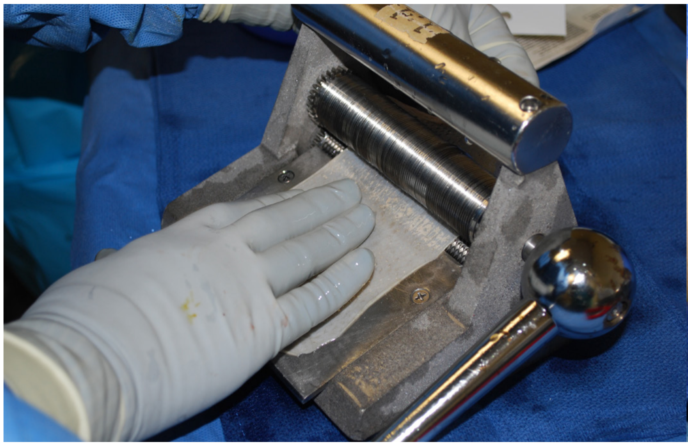


Figure 17. Harvested autograft can be applied directly (sheet graft) or meshed at ratios of 1.5:1 up to 6:1.

Figure 18. Application of split-thickness skin graft (mesh 1.5:1) with tacking sutures of 4-0 chromic.

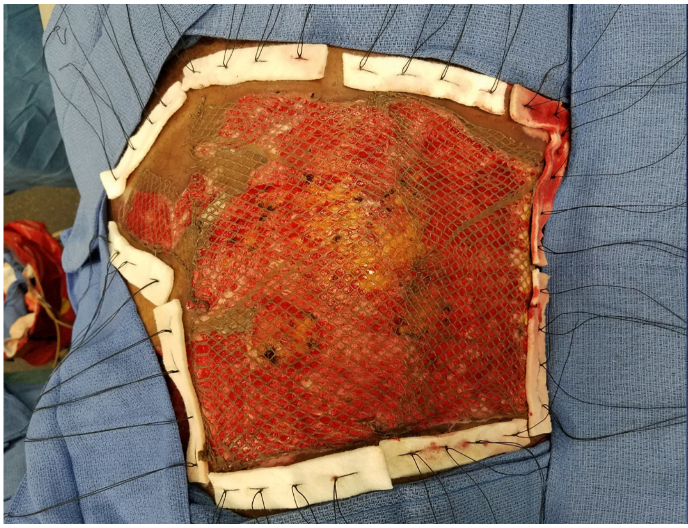


Figure 19. Broad-mesh graft applied to large area, with sutures around the edges of the wound to be used for fixation of bolster dressing.

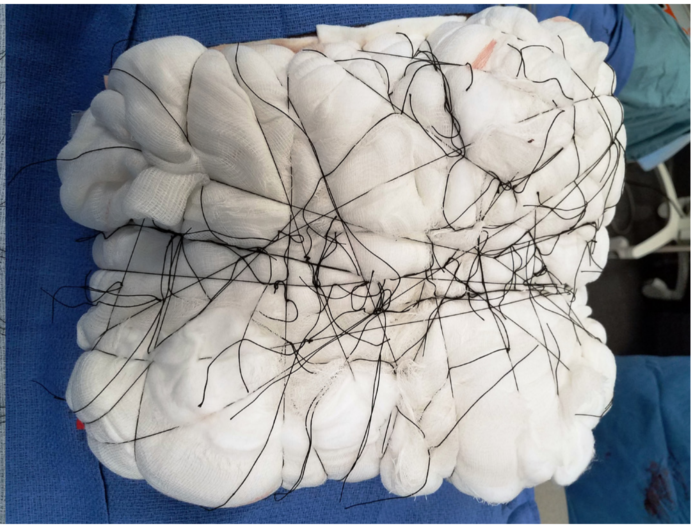
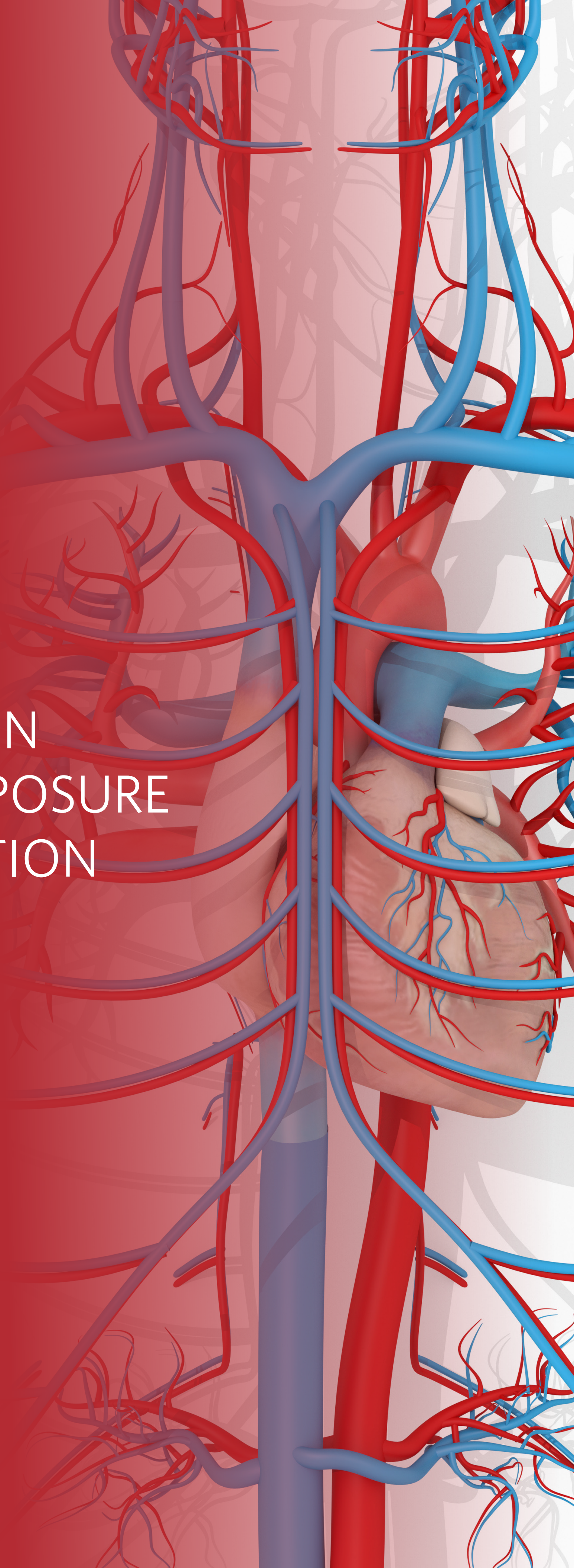


Figure 20. Bolster dressing (2-0 braided nylon sutures, cotton roll, and dressing) placed on top of graft for fixation.

Figure 21. Negative-pressure wound device used for application of skin graft on the scalp.

CHAPTER 26
EMERGENCY CESAREAN SECTION: UTERINE EXPOSURE AND INFANT EXTRACTION



Emergency Cesarean Section: Uterine Exposure and Infant Extraction

This chapter will discuss the technique for an emergency cesarean section. The major emphasis of this lab experience will be on standard and emergency surgical technique, pelvic anatomy, and infant extraction. Additionally, the indications and techniques for perimortem cesarean delivery will also be presented. Postpartum hemorrhage as a complication of delivery will be covered in chapter 27.

Learning Objectives

By the end of the ASSET course, participants should be able to do the following:

1. Describe indications for emergency cesarean section.
2. Describe techniques and pertinent anatomy encountered during cesarean section.
3. Demonstrate the steps of an emergency cesarean section.
4. Understand the indications and technique for perimortem cesarean delivery.

General Considerations

- Potential indications for emergency cesarean delivery are not well established but may be divided into maternal and fetal indications:
  - Maternal indications include:
    - Distress
    - Failure of labor to progress
    - Abnormal placentation with accreta or percreta
    - Prolapsed umbilical cord or fetal extremities
    - Acute cardiopulmonary or traumatic arrest
    - Cardiac/pulmonary disease, cerebral aneurysm, or active herpes simplex infection (generally elective cesarean)
  - Fetal indications include:
    - Evidence of fetal distress, such as abnormal or nonreassuring fetal heart tones
    - Breech or transverse lie
    - Uterine trauma with perforation or rupture

Female Pelvic Anatomy

- Review of female pelvic anatomy with orientation of fallopian tubes, round ligament, broad ligament, ovaries, and bladder around the gravid uterus (Figure 1).

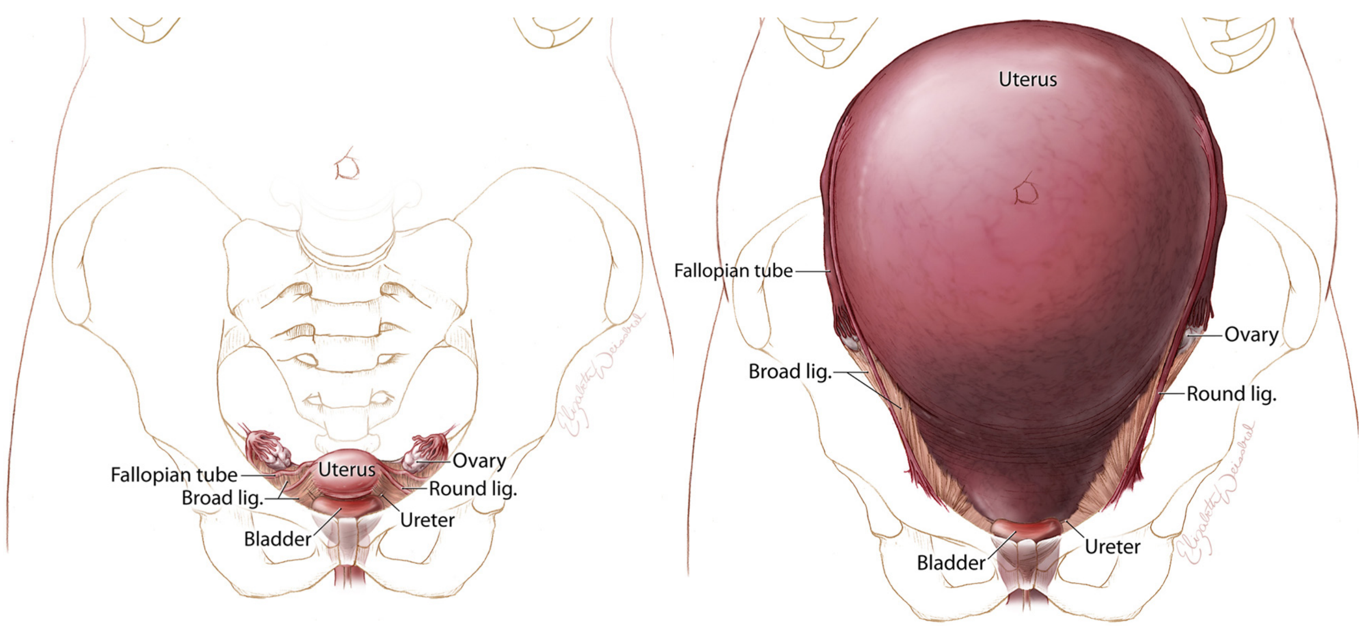


Figure 1. Relevant female pelvic anatomy in gravid state.

Surgical Steps

- Anesthesia is not required for patients with acute cardiopulmonary or traumatic arrest.
- Preoperative antibiotics should be given, if possible.
- Positioning should be carefully done and the patient placed supine, with a left lateral tilt of 15–30° to displace the uterus off of the inferior vena cava.
- The most commonly used incision is the Pfannenstiel.
- An acute care surgeon faced with the prospect of performing an emergency cesarean may find it more expeditious (and familiar) to perform a midline incision, especially when performing a perimortem procedure.
- Landmarks for the Pfannenstiel incision are the pubic symphysis and the anterior superior iliac spine, bilaterally.
- The incision should be planned two fingerbreadths above the pubic symphysis and extending bilaterally approximately 6 cm in a semicurvilinear fashion (Figure 2).
- The incision is carried through to the underlying layer of fascia with sharp dissection. The superficial epigastric vessels will be seen in the subcutaneous layer and may need to be ligated for hemostasis (Figure 3).
- The anterior rectus fascia is cleared of any remaining subcutaneous fat and is then incised in the midline prior to making lateral extensions in the fascia.
- The fascia is elevated from the underlying rectus muscle and divided bilaterally in a transverse fashion with curved Mayo scissors (Figure 4).
- The superior fascial edge is grasped with a Kocher clamp on either side of the midline, and the fascial sheath is released from the underlying rectus muscle with sharp dissection (Figure 5). This dissection is carried down to the level of the pubic symphysis.
- Any perforating blood vessels between the fascia and the rectus muscles will need to be cauterized to achieve hemostasis.
- The rectus muscles are then separated at the midline in order to identify the underlying peritoneum. The peritoneum can then be entered (Figure 6).
- The peritoneal incision should then be extended laterally to the level of the skin edge.
- If the bladder is overlying or in close proximity to the proposed uterine incision, a "bladder flap" should be performed. This is accomplished by incising the vesicouterine serosa and digitally dissecting the bladder away from the lower uterine segment.

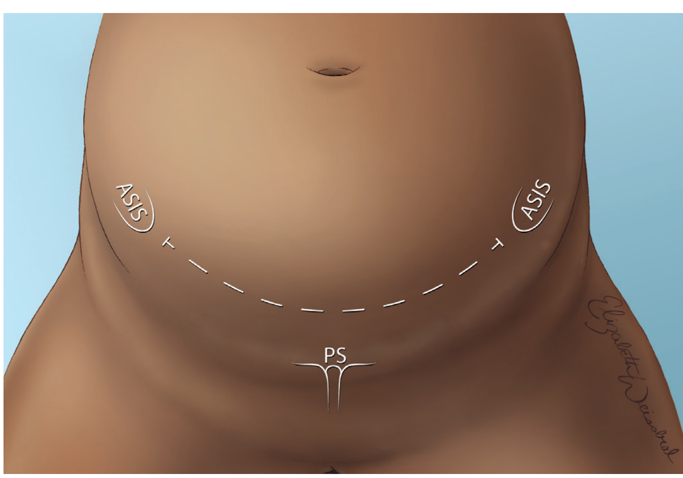


Figure 2. The classic Pfannenstiel incision is placed two finger breadths above the pubic symphysis and extended towards the anterior superior iliac spine (ASIS), bilaterally.

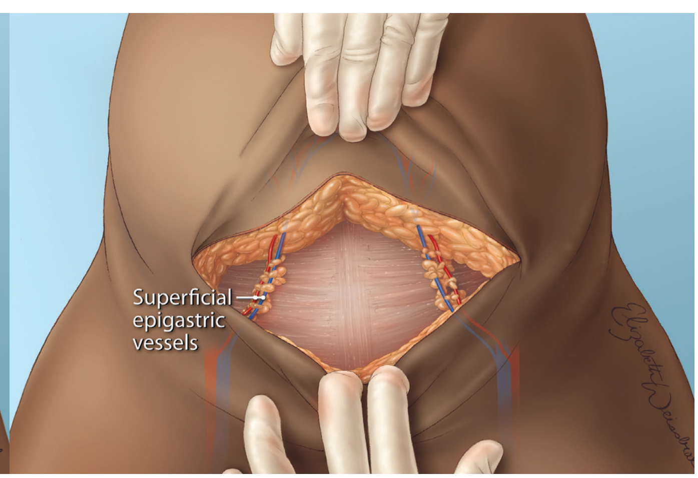


Figure 3. The superficial epigastric vessels will be encountered with further dissection and should be ligated or cauterized.

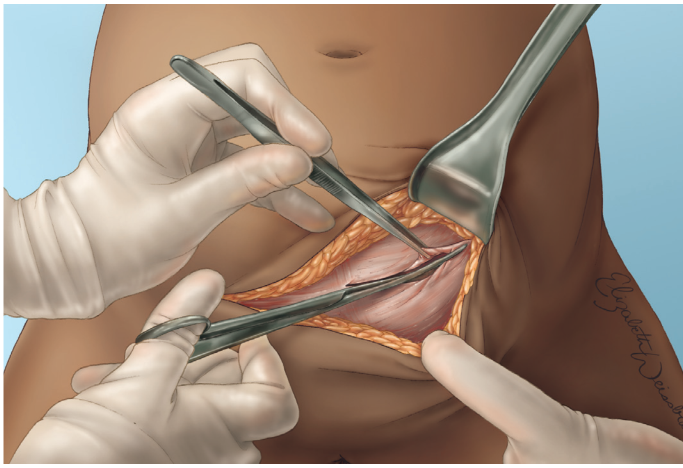


Figure 4. The anterior rectus fascia is elevated off of the rectus muscle and opened transversely.

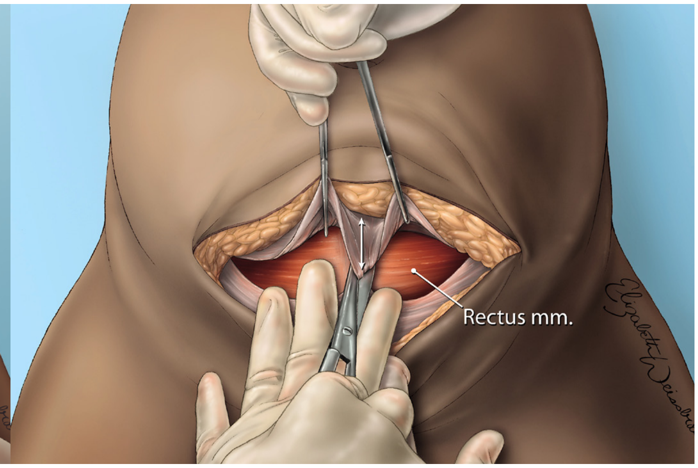


Figure 5. The superior fascial edge is grasped on either side of the midline, and the fascial sheath is dissected free from the underlying rectus muscle.

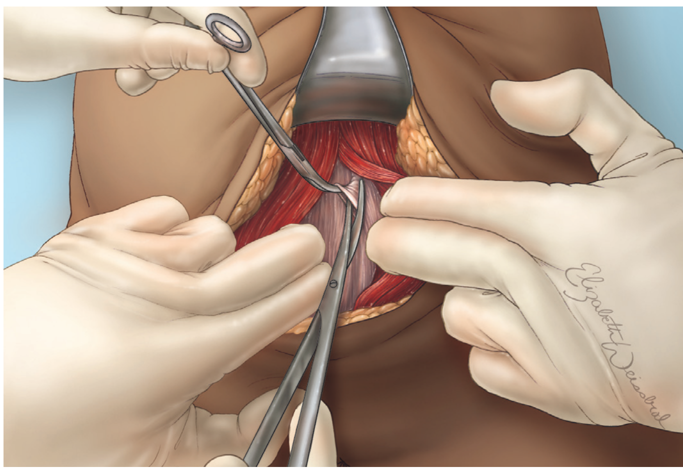


Figure 6. The peritoneum is opened at the midline and extended bilaterally while avoiding underlying structures.

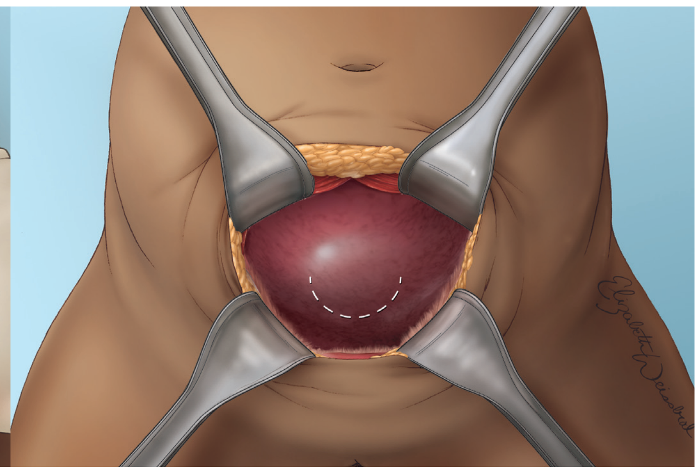


Figure 7. The hysterotomy is made in the lower uterus using an exaggerated U-shaped incision to avoid the uterine arteries.

- The transverse uterine incision (hysterotomy) should be made approximately 1 cm below the upper margin of the bladder (Figure 7) or higher, if the patient has been laboring, to avoid the cervix and vagina.
- The hysterotomy incision is made in an exaggerated U-shape to avoid extension to the uterine arteries (Figure 7).
- The incision is carried down in a single plane, layer by layer, to the level of the amniotic membranes. Suction should be used to keep the incision clear of blood.
- The surgeon should digitally palpate the incision after each pass to evaluate remaining thickness. If bleeding obscures visualization, the incision edges can be grasped with Allis clamps and elevated away from the underlying infant.
- If sufficiently thin, the muscle can be entered digitally to avoid cutting the infant.
- Once the amniotic membranes are visualized, the incision is manually extended in the cephalad and caudal directions in order to accommodate delivery (Figure 8).
- If the hysterotomy is not large enough to allow delivery, sharp extension can be done with scissors to create a J-incision (Figure 9).

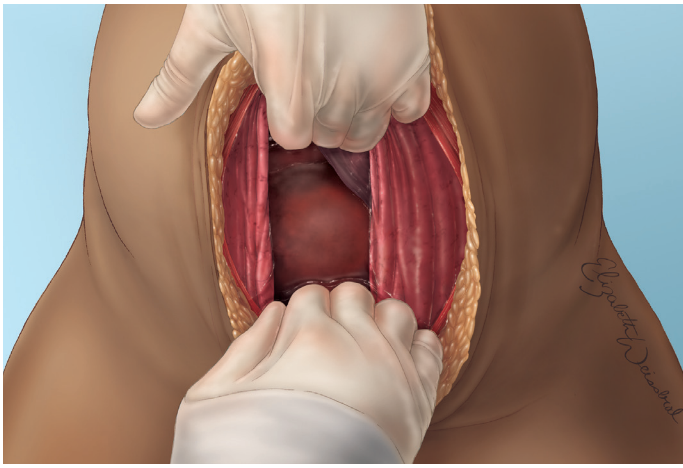


Figure 8. The hysterotomy is manually extended.

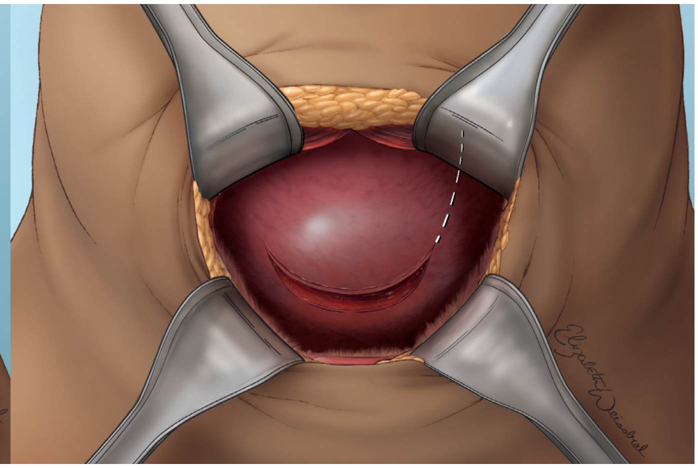


Figure 9. If necessary, the hysterotomy can be extended into a J-shaped incision.

- In the case of a cephalic (head towards hysterotomy wound) presentation, the surgeon's hand should cup the infant's head, then elevate the infant to the level of the hysterotomy, while the assistant provides pressure on the fundus (Figure 10).
- After the head is delivered, any nuchal cord (any portion of the umbilical cord that is wrapped around the infant's neck) should be reduced. The anterior shoulder is delivered using downward traction, followed by upward traction to deliver the posterior shoulder and the rest of the infant.
- If the infant presents breech, the hips/sacrum of the infant should be elevated to the hysterotomy and the legs delivered. Fundal pressure is used to help deliver the infant to the level of the scapula. The infant arm is delivered, and the infant is rotated 180° for delivery of the other arm. Once the arms are delivered, the head is stabilized and delivered (Figure 11).
- Following delivery of the infant, the umbilical cord should be double-clamped and then cut.

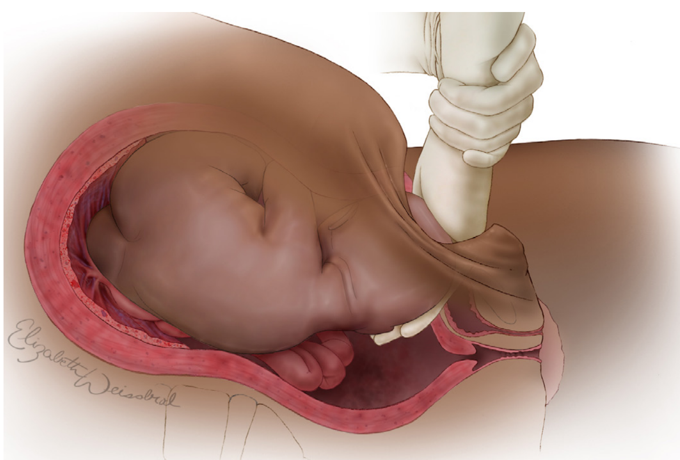


Figure 10. For a cephalic presentation, the surgeon's hand is used to cup the infants head and deliver it to the hysterotomy.

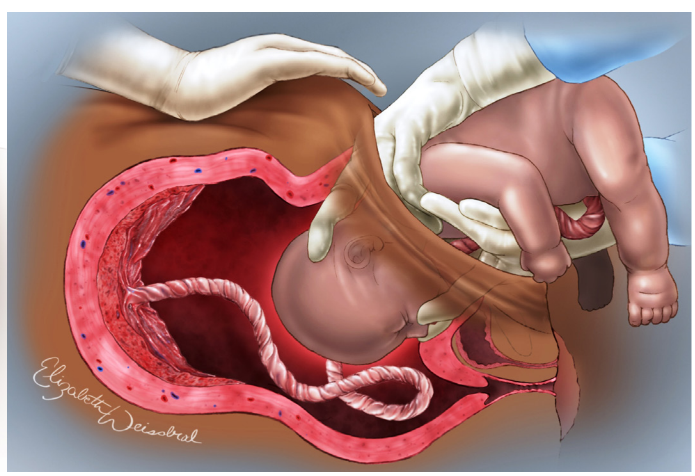


Figure 11. Cesarean delivery of an infant with a breech presentation.

- Gentle traction should then be put on the umbilical cord to the placenta, with internal uterine massage to facilitate placental separation (Figure 12).
- After delivery of the placenta, the uterus should be exteriorized into the wound. The fundus is wrapped in a moist lap sponge, and manual uterine massage is continued.
- The contents of the uterus are cleared with a dry lap sponge wrapped around the surgeon's hand (Figure 13).
  - In the event of significant uterine hemorrhage, the uterus should be packed and manually compressed, as discussed in chapter 27.
- Closure of the hysterotomy is done with absorbable sutures in a running locked fashion anchored at either apex (Figure 14). An additional imbricating layer can be used if needed.
- Any remaining areas of bleeding can be over sewn with figure-of-eight sutures as needed.
- The uterus is returned to the abdomen, and the rectus muscles are allowed to return to their original position. The anterior rectus fascia is closed using a running suture.

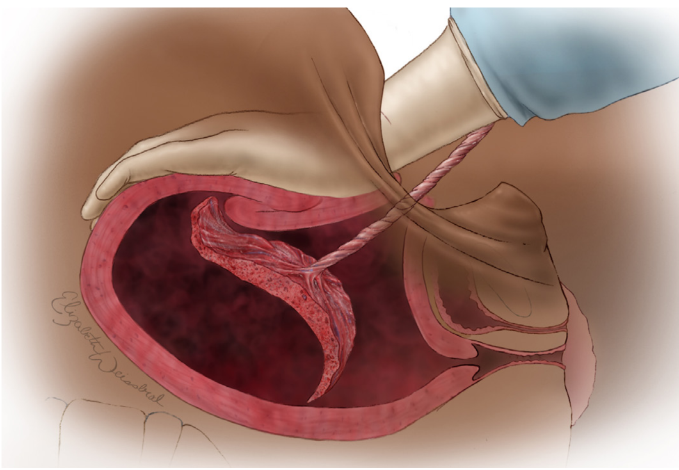


Figure 12. After delivery, gentle traction is applied to the umbilical cord while performing uterine massage to facilitate placental separation.

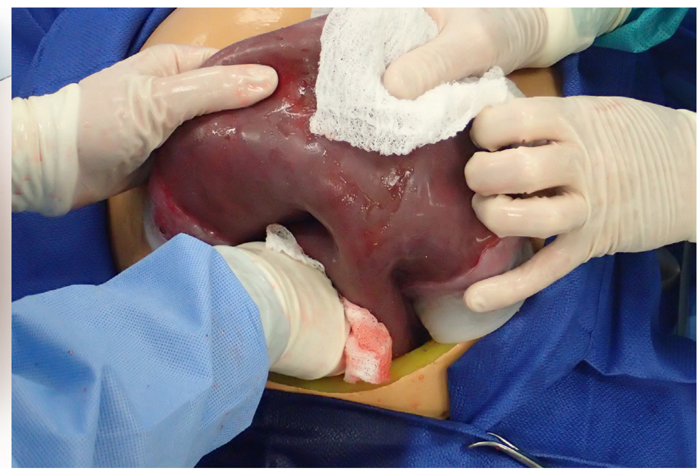


Figure 13. The uterus is exteriorized, and the uterine contents are cleared using a lap pad over a hand inserted into the hysterotomy.

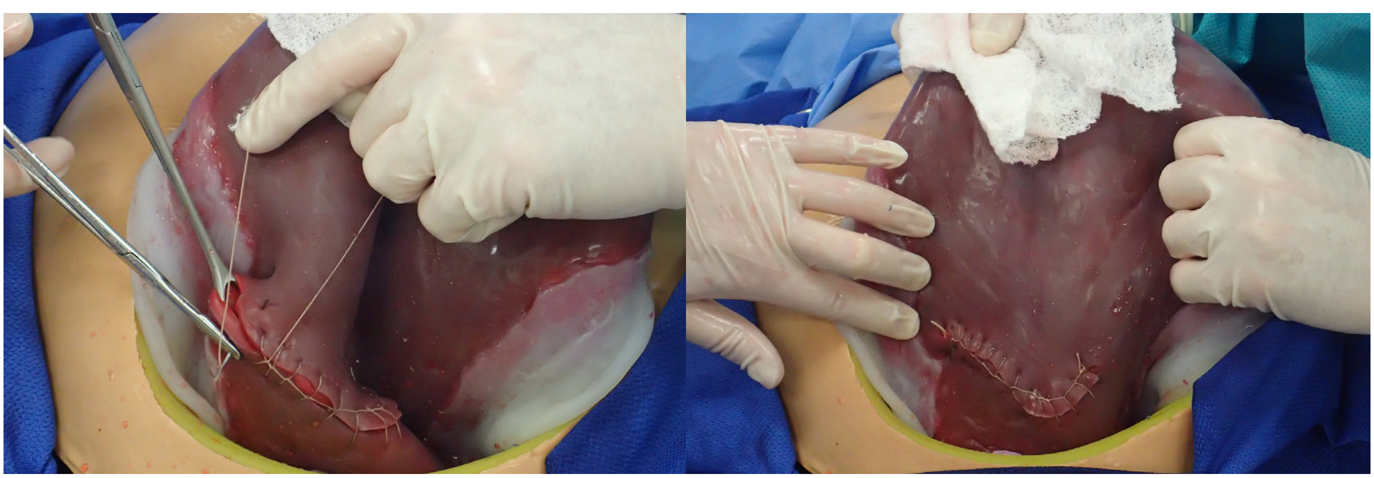


Figure 14. The hysterotomy is closed using an absorbable, running locking suture, as seen being performed (left) and completed (right).

Perimortem Cesarean Delivery (PMCD) Considerations

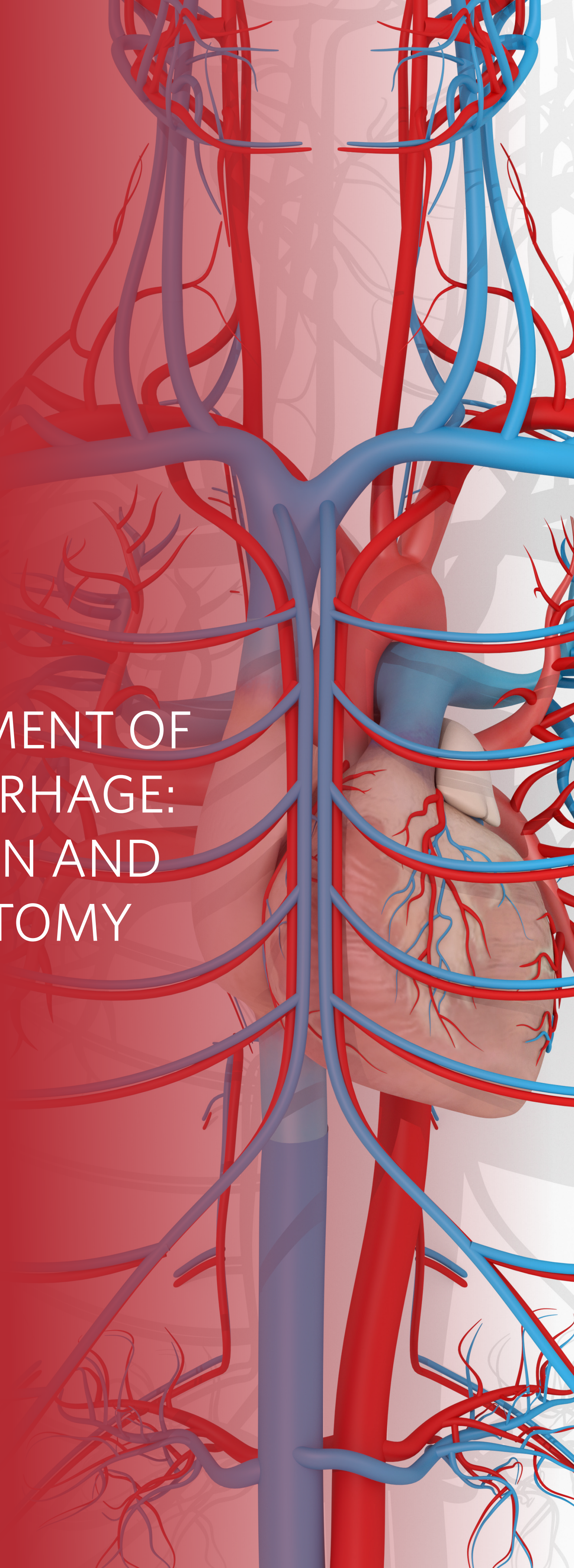
- Perimortem cesarean delivery (PMCD), when appropriately applied, can save the life of both the mother and the infant.
- The most common indications for PMCD are traumatic or nontraumatic cardiopulmonary arrest of the mother.
- Several factors must be considered in deciding whether to undertake PMCD:
  - The estimated gestational age (EGA) of the fetus:
    - A fetus with EGA of less than 24 weeks is unlikely to survive.
    - EGA can be difficult to obtain in an emergency. Fundal height is used as a crude measure, and a fundal height of 4 cm above the umbilicus is consistent with an EGA of 24 weeks.
  - The time from maternal arrest:
    - To increase the likelihood of infant survival, the procedure should be performed as soon after maternal arrest as possible.
    - Best outcomes are achieved if PMCD is initiated within four minutes of maternal arrest when resuscitative measures have failed.
    - PMCD should be attempted even in the face of prolonged maternal downtime if circumstances suggest that the fetus is potentially viable.
- When previous maternal resuscitative efforts have failed, cesarean delivery is beneficial to both the infant and the mother. Emptying the uterus improves maternal physiology and the effectiveness of cardiopulmonary resuscitation.

Perimortem Cesarean Delivery (PMCD) Technique

- PMCD should be performed by the available physician with the most surgical experience.
- If possible, a neonatologist should also be in attendance.
- The mother should be supine with a left lateral tilt.
- Prepping and draping are not necessary and should not delay the procedure.
- Maternal resuscitation efforts should not be interrupted and should continue while PMCD is being done.
- A vertical midline incision is indicated, as this will allow evaluation and control of any other traumatic intra-abdominal injuries the mother may have sustained.
- Also unlike in an elective cesarean section, in PMCD the uterine incision is made vertically, from the fundus to just above the anterior reflection of the bladder.
- When the uterus is entered, insert the index and middle fingers to lift the uterine wall away from the fetus, and extend the incision as needed.
- Deliver the infant, clamp and divide the umbilical cord, and hand the infant immediately to someone trained in resuscitation.
- A length of cord should be clamped at each end and saved for later cord gas evaluation.
- The placenta should be removed and the uterus massaged.
- If the resuscitation team believes that the mother has a chance of survival, a careful, layered closure should be undertaken, as previously described.
- Other life-threatening injuries should be addressed, as indicated by damage control principles.

CHAPTER 27

OPERATIVE MANAGEMENT OF POSTPARTUM HEMORRHAGE: UTERINE COMPRESSION AND CESAREAN HYSTERECTOMY



Operative Management of Postpartum Hemorrhage: Uterine Compression and Cesarean Hysterectomy

This chapter will discuss operative management of postpartum bleeding. Though the major emphasis of this lab experience is operative management of postpartum hemorrhage (PPH), a general review of the principles of diagnosis and initial medical management will also be presented.

Learning Objectives

By the end of the ASSET course, participants should be able to do the following:

1. Describe indications for operative management of postpartum hemorrhage (PPH).
2. Describe techniques for compression sutures, Bakri balloon placement, and uterine artery ligations for controlling PPH.
3. Understand indications and describe techniques for cesarean hysterectomy.
4. Demonstrate the steps in surgical exposure of the uterus, ligation of uterine arteries, and cesarean hysterectomy.

General Considerations

- PPH is a common and potentially life-threatening event most commonly defined as estimated blood loss greater than one liter after either vaginal or cesarean delivery, a decrease in hematocrit by 10 percent, and/or the need for transfusion.
- PPH is most common at the time of cesarean section.
- Identify the source of PPH:
    - Tone—The majority of cases are caused by uterine atony, and medical management largely targets this mechanism.
    - Iatrogenic—At cesarean section, extension of the uterine incision can lacerate bordering vessels. At vaginal delivery, bleeding from cervical or perineal lacerations may occur.
    - Tissue—Retained placental fragments after vaginal delivery, or an abnormal placenta (accreta, previa, etc.) encountered at the time of cesarean section, can worsen bleeding and prevent effective contraction of the uterus.
    - Thrombin—Coagulopathy, either preexisting or as a result of ongoing bleeding
- Indications for operative management:
    - Following vaginal delivery, continued bleeding that is unresponsive to medical interventions, or ongoing hemodynamic instability
    - During cesarean section, significant bleeding that is unresponsive to uterine massage or uterotonics, or bleeding resulting from vascular injury or abnormal placentation

Initial Management

- Identify the bleeding source and resuscitate the patient, activating the massive transfusion protocol to achieve balanced resuscitation.
- Identify whether the placenta is intact and perform a manual sweep of uterus, either transvaginally or through the hysterotomy, removing any remaining tissue or membrane fragments.
- Consider abdominal sonogram to evaluate for retained products.

ATONY

- Atony is caused by failure of the uterus to contract around the site of placental detachment.
- First-line treatment is with bimanual uterine massage (Figure 1 for vaginal delivery, and Figure 2 for cesarean section).
- Medication management follows quickly after uterine massage (Table 1).
- Operative management with compression or ligation sutures is indicated for unresponsive atony, placenta previa or suspected accreta, or when used with other adjunct treatments like tamponade devices.
    - The most common suture used is 0 or 1-chromic.

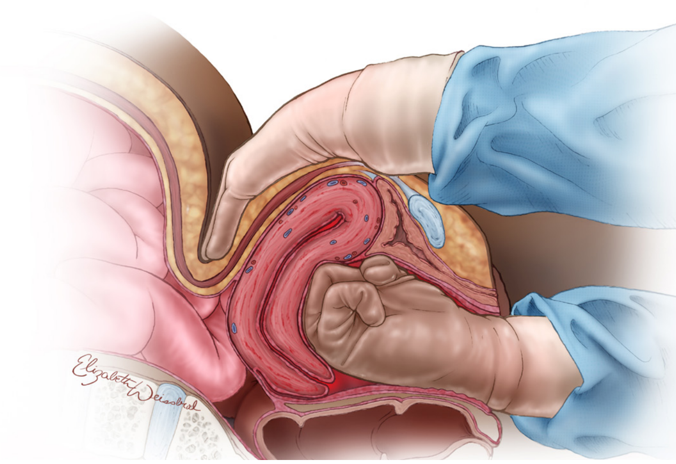


Figure 1. Bimanual uterine massage following vaginal delivery.

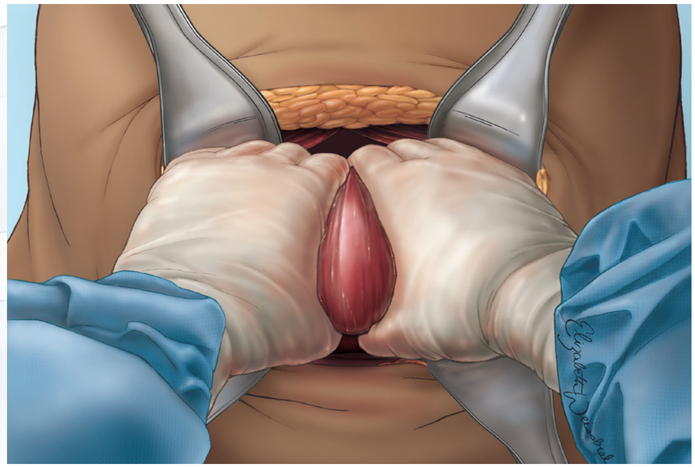


Figure 2. External uterine massage at the time of cesarean section.

Table 1: Medications/Dosage for Postpartum Hemorrhage*

MEDICATION	DOSE	ONSET OF ACTION	CONTRAINDICATIONS
oxytocin (Pitocin)	10–40 units in 500–1000 cc NS or RL via rapid IV infusion	2–3 minutes	Rare, hypersensitivity to medication
methylergonovine (Methergine)	0.2 mg intramuscular OR into myometrium Q2–4 hours	3–5 minutes	Hypertension, preeclampsia, asthma, Raynaud's syndrome
prostaglandin F2alpha (Hemabate)	0.25 mg intramuscular OR into myometrium Q15 min (up to 8 doses)	Peak concentration at 15 minutes	Asthma, renal disorders, pulmonary hypertension, active hepatic, pulmonary or cardiac disease
misoprostol (Cytotec, PGE-1)	600–1000 mcg oral, per rectum or sublingual x 1 dose	3–5 minutes	Rare, hypersensitivity to medication or prostaglandins
tranexamic acid (TXA)	1 g IV over 10 min (add 1 g vial to 100 mL NS and give over 10 min)	5–15 minutes	Subarachnoid hemorrhage, active intravascular clotting, hypersensitivity to TXA

*Adapted from American College of OB/GYN Practice Bulletin #183: Postpartum Hemorrhage, Oct 2017

- **The B-Lynch Suture** (Figure 3) is performed as follows:
  - The suture enters inferior to the uterine incision and exits above the superior edge of the incision.
    - In most cases, the hysterotomy will have already been closed; it is not reopened, but the sutures are placed in the same locations.
  - The suture is passed over the top of the uterus and through the posterior uterus at the same level and same side as the suture previously passed through either side of the hysterotomy.
  - The suture is passed laterally across the posterior side of the uterus and then brought back over the top of the uterus.
  - The suture is then passed across the hysterotomy incision, from superior to inferior, on the side of the hysterotomy opposite to where the suture started.
  - The assistant should then manually compress the uterus as the surgeon ties down the suture.

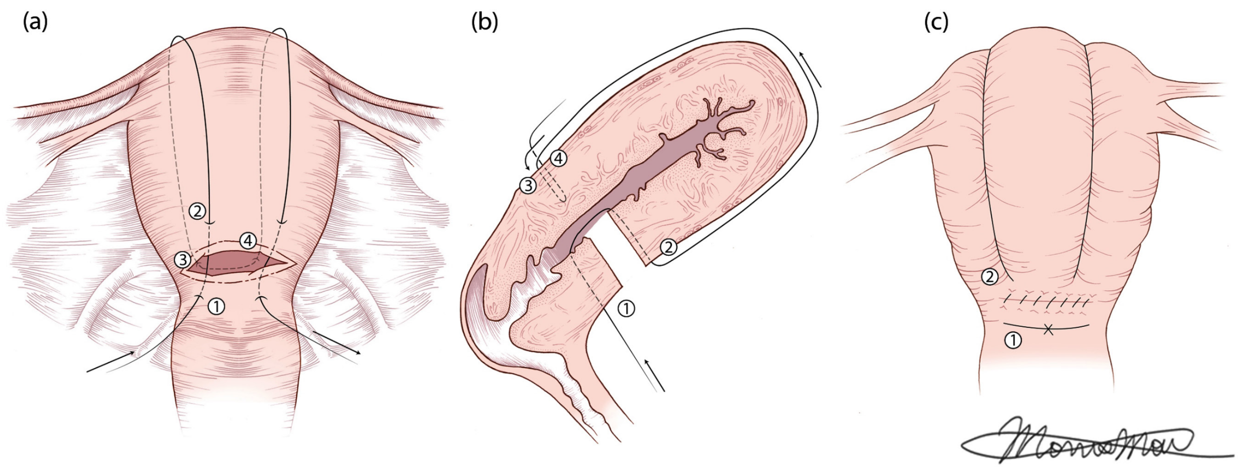


Figure 3. The steps of the B-Lynch suture are shown from the anterior-posterior (a) and lateral (b) viewpoints, with the completed effort shown on the right (c).

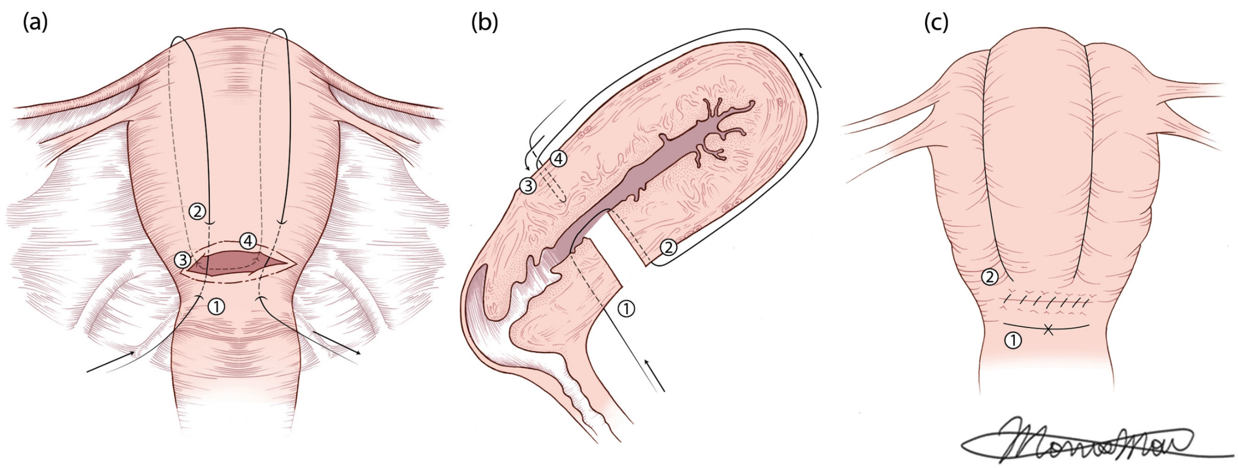


Figure 4. The Hayman suture, as shown from the anterior-posterior (a) and lateral (b) viewpoints, with the completed effort shown on the right (c).

- **The Hayman suture** (Figure 4), which is an alternative to the B-Lynch suture, is performed as follows:
  - A straight needle is placed though the lower uterine segment from anterior to posterior, just above the bladder reflection.
  - Two to four sutures are placed and then tied across the top of the fundus to effect uterine compression.
  - If necessary, horizontal sutures can also be placed for specific problem areas.
- **The O'Leary suture** (Figure 5) is a rapid method for uterine artery ligation to decrease flow to the uterus and is performed as follows:
  - A suture is placed at the level of the cervical os around the uterine arteries bilaterally.
  - Two to three centimeters of myometrium should be included in the stitch, which is passed through the avascular area of the broad ligament lateral to the uterine artery. This should be done in a single pass to decrease the risk of vessel/ureter injury that comes with multiple attempts.

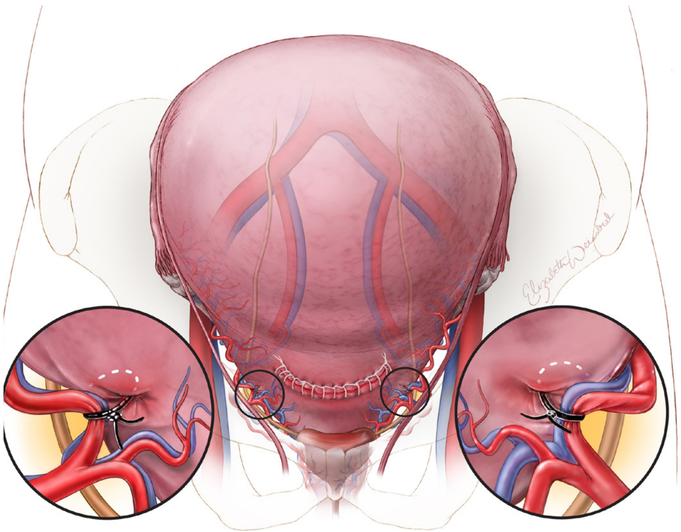


Figure 5. The O'Leary suture, depicted above, involves ligation of the uterine artery while avoiding the ureters.

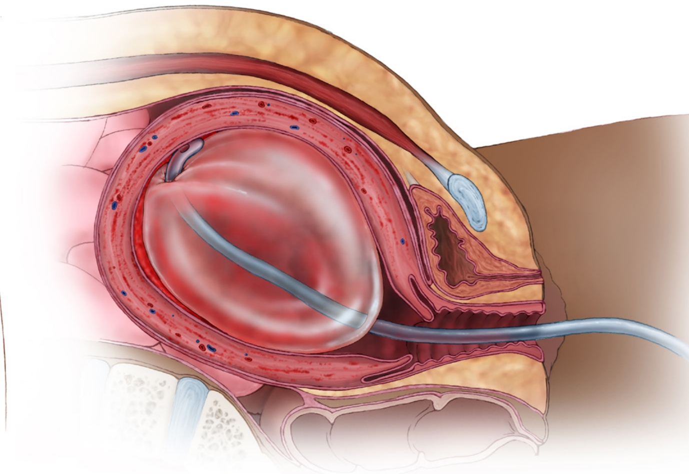


Figure 6. Placement of a Bakri balloon.

  - The process can be repeated at the superior portion of the uterine artery.
  - An attempt should be made to identify and avoid the ureter prior to stitch placement. If this is not possible, palpate the uterine artery, pinch and retract the tissue lateral to the artery, and then place the suture medial to your fingers to avoid the ureter.
- Intrauterine tamponade devices
  - The Bakri balloon (Figure 6) is a common tamponade device that can be placed either through the vagina during vaginal delivery or via the hysterotomy at the time of cesarean section, with the distal end pulled through the cervix and vagina.
  - The balloon is filled with 500 mL of sterile fluid, placed on tension, left in place for 12–24 hours, slowly emptied at a rate of 100 mL per hour, and then removed.
  - The balloon can be used alone or after uterine compression suture placement. The device can also be augmented with vaginal and uterine packing.
  - If the commercial device is unavailable, a "homemade" uterine tamponade balloon can be created with a condom and Foley catheter.
- Endovascular control of postpartum hemorrhage
  - Transcatheter embolization of the uterine arteries is an alternative to the techniques described above.
  - Resuscitative endovascular balloon occlusion of the aorta (REBOA) has been increasingly used as an adjunct to hemorrhage control in postpartum hemorrhage, recognizing that this is only a temporizing measure while preparing for one of the definitive procedures previously described. The technique for REBOA is described in chapter 22 of this manual.

PERIPARTUM HYSTERECTOMY

- Hysterectomy should be considered when all other interventions for peripartum hemorrhage have failed.
- Hysterectomy can also be considered as a planned procedure with suspected accreta. This must be discussed with the patient, as it will result in permanent sterilization.
- Exposure via Pfannenstiel incision was discussed in chapter 26.
- A vertical incision should be considered when placental abnormalities are suspected, or in women with history of multiple cesarean

sections. A self-retaining retractor should be used (Figure 7).

- If needed, control active bleeding before starting the hysterectomy by clamping the uterine arteries prior to beginning dissection (Figure 11).
- Curved Kelly clamps are placed as close to the uterus as possible across each fallopian tube and utero-ovarian ligament bilaterally (Figure 8), and the tissue is divided. Take care to avoid the vasculature that is engorged due to pregnancy. These pedicles can be sutured after the uterine arteries are secured.
- Large absorbable sutures are placed 1 cm proximal and 1 cm distal to the area of planned division of the round ligament. The round ligament is then divided, with the incision extended inferiorly into the broad ligament 1–2 cm (Figure 9).
- If a bladder flap was made as part of the cesarean section, then ensure adequate exposure for the hysterectomy. Identify the ureters in the retroperitoneal space (Figure 10).
- Open the posterior leaf of the broad ligament, with extension inferomedially toward the uterosacral ligaments.

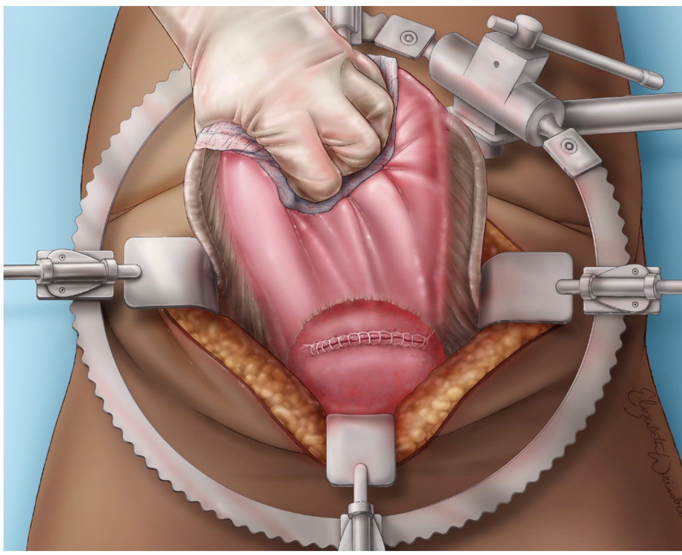


Figure 7. Placement of self-retaining retractor.

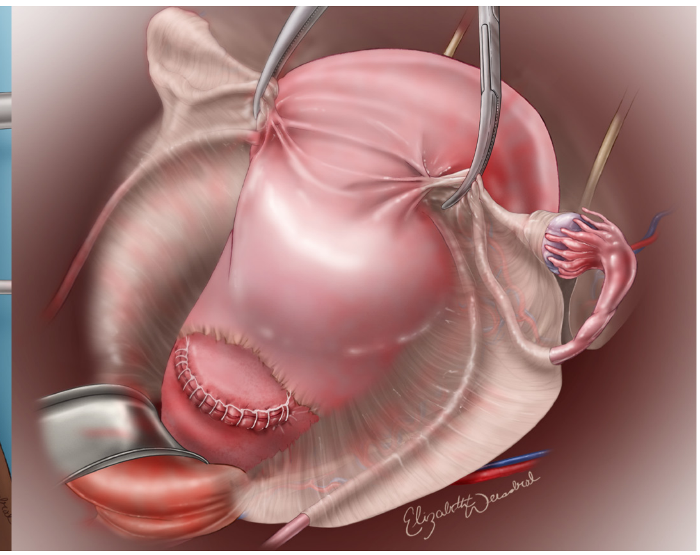


Figure 8. Clamps are placed across the fallopian tubes and utero-ovarian ligament bilaterally.

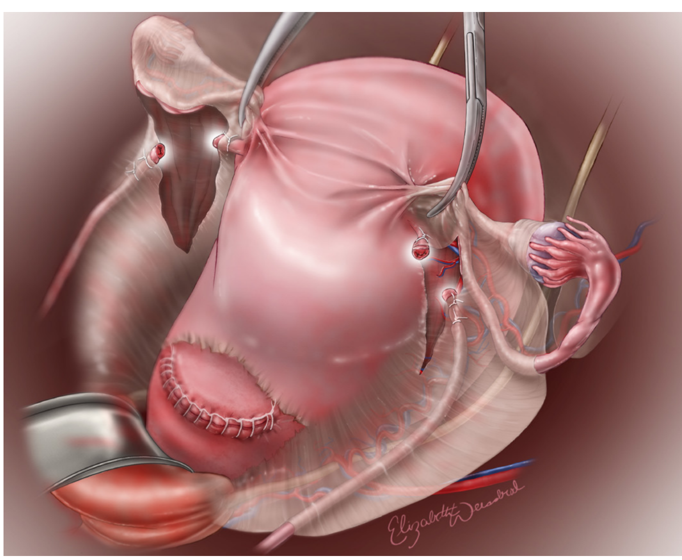


Figure 9. Division of the round ligaments and extension of the incision into the broad ligaments bilaterally.

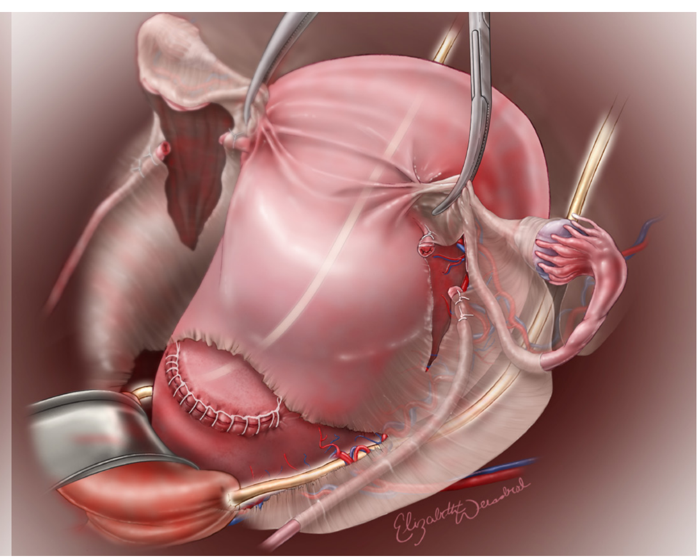


Figure 10. The ureters are identified in the retroperitoneal space.

- The uterine vessels are skeletonized, doubly clamped, and divided prior to ligation, taking care to avoid the ureter (Figure 11).
- A more efficient option for ligation of the uterine vessels is to use a surgical stapler. This must be held against the uterus to avoid the ureter.
- A supracervical technique is most often used, as the cervical os is difficult to identify in a patient who has been in labor with a dilated/effaced cervix.
    - After ligation of the uterine arteries, the uterus is amputated from the cervix, with an attempt to make the incision just above the internal cervical os. A V-cut can be made to help with closure (Figure 12).
    - The cervical stump is then closed using figure-of-eight absorbable sutures (Figure 13).
- If the patient was in advanced labor and the cervix is dilated, it can be more difficult to identify the cervical edges. In these cases, careful inspection after removal of the uterus is important to make sure you adequately close the cervical opening.
- Inspect all surrounding structures for injury.

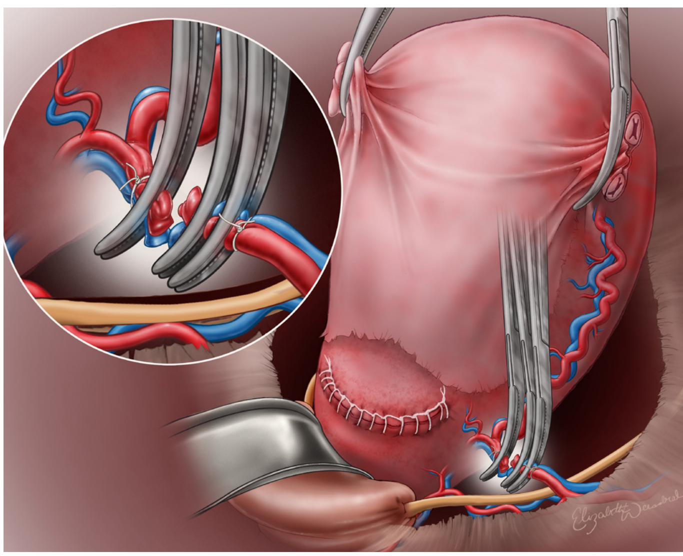


Figure 11. The uterine vessels are skeletonized, doubly clamped, and divided prior to ligation, taking care to avoid the ureter.

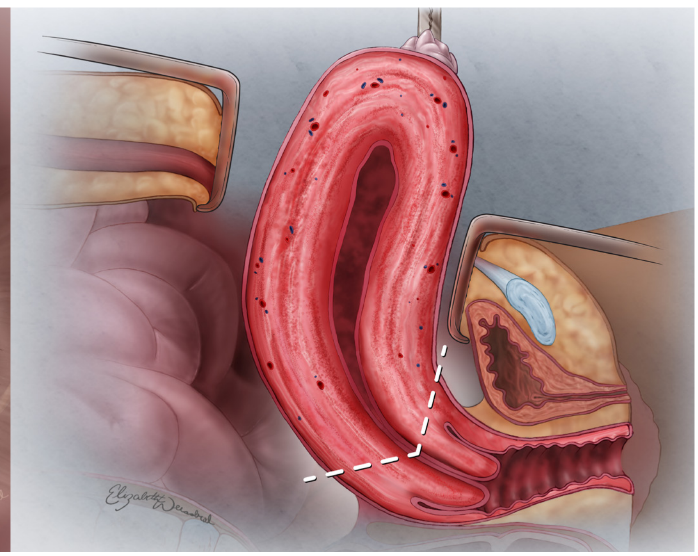


Figure 12. The V-cut incision used to amputate the uterus from the cervix.

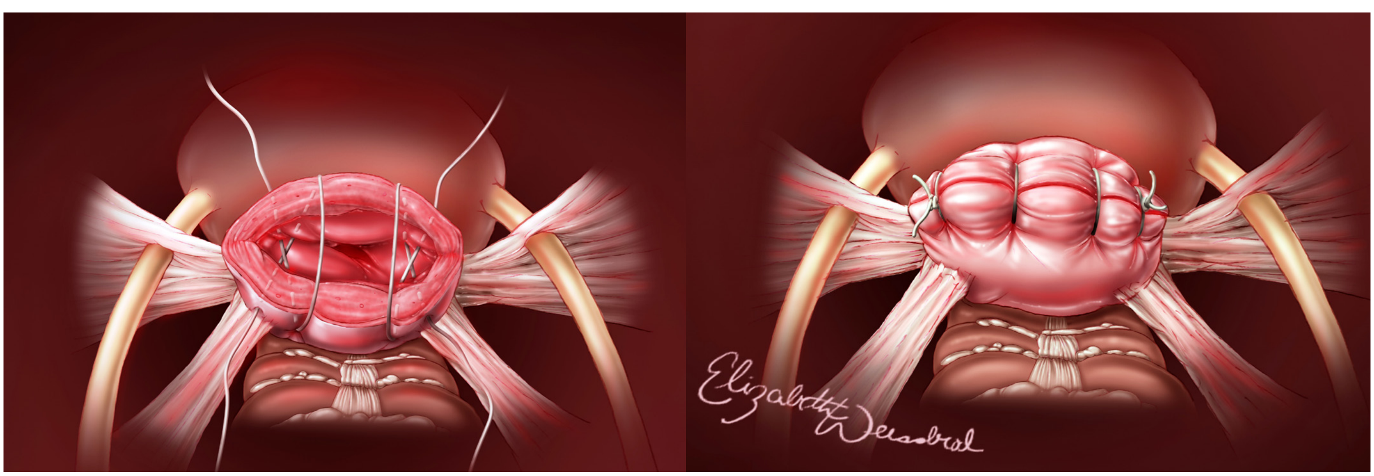
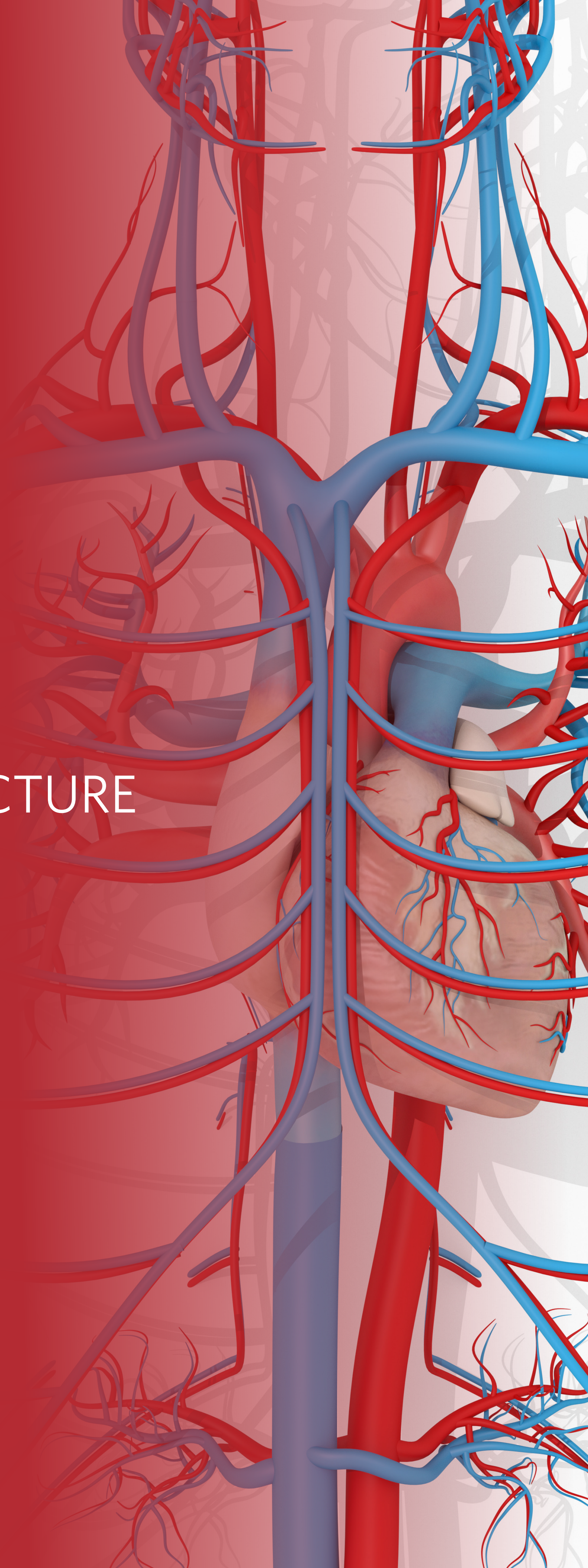


Figure 13. Closure of the cervical stump is accomplished with absorbable figure-of-eight sutures.

CHAPTER 28
DAMAGE CONTROL ORTHOPAEDICS: FRACTURE MANAGEMENT



Damage Control Orthopaedics: Fracture Management

This chapter will present the key concepts of damage control orthopaedics (DCO), with a focus on the principles of external fixation and open fracture debridement.

Learning Objectives

By the end of the ASSET course, participants should be able to do the following:

1. Identify the following critical orthopaedic injuries:
   a. Long bone fractures
   b. Pelvic fractures
   c. Open fractures
   d. Dislocations and fracture dislocations of large joints
   e. Compartment syndrome
2. Understand the goals of damage control orthopaedic procedures:
   a. Control hemorrhage
   b. Decrease contamination
   c. Prevent or treat compartment syndrome
   d. Prevent further soft tissue damage
   e. Facilitate transfer
3. Understand and/or demonstrate damage control skills associated with critical orthopaedic injuries, including the following:
   a. Stabilization of a pelvic fracture with a binder or sheet
   b. Fracture reduction
   c. Limb immobilization with splinting
   d. External fixation of fractures of the lower extremity and pelvis

General Considerations—Initial Management

- Control of compressible external hemorrhage
  - Direct pressure
  - Wound packing
  - Tourniquet
- Control of bleeding from pelvic fractures
  - Pelvic binder
  - External fixation
  - Angioembolization
  - Preperitoneal pelvic packing
  - REBOA
- Assessment of neurovascular status
  - Hard and soft signs of vascular injury
  - Ankle-brachial index
  - Peripheral nerve examination
- Assess for evidence of open fracture (broken skin communicating with the fracture).
- Reduction and stabilization
  - Grossly deformed extremities should undergo gentle closed reduction and splinting prior to imaging.
  - Fracture instability can lead to soft tissue and vascular compromise.
- Principles of reduction
  - Reduction involves restoring the anatomical alignment of a fracture or dislocation of a deformed limb. Reduction allows for the following:
    - Tamponade of bleeding at the fracture site
    - Reduction of traction on surrounding soft tissue with reduced swelling
    - Decreased pressure on the skin, helping prevent skin necrosis
    - Reduced risk of secondary nerve injury
    - Restoration of any affected blood supply
  - Once fracture reduction is achieved, it must be stabilized by a splint or external fixation:
    - Choice of immobilization depends on local resources and level of experience.
    - The basic rule of splinting is that the bone above and below a joint fracture should be immobilized following reduction.

    - In general, external fixation is preferable to splinting in the setting of extensive soft tissue or vascular injury.
    - Larger bones, especially the femur, are better stabilized by external fixation.
- Monitor for compartment syndrome.

Management of Open Fractures

- Open fractures are most often classified using the system described by Gustilo et al., defined as follows:
  - Type I—wound ≤ 1 cm, minimal contamination
  - Type II—wound > 1 cm, without extensive soft tissue injury
  - Type III—high-energy open fractures
    - IIIA—adequate soft tissue coverage of fractured bone is possible with remaining tissue
    - IIIB—extensive soft tissue injury with periosteal stripping and bony exposure; needs tissue reconstruction
    - IIIC—arterial injury requiring repair
- The greatest factor in reducing infection is the length of time to antibiotics. The goal is less than two hours from the time of injury.
- All open fractures require gram-positive antibiotic coverage and tetanus toxoid as soon as possible. Broad-spectrum antibiotics should be considered for all type III and/or grossly contaminated fractures.

Operative Principles

- Open fractures require formal (operative) debridement and irrigation.
- The timing of surgery will depend on the anatomic extent of injury and the patient's physiologic status:
  - Surgery should be performed after the patient has been adequately resuscitated.
  - Complex open fractures, mangled limbs, and heavily contaminated wounds will be prioritized, because their physiologic impact is significant.
  - Simple open fractures are ideally treated within six to eight hours.
- Surgical debridement should consist of a deliberate exploration of the entire zone of injury with the goals of removal, retention, and preservation:
  - **Remove**
    - Gross contamination and foreign bodies
    - Necrotic muscle and skin
    - Nonarticular bone fragments devoid of significant soft tissue attachments
  - **Retain**
    - Major articular fragments
    - Marginal muscle
    - All viable tissue should be preserved in order to permit the greatest number of definitive care options.
  - **Preserve**
    - Peripheral nerves (tag to facilitate identification)
    - Blood vessels
    - Bone fragments with significant soft tissue attachments (i.e., bone fragments with a reasonable vascular supply)
- Irrigation: The preferred technique is to use a large volume of normal saline delivered by a low-pressure system (such as cystoscopy tubing). High-pressure pulsatile lavage is **not** recommended.
- Remember that wounds can evolve over time. In blast or high-energy wounds, it is uncommon for muscle and skin to progress to necrosis in spite of initially appearing viable. In such cases, the wound should be left open and reexplored.

External Fixation—Equipment

- A vital component of DCO is reduction of fractures followed by stabilization with splints and/or external fixators.
- Modern external fixation sets include a variety of types of hardware allowing frames to be individualized to each injury.
- The basic components (Figure 1) required for external fixation are as follows:

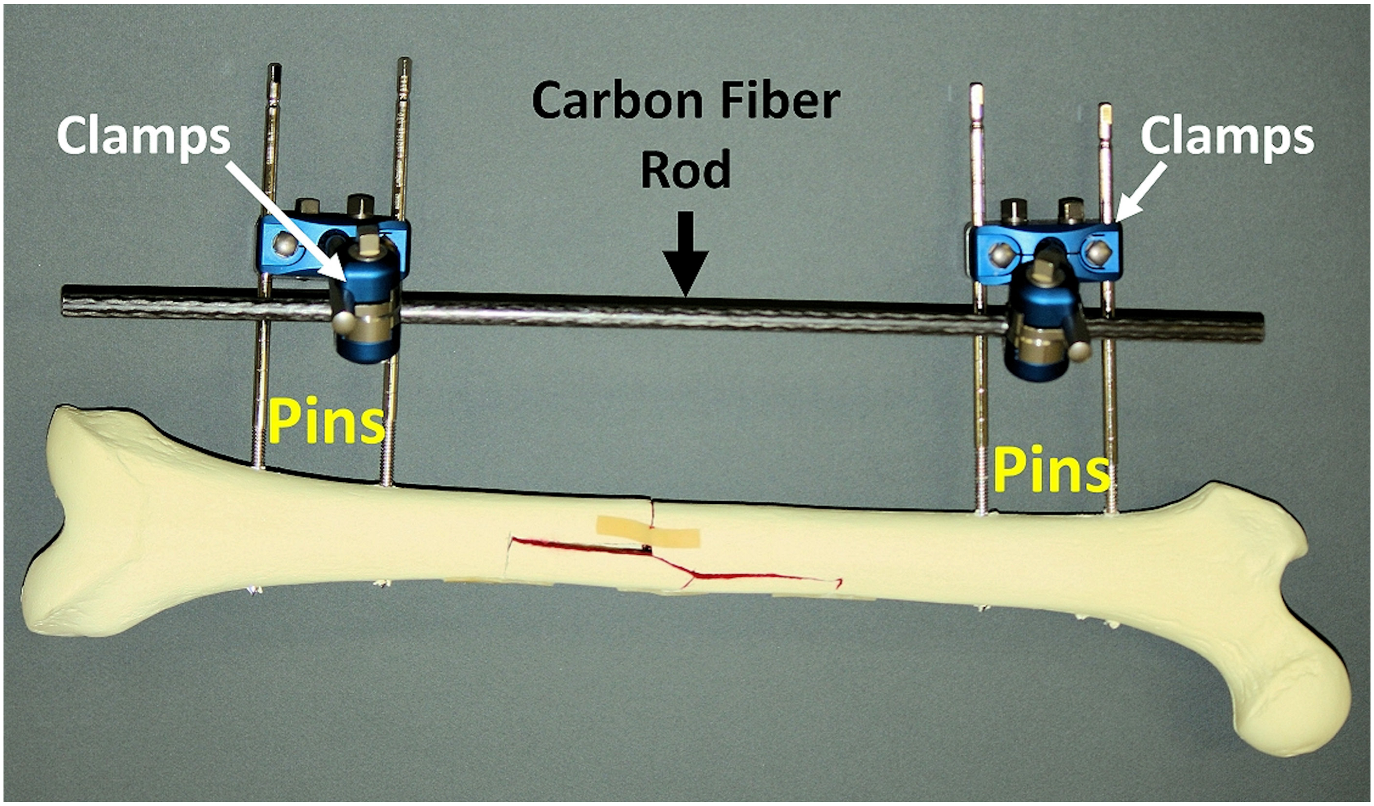


Figure 1. The basic components of an external fixation device.

- A **drill**: Battery-powered drills are the most common, but a hand brace can be used in an austere environment to insert the pins.
- A **drill guide/tissue protector** is inserted into the incision down onto the bone to protect soft tissue from the pin and facilitate placement into the bone.
- **Half pins** (Schanz screws): Fracture pattern and location will dictate the choice of pins, which come in a variety of lengths and diameters. Generally, 5–6 mm pins are used for the femur and tibia. Self-drilling, self-tapping pins are preferable for DCO, as they do not require predrilling, thus saving time. The pin is the critical link between the bone and the frame.
- **Clamps**: Coming in a variety of shapes and sizes, clamps provide a secure connection between the pins and the rod(s).
- **Rods (or bars)**: Rods were originally made of stainless steel and aluminum alloy but are now more commonly carbon fiber due to increased strength and facilitation of subsequent imaging.

External Fixation—Technique

- Knowledge of anatomy is critical for the proper placement of external fixation pins and to prevent complications.
- Major nerves, vessels, and organs (in the case of pin placement for pelvic fractures) must be avoided.
- Intraarticular pin placement should be avoided.
- Tendon impalement should be avoided.
- The "safe zones" for external fixation pin placement in the femur (Figure 2) and tibia (Figure 3) are seen below.

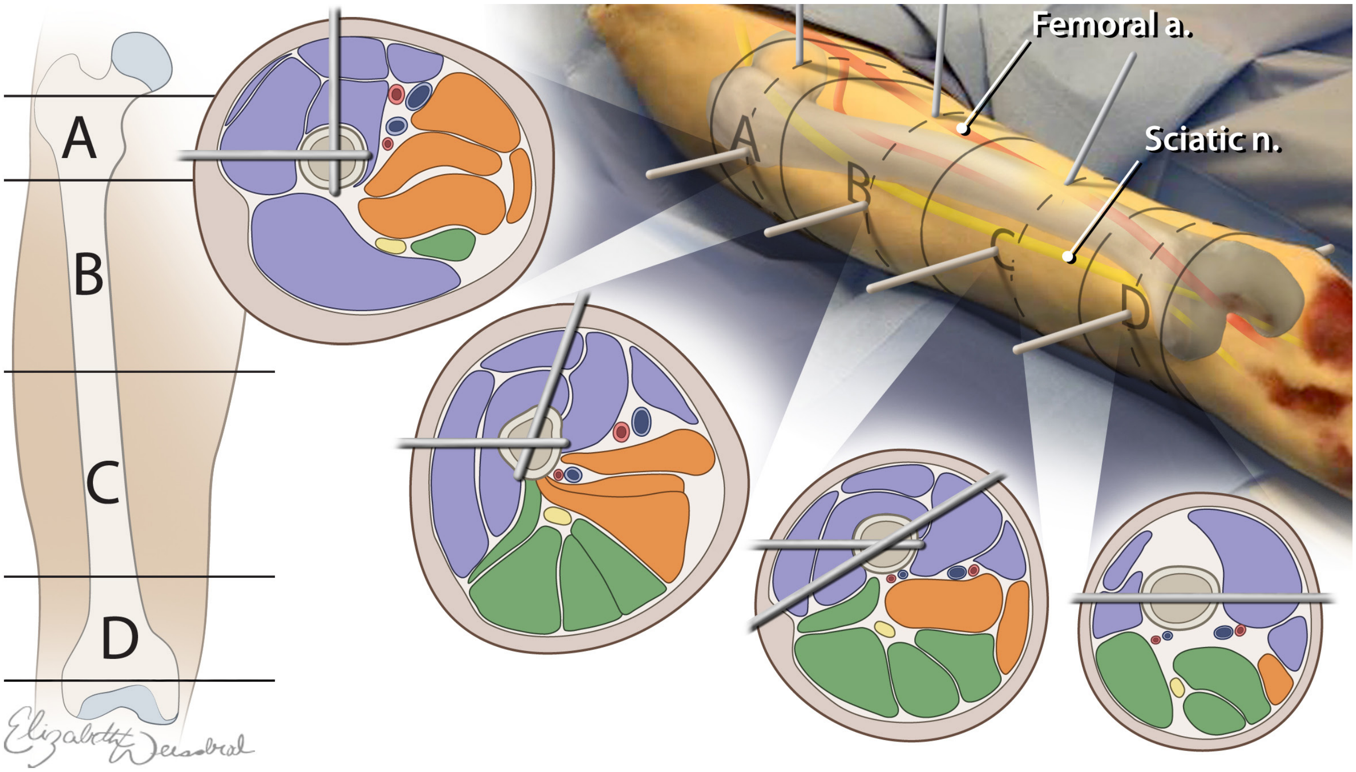


Figure 2. The safe zones for external fixation pin placement in the femur.

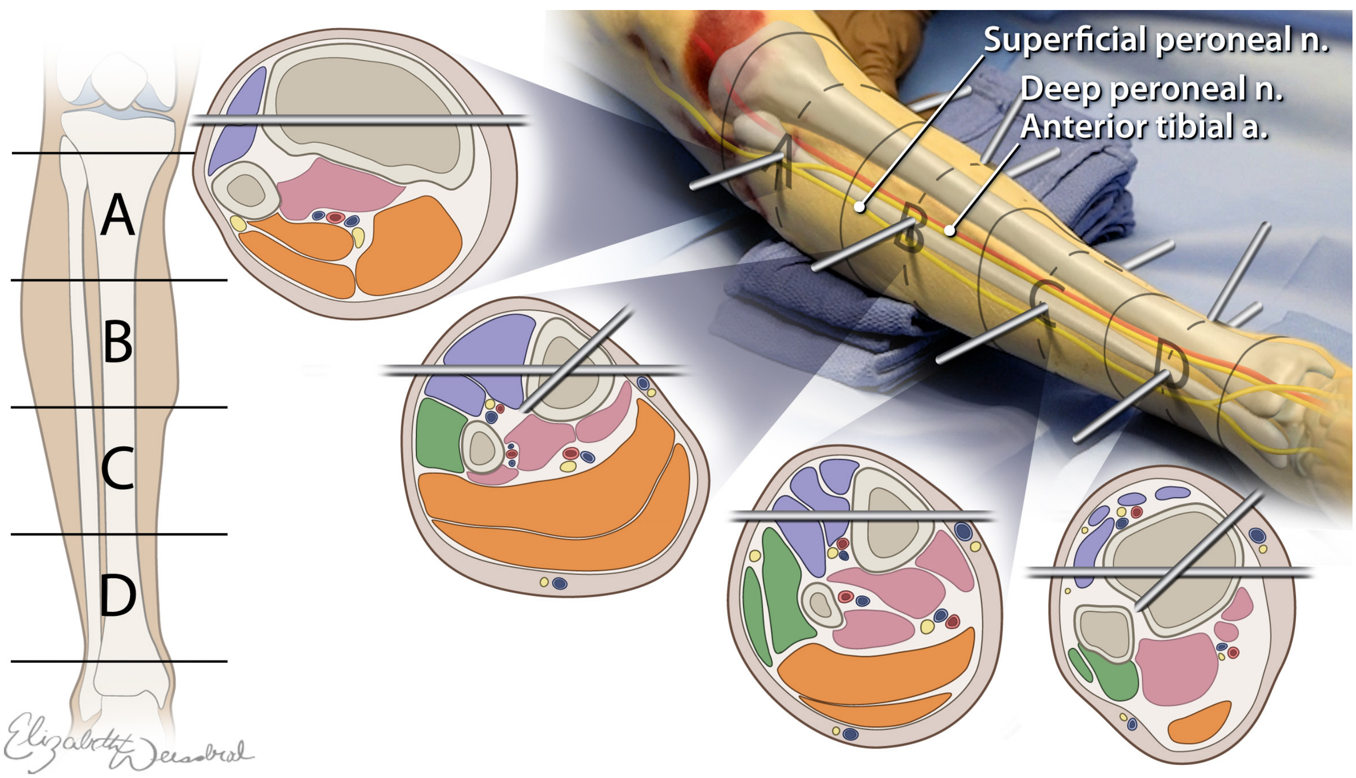


Figure 3. The safe zones for external fixation pin placement in the tibia.

- The basic steps of pin placement are as follows:
  - Provisionally reduce and align the fracture.
  - Identify the fracture site (with imaging if possible).
  - Make a 1 cm skin incision at the desired site of insertion (within a safe zone).
  - Spread soft tissues down to the bone and insert the drill guide/tissue protector onto the bone cortex.
  - Insert the self-drilling, self-tapping pin through the drill guide/tissue protector and then through both cortices of the bone using the drill.
  - The pin should be positioned to go through the center of the cross-section of the bone (Figure 4).
  - Once the first cortex is penetrated, there will be a detectable drop in resistance, which will return once the second cortex is entered. Care must be taken to avoid plunging beyond the far cortex, as this may result in injury to major vessels or nerves (Figure 4).
  - The ideal construct for stability consists of placing one pin as close to the fracture as possible (greater than two fingerbreadths) and another pin as far away as possible within the same bone, with two pins (four total) on either side of the fracture.
  - As pins are placed, the pin clamp(s) and rod can be used as a guide to determine the insertion sites of subsequent pins.
  - Using additional clamp(s) and rod(s), the pins are connected. With the limb aligned, the final frame can be secured.
  - Pin clamps should be placed 1.5–2 cm from the skin to maximize stability.
  - Additional rods can be added to improve stability.
  - A number of frame types can be constructed, depending on the fracture site and the desired alignment.
  - External fixator pin sites can become the sites of infections. Daily cleaning with chlorhexidine solution and dressing with iodine-soaked gauze is essential to minimize infection.

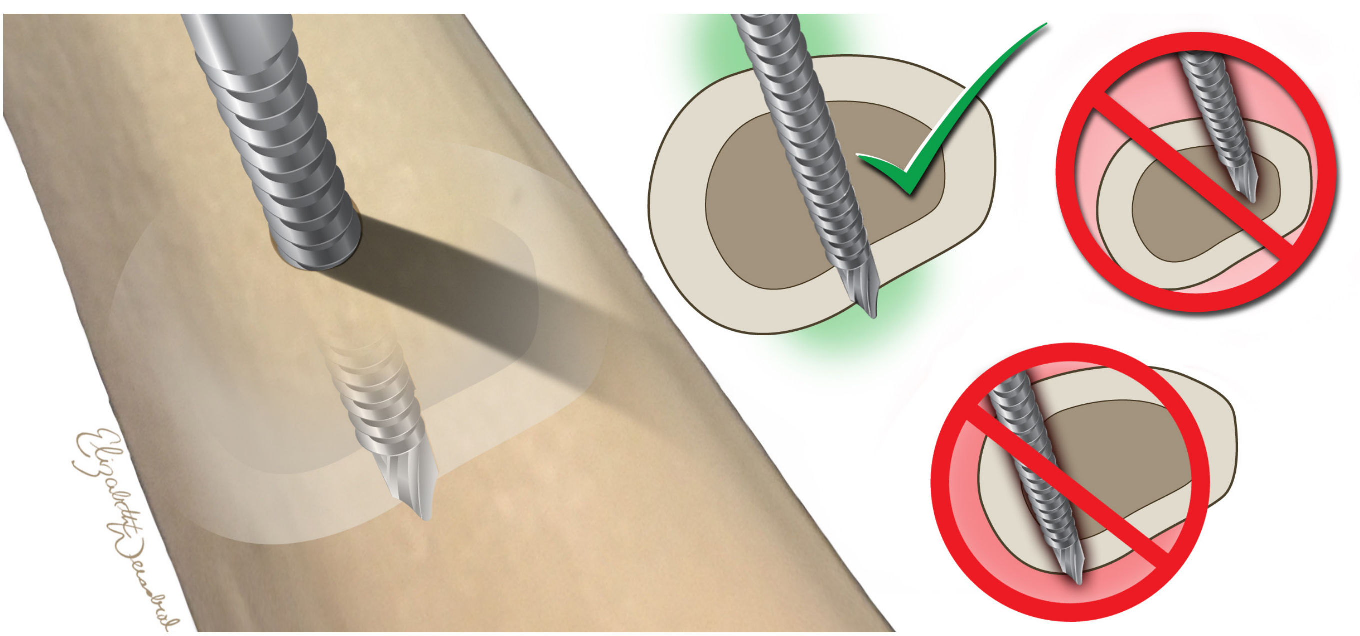


Figure 4. The pin is positioned through the center of the cross-section of the bone to avoid errant placement and is advanced through the second cortex.

External Fixation—Femoral Shaft Fractures

- Femoral shaft fractures are stabilized using pins (5 or 6 mm) placed laterally or anterolaterally in the safe zones (Figure 2) both proximal and distal to the fracture (Figures 5–10).
- The advantage of lateral pin placement is that it will not interfere with future prone positioning to treat other injuries.
- Two external fixation methods can be used to obtain final reduction and alignment of a femoral shaft fracture:

1. Place the most proximal and distal pins first and attach a long rod. The leg is then positioned into the desired alignment, and the clamps are tightened. The pins closest to the fracture are then placed, using the rod and attached pin clamps as a guide. Desired alignment is confirmed, and the whole construct is tightened for final configuration (Figures 5–10).
2. Connect the two proximal pins and the two distal pins with short rods. The rods serve as handles that will assist with fracture reduction and alignment, with an additional rod attached to and spanning the previously placed ones (Figures 11 and 12).

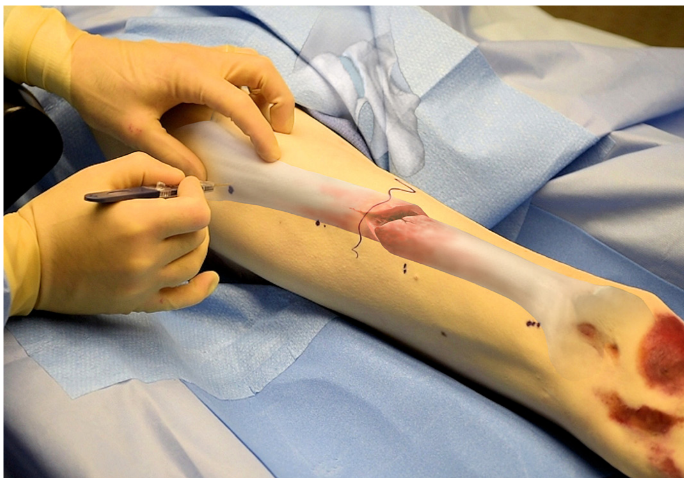


Figure 5. The pin sites for external fixation of this right femoral shaft fracture are marked on the lateral thigh.

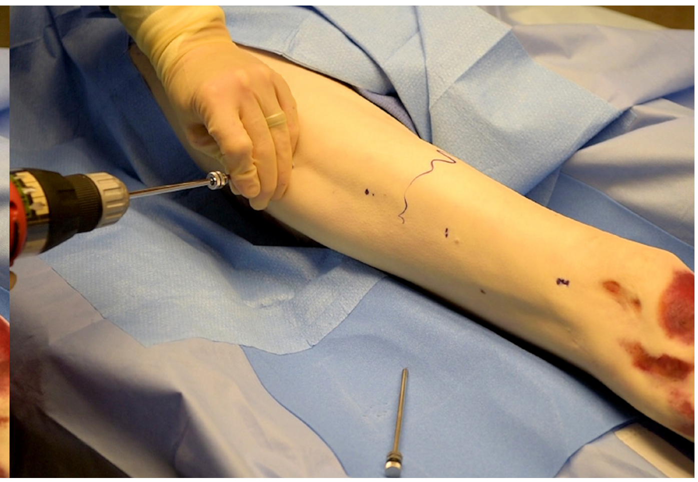


Figure 6. The drill guide/tissue protector is placed in the proximal pin site incision, and the pin is inserted into the bone.

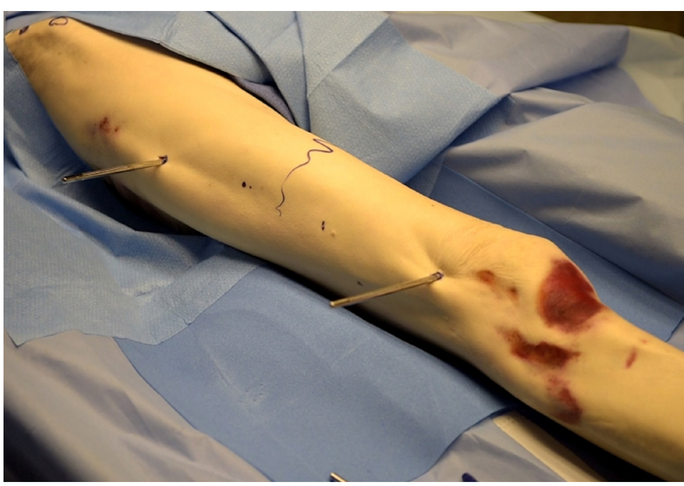


Figure 7. The proximal and distal pins have been placed.

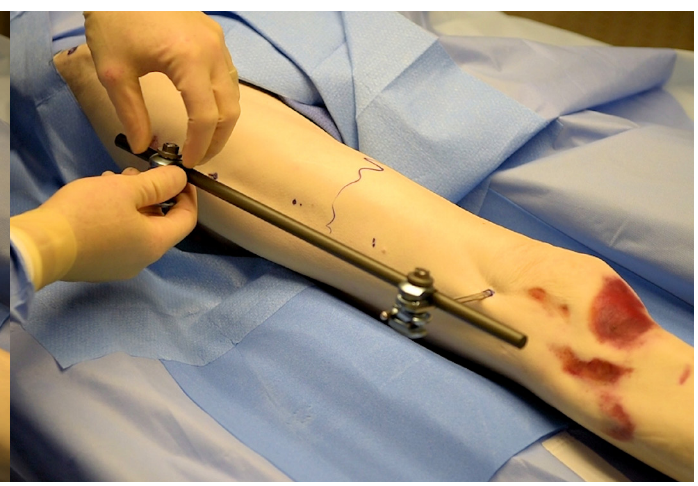


Figure 8. Pin clamps and a rod are attached. The fracture is provisionally reduced and aligned.

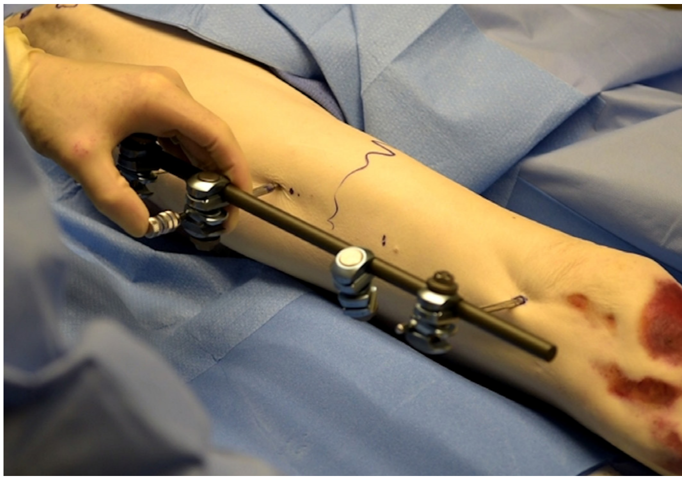


Figure 9. With the leg provisionally aligned using the outermost pins, the rod and pin clamps are used to guide placement of the additional pins.

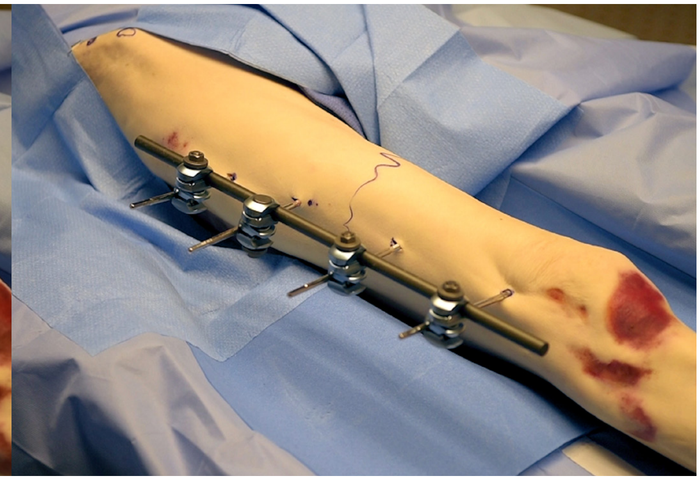


Figure 10. The final construct of an external fixator for a mid-shaft fracture of the right femur.

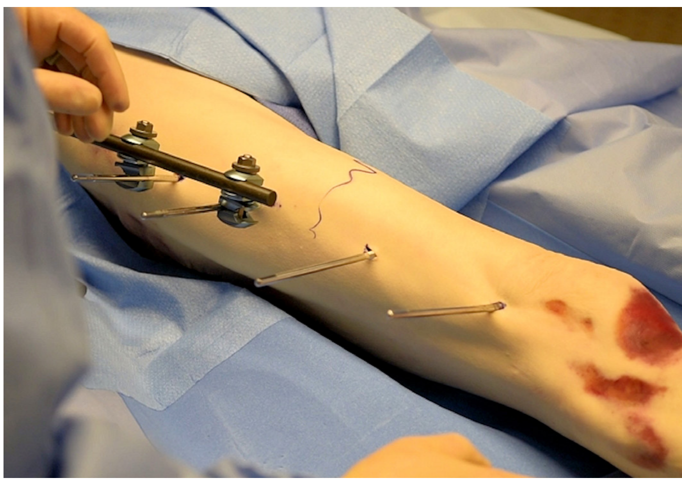


Figure 11. The two pins on the proximal side of the fracture are joined with a short rod.

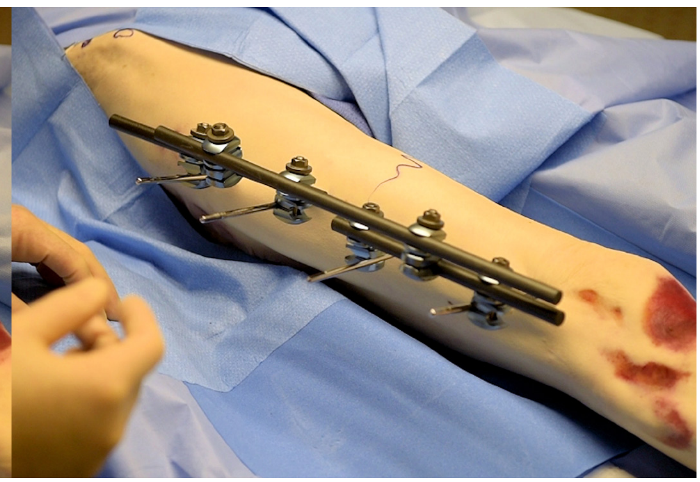


Figure 12. A second short bar joins the two pins distal to the fracture, and the short rods are connected to a longer rod once the fracture is aligned.

External Fixation—Tibial Shaft Fractures

- Fractures of the tibial shaft are stabilized using pins (5 or 6 mm) placed in the safe zones on the medial aspect of the tibia (Figure 3).
- The steps for placing an external fixation device for a tibial shaft fracture are depicted in Figures 13–18 below.

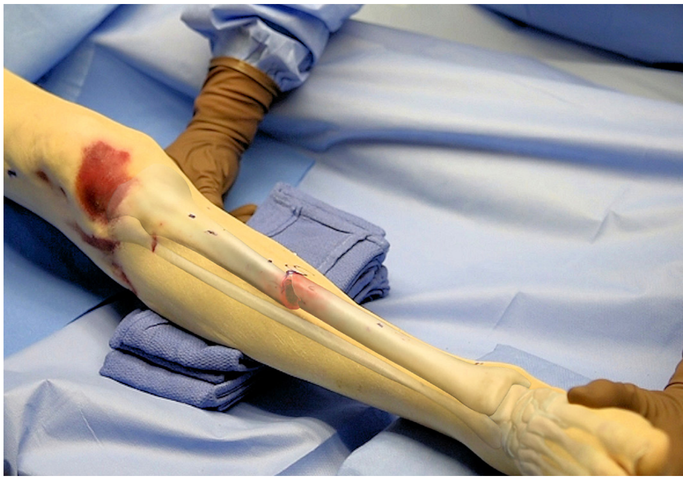


Figure 13. The planned pin sites for this right tibial fracture are marked on the medial aspect of the tibia.

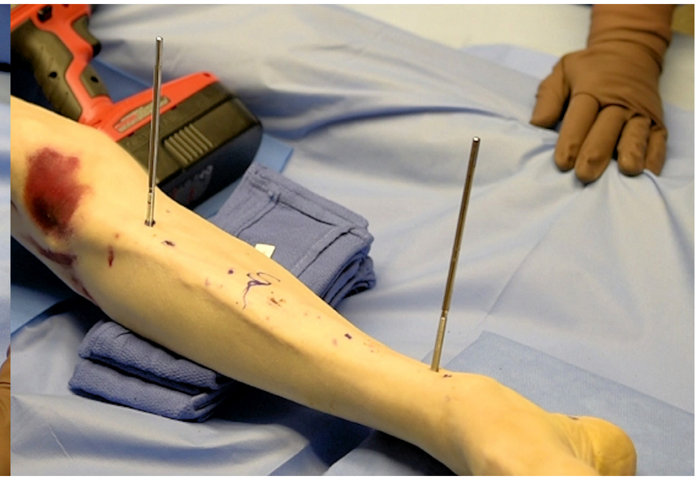


Figure 14. The most proximal and distal pins are placed into the bone.

Figure 15. The proximal and distal pins are joined with a stabilizing rod. After provisional alignment, a pin clamp is placed on the rod to mark the site for the second proximal pin.

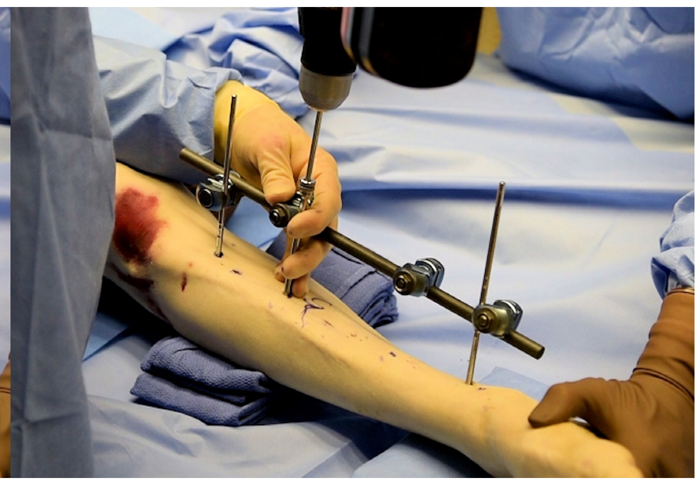


Figure 16. The drill guide/tissue protector is placed in the pin clamp and is used to guide placement of the pin into the bone. This is repeated on the distal side of the fracture.

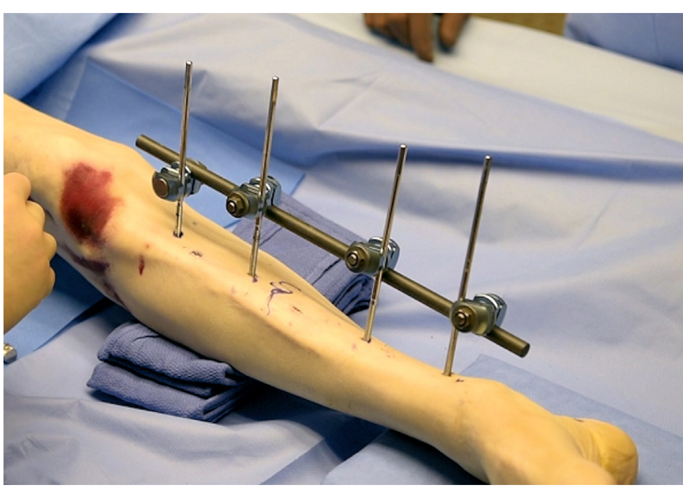


Figure 17. Final reduction and alignment are accomplished, and the clamps are secured to form the final construct.

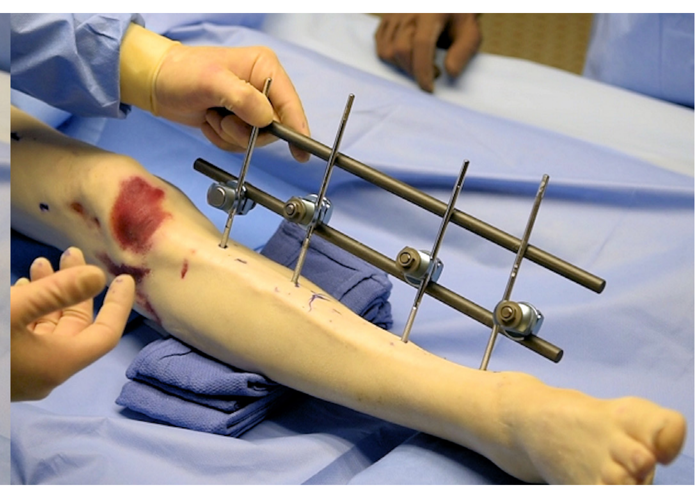


Figure 18. A second rod can be added to increase stability of the construct.

External Fixation—Distal Femur and Proximal Tibia Fractures

- Fractures of the distal femur or proximal tibia/tibial plateau will require a knee-spanning external fixation for stabilization.
- A fracture dislocation of the knee may also require knee-spanning external fixation.
- Pins in the femur can be placed in the lateral position, as described above in the section on femoral shaft fractures. More commonly, the pins will be placed in the anterior thigh, taking care to avoid the suprapatellar pouch by placing the pins at least a handbreadth above the superior pole of the patella (Figure 19).
- A "bump" should be placed under the knee to create a small amount of flexion to relieve stretch on the neurovascular bundle.
- Two pins are placed in the anterior portion of the femur and two pins in the medial portion of the tibia (Figure 19).
- Rods are attached to the pin clamps and are used to create a construct that spans the knee (Figure 20). Additional rods and clamps can be added to improve stabilization.

External Fixation—Distal Tibia Fracture and Ankle Instability

- When a fracture is too distal on the tibia to allow pin placement above the metaphysis, or if the ankle joint is unstable, an ankle-bridging external fixator will be required.
- The proximal portion of an ankle-bridging construct is anchored with pins placed in the tibia above the fracture (Figure 21).
- The distal portion of the ankle-bridging construct requires a calcaneal pin:
  - An incision is made over the medial aspect of the center of the calcaneus (a fingerbreadth below and behind the medial malleolus) (Figure 21). The posterior tibial artery and posterior tibial nerve should be avoided by placing the pin in the posterior part of the calcaneal tuberosity.
  - A centrally threaded pin (Figure 22) is drilled, from medial to lateral, completely through the calcaneus and through the skin of the lateral foot (Figure 23).
  - The pin is advanced until bicortical purchase with the threads is obtained.
- Pin clamps and stabilizing rods are added to complete the construct (Figure 24).

Figure 19. Two pins are placed in the anterior portion of the distal right femur and two pins in the medial aspect of the tibia.

Figure 20. A knee-spanning construct is fashioned to the desired alignment and tightened.

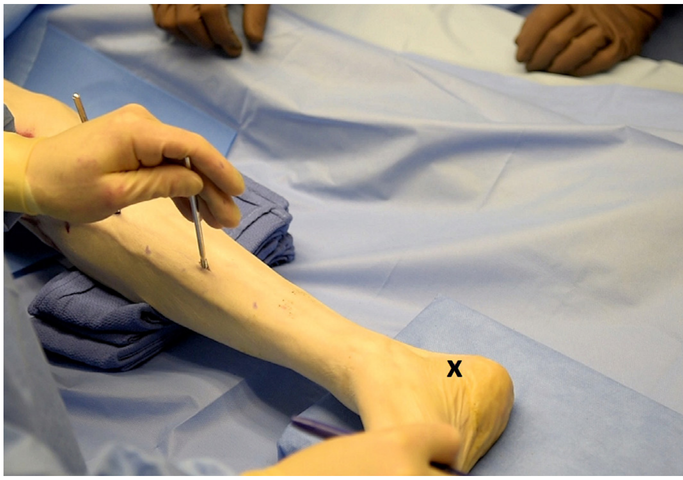


Figure 21. Two pins are placed in the medial portion of the right tibia above the fracture, and the incision site for the calcaneal pin is marked (x).

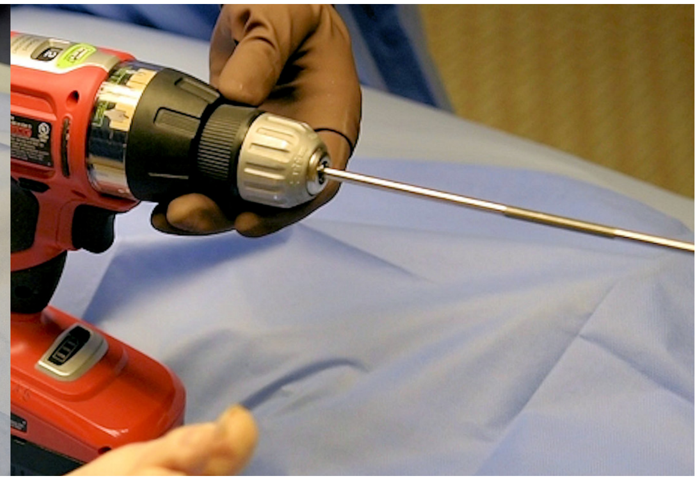


Figure 22. A centrally threaded pin will be passed through the calcaneus, from medial to lateral, such that the threads engage both cortices of the bone.

Figure 23. The centrally threaded pin is drilled through the calcaneus from medial to lateral, exiting the skin and advancing until the threads engage both cortices.

Figure 24. Pin clamps and rods are used to create a stable construct.

Pelvic Fractures—General Considerations and Management

- The physiological consequences and initial management of hemodynamically unstable pelvic fractures is well described in chapter 21.
- The optimal approach to the management of complex and/or unstable pelvic fractures requires a multidisciplinary effort to control the hemorrhage and to provide temporary and ultimately definitive fixation.
- Unstable fractures include anterior-posterior compression (open book), lateral compression, and vertical shear injuries (Figure 25).
- The pelvic ring should be promptly closed with a pelvic binder while the patient undergoes resuscitation and adjunctive control of hemorrhage (pelvic packing, REBOA, and/or angioembolization), as described in chapter 21.
- Consideration should also be given to external fixation of the pelvis.

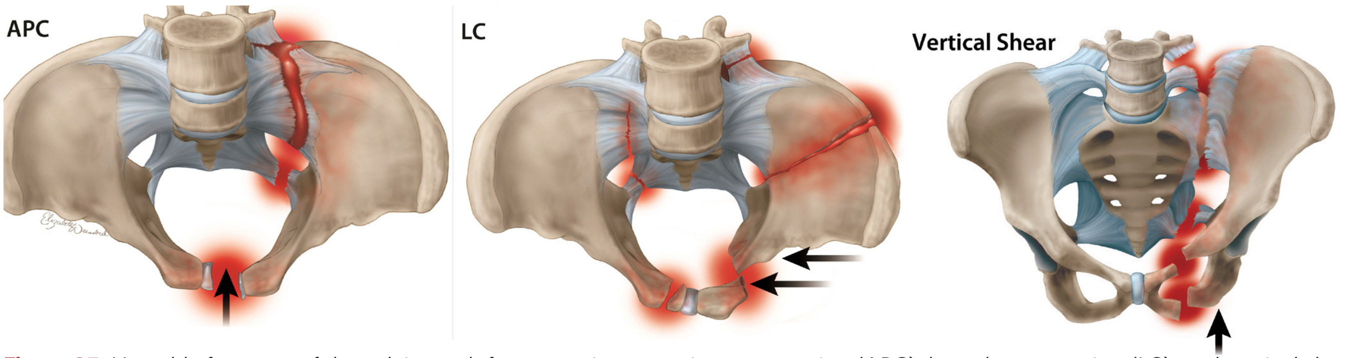


Figure 25. Unstable fractures of the pelvis result from anterior-posterior compression (APC), lateral compression (LC), and vertical shear mechanisms.

External Fixation of the Pelvis

- External fixation of the pelvis is indicated for temporary (or in some cases, definitive) stabilization of unstable pelvic ring fractures.
- It is important to remember that external fixation controls and stabilizes the **anterior** pelvic ring, and in most cases definitive fixation will be required (in a delayed fashion) for associated **posterior** ring injuries.
- Pins are placed in either an iliac crest or a supraacetabular arrangement (Figure 26).
- Though either technique can be done without x-ray guidance, supraacetabular pins are much more difficult to place. As such, the iliac crest technique is preferred in the hands of nonspecialists practicing DCO and will be described below.

Pelvic External Fixation Using Iliac Crest Technique

- Prep the bilateral pelvic brim/hip regions utilizing a chlorhexidine or Betadine solution. It is also prudent to include the abdomen in the prep area in case hemorrhage control via laparotomy is required.
- Internal rotation of the feet and traction on the leg(s) may help with reduction of the pelvic fracture.
- The anatomic landmark for pin placement in the pelvis is the anterior superior iliac spine (ASIS) bilaterally. This should be marked and the skin incised longitudinally, approximately 2 cm posterior to the ASIS, for pin placement (Figure 27).

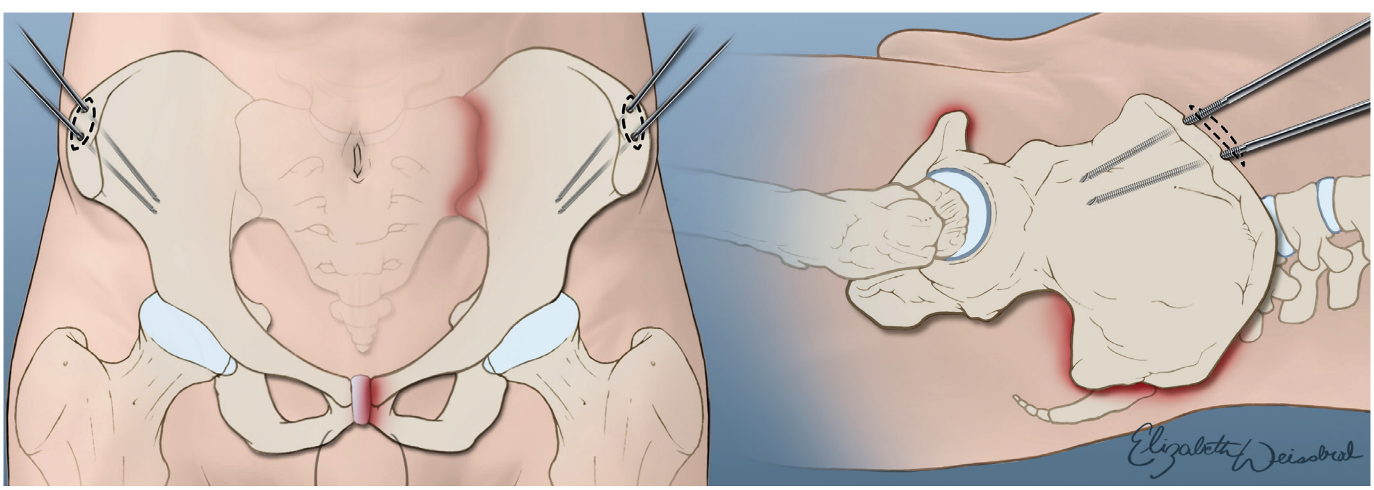


Figure 26. Pin placement for external fixation of the pelvis in the iliac crest (superior) or the supraacetabular (inferior) arrangement.

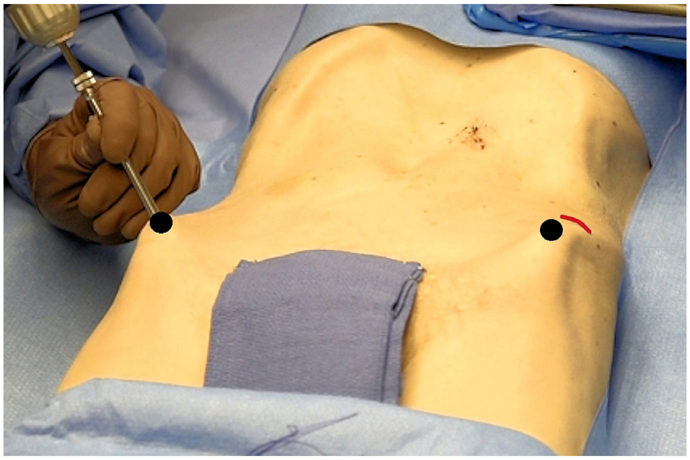


Figure 27. The anterior superior iliac spine (black dots) is identified, and the incision for pin insertion (red line) is made longitudinally 2 cm posterior to this landmark.

- Pins are placed in each hemipelvis, with a trajectory toward the ipsilateral greater trochanter (Figure 28). Additional pins can be placed to increase stability.
- Once the pins are placed, pin clamps and rods are used to create an A-shaped frame across the pelvis (Figures 29 and 30).
- The pelvis is then reduced to the desired alignment, and the frame is tightened. The bars can be angled down toward the feet should abdominal surgery be required.
- Additional pins and bars can be added to the construct to increase stability if needed.

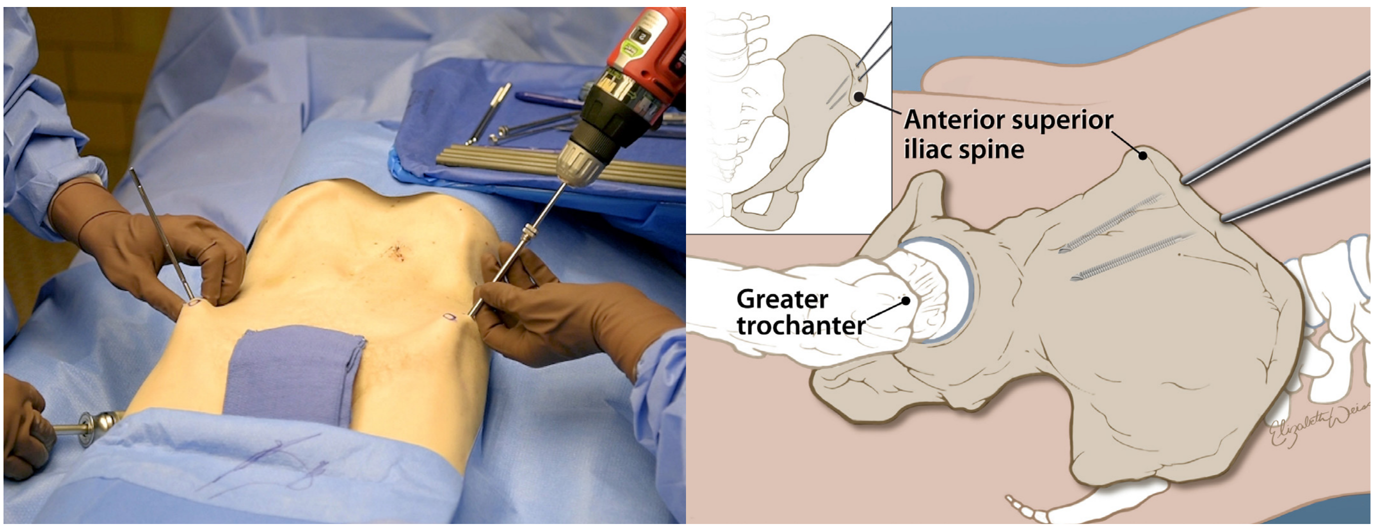


Figure 28. Using the drill guide/tissue protector, pins are placed in each hemipelvis.

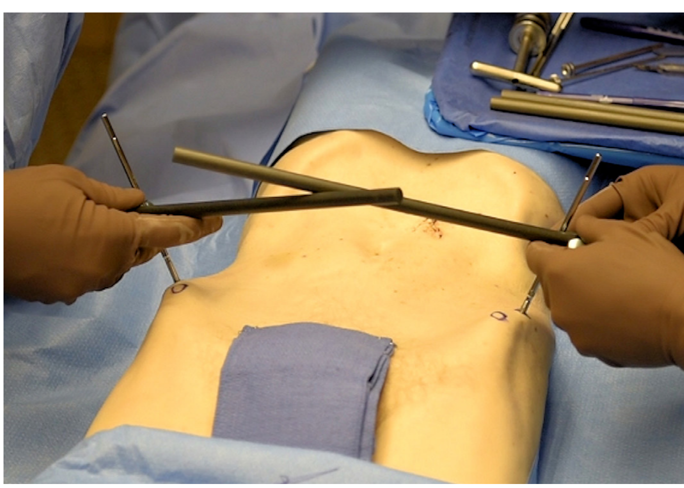


Figure 29. Pin clamps are used to connect rods to the pins; the rods are brought across the pelvis.

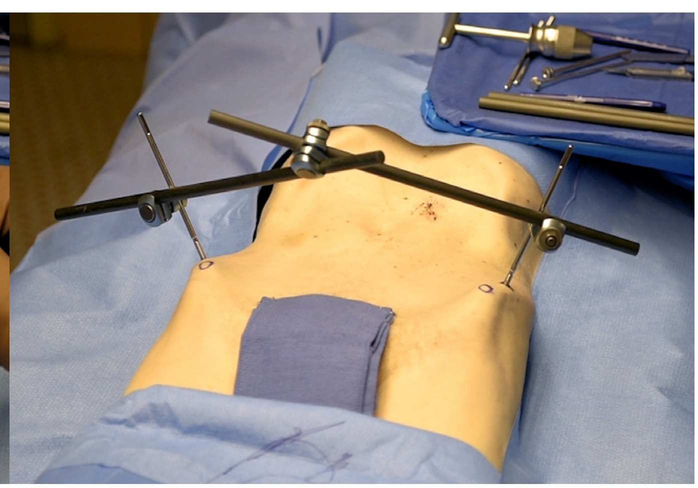
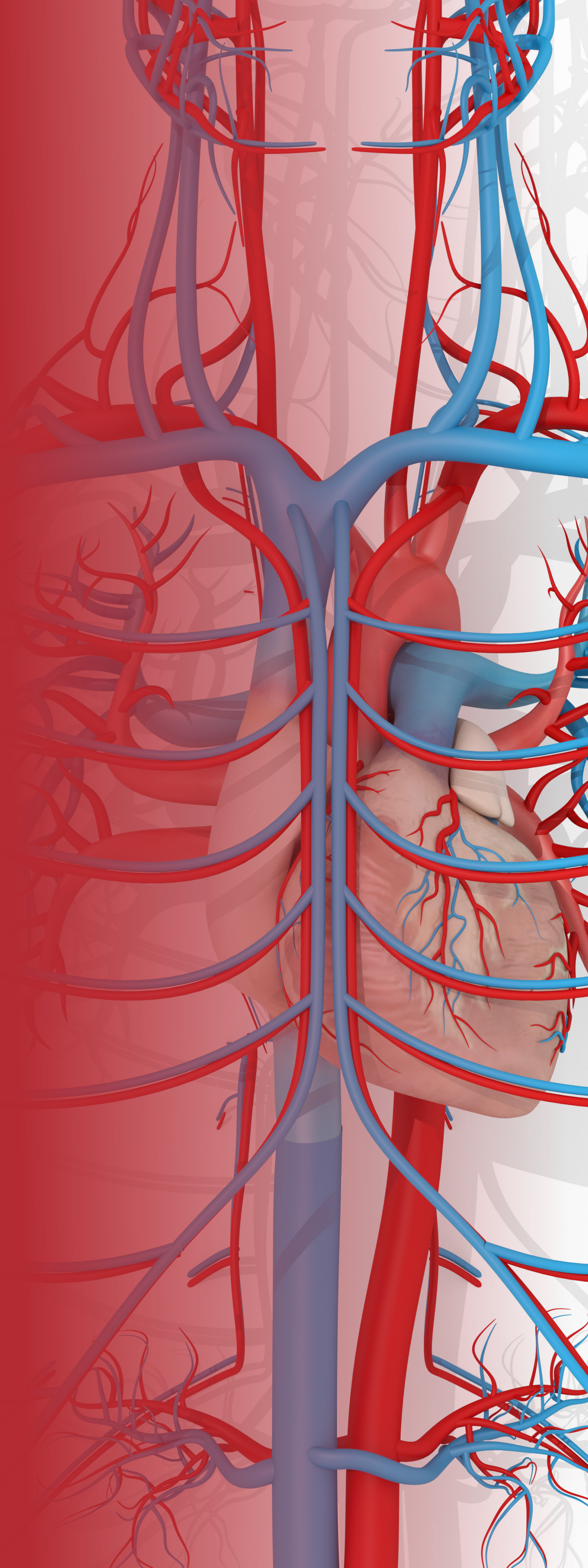


Figure 30. The rods are then joined to form an A-shaped construct.

CHAPTER 29
UPPER EXTREMITY AMPUTATIONS



Upper Extremity Amputations

This chapter will discuss the parameters used to determine limb viability. General principles for the treatment of traumatically amputated limbs, from initial (damage control) surgery to definitive shaping and closure, will be presented. The techniques for definitive amputation of the upper extremity above and below the elbow will also be presented.

Learning Objectives

By the end of this module, participants should be able to do the following:

1. Discuss the parameters used to determine limb viability.
2. Discuss the decision-making process to determine whether to do damage control or to perform a formal amputation.
3. Discuss the initial management of traumatic amputations and near-amputations of the upper extremity.
4. Demonstrate formal above-the-elbow amputation with tension-free closure.
5. Demonstrate formal below-the-elbow amputation with tension-free closure.

General Considerations

- Determining limb viability after injury can be very challenging. No parameters clearly predicting limb loss are currently available.
- In remote or resource-constrained settings, the threshold for amputation may be lower.
- When deciding upon primary amputation versus limb salvage, the likelihood of meaningful limb function and the systemic consequences are key factors.
- Vessel exposure, revascularization, timely bony fixation, and adequate soft tissue debridement and coverage, as delineated in other chapters, are the pillars of extremity salvage. Resultant limb function may be poor even if salvage is technically accomplished.
- In patients who have been selected for damage control management, the focus should be on control of hemorrhage and rapid debridement of any nonviable tissue, leaving as much healthy tissue and bone as possible.
- If perfusion can be restored to the limb (either formally or with temporary shunting), any decision regarding amputation for nerve or bone loss can potentially be deferred.
- In the acute setting, it may be better to leave the wounds open and bring the patient back to the operating room in a delayed fashion once the physiology has been restored, allowing for further evaluation of the tissues, along with consideration for definitive debridement and formal amputation.
- Amputations that result from blast wounds (such as those seen in combat actions) should never be initially formally closed, as these wounds are heavily contaminated. Even with meticulous and extensive debridement, these wounds almost always need additional debridement prior to formal shaping and closure of amputations.

Surgical Principles

- Tourniquets can be used to minimize blood loss during the procedure.
- The level of amputation is the most distal area with adequate perfusion to provide healing and a functional stump.
- All nonviable tissue must be removed.
- Low-pressure irrigation or lavage with normal saline is important to decrease bacterial count and soiling. High-pressure pulse lavage irrigation should be avoided.
- Open circular or "guillotine" amputations should be avoided, as this sacrifices viable soft tissue and leads to the need for more proximal revision.
- Suture ligature is preferred to electrocautery for control of transected vessels.
- Nerves should be sharply transected with distal traction (Figure 1) to minimize the formation of postoperative neuromas.

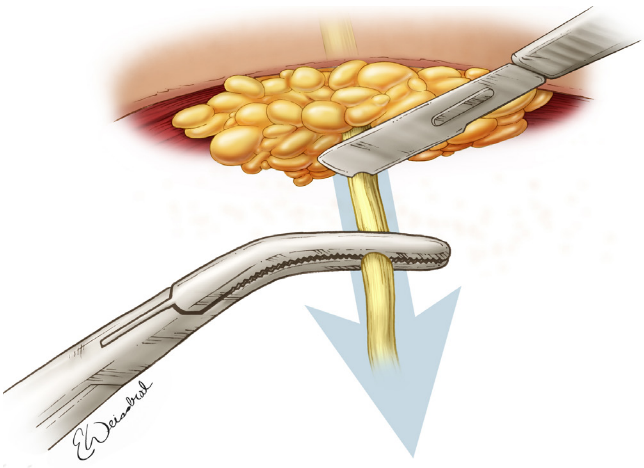


Figure 1. To minimize postamputation neuromas, nerves should be transected sharply while applying distal traction; this allows the nerve stump to retract proximally.

- Initially, nonviable bone should be debrided, but formal division and shaping of the bone can be left to definitive closure of the amputation.
- During definitive shaping and closure of the amputation, the bone is resected proximal to the skin and muscle flaps where periosteum is adherent to the bone. Bone edges should be filed after transection to remove sharp or irregular edges.
- As long as adequate vascularized muscle is present to cover the bones, skin grafts can be used to preserve limb length and joints.
- Formal closure is accomplished in a multilayered fashion.
- Closed suction drains are recommended to reduce dead space.

Above-the-Elbow Amputation

- An above-the-elbow (supracondylar) amputation is defined as amputation at any level from the supracondylar region to the axillary fold.
- The patient is placed in the standard supine position, with the injured arm abducted 90° on an arm table board.
- As much length as possible should be preserved, but the level of bone sectioning should be a least 4 cm proximal to the elbow joint.
- A “fish-mouth” incision is made with equal anterior and posterior flaps, the length of each being half the diameter of the arm at that level (Figure 2).

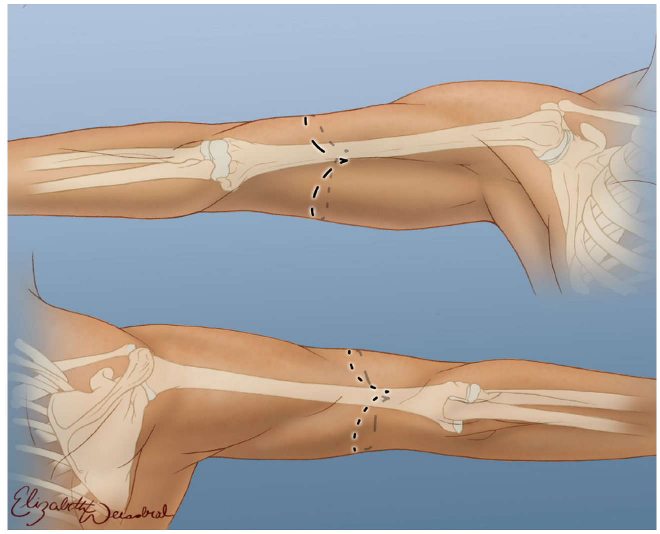


Figure 2. “Fish-mouth” incision lines are marked with a pen to create equal anterior and posterior flaps.

- The brachial artery is identified in the groove between the triceps and biceps muscles, with the median nerve running medially (Figure 3). The brachial artery is ligated and the median nerve transected sharply with a scalpel as seen in Figure 1.
- The ulnar nerve is located about 2–3 cm posterior to the median nerve, below the medial aspect of the triceps muscle. The radial nerve courses on the posterior aspect of the humerus. Both nerves should be identified and transected sharply with distal traction, as seen in Figure 1.
- All the muscles are divided circumferentially, with the anterior muscles divided at least 1.5 cm distal to the amputation level.
- The triceps muscle is freed from the olecranon, leaving a flap long enough to cover the bone (usually 4–5 cm).
- The tissues around the humerus are cleared with a periosteal elevator, and the bone is divided with a saw (Figure 4). The bone edges are filed with a rasp to remove any irregularities or sharp edges.

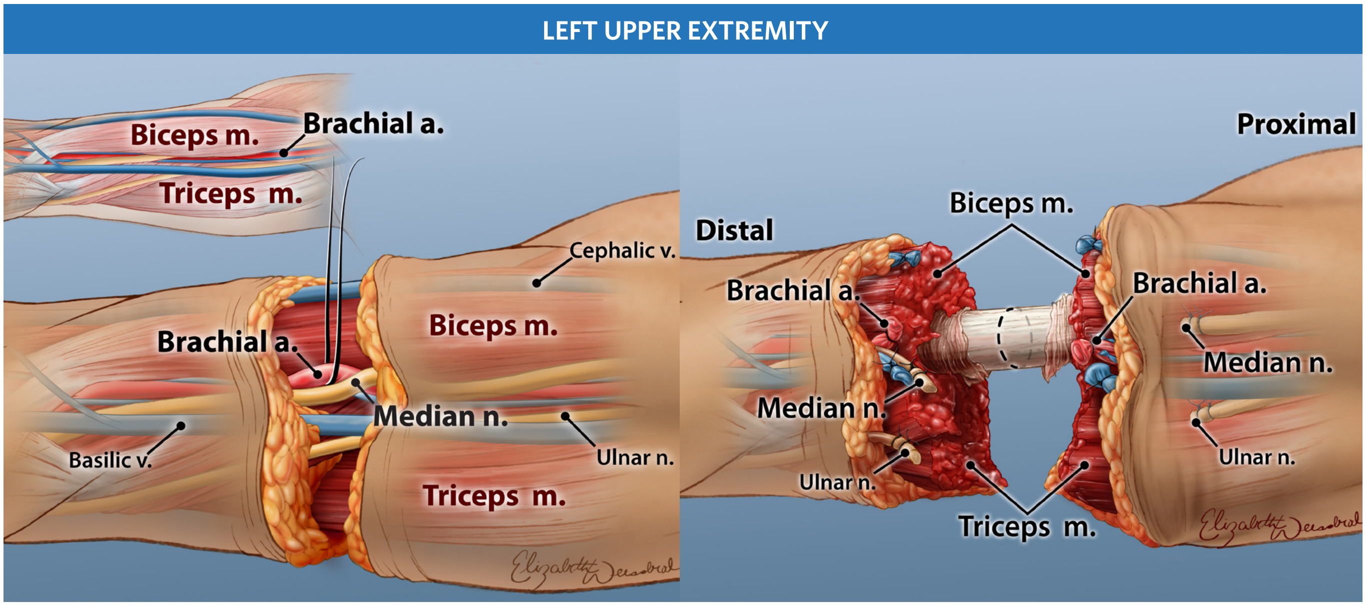


Figure 3. The anterior compartment muscles are divided, and the brachial artery is identified. The median nerve is seen running medially.

Figure 4. The humerus is cleared circumferentially and transected with a Gigli saw.

- A tension-free myofascial flap is created by bringing the triceps over the bone edge and suturing the tendon to the fascia over the anterior muscles.
- A closed suction drain is placed deep to the fascia, and the skin is closed with interrupted nonabsorbable sutures or staples.

Below-the-Elbow Amputation

- When planning a below-the-elbow amputation, it is important to preserve as much length as possible, as forearm rotation and strength are proportional to length retained.
- Underlying soft tissues in the distal forearm consist of relatively avascular structures, such as fascia and tendon, and may not always offer adequate padding for the bony stump.
- A compromise between adequate functional length and wound healing is amputation at the junction of the distal and middle third of the forearm.
- A short below-elbow stump (at least 4–5 cm long) is preferable to a through- or above-the-elbow amputation.
- The patient is placed in the standard supine position, with the injured arm abducted 90° on an arm table board.
- A "fish-mouth" incision is performed to create equal volar and dorsal flaps (Figure 5).
- The radial artery is identified laterally and the ulnar artery medially (Figure 6). Both arteries should be ligated.
- The radial and ulnar nerve are identified, placed under distal traction, and divided sharply, as seen in Figure 1.
- After the muscles are divided, the median nerve can be identified deep between the radius and ulna, lying on the interosseous membrane. The median nerve should be transected sharply while under distal traction.
- The soft tissue around the ulna and radius is cleared with periosteal elevator, and both bones are divided equally with a saw. Bone edges are filed with a rasp.
- The anterior and posterior deep fascia are reapproximated and closed over the divided bones in a tension-free fashion.
- The skin is closed with interrupted mattress sutures.

LEFT UPPER EXTREMITY

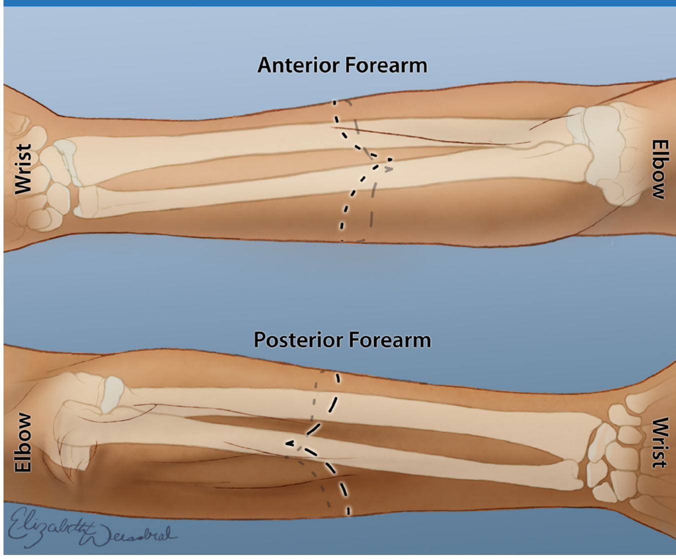


Figure 5. Lines for the "fish-mouth" incision are marked with a pen. This incision will ensure equal anterior and posterior flaps.

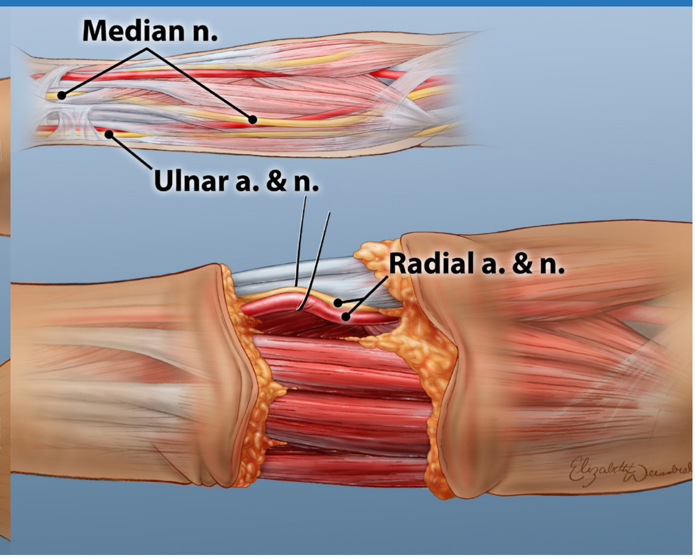


Figure 6. The radial artery is identified laterally, as shown on the photo, and must be ligated.

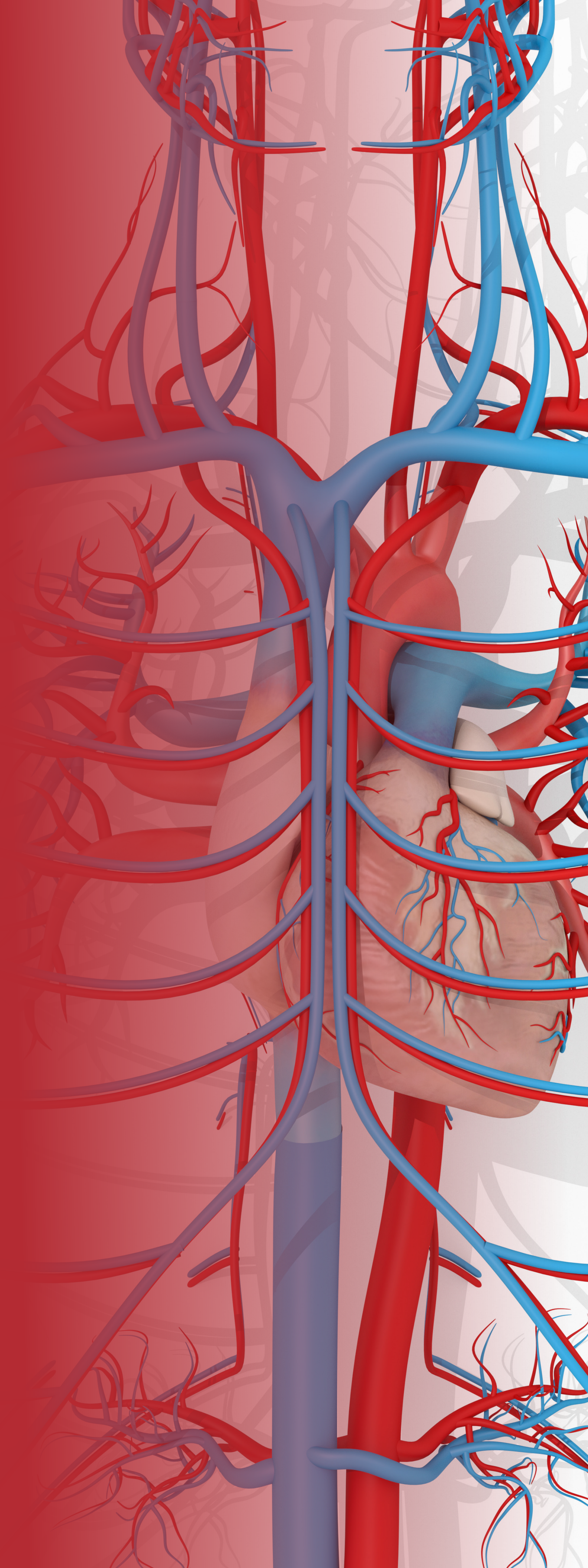
Postoperative Care

- A soft, compressive dressing is applied to the stump.
- An elastic bandage is applied over the dressing, with more pressure distally than proximally to prevent stump edema.
- Rigid dressings and casts are unnecessary in the upper extremity.
- Immediate active range of motion for remaining joints should be implemented to prevent joint contraction.

Pitfalls and Complications

- Failure to fashion a tension-free myofascial flap can lead to ischemia or wound dehiscence.
- Inadequate debridement can lead to infectious sequela, including wound breakdown, sepsis, and abscess formation.
- Premature closure of wounds prior to adequate debridement or correction of patient physiology must be avoided.
- Traditionally taught (and antiquated) circular or guillotine amputation techniques will result in inadequate tissue to cover the bone.
- Areas of tissue injury that are not clearly necrotic or unsalvageable should be preserved at the initial operation and reassessed at the next operation.
- Joint contractures are prevented by immediate postoperative active motion.

CHAPTER 30
LOWER EXTREMITY AMPUTATIONS



Lower Extremity Amputations

This chapter will provide an overview of the types of amputations of the lower extremity. The general considerations and surgical principles of lower extremity amputations overlap considerably with those of the upper extremity (chapter 29). The techniques for below-the-knee, through-the-knee, and above-the-knee amputations, as well as hip disarticulation, will be presented.

Learning Objectives

By the end of this ASSET module, participants should be able to do the following:

1. Discuss the levels of amputation of the lower extremity and indications for damage control techniques.
2. Demonstrate formal definitive closure of a below-the-knee amputation with tension-free closure of the stump and adequate posterior flap.
3. Demonstrate formal definitive closure of a through-the-knee amputation with tension-free closure.
4. Demonstrate formal definitive closure of an above-the-knee amputation with tension-free closure.
5. Outline the steps for performing a hip disarticulation.

General Considerations and Surgical Principles

- The general considerations and surgical principles for the management of patients with or needing amputations of the lower extremity are very similar to those outlined in the previous chapter (chapter 29) on upper extremity amputations.
- As with the upper extremity, scoring systems or parameters do not accurately predict the need for amputation. Furthermore, for lower extremity injuries, the loss of plantar sensation immediately after injury does not accurately predict long-term functional outcomes; likewise, sensation is not necessarily an indication for amputation.
- Amputations should be carried out at the lowest level possible, with preservation of as much viable tissue as possible at the first operation and more formalized shaping and closure of the amputation site at a subsequent operation.
- It must be kept in mind that the desired end goal of amputation is ability to bear weight, and for this reason, adequate soft tissue coverage over the end of the stump is more important than extra length.
- The classically described levels of amputation for the lower extremity are seen in Figure 1.
- Functionally, below-the-knee amputation is superior to above the knee, which increases energy expenditure by 65 percent above baseline and is more likely to result in joint contracture.

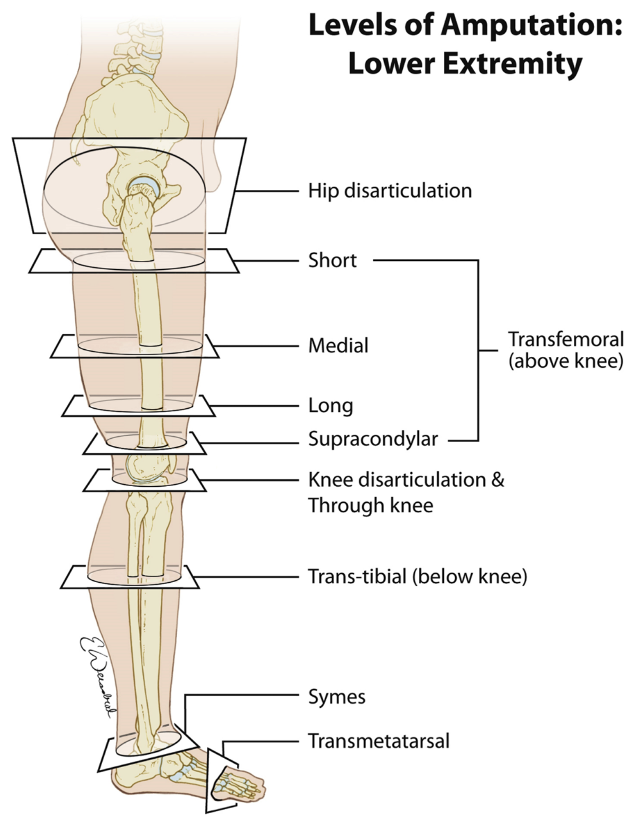


Figure 1. The classically described levels of amputation of the lower extremity.

- If below-the-knee amputation is not possible, knee disarticulation should be considered before above-the-knee amputation.
- As with the upper extremity, it is best to leave the wounds open after hemorrhage control, restoration of perfusion, and thorough debridement, delaying formal shaping and closure of the amputation for a subsequent return to the operating room.
- In complex blast injuries or wounds with significant soft tissue injury, contamination may be extensive, with debris forced well outside the zone of apparent injury. This necessitates meticulous and repeated debridement, with extension of the wounds and development of atypical skin or tissue flaps, if indicated.
- In traumatic amputations following blasts, the zone of soft tissue generally extends much further proximal than the damage to the bone.
- The amputated limb may be a source of autologous veins or arteries for subsequent vascular repair.

Below-Knee (Transtibial) Amputation (BKA)

BKA CONSIDERATIONS

- It has long been accepted that the middle third of the lower leg is the best site for a BKA, creating a stump 14–18 cm below the knee joint (Figure 2).
- Circulation in the lower third of the leg is relatively poor, and though satisfactory results can be obtained at this level, the presence of poor perfusion or significant soft tissue trauma may necessitate a higher level of amputation.
- The anterior aspect of the tibial crest, which lies close to the surface of the skin, should be slightly beveled.
- The fibula is normally non–weight-bearing, and in short stumps it is advisable to completely excise it. For stumps of average length, it is advisable to section the fibula 2–3 cm above the end of the tibia to facilitate fit in a prosthetic socket (Figure 2).

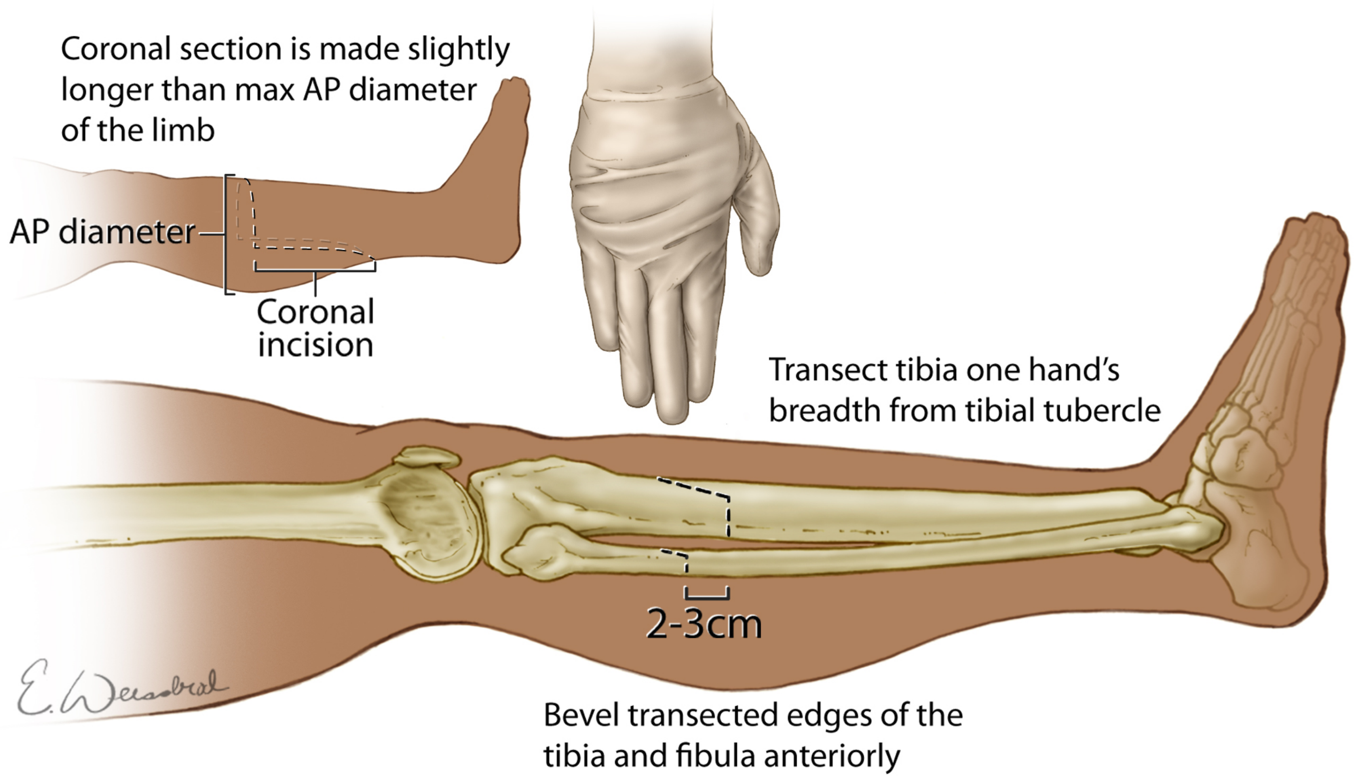


Figure 2. The incisions used for a classic below-knee amputation, depicted on a right leg.

BKA SURGICAL TECHNIQUE

- The entire leg is prepped circumferentially to the groin.
- A small bump placed under the ipsilateral hip to internally rotate the leg is helpful.
- A sterile tourniquet can be applied to the thigh.
- The classic BKA incision involves the creation of a long posterior myocutaneous flap (Figure 3).
- The anterior transverse skin incision is made 10–12 cm (roughly one hand width) below the tibial tuberosity and extended to the lateral aspects of the calf.
- For the posterior flap, the coronal (anterolateral) incision is extended along the vertical axis of the calf for slightly longer than the maximum anteroposterior diameter of the limb, or about 1.5 times the length of the anterior flap (Figures 2 and 3).
- The posterior flap should be distal to the musculotendinous junction of the gastrocnemius muscle.
- The distal ends of the flap should be rounded to prevent redundancy.
- The skin and subcutaneous tissue are divided sharply, and the saphenous vein is ligated (Figure 4).
- The muscular attachments to the tibia are cleared with a periosteal elevator, and the interosseous membrane is divided sharply. The tibia is then divided with a saw (Figure 5), the anterior lip is beveled, and any sharp edges are filed smooth with a rasp.
- The lateral compartment muscles are divided sharply. The fibula is identified and cleared from soft tissue using a periosteal elevator. The fibula is resected, leaving a length of about 2–3 cm shorter than the tibial stump (Figure 6), and any sharp edges are filed smooth with a rasp.
- The anterior compartment muscles are transected sharply, and the anterior tibial artery and vein, as well as the deep peroneal (fibular) nerve, are identified. The vessels are suture ligated, and the nerve is divided sharply with distal traction to allow the nerve ending to retract proximally.
- The muscles of the posterior compartment are divided, utilizing an amputation knife or a scalpel to create a tapered posterior musculofascial flap (Figure 7).
- Enough of the soleus muscle should be removed to prevent excessive bulk or tension in the closure of the flap.

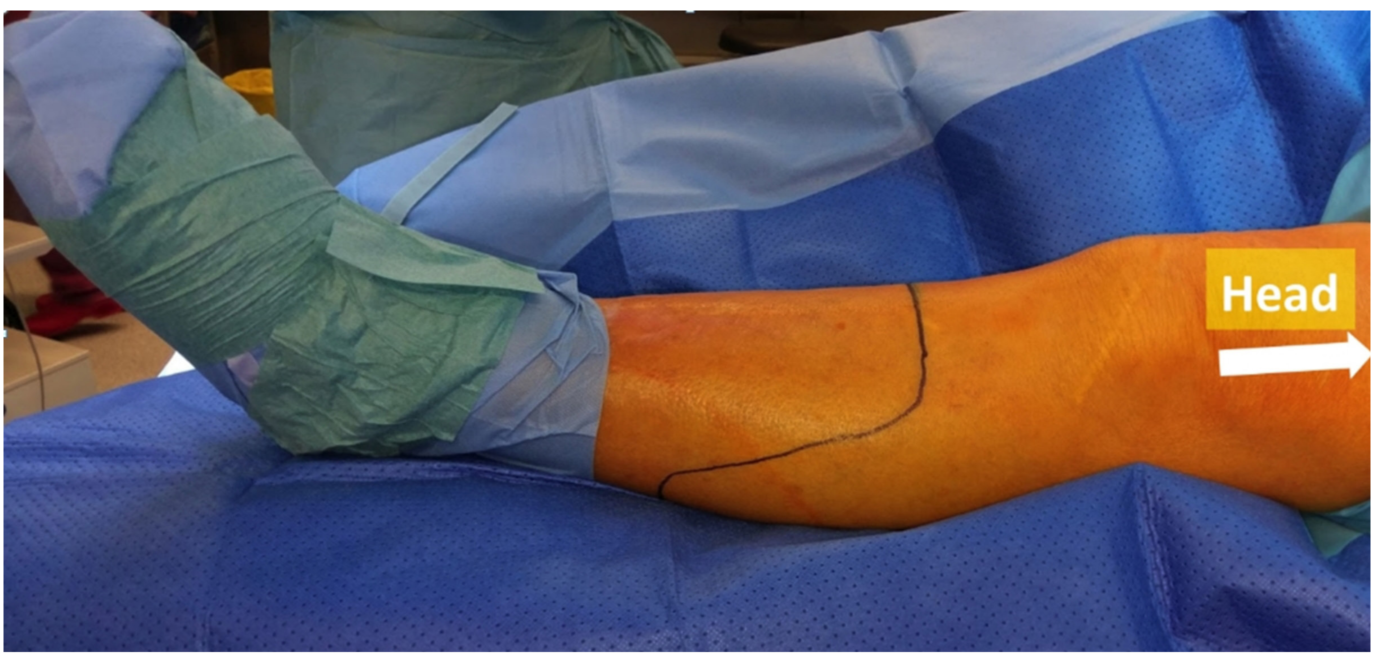


Figure 3. The skin incisions used for a classic below-knee amputation, as marked on the left leg.

LEFT LOWER LEG

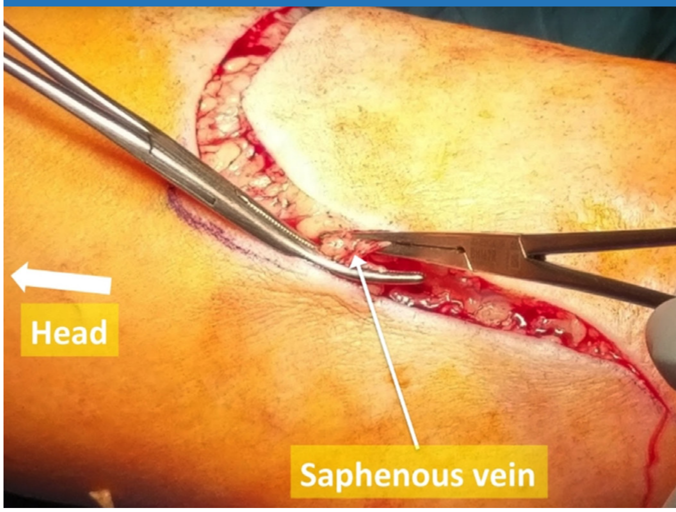


Figure 4. The saphenous vein is identified on the medial aspect of this left leg and is ligated.

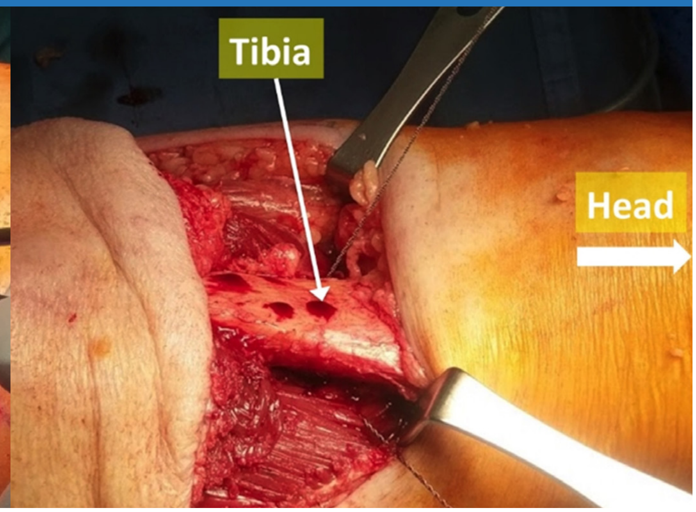


Figure 5. The tibia on this left leg is divided with a Gigli saw.

LEFT LOWER EXTREMITY

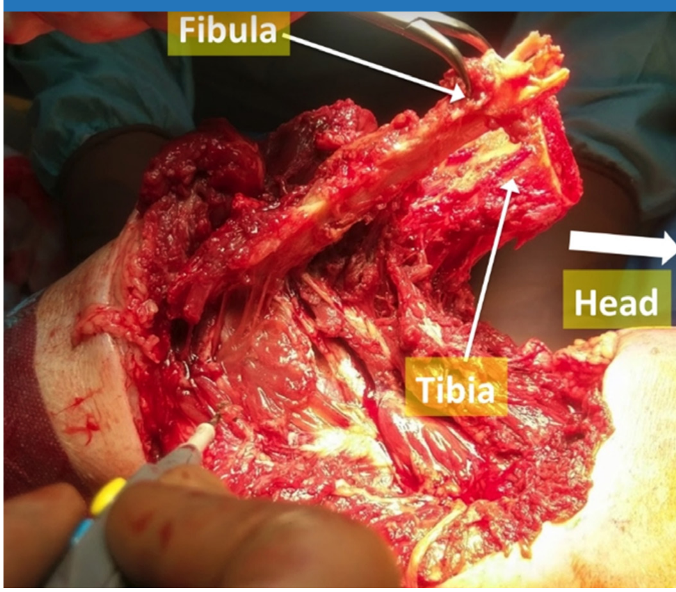


Figure 6. The tibia and fibula are both transected, with the fibula at a higher level (2–3 cm) than the tibia.

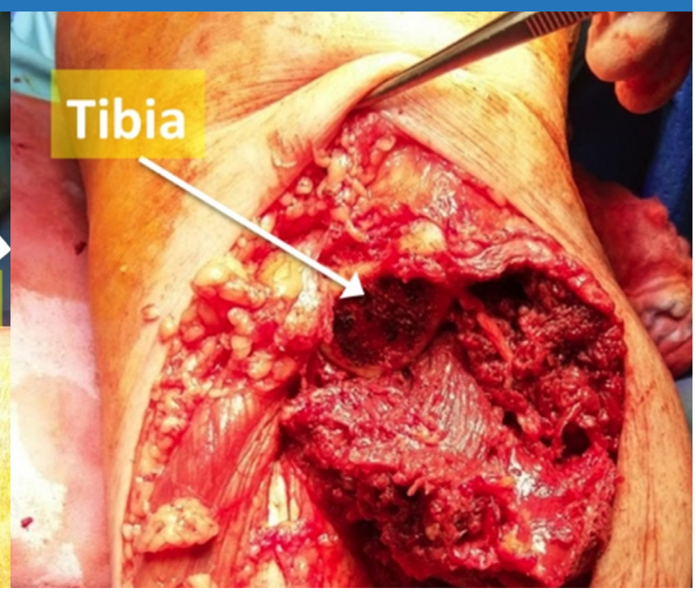


Figure 7. The posterior compartment muscles have been divided to create the posterior musculofascial flap.

- The posterior tibial and peroneal vessels should be suture ligated when encountered. The tibial nerve should be transected sharply while employing distal traction to allow the nerve ending to retract proximally (Figure 8).
- The adequacy of hemostasis is checked, and the resulting myofascial flap is rotated over a drain to cover the transected bones.
- The posterior fascia is closed and sewn to the anterior fascia with interrupted absorbable sutures to create a tension-free closure (Figure 9). Tension-free closure **must** be ensured.
- The skin is closed without tension using interrupted mattress sutures (Figure 10).

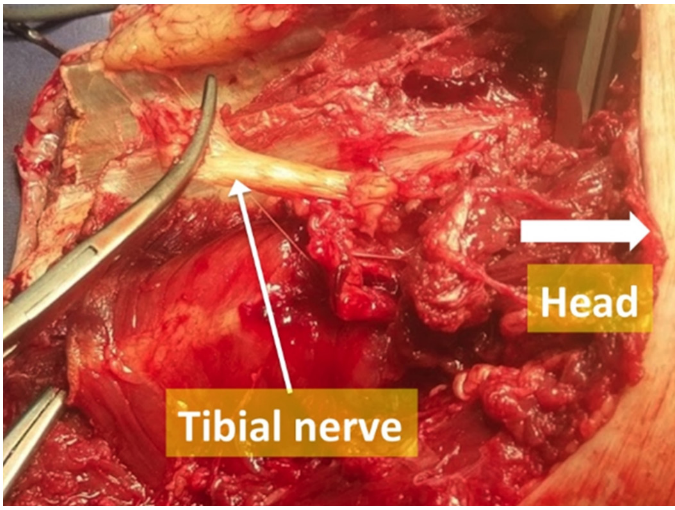


Figure 8. The tibial nerve is identified. The posterior compartment muscles have been divided.

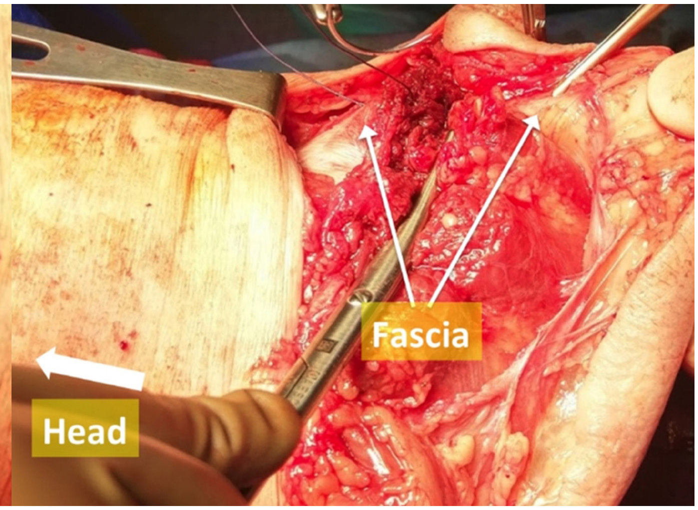


Figure 9. The posterior fascia is closed with interrupted absorbable sutures.

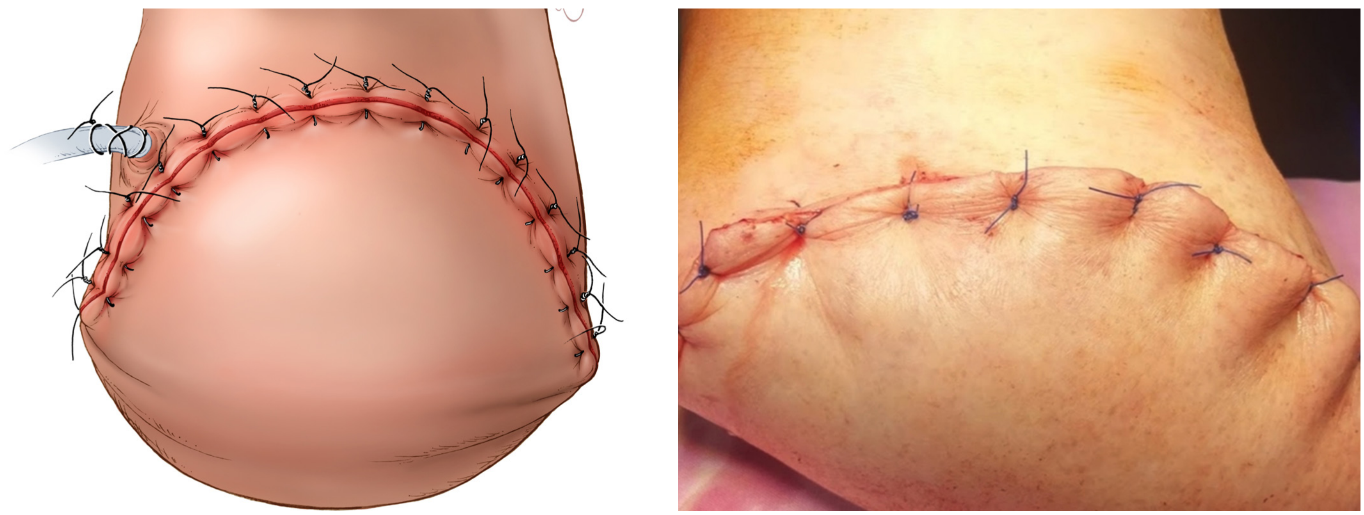


Figure 10. The skin is closed without tension using interrupted mattress sutures, with (left) or without (right) a drain.

BKA PITFALLS

- Failure to create a posterior flap long enough to cover the tibia will place the suture line under tension.
- Failure to make a smoothly curved posterior incision may result in excess skin and "dog-ears."
- Removal of too much soleus muscle from the posterior flap may cause pain and irritation of the skin.
- Failure to transect the fibula 2–3 cm proximal to the tibial transection may result in pain and difficulty in fitting a prosthesis.

Knee Disarticulation (Through-Knee Amputation/TKA)

TKA CONSIDERATIONS

- A classically described knee disarticulation leaves the femur and patella untouched, offering some advantages over an above-knee amputation.
- While also referred to as a *through-knee amputation* (TKA), that is a more generic term that may or may not include removal of the patella and excision of parts of the condyles, depending on the procedure used.

- This is the least traumatic of the amputation surgeries and can be done under regional or even local anesthesia.
- The thigh muscles are completely preserved, and thus there is no muscular imbalance.
- The stump permits total end weight-bearing, and the bulbous shape permits easy and firm attachment of prosthetic devices. However, as TKAs are less common, prosthetists are less experienced and have to work harder to get a good fit. This had led some to favor excising portions of the condyles, as seen in Figure 11.
- Proprioception, control of prosthesis, and sensation of weight-bearing are superior after TKA compared to more proximal amputations.
- The maintenance of cartilage over the distal femur decreases infection and greatly reduces the possibility of bony overgrowth.
- In cases where there is significant trauma around the knee, the presence of soft tissue injury may preclude the stump from having good, comfortable, scar-free padding that would allow end weight-bearing.
- Failure rates and reamputation rates are higher with TKA than with above-knee amputation.

TKA SURGICAL TECHNIQUE

- Multiple variations of the technique are described, with some leaving the patella and some removing it. Additionally, some report excising the bulbous portion of the condyles on the medial, lateral, and posterior aspects (Figure 11).
- The patient is placed in a supine position with access to the hip.

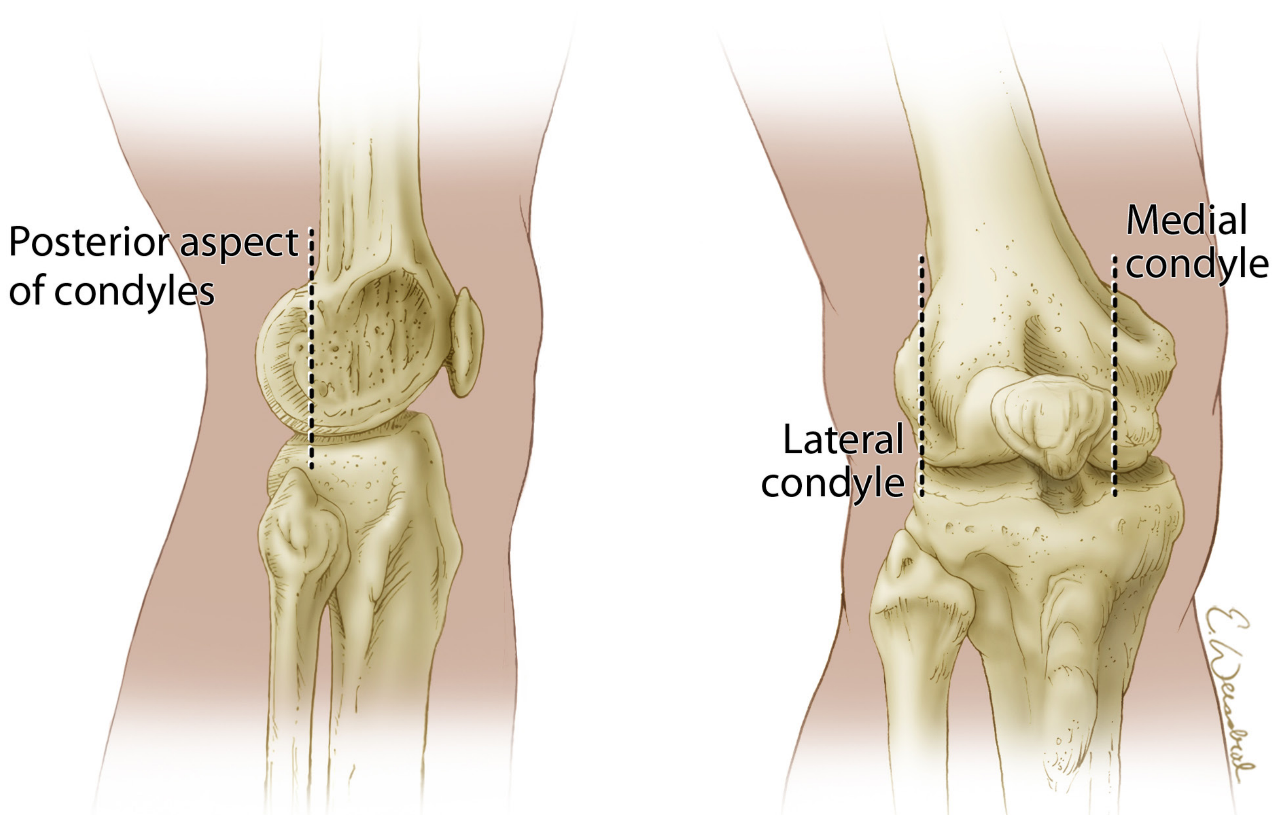


Figure 11. The lines of condylar excision proposed for one variation of a through-the-knee amputation, as seen on the right leg.

- A sterile tourniquet is applied to the thigh.
- The skin incision is made, with the anterior flap extending to the tibial tuberosity. A posterior flap longer than the anterior flap is made, with the final trimming of the skin delayed until wound closure (Figure 12).
- The knee is flexed, and the distal anterior skin is dissected from the patellar tendon and the tibial tubercle, taking care not to button-hole the skin.
- The patellar tendon is transected at its distal insertion, and the fat pad is incised.
- The knee joint capsule is entered and divided circumferentially just distal to the menisci.
- The hamstrings and collateral ligaments are released from their distal insertions below the knee, preserving as much length as possible.
- The knee is maximally flexed, and the posterior knee capsule is released from the tibia.
- The heads of the gastrocnemius muscles are divided 3 cm below knee level to preserve the blood supply from the superior geniculate artery.
- The major vessels are divided and suture ligated at the level of the knee, and the nerves are ligated and sharply transected while applying gentle distal traction such that the cut ends retract proximally.
- The leg is positioned with the hip extended to avoid creating excessive tightness in the rectus femoris muscle and resultant hip flexion contracture.
- The patellar tendon is further mobilized from the overlying skin, and if retained, the patella is positioned such that the apex is level with the femoral condyles.
- The patellar tendon is then sutured to the cruciate ligaments, as depicted in Figure 13.
- The hamstring (biceps femoris, semimembranosus, and semitendinosus) tendons are also sewn to the cruciate ligaments (Figure 13), with the posterior capsule also sewn to the remaining joint capsule to create a cushioned stump.
- A subcutaneous suction drain may be placed, the skin is trimmed, and a tension-free closure is created with interrupted sutures (Figure 14).
- Care should be taken to avoid skin tension at the suture line and especially over the condyles.

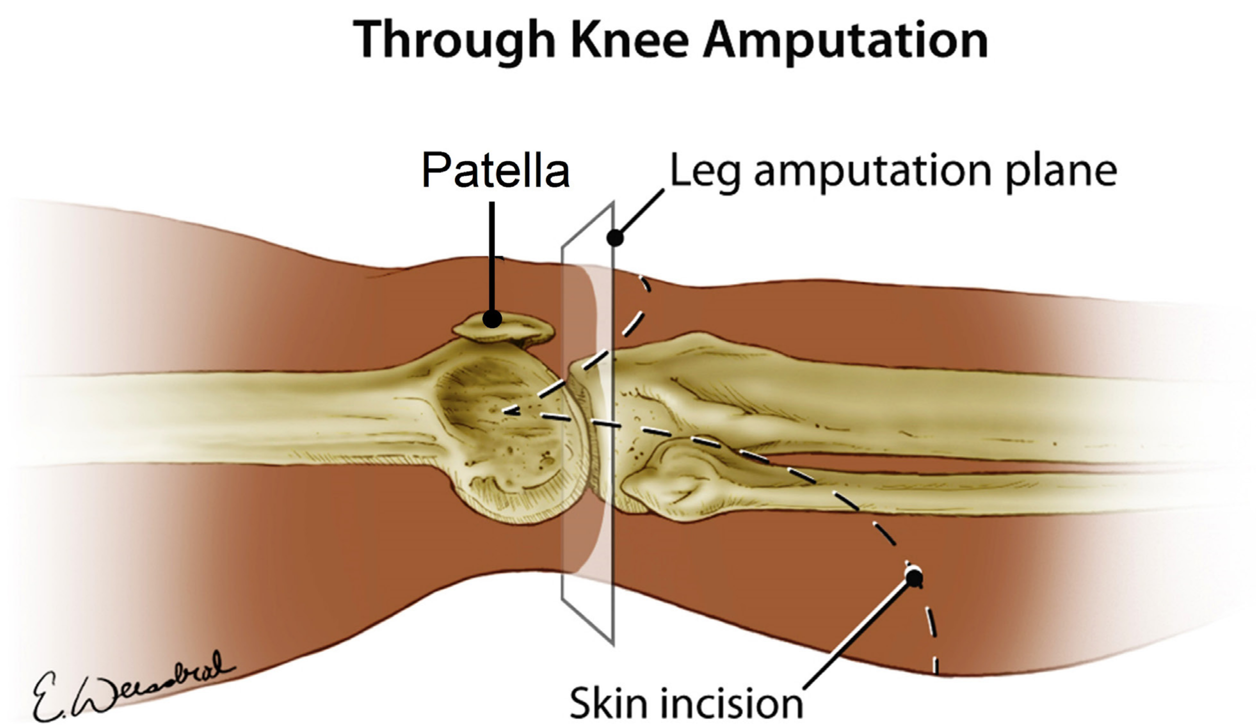


Figure 12. The skin incision and plane of the amputation used in a through-the-knee amputation.

RIGHT LEG

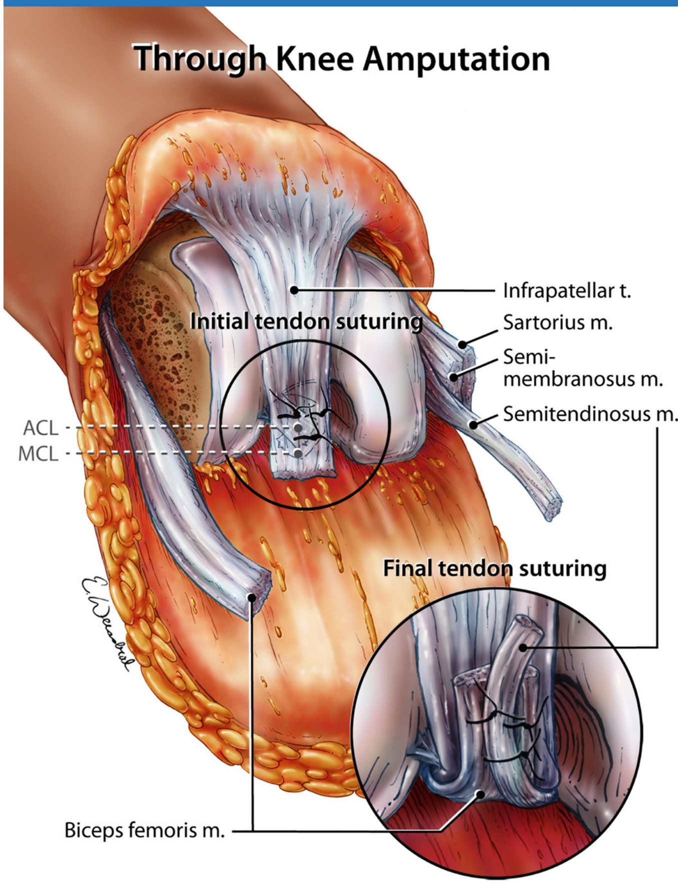


Figure 13. The patellar tendon is sewn to the cruciate ligaments, followed by the hamstring tendons.

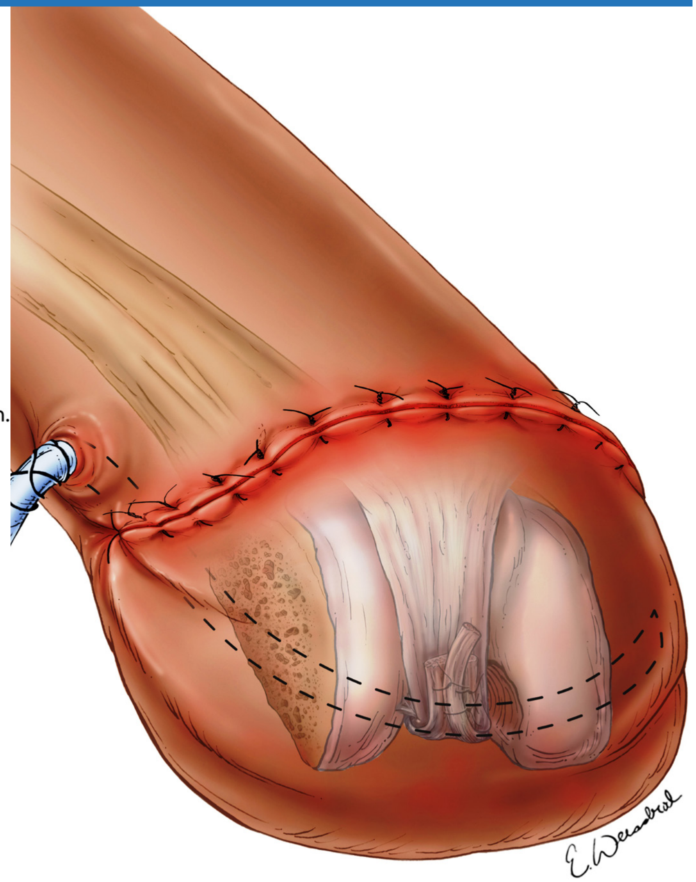


Figure 14. Closure of the through-knee amputation wound.

TKA PITFALLS

- Failure to create a posterior flap long enough to cover the stump.
- Incorrect placement of the patella (if retained) can lead to pain and skin breakdown.
- Proper prosthetic fitting is more complicated than other amputation levels, most often due to lack of familiarity with providing devices for this uncommonly performed procedure.
- Failure to make a smooth curve of the posterior incision may result in excess skin and "dog-ears."

Above-the-Knee (Transfemoral) Amputation (AKA)

AKA CONSIDERATIONS

- While the major goal of AKA is wound healing, the procedure should be done with consideration of biomechanical principles and muscle preservation.
- The energy expenditure for individuals with an AKA is 65 percent or more above normal for level walking at regular speed.
- The longer the residual limb, the greater the functional ability and the better the ability to suspend and align a prosthesis.
- The goal of surgery should be the creation of a dynamically balanced residual limb with good motor control and sensation.

AKA SURGICAL TECHNIQUE

- If needed, a sterile tourniquet can be placed as high on the thigh as possible and released prior to setting muscle tension.
- The patient is placed supine with a bump under the hip, and the lower abdomen, hip, thigh, and entire leg are prepped. In the setting of polytrauma, prepping the entire torso and the contralateral leg may be indicated.
- The knee and hip are flexed to 90°, with the limb supported by an assistant.
- For classically described AKA flaps, a pen is utilized to mark a "fish-mouth" incision, with the lateral apex about one hand breadth (10–12 cm) from the upper border of the patella and inferior to the edge of the femur (Figure 15).
- The anterior flap is generally 3–5 cm longer than the posterior flap (Figures 15 and 16) to ensure that the scar is located posteriorly.
- The skin flaps may need to be made longer than initially thought to avoid having to shorten the bone too much.

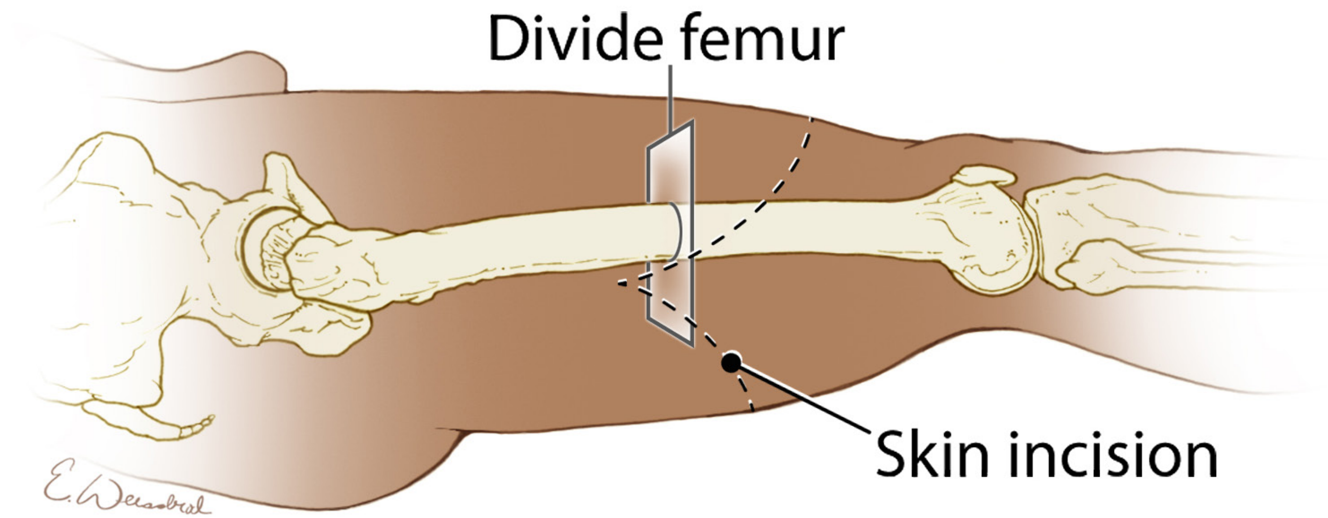


Figure 15. The skin incision and plane of the amputation used in an above-the-knee (transfemoral) amputation, depicted on a right leg.

Figure 16. The skin incision used in an above-the-knee (transfemoral) amputation, depicted on the left thigh (head to the right).

- Any flap configuration that will enhance feasible preservation of length with adequate soft tissue coverage is acceptable.
- The skin and subcutaneous tissue should be divided circumferentially, and the saphenous vein should be ligated.
- Muscles should not be sectioned until they have been identified.
- The quadriceps should be detached just proximal to the patella to retain some of its tendinous portion.
- The smaller anterior compartment muscles are sharply divided to the bone a few centimeters distal to the planned osteotomy site.
- The periosteal soft tissues are circumferentially cleared with a periosteal elevator (Figure 17).
- The femoral artery and vein are identified under the sartorius muscle (Figure 18) and are individually ligated.
- The adductor magnus is detached from the adductor tubercle and reflected medially to expose the femoral shaft.
- The adductor muscles are divided a few centimeters beyond the proposed osteotomy.
- The femur is exposed above the condylar level and is cut with an oscillating blade or Gigli saw, transecting the femur approximately 7.5–10 cm above the knee joint (Figure 19).
- The sharp edges of the bone are smoothed using a rasp (Figure 20).
- The posterior compartment muscles are divided sharply 2–3 cm distal to the osteotomy site. The sciatic nerve should be ligated and sharply divided as proximally as possible such that it will retract into the muscle compartment.
- The size and shape of the flaps in relationship to the cut end of bone are checked and trimmed if necessary to ensure adequate approximation without tension.

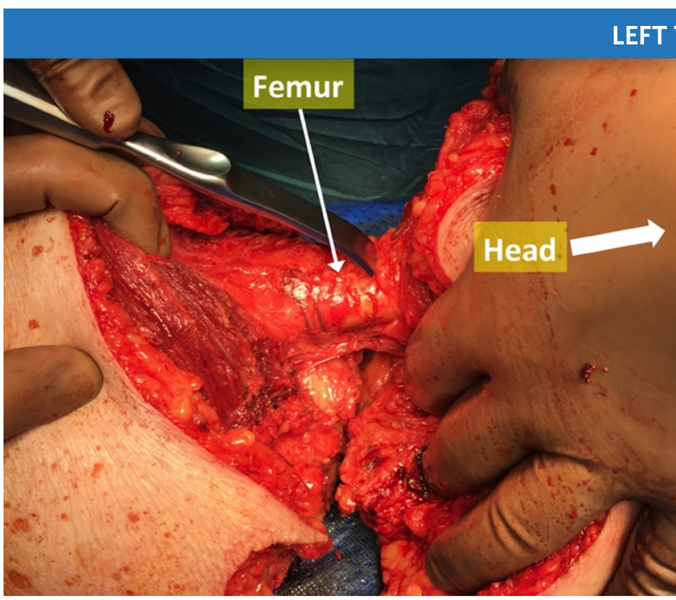


Figure 17. This picture shows how soft tissue is cleared using a periostal elevator.

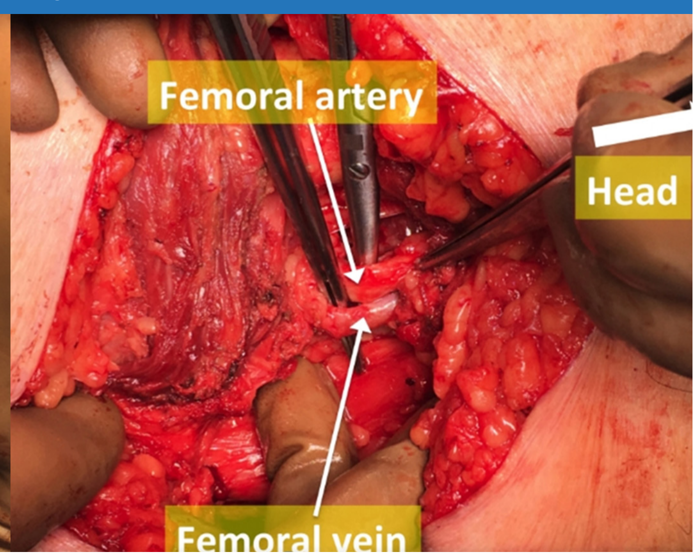


Figure 18. The femoral artery and vein are identified.

LEFT THIGH

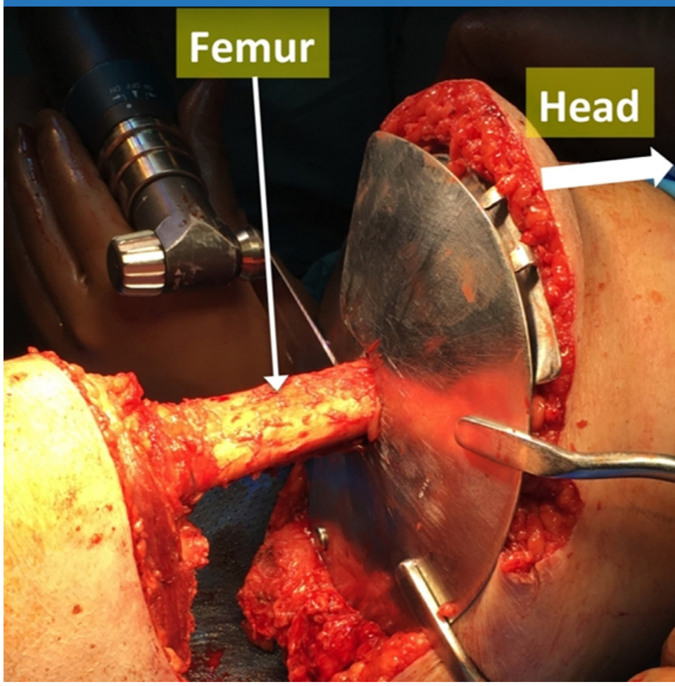


Figure 19. A transverse osteotomy is performed using a pneumatic saw. A malleable retractor is used to protect the soft tissue.

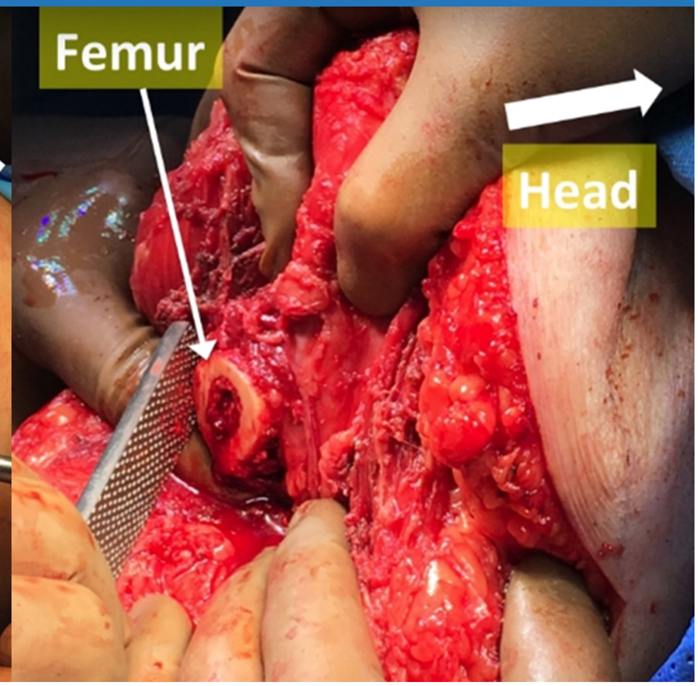


Figure 20. Sharp edges of the femur are smoothed using a rasp.

- Hemostasis is ensured, and bone wax is applied to the stump if there is oozing.
- A series of holes (three to six) may be drilled 1 cm proximal to the bone end (Figures 21 and 22) to allow for myodesis (attachment of muscle to bone).
- The number of holes required to provide adequate coverage of the stump is variable, and additional myodesis holes can be added as necessary.
- Myoplasty is performed by bringing the muscles over the femur to provide soft tissue coverage to the residual bone.
- Opposing muscle groups are sewn together (flexor to extensor, abductor to adductor) and anchored to the femur where possible (Figure 23). This should be done with the femur in full extension to minimize contraction.

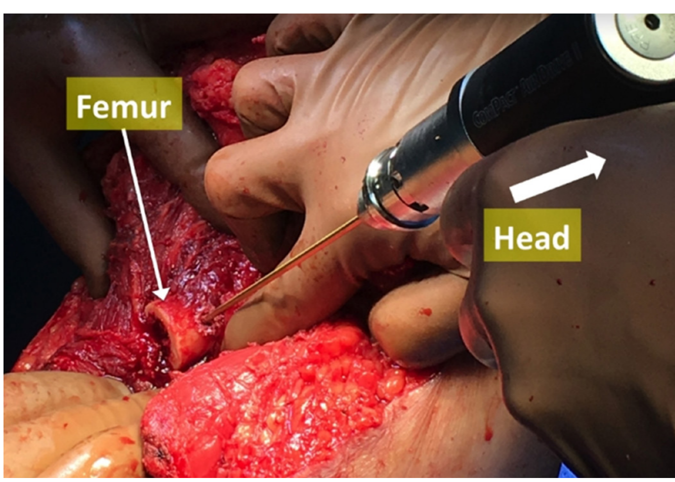


Figure 21. A drill is used to create a hole in the bone for subsequent myodesis.

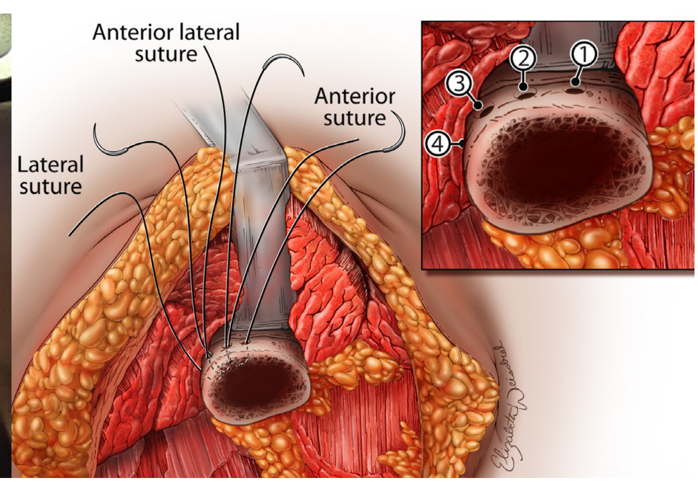


Figure 22. Sutures are passed through the holes created and then used to attach the muscles.

- The quadriceps is secured to the adductor flap to complete the myoplasty (Figure 24).
- The deep fascia is closed with interrupted absorbable sutures, starting at the midline to avoid any discrepancies between the anterior and posterior flaps. This is followed by continued segmental closure of the more superficial fascia (Figure 25).
- The skin is then closed without tension using interrupted mattress sutures (Figure 26).
- Generally, one or two closed suction drains are left below the flaps and brought out laterally or medially above the suture line.

AKA PITFALLS

- Failure to preserve as much femoral shaft length as possible to improve function and prosthetic fit
- Failure to ensure enough tissue for adequate coverage of the femur.
- Failure to myodese the adductor and medial hamstrings to the bone to prevent muscle slippage over the end of the stump.
- Until the wound is soundly healed, no attempt should be made to apply compression bandaging to mold the stump.

RIGHT THIGH SEEN FROM FOOT OF BED

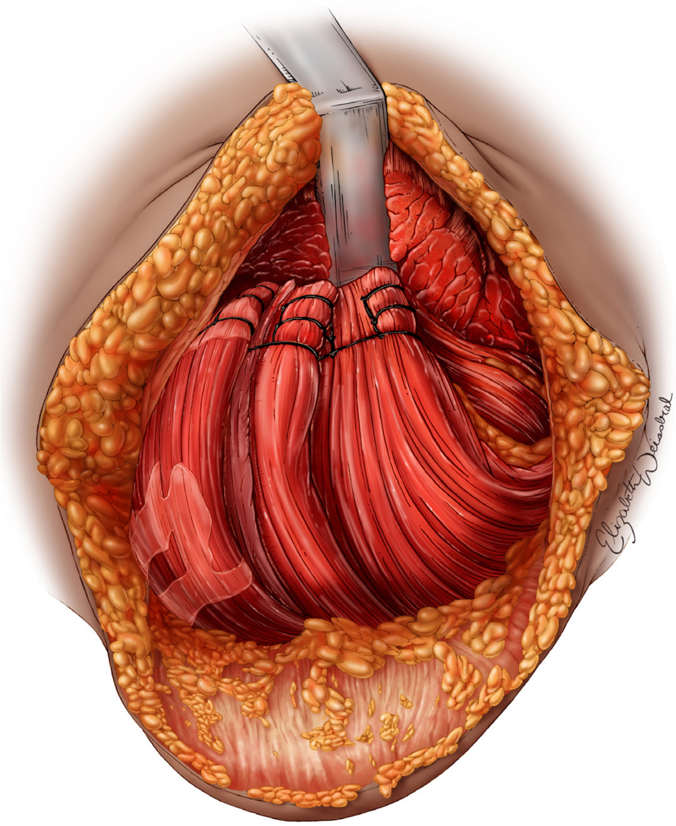


Figure 23. Opposing muscle groups have been anchored to the femur and to each other.

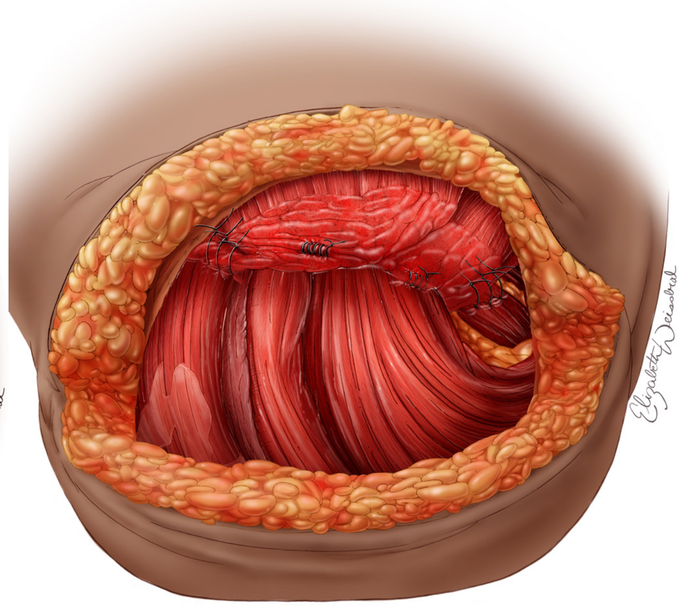


Figure 24. The quadriceps is sewn to the adductor flap to complete the myoplasty.

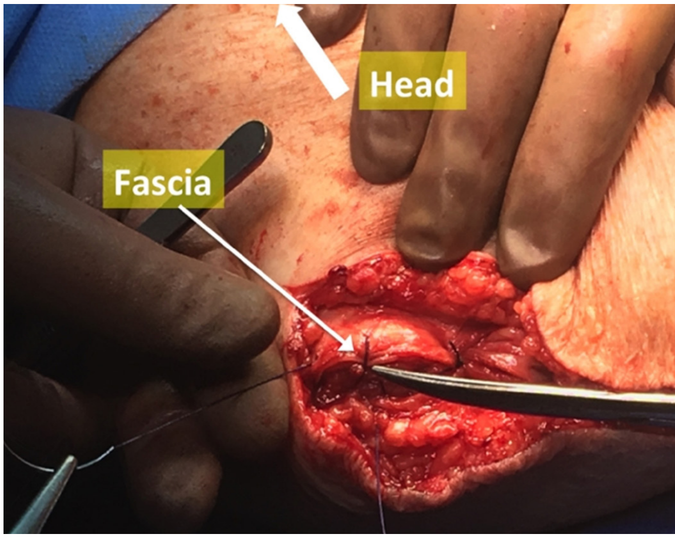


Figure 25. The fascia is closed with interrupted absorbable sutures.

Figure 26. The wound is closed without tension using interrupted mattress sutures.

Hip Disarticulation

- Hip disarticulation is the surgical removal of the entire lower limb by transection of the hip joint.
- Hip disarticulation is rarely required or performed but has been more common in the recent wars in Iraq and Afghanistan for hemorrhage control or in cases of massive lower extremity devitalization.
- The basic steps of the procedure are included here for the sake of completeness. It is advisable to seek experienced help if available to perform this procedure.

Hip Disarticulation Surgical Technique

- The patient is placed in a lateral position.
- A racket-shaped incision is made, with its apex medial to the anterior superior iliac spine (Figure 27).
- The incision is marked, and the skin and subcutaneous tissue are divided, with the first steps being to expose the femoral triangle and to identify and individually ligate the femoral neurovascular bundle (Figure 28).

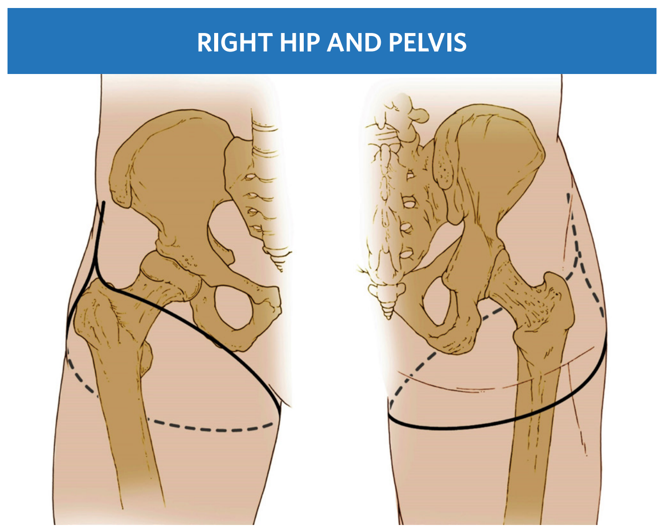


Figure 27. The racket-shaped incision used for hip disarticulation, as depicted on a right hip from anterior (left) and posterior (right).

- The muscles of the anterior-medial thigh are identified and divided in a methodical fashion, starting with the sartorius, rectus femoris, and pectineus, which are divided at their origins (Figure 28).
- The iliopsoas muscle tendon is divided at its distal insertion on the lesser trochanter, and the adductor muscles are released from their origins on the pelvis to expose the joint capsule (Figure 29).

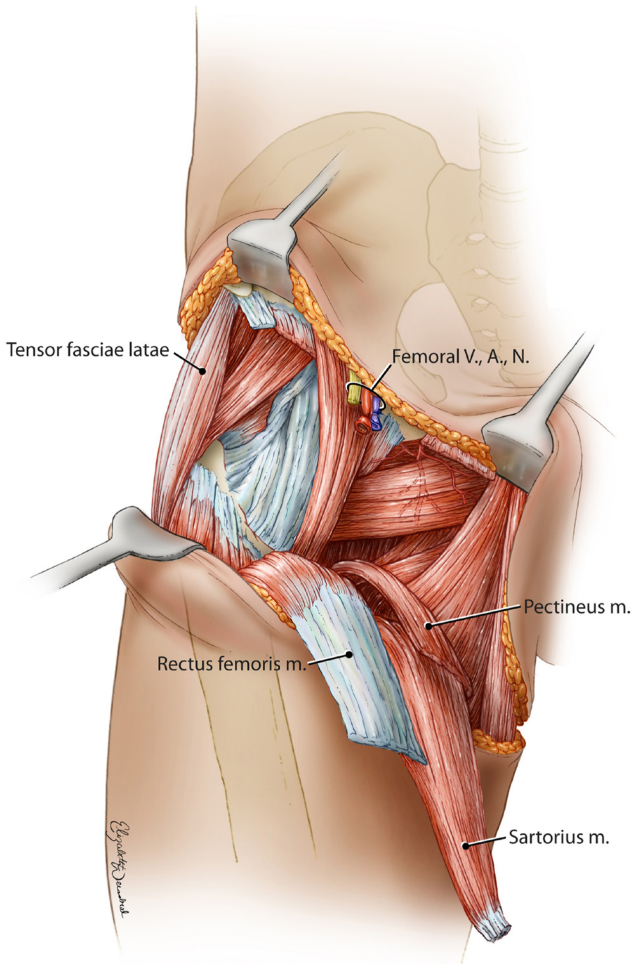


Figure 28. The femoral vessels and nerve are ligated, and the rectus femoris, sartorius, and pectineus muscles are divided at their origins.

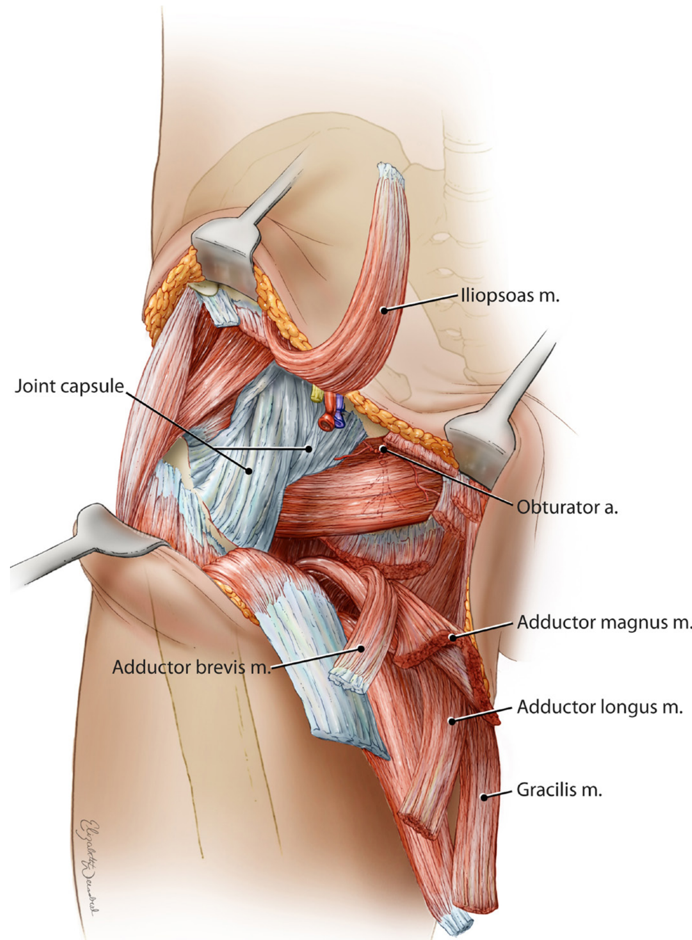


Figure 29. The iliopsoas muscle tendon is divided at its distal insertion on the lesser trochanter, and the adductor muscles are released from their origins on the pelvis to expose the joint capsule.

- The obturator artery (Figure 29) and nerve are carefully ligated and transected.
- The tensor fasciae latae and gluteus maximus (Figure 30) are divided, leaving sufficient length from their origins to be swung across the empty femoral socket on completion of the hip disarticulation.
- The muscles inserting onto the greater trochanter (gluteus medius and minimus, piriformis, obturator internus and externus, and gemelli muscles) are removed to complete the exposure of the joint capsule, which can then be opened with disarticulation of the femoral head.
- The hamstring muscles are detached from their origin, and the sciatic nerve is identified, ligated, and divided after applying distal traction to allow it to retract up into the remaining tissues.
- This completes the dissection, and the wounds are closely inspected for hemostasis.
- Following removal of the limb, the acetabulum is covered by approximating preserved muscles (Figure 31), with the quadratus femoris approximated to the iliopsoas and the obturator externus to the gluteus.
- The remaining fascia is closed in layers over closed suction drains, and the skin is approximated with interrupted sutures in a tension-free fashion.

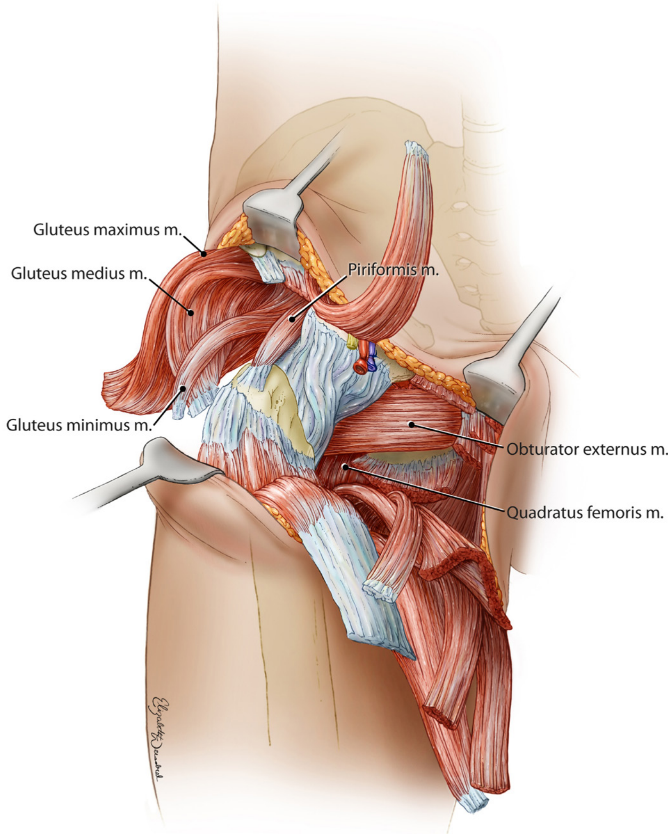


Figure 30. The tensor fasciae latae and gluteus maximus are divided, leaving sufficient length to cover the empty femoral socket.

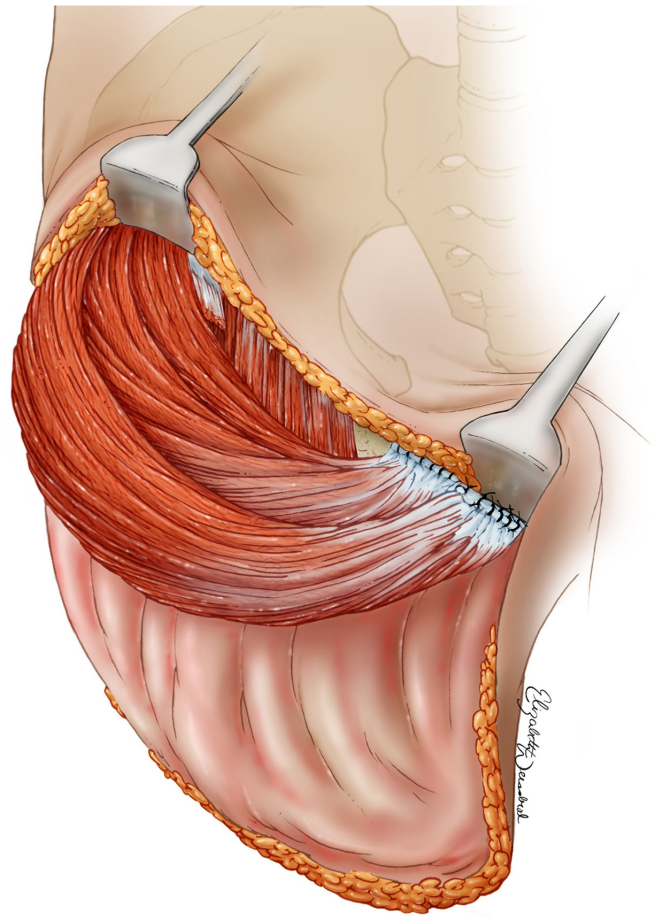
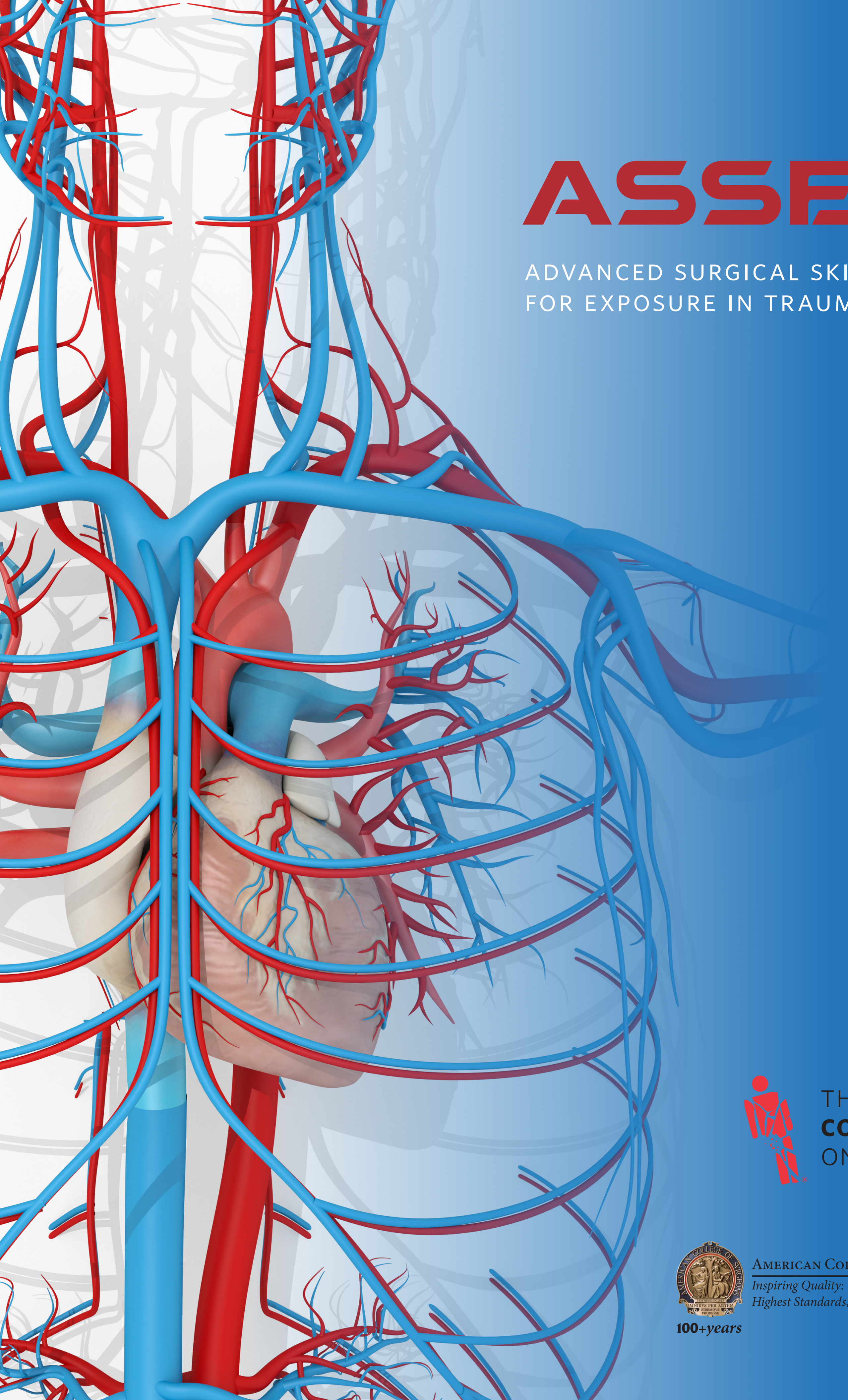


Figure 31. The acetabulum is covered by approximating the quadratus femoris to the iliopsoas and the obturator externus to the gluteus muscle.

Hip Disarticulation Pitfalls

- Hip disarticulation is a radical procedure with obvious implications for limb functionality and carries with it high rates of complications and mortality.
- The best outcomes are achieved with multidisciplinary care, and formal disarticulation should be done with as much experienced help as possible.
- Development of postoperative infection following a hip disarticulation done for trauma is associated with high mortality. As such, it is imperative that adequate debridement be accomplished and optimization of physiology be achieved prior to formal shaping and closure of such wounds.



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