Paula Ferrada
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Editors

Atlas of Trauma

Operative Techniques, Complications and Management

Springer

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ISBN 978-3-030-26870-1 ISBN 978-3-030-26871-8 (eBook)
https://doi.org/10.1007/978-3-030-26871-8

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

We dedicate this book to all surgeons who practice trauma care and for all professionals who pour their hearts and souls to help patients survive grave injuries.

Preface

Regardless of the sub-specialization or the place where we practice, the majority of surgeons will need at some point to take care of trauma patients. This is crucial in situations of a natural disaster and war or in places where the social situation can result in violence.

Trauma is a disease that when it requires surgery, it is more technically challenging than any other elective procedures. In acutely injured patients, the anatomy is distorted, the physiological state is labile. In order to save a life trauma procedures need to be done fast and efficiently. Therefore, it is imperative that we all place our efforts in training ourselves and those who come after us to be the best technicians we can be. In trauma, patient lives depend on our technical ability and capacity to work under pressure.

This atlas is the collaborative work of surgeons from Latin America and North America, describing techniques that can come in handy when treating trauma patients.

Richmond, VA, USA — Paula Ferrada
Cali, Colombia — Ricardo Ferrada

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Neck Exploration

1

Stefan W. Leichtle and Paula Ferrada

Introduction

Severe trauma to the neck is rare but can rapidly become life-threating. Even patients without immediate concern for airway loss or exsanguinating hemorrhage are at risk for permanent, potentially disabling neurologic deficits. Neck trauma requires rapid, systematic assessment and timely, appropriate interventions to ensure best outcomes. Despite the high stakes, a majority of patients with blunt and even penetrating neck trauma will not require operative intervention [1].

The structure of this chapter follows the presentation of a trauma patient with injury to the neck from (1) presentation to the Emergency Department (ED) to (2) the initial diagnostic and management decisions to (3) the Operating Room (OR) for neck exploration. The chapter focuses on concise reviews of anatomy, physiology, decision-making, and operative steps.

In the Emergency Department: Initial Assessment and Airway Management

Initial attention must follow Advanced Trauma Life Support protocols and focus on the safety of the patient's airway. When arrival of a trauma patient with neck injury to the ED is anticipated, a cricothyroidotomy set (or its individual components required for this procedure), should be readily available: a size 11 or 15 scalpel, Kelly clamp, tracheal hook, and size 6 Fr endotracheal tube (ETT) or tracheostomy canula. A plan for airway management should be clearly laid out between the trauma surgery, ED, and anesthesiology teams present in the trauma bay. Cricothyroidotomy should not necessarily be considered an option of last resort (when the patient is severely hypoxic), but might well be one of the first maneuvers, depending on a patient's presentation.

Any patient with a compromised airway upon arrival to the ED should undergo immediate endotracheal intubation, which may be difficult or impossible in severe facial trauma, or expeditious cricothyroidotomy. If a patient's airway is threatened but still maintained, intubation in the OR rather than the ED should be considered, where a non-surgical or surgical airway can be established under more favorable circumstances.

Procedure: Cricothyroidotomy

- Palpate the thyroid cartilage, which is usually the most obvious bony prominence of the anterior neck and is located about 4–5 finger breadths above the sternal notch. The cricothyroid membrane is immediately below, between the thyroid cartilage superiorly and the cricoid cartilage inferiorly.
- Stabilize the thyroid cartilage with your non-dominant hand and perform a vertical skin incision extending from the thyroid cartilage toward inferior. A 1–1.5-inch-long incision should suffice, but there should be no hesitation to extend the incision if needed for better exposure.
- Feel for the cricothyroid membrane (in the setting of bleeding this is often more a palpable than visible structure) and make a horizontal incision through it. Be careful not to back wall into the esophagus, particularly when using an 11 vs. 15 blade.
- Dilate the opening with a Kelly clamp or tracheal dilator, if available.
- If available, use a tracheal hook to pull up the thyroid cartilage. This stabilizes the trachea.
- Insert an appropriately sized ETT (usually 6 Fr) or tracheostomy canula and secure it.
- Check end-tidal CO_2 to confirm correct placement in the airway.

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P. Ferrada, R. Ferrada (eds.), *Atlas of Trauma*, https://doi.org/10.1007/978-3-030-26871-8_1

If the airway is secure, or once it has been secured, systematic assessment of the neck continues. Traditionally, the neck has been divided in three zones (Fig. 1.1):

- Zone 1, from sternal notch/clavicles to cricoid cartilage
- Zone 2, from cricoid cartilage to the angle of mandible
- Zone 3, from the angle of the mandible to the skull base

Initial assessment and management has evolved from this zone-based approach (historically, "mandatory exploration for zone 2 wounds") to a selective approach taking into account individual patient stability and signs of injury [2]. Determination of injury zone is still helpful for clear communicating, to anticipate damaged structures, and to prepare for operative intervention. It is important to realize that penetrating wounds can easily traverse a zone, e.g., a zone 2 stab wound might well extend into zone 1.

Zone 1 injuries may require (partial) sternotomy or thoracotomy (Fig. 1.2). Injured structures may include:

- Mediastinal and superior thoracic vessels: innominate, proximal common carotid, subclavian, and vertebral arteries; internal jugular vein (IJ).

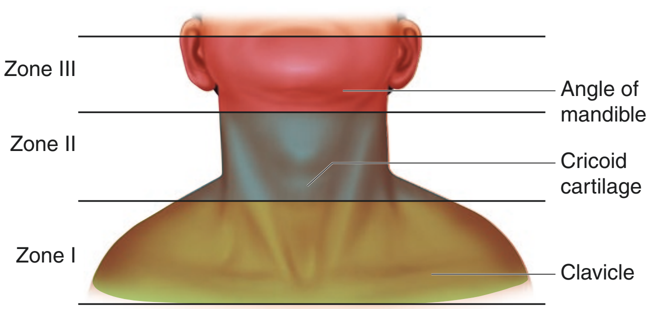


Fig. 1.1 Zones of the neck

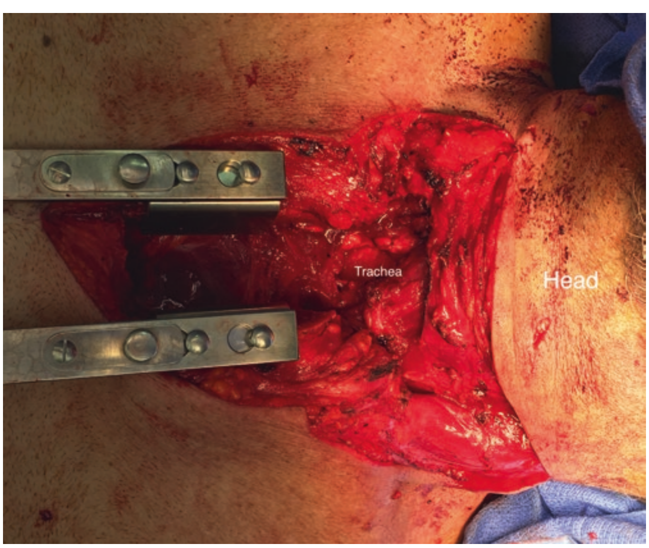


Fig. 1.2 Partial sternotomy for low tracheal injuries

- Esophagus and trachea.
- Apex of the lung, thoracic duct, and brachial plexus.

Zone 2 is most accessible surgically, and an incision along the anterior border of the sternocleidomastoid muscle (SCM) is most versatile. Injured structures may include:

- Distal common, internal, external carotid arteries; vertebral artery; IJ and external jugular vein.
- Esophagus and trachea.
- Vagus nerve.

Zone 3 injuries are most difficult to access surgically and may involve the cranium. Exposure may require dislocation of the mandible or resection of the styloid process. If possible, temporary hemorrhage control (e.g., with a Foley catheter, described below), preoperative imaging, and use of endovascular techniques are preferable to immediate operative exploration. Injured structures may include:

- Distal carotid and vertebral arteries.
- Pharynx.
- Vagus, glossopharyngeal, and hypoglossal nerves.

In the ED: Hemorrhage Control and Systematic Assessment

Severe active hemorrhage from a neck wound might require rapid hemostasis before further diagnostics or definitive surgical control can be planned. Even in the neck, direct compression is the initial maneuver and can control bleeding in many cases. For non-compressible hemorrhage in the neck or upper chest, balloon tamponade with a Foley catheter is an effective method to provide temporary hemostasis.

Procedure: Balloon Tamponade of Non-compressible Hemorrhage in Neck or Chest

- Insert a large (16 or 18 Fr) Foley catheter carefully into the wound and inflate the balloon with a small amount of saline until bleeding stops.
- If inflation alone does not stop the hemorrhage, the catheter might have to be pulled back slowly to achieve hemostasis (Fig. 1.3).
- Clamp the catheter and secure it with suture or tape.
- Once temporary hemostasis has been achieved, obtain imaging if needed or transport the patient to the OR.

Once the patient's airway has been secured and initial injuries have been assessed, management proceeds based on the patient's hemodynamic status and presence or absence of "hard signs" of vascular or aerodigestive injury. Any patient who is unstable (with neck trauma as likely cause) or has hard signs of vascular or aerodigestive injury should go directly to the OR. Patients with "soft signs" of injury might still require operative intervention but can usually undergo imaging workup first as long as they are not unstable or at risk for airway loss.

Hard signs of vascular or aerodigestive injury are:

- Pulsatile bleeding or expanding hematoma
- Audible bruit or palpable thrill overlying the major vascular structures
- Hemodynamic instability not explained by other injuries
- Neurologic deficits not explained by other injuries
- Air bubbling from the neck (Fig. 1.4)
- Severe hematemesis or hemoptysis

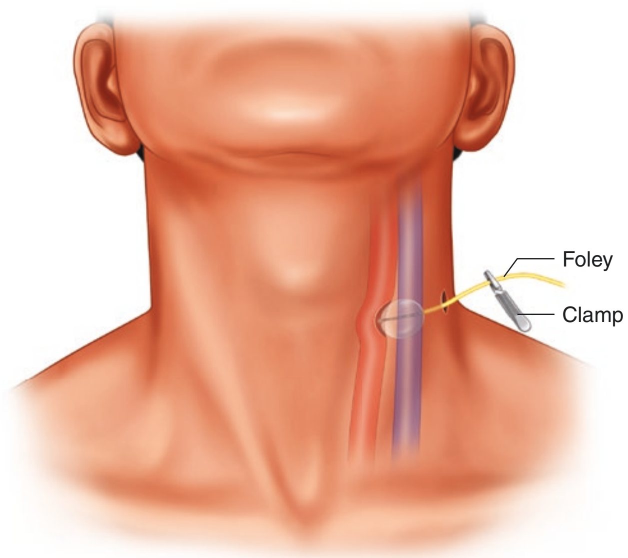


Fig. 1.3 Foley tamponade

Fig. 1.4 Hard sign of aerodigestive injury: air bubbling from neck

Soft signs of vascular or aerodigestive injury are:

- Reported active bleeding or severe blood loss in the field
- Hematoma without active expansion
- Small amount of hematemesis or hemoptysis

In the ED: Imaging for Neck Trauma

Computed tomography angiography (CTA) of the neck has essentially replaced traditional angiography as initial imaging tool. A negative neck CTA rules out significant vascular injury with very high sensitivity and specificity [3]. It is important to inject the IV contrast for the CTA on the contralateral side of the anticipated injury to adequately visualize the subclavian vessels without artifact from the contrast bolus. CTA of the neck might be limited if metallic shrapnel is present in the neck, and it is less sensitive for esophageal and tracheal injury. If there is concern for aerodigestive injuries (based on trajectory, clinical signs, and/or imaging findings; Fig. 1.5), a bronchoscopy and swallow study with water-soluble contrast should be performed to rule out tracheal and esophageal injury, respectively. Upper endoscopy in addition to a contrast study is the most sensitive way of ruling out digestive tract injury. If the neck CTA demonstrates isolated venous injury including the IJ, *hemodynamically stable* patients can still be successfully managed non-operatively [4].

In the OR: Preparation and Positioning

Despite the advent of endovascular treatment options and increasing prevalence of hybrid operating rooms, open operative repair remains the mainstay of surgical treatment for

Fig. 1.5 Large amount of air near trachea on imaging: concern for aerodigestive injury

vascular injuries in the neck [5]. The following instruments and tools should be available:

- Vessel loops and vascular clamps, e.g., Bulldog clamps
- Argyle shunts (Medline Inc.) of various sizes (8, 10, 12, and 14 Fr), or other shunt types depending on local availability
- Arterial embolectomy catheters of various sizes, e.g., 3 and 5 Fr
- Heparin flush (5000 units in a syringe with 100 ml of normal saline) for local, *not systemic*, administration
- Thoracotomy and sternotomy set (at least sternal saw/Lebsche knife and Finochietto retractor)

The patient is positioned supine with both arms tucked to allow for good access to both sides of the neck. If the cervical spine has been cleared (generally, patients with penetrating neck trauma do not require c-spine immobilization), slight extension (shoulder roll) and contralateral rotation of the neck for unilateral injuries are helpful. Standard trauma prep, i.e., from head to bilateral knees, allows for access to the chest and lower extremities to harvest a venous conduit, if needed. For optimal exposure and to facilitate orientation, the mandible, angle of the mandible, and mastoid process should be visible. Ideally, to allow for optimal visibility of the entire face, use a transparent drape or forgo the top drape.

In the OR: Neck Exploration

The most versatile and commonly used incision for neck trauma follows the anterior aspect of the SCM. This incision can be extended (1) onto the chest if sternotomy is required; (2) across the neck to access trachea and esophagus from anterior; and (3) to the contralateral side of the neck if bilateral exposure is necessary (Fig. 1.6). For anterior injuries to the trachea and esophagus, a collar incision with the head in midline can be performed. This incision can also be extended to either side of the neck and onto the chest if needed (Fig. 1.7).

Procedure: Anterior Sternocleidomastoid Incision to Expose the Major Structures of the Neck

- Similar to the incision used for elective carotid endarterectomies.
- Extension to a (partial) median sternotomy might be necessary for lower tracheal and superior mediastinal injuries.

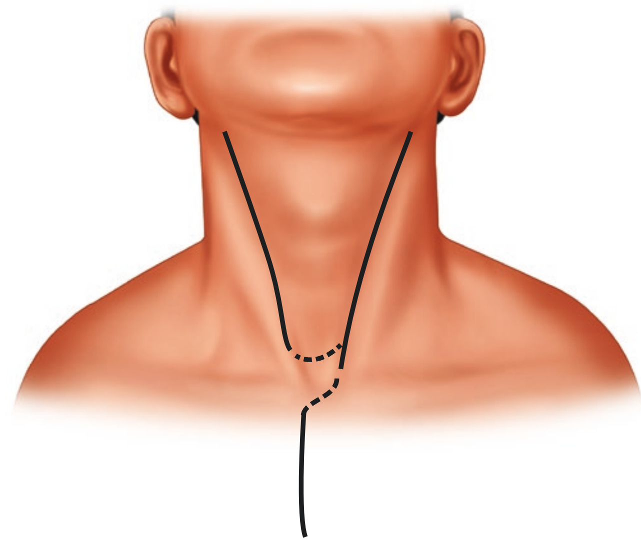


Fig. 1.6 Incisions for neck trauma

- Perform a longitudinal skin incision along the palpable anterior edge of the SCM, with maximal extension from the sternal notch to the mastoid process.
- Incise the platysma with electrocautery.
- Retract the SCM laterally to expose the neurovascular bundle (carotid sheath).
- The IJ is usually encountered first (anterolateral), with the facial vein entering it from medial. This junction correlates with the level of the carotid artery bifurcation and the thoracic cartilage of the trachea.
- Ligate the facial vein with a 3-0 silk suture to allow for mobilization of the carotid sheath.
- Open the carotid sheath sharply. The following **relevant anatomy** will usually be encountered:
  – The IJ is located anterolaterally, the carotid artery medially, and the vagus nerve posteriorly between them.
  – The common carotid artery bifurcates into internal and external carotid artery at the level of the facial vein/thyroid cartilage. Distal to the bifurcation, the external carotid artery is located medially to the internal carotid artery, until it eventually crosses over the internal carotid artery to cross the ramus of the mandible and into the parotid gland.
  – The first branches of the external carotid artery (important for vascular control) are superior thyroid and lingual arteries. The internal carotid artery has no branches and eventually enters the skull behind the styloid process.
  – Close to the cranium, the carotid arteries are crossed by the posterior belly of the digastric muscle, the hypoglossal nerve, and the glossopharyngeal nerve.

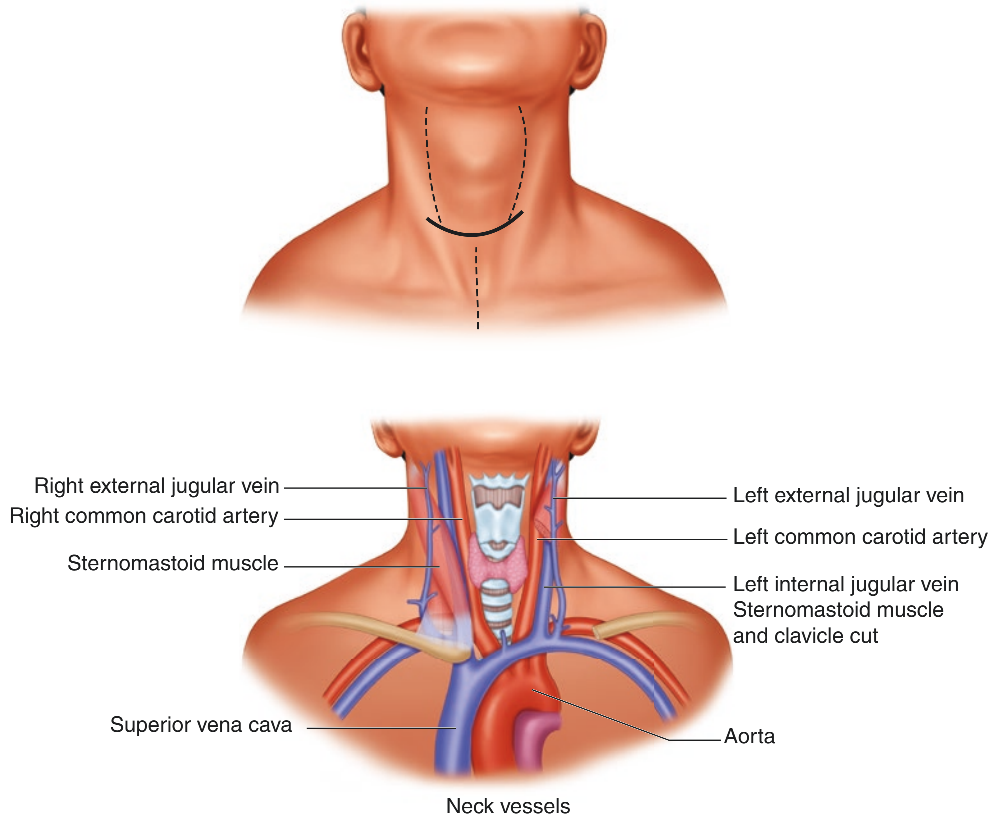


Fig. 1.7 Incisions for neck trauma

  - Take to avoid causing traction injury to the hypoglossal nerve.
  - Techniques for surgical exploration of this area include subluxation of the mandible as well as removal of the styloid process. Alternatively, an intraoperatively used Foley catheter can be excellent for temporary hemostasis in this area.
  - Inferiorly, the omohyoid muscle is the gatekeeper of the thoracic inlet and extends across the carotid sheath. It can be divided if proximal exposure is required.
- Place vessel loops around the common, internal, and external carotid arteries, IJ, and vagus nerve to facilitate identification and to allow for vascular control if necessary.
- If there is massive bleeding from an obvious vessel lumen, a size 3 Fr Fogarty catheter can be used intraluminally to provide control.
- Proceed depending on the findings:
  - **IJ injury**
    - For destructive injuries or in an unstable patient, ligate the IJ proximally and distally.
    - Repair can be attempted if it can be done promptly and with no more than 50% stenosis
  - Common or internal **carotid artery injury**
    - Should essentially always be repaired or shunted (see below).
  - Unilateral **external carotid artery injury** can be ligated.
  - Bleeding that appears to originate from behind the carotid sheath can indicate **vertebral artery injury**.
    - Pull the carotid sheath medially and expose the transverse processes of the cervical spine by pushing the paravertebral muscle aside
    - This might allow for access to and clipping of segments of the vertebral artery, but more often temporary hemostasis with a balloon catheter or bone wax and subsequent use of angiography and embolization is preferable.
- Once any vascular injuries have been addressed, proceed with exploration of trachea and esophagus.
  - Retract the carotid sheath and structures within towards lateral.
  - Watch for the recurrent laryngeal nerve in the tracheoesophageal groove between trachea anteriorly and esophagus posteriorly.
  - If a **tracheal injury** is found, proceed with repair (see below, Fig. 1.8).
  - A nasogastric tube in the in esophagus can help with its identification.
  - At the level of the cricoid cartilage of the trachea, the pharynx transitions into esophagus, which is about 15 cm from the incisors.

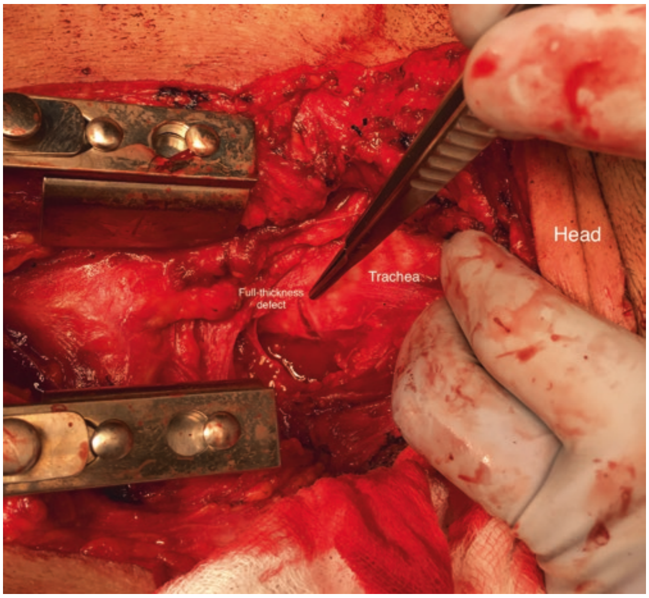


Fig. 1.8 Tracheal injury from stab wound

- The middle thyroid vein may need to be ligated to mobilize the esophagus.
- Exposure and exam of the esophagus can be facilitated by placing a Penrose drain around it.
- If an **esophageal injury** is found, proceed with repair (see below).
- The esophagus has no serosa, only a circular and longitudinal muscular layer, which places repairs at a higher risk for failure.

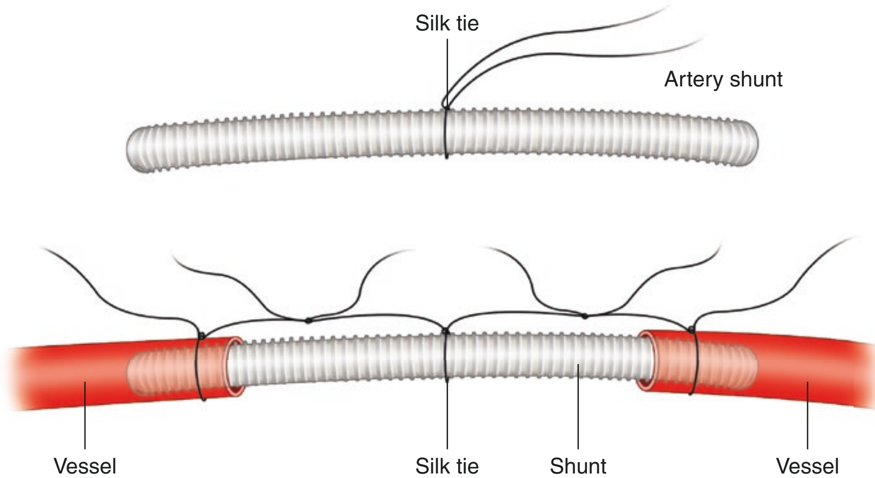
Procedure: Collar Incision

- This incision affords excellent exposure of the trachea, but is not ideal if major vascular injury is expected.
- It is similar to the incision used in elective thyroidectomy, but more generous.
  - Curved incision two fingers above the sternal notch, extending to bilateral SCMs.
  - If present, an existing anterior skin defect (e.g., stab wound) can be extended.
- Divide the platysma and raise subplatysmal flaps.
- Watch out for/ligate the anterior jugular veins with a 3-0 silk tie.
- Split the paired strap muscles; divide them, if necessary, for better exposure.
- Carefully divide the thyroid isthmus with electrocautery and oversew the cut edges for hemostasis.
- If a **tracheal injury** is found, proceed with repair (see below).
- Extend the incision towards lateral if better exposure is needed to access vascular structures or esophagus (see Fig. 1.7).

Procedure: Carotid Repair or Shunting

- As in all vascular repairs, proximal and distal control needs to be established before the repair attempt.
- Vessel loops greatly help with initial dissection and rapid vascular control, but vascular clamps such as Bulldog clamps are helpful for the subsequent repair.
- Due to the risk of ischemic stroke by carotid artery manipulation, the internal carotid artery should be occluded first (prevents embolus to the brain), followed by common and lastly external carotid artery. Unclamping occurs in reverse. The mnemonic for this sequence is "I – C – E" (clamp) and "E – C – I" (unclamp).
- Systemic heparin administration is often contraindicated in a trauma patient. A useful alternative is the use of heparinized saline to flush the carotid artery prior to occlusion, and again before re-establishing blood flow. A heparin flush can be mixed using 5000 units in 100 ml normal saline or following local protocols.
- Once vascular control has been established, several options are available for repair or shunting of the carotid artery as temporary measures.
  - **Primary repair**
    - Debride non-viable tissue. This is particularly important in blast injuries.
    - Ensure that there is no injury to the backwall.
    - Repair the artery with 5-0 or 6-0 Prolene suture, but only if this is possible without causing significant stenosis.
  - **Patch repair**
    - Use this method instead of primary repair if the latter would result in stenosis.
    - Debride non-viable tissue. This is particularly important in blast injuries.
    - Ensure that there is no injury to the backwall.
    - Repair the artery with a patch of bovine pericardium or PTFE, using 5-0 or 6-0 Prolene suture.
    - Depending on the size of the defect and anticipated duration of repair, temporary shunting should be considered (see below).
  - **Interposition graft**
    - This is the definitive repair for large defects that are not amenable to patch repair.
    - Debride non-viable tissue. This is particularly important in blast injuries.
    - Harvest the saphenous vein and use as a reverse vein graft, or use a PTFE conduit.
    - Place a shunt to ensure adequate cerebral blood flow during the repair (see below).
  - **Temporary shunt** (Fig. 1.9)
    - A shunt ensures adequate cerebral blood flow during more extensive vascular repairs or while waiting for vascular surgery support, and for stabilization of an unstable patient in a damage-control setting.

Fig. 1.9 Temporary shunting



- Various types of shunts exist, and it is important to become familiar with the shunts that are available at your local institution.
- Argyle shunts are probably the most versatile and easiest to use. The largest size that fits easily should be chosen, but it is important not to cause intimal damage by attempting to insert a shunt that is too large.
- If shunting is the primary goal of the operation (with definitive repair planned for another time), *do not* debride non-viable tissue. This would result in additional tissue loss after shunt removal during definitive repair.
- Place a 3-0 silk tie firmly around the mid-portion of the shunt.
- Insert the shunt proximally first and secure it in place with a 3-0 silk tie. Do not cut the suture yet.
- Place the tie as close to the cut-end as possible to minimize the amount of vessel that needs to be debrided for the definitive repair.
- Flush the shunt, insert it into the distal segment, and secure it.
- Tie the proximal and distal silk sutures to the earlier placed silk suture around the middle of the shunt to secure it in place and prevent dislodgement.

Procedure: Tracheal Repair

- Debride devitalized edges, which is particularly important in blast injury (gunshot wounds).
- Limit mobilization of the trachea to avoid interruption of its blood supply.
- Ensure that there is no backwall injury before repairing an obvious anterior laceration.
- Repair the trachea primarily with full thickness bites using 3-0 absorbable suture such as PDS.
- Reinforce with the repair with a flap. The strap muscles are usually ideal to use.
- Only in case of destructive tracheal damage a protective tracheostomy with the cuff placed distal to the repair site might be required.

Procedure: Esophageal Repair

- Debride any devitalized tissue and inspect for backwall injury.
- Repair the esophagus in two layers with 3-0 absorbable suture. The inner layer needs to approximate the mucosa. The intraluminal mucosa injury might be more extensive than obvious from the outside, and the outer muscle layers might have to be opened carefully to expose and repair the mucosal defect.
- Be careful to avoid narrowing of the esophagus. Repair over a bougie, or at least naso-gastric or oro-gastric tube is helpful.
- Always reinforce the repair with a flap, most often a strap muscle. This is even more important in case of concomitant tracheal injury to avoid fistula formation.
- Leave a closed-suction drain near the repair.
- Creation of an esophagostomy is rarely necessary and limited to devastating, extensive blast injuries.

Postoperative Care

Patients with blunt neck trauma or penetrating trauma through the platysma need to undergo careful neurologic examination postoperatively. A focus should be on cranial nerve function and neurologic deficits suggestive of a stroke. Postoperative CTA neck can quantify possible stenosis after repair. Unless contraindicated, patients should be started on aspirin postoperatively. Patients who underwent esophageal repair should have a swallow study with water-soluble contrast prior to initiating a diet and removing the closed-suction drain.

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2 Operative Exposures for Chest Trauma: The Median Sternotomy and Left Anterolateral Thoracotomy

Aditi Kapil and Paula Ferrada

This chapter will focus on two exposures to evaluate chest trauma and the indications to use a left anterolateral thoracotomy vs. a median sternotomy. A patient with thoracic trauma requires logical and sequential evaluation; only about 20% of thoracic trauma requires an operation. It is important for the surgeon to evaluate whether the patient needs a damage control thoracic procedure or a formal surgical intervention.

Traumatic injury to the chest can occur in one of two ways: penetrating or blunt. Either etiology may have different manifestations and different treatment plans including different operative approach.

Objectives of this chapter:

- Indications of either median sternotomy or left anterolateral thoractomy
- Surgical techniques for both operative exposures
- Pitfalls to either exposure

Indications for a Left Anterolateral Thoracotomy

This is the preferred incision for resuscitative thoracotomy, suspected injuries of the lung, posterior heart, and cross clamping the aorta. However, it provides poor exposure to the great vessels. For penetrating injuries, you must evaluate the entire patient; this step can help determine the site of hemorrhage and optimizes the success of a resuscitative thoracotomy.

This incision allows for extension of the thoracotomy to the right for a clamshell thoracotomy for suspected injuries to superior mediastinal vessel injuries.

Operative Technique for Left Anterolateral Thoracotomy

- The incision is made through the fourth interspace superior to the fifth rib. The incision is carried out from the edge of the sternum to the posterior axillary line (Fig. 2.1).
- Aim the incision toward the tip of the scapula.
- Pectoralis major and minor muscles are encountered and divided along the anterior part of the incision. Serratus anterior muscle is divided on the lateral/posterior part of the incision.
- The intercostal muscles are divided immediately superior to the rib using large scissors and then the pleural cavity is incised using scissors.
- Even before the retractor is placed the operator can press against the spine and hold pressure in the aorta to avoid exsanguination (Fig. 2.2). Due to exsanguination the surgeon cannot feel the aorta. For this reason pressure with fingers should be made against the vertebral body, it doesn't matter if pulsations are felt or not.

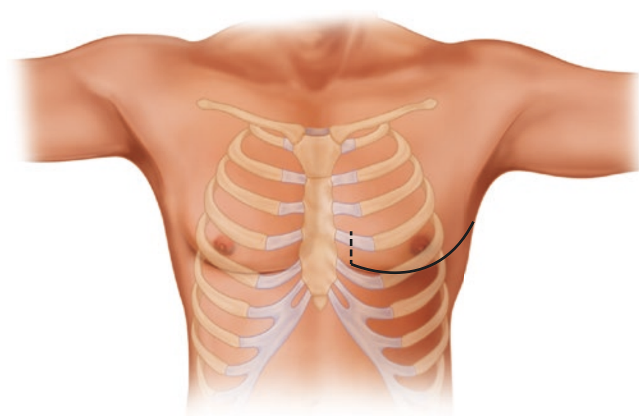

Fig. 2.1 Left anterolateral thoracotomy incision

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P. Ferrada, R. Ferrada (eds.), *Atlas of Trauma*, https://doi.org/10.1007/978-3-030-26871-8_2

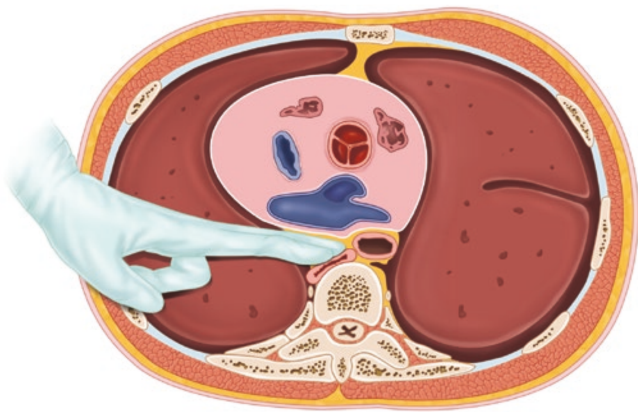


Fig. 2.2 Manual compression of the aorta

- The Finochietto rib spreader is inserted with the handle pointed toward the bed and toward the axilla.
- Pull the lung upward to have more space to maneuver. You can take down the inferior pulmonary ligament, but this is not always necessary.
- In order to clamp the aorta the operator must cut the parietal pleura, otherwise the clamp will slide off the vessel (Fig. 2.3)
- To open the pericardium, take care in not lacerating the phrenic nerve. Open the pericardium longitudinally (Fig. 2.4).
- With the chest open, the operator can also apply bi-manual open cardiac massage. Be careful in not causing damage of the cardiac muscle with the fingers. The heart must be held between the palms (Fig. 2.5).
- This incision can be extended as a clamshell (Fig. 2.6).

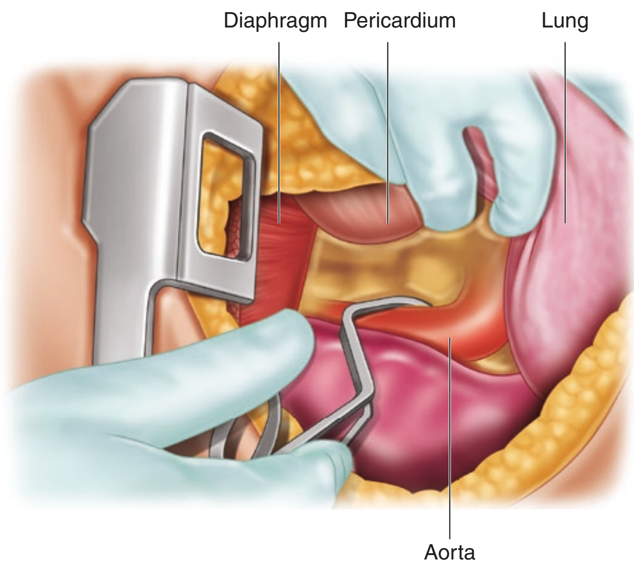


Fig. 2.3 Clamping the aorta

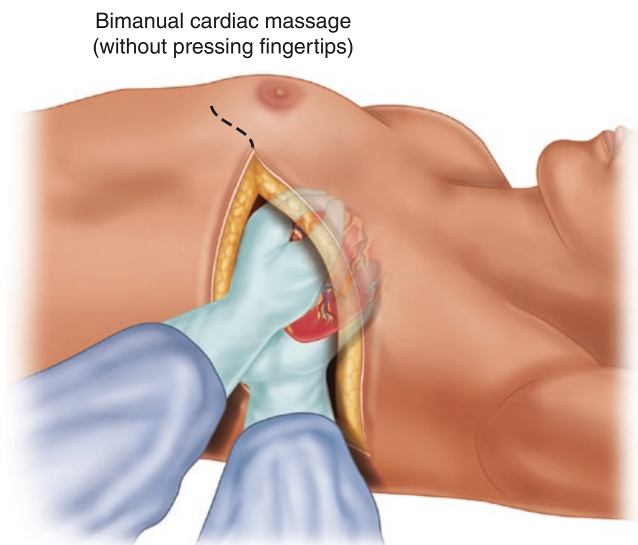
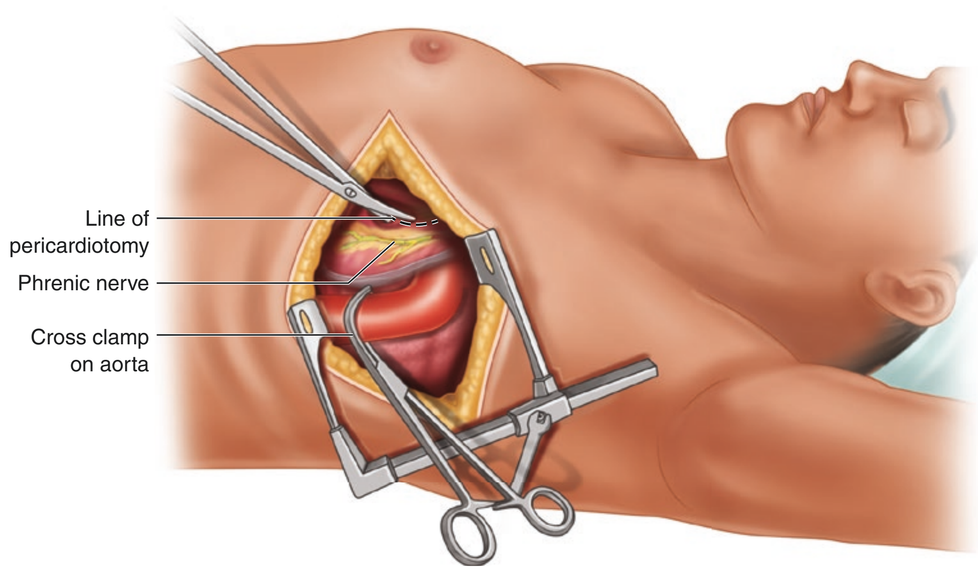


Fig. 2.5 Cardiac massage—notice two hands

Fig. 2.4 Opening the pericardium



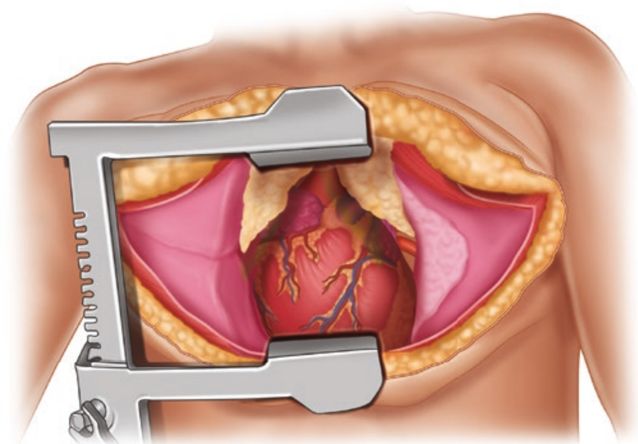


Fig. 2.6 Clamshell thoracotomy

Pitfalls

- The incision does not follow the intercostal space, making the entry into the chest difficult. Incision should curve upward towards the axilla
- Excessive rib spreading may cause rib fractures and increased pain in the postoperative course.
- The retractor may cause injury to the internal mammary artery, leading to subsequent bleeding.

Indications for Median Sternotomy

This is the preferred incision for penetrating injuries to the anterior chest, allowing exposure of the heart, lungs, middle-to-distal trachea, and the left main bronchus.

This does not allow exposure to the posterior mediastinal structures and does not provide the ability to cross clamp the aorta for resuscitation purposes. The median sternotomy allows exposure to the upper mediastinal vessels and can be extended on to the neck with a sternocleidomastoid incision or a clavicular incision to allow more exposure to the carotid or subclavian vessels.

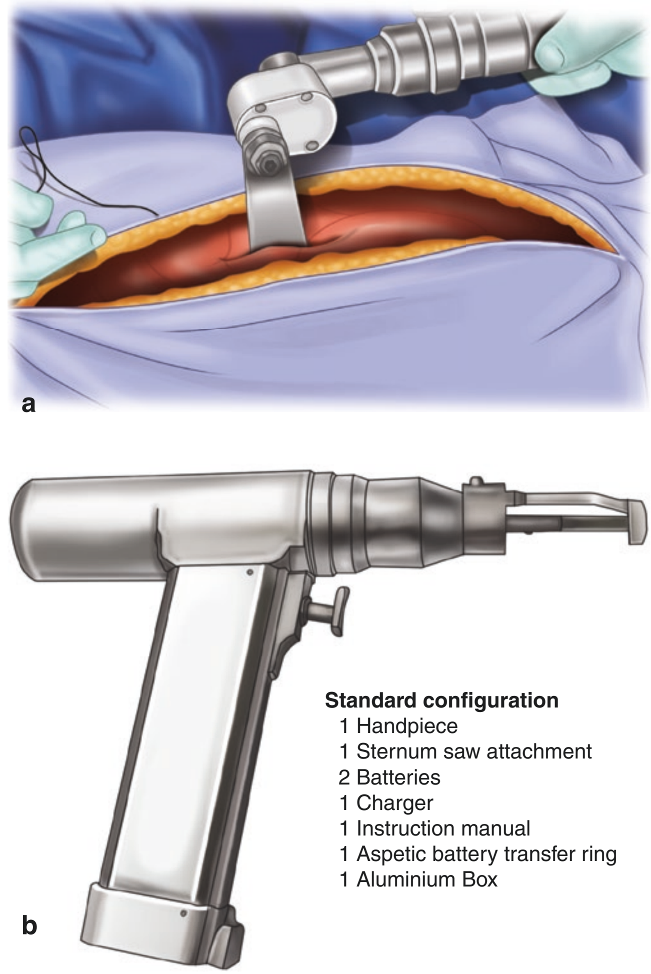
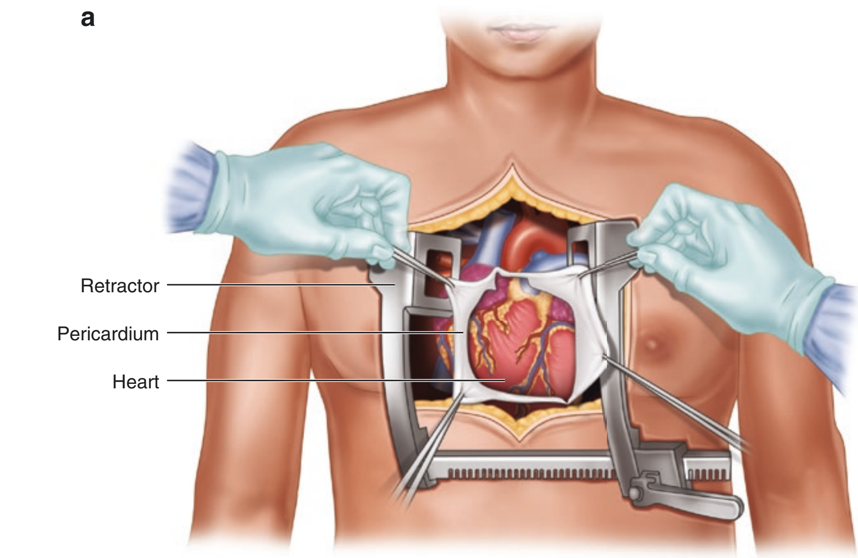


Fig. 2.7 Sternal saw

Operative Technique for Median Sternotomy

- Prep the patient from chin to mid-thigh.
- Make a vertical midline incision over the center of the sternum from the suprasternal notch to the xiphoid.
- Continue the incision down through the decussation of pectoralis fascia onto the sternum with electrocautery.
- The interclavicular ligament, at the suprasternal notch, is cleared using a combination of sharp and blunt dissection. Make sure to finger sweep below the manubrium to release areolar attachments. This moves the innominate vein and surrounding tissues posterior so they are not injured with the sternal saw (Fig. 2.7).
- Bluntly detach the underlying fat below from the xiphoid.
- Score the sternum with electrocautery in the midline to direct the pneumatic saw or Lebsche knife.
- Place the hook of the pneumatic saw under the suprasternal notch and lift the sternum upward.
  – Ask anesthesia to hold ventilation and divide the sternum along the midline. Maintain upward traction along the entire length. Toeing the right-angle piece upward will help the saw stay on the sternum.
  – When using a Lebsche knife, it is best to start inferiorly to superior due to the force required when hammering the knife. Ideally, it should only take four blows of the hammer to split the sternum. Due to the strength of the strike, the patient's head would impede the force required to hit the knife.
- Place a Finocheitto retractor in the upper part of the sternotomy and spread the sternum (Figs. 2.8 and 2.9).

Fig. 2.8 Median sternotomy



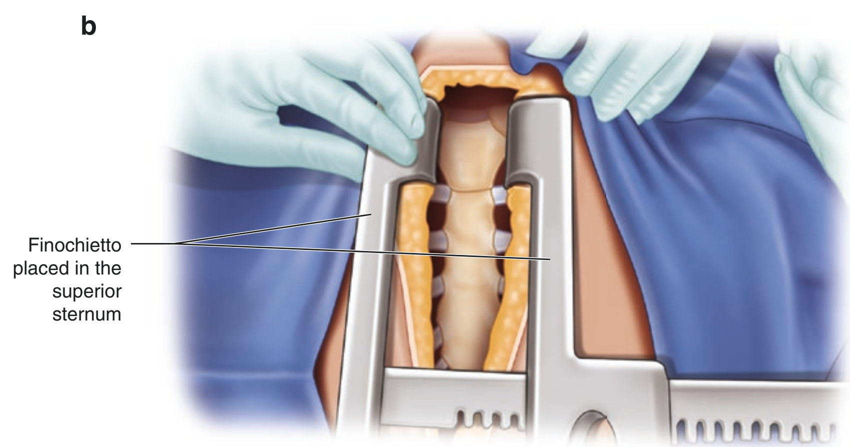
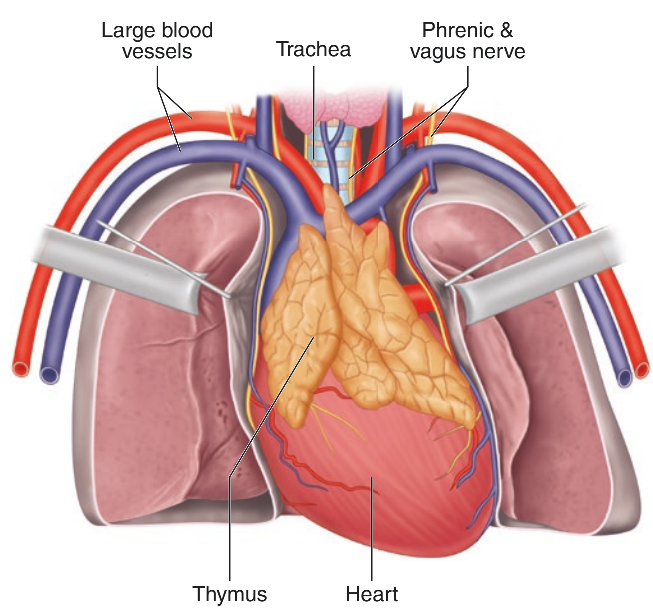


Fig. 2.9 Structures to which the median sternotomy gives access



Pitfalls

- Failure to clear soft tissue at the suprasternal notch leads to failure of the pneumatic saw.
- Median sternotomy goes off midline and through the costal margins, leads to complications to closure and risk of sternal dehiscence.
- Finocheitto retractor is placed in the lower part of the sternotomy. This is the weakest point of the sternum and increases risk of sternal fracture.

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3 Cardiac Penetrating Trauma

Ricardo Ferrada

Introduction

In cardiac trauma there are two basic scenarios:

1. The patient is stable. In this case the best access is median sternotomy, because:
   - It is less painful for the patient
   - The exposure for the heart and the great vessels is optimal

   The disadvantage is that this approach provides limited access to other potentially injured structures, such as the lung, subclavian vessels, aorta, and intercostal vessels.
2. The patient is unstable. In this case the anterolateral thoracotomy offers several advantages:
   - It is faster
   - It can be made with basic instruments
   - It allows access to several structures besides the heart

   Both techniques are described in Chap. 2.

   Once the chest has been opened, the surgeon may find:

- Cardiac tamponade
- Hemothorax if the wound on the pericardium is a big one

Surgical Technique

Once inside the thoracic cavity, the surgeon must make three maneuvers almost simultaneously:

1. *Positioning of the endotracheal tube*. If the patient arrives in agonal condition, the correct position of the endotracheal tube must be assessed. This is a crucial step, lasting 1 or 2 seconds, which is made by verifying the lungs' movements with the anesthesiologist insufflations. Even in experienced hands the esophageal intubation can happen. Auscultation is not possible in this setting due to the speed of the maneuvers and because at the same time the surgeons prepare the area with iodine solution. Esophageal intubation results in a severe hypoxemia, and due to previous agonal condition, nonreversible cardiac arrest follows. In an emergency surgery setting with an open chest, the best way to ensure that the endotracheal tube is in the right place is by watching the lungs expand.
2. *Hemorrhage control*. As previously noted, a number of these patients have injuries in addition to cardiac. Placing a lung clamp or vascular clamp on the pulmonary hilum is an important adjunct maneuver. When the hemorrhage is exsanguinating, the heart is empty, and it is flaccid on palpation. In these cases, the aorta must be occluded, which is a very easy maneuver. However, unless the surgeon is very experienced, it is wiser to perform the occlusion with fingers rather than with a clamp at this moment. Clamping without direct inspection can result in injury to the esophagus or aortic small branches. For this reason, the surgeon should not intend to palpate the aorta, because it is also empty. Instead, the fingers should be placed against the vertebral bodies as a temporary occlusion (Fig. 3.1). Once identified, the surgeon must ask the assistant to do it. This allows the surgeon to do other maneuvers, but more importantly avoids tremors in his hands due to the effort. In these cases, it is very important that the surgeon be calm, both mentally and physically.
3. *Pericardial sac opening*. In cardiac tamponade, the next step is to open the pericardium, which is faster and better for prognosis. To accomplish this, the sac is captured with a Kelly forceps and the incision is made with a scissor, avoiding the phrenic nerve (Fig. 3.2, Video 3.1). When pericardial tamponade is released, hemodynamics

Electronic supplementary material The online version of this chapter (https://doi.org/10.1007/978-3-030-26871-8_3) contains supplementary material, which is available to authorized users.

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P. Ferrada, R. Ferrada (eds.), *Atlas of Trauma*, https://doi.org/10.1007/978-3-030-26871-8_3

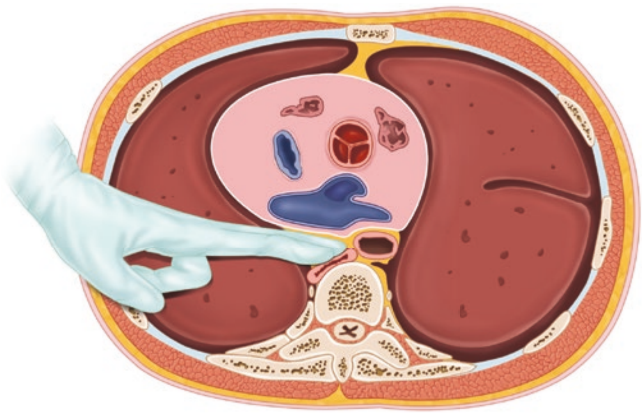

Fig. 3.1 A finger placed against the vertebral bodies as temporary occlusion

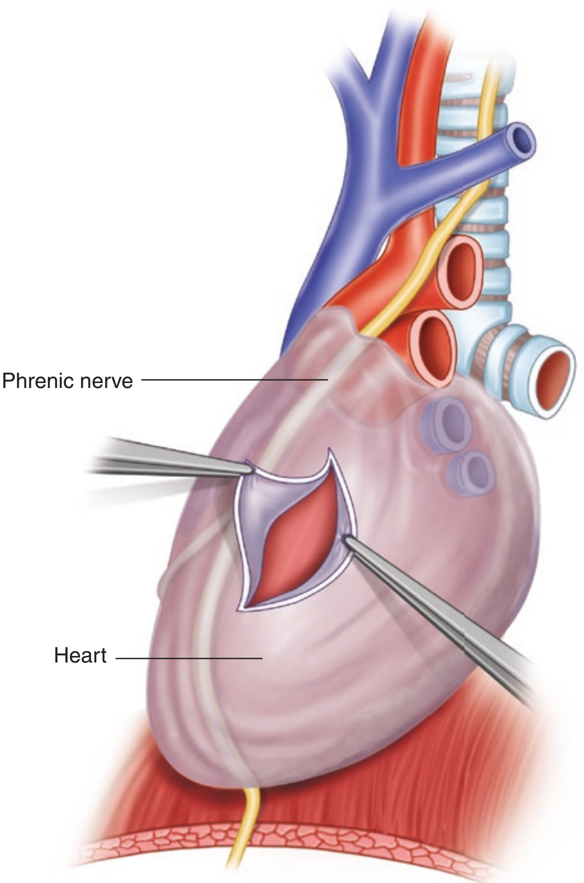

Fig. 3.2 The sac is captured with a Kelly forceps and the incision is made with a scissor, avoiding the phrenic nerve

improves, but tachycardia usually persists. It is wiser not to suture the myocardium at this moment, because of increased difficulty. Instead, put a finger on the wound, thus preventing blood loss, and wait for a few minutes until the cardiac rhythm becomes normal (Fig. 3.3). Besides the intravenous fluids, the anesthesiologist can help with a temporary vagal maneuver or medication that makes the suture a lot easier.

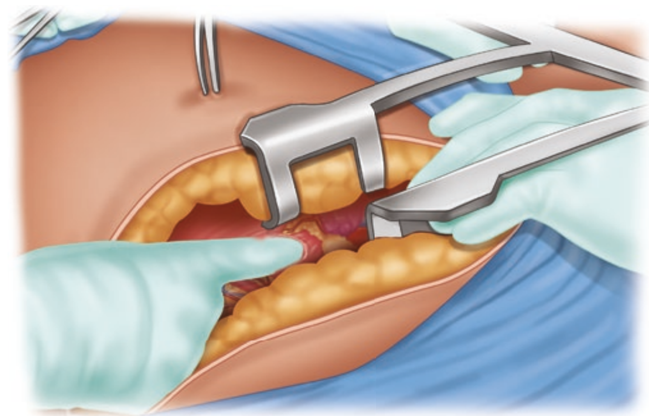

Fig. 3.3 It is wiser not to suture the myocardium; instead, put a finger on the wound to prevent blood loss and wait a few minutes until the cardiac rhythm becomes normal

Myocardial Suture

When blood is expelled in every contraction, once the pericardium is opened, a finger must occlude the hole. At this moment it is not important to occlude it completely. A small leak is expected and gentle pressure on the heart will prevent arrythmias or cardiac failure.

Most of the patients are young. and interrupted simple sutures without pledges are well tolerated. Patients older than 50 and/or with previous hypertension have friable myocardium. Hence Teflon or pericardium felt pads are used (Fig. 3.4). In those particular patients, all caution should be taken to avoid myocardium tearing by following the heart movements.

It is important for the surgeon to take a minute to calm down to prevent tremor in the hands. Once the gross blood loss is controlled, there is no hurry. Tachycardia implies the risk of a tear on the heart. More importantly, cardiac frequency slows down, which makes the suturing process easier.

In preparing the suture, note that no more than 2 or 3 stitches are usually necessary. The suture most commonly used is polypropylene. It is better to use two needle-holders, one for the surgeon and the other for the assistant (Fig. 3.5). The surgeon crosses the heart with the needle and the assistant receives it, avoiding a tear, by following the heart movements and the needle curve. A few milliliters of saline on the hands helps with making the knots.

The entire wall is sutured in right ventricular wounds, and in the left part of it. Atrial wounds are clamped with a

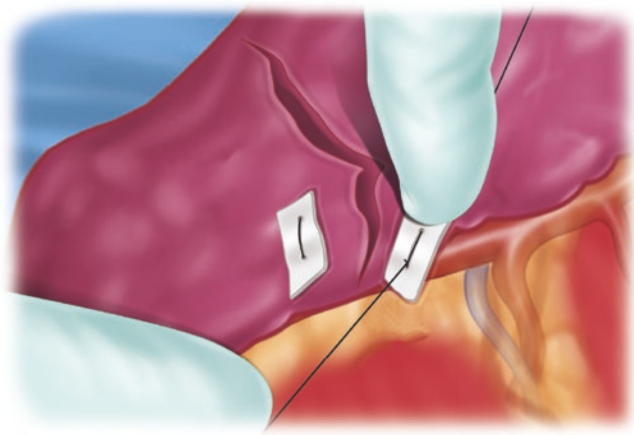

Fig. 3.4 Patients older than 50 and/or with previous hypertension have friable myocardium. Hence Teflon or pericardium felt pads are used

Satinsky forceps and stitched with a running suture. In the atrium it is better to perform the suture over a Satinsky clamp, because the wall is thin and fragile (Fig. 3.6).

Wounds closer to the coronary artery are sutured running beneath the vessel in order to avoid its closure (Fig. 3.7). Wounds of the coronary vessel can result in significant ischemia, arrhythmias, and death. Most of them, however, produce minimal effects in spite of the elevated ST segment. Accordingly, if the proximal coronary artery is wounded, repair is intended with 6-0 or 7-0 TiCron or polypropylene separated suture. If it is technically impossible and a local cardiovascular team are not available, then the artery is ligated under EKG monitoring. A 10-minute surveillance is recommended for arrhythmias or hemodynamic decompensation. If this is not tolerated, then the suture is removed, and gentle digital compression is made until the bypass is initiated.

Pericardium Closure

In median sternotomy, the pericardium can be left open. In left anterior thoracotomy, however, the opened pericardial sac can result in heart luxation, which produces cava veins occlusion, heart failure, and death. Accordingly, in left anterior or anterolateral thoracotomy the pericardial sac is closed with an interrupted suture, avoiding the lower one or two stitches. This avoids fluid accumulation and reduces post-pericardiotomy syndrome.

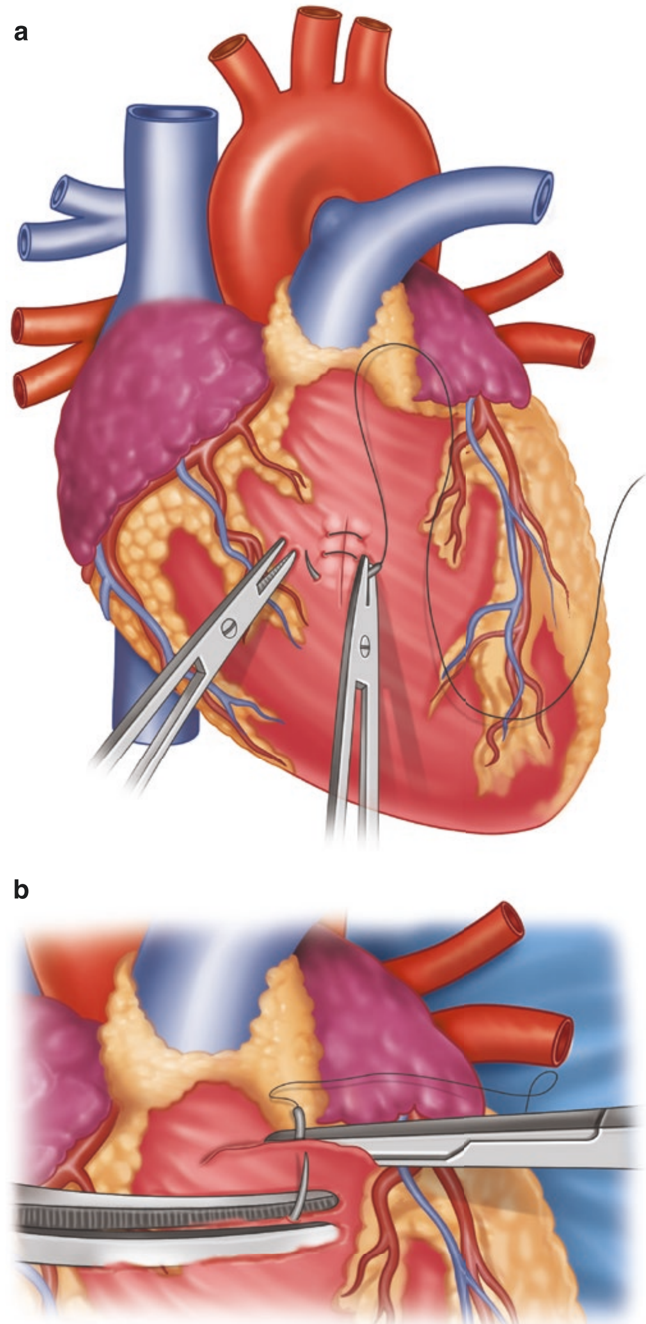

Fig. 3.5 (**a**) and (**b**) Usually no more than 2 or 3 stitches will be necessary. The suture most commonly used is polypropylene 00 or 000 with a hemi-circle, not cutting needle. It is better to use two needle-holders, one for the surgeon and the other for the assistant

One problem not addressed in the literature on the subject is heart dilatation during the procedure. When it is increasing, it has to be assumed to be acute cardiac failure, and the surgeon must make a manual massage. In our experience, other techniques, such as clamping the cava veins, lead to cardiac arrest. If after the procedure the heart is far larger than the pericardial sac, then a prosthetic material can be used to enlarge the sac. If available, the advantage of PTFE or Dacron prothesis is the patient does not necessarily have to go again to the OR (Video 3.2).

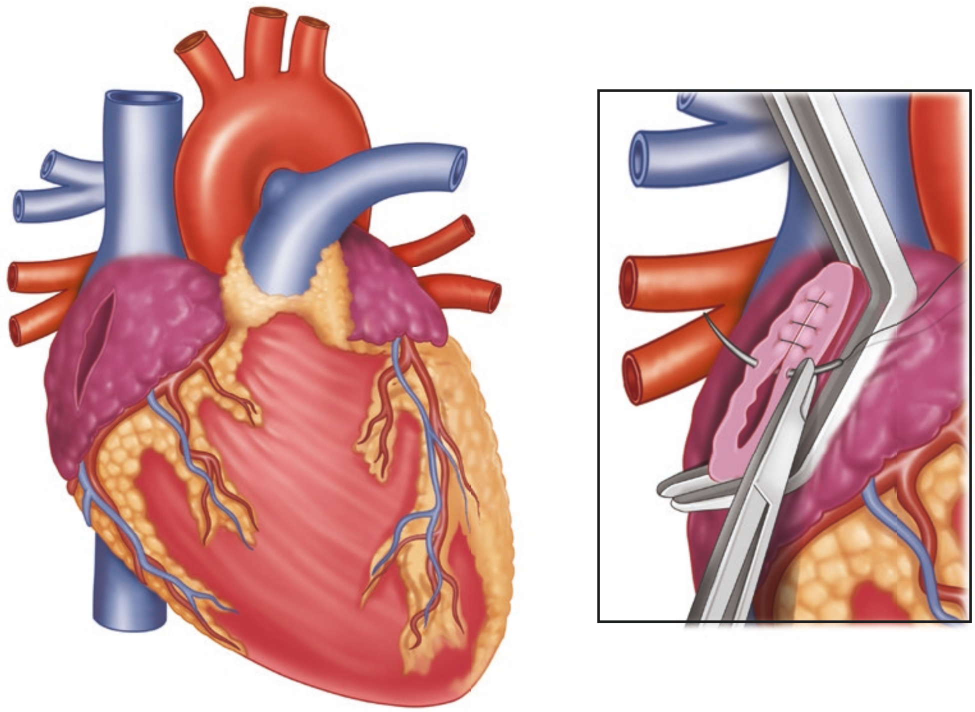

Fig. 3.6 The entire wall is sutured in right ventricular wounds, and in the left part of it. Atrial wounds are clamped with a Satinsky forceps and sutured with a running suture. In the atrium is better to perform the suture over a Satinsky clamp, because the wall is thin and fragile

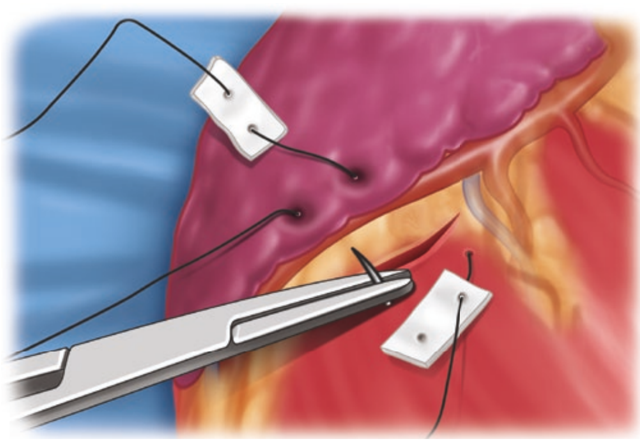

Fig. 3.7 Wounds close to the coronary artery are sutured running beneath the vessel to avoid its closure

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4 Open Repair of Traumatic Thoracic Aortic Injury Without Shunt, and Using a Woven Dacron Graft

Aurelio Rodriguez and David C. Elliott

Preoperative Preparation

1. Place multiple large-bore intravenous lines.
2. Utilize double-lumen endotracheal tube.
3. Place right radial arterial monitoring line.
4. Consider PA catheter.
5. Ensure all IV fluids are warmed.
6. Ensure generous blood supply available.

Initial Incision and Exposure

1. Position for a left posterolateral thoracotomy. Do not over-flex the table.
2. Make a standard thoracotomy incision through fourth intercostal space.
3. Instruct the anesthesiologist to deflate left lung using double-lumen ET tube, allowing exposure of mediastinal structures.

Operative Steps

See Figs. 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, and 4.10.

Fig. 4.1 Dissect out left subclavian artery and control it with umbilical tape

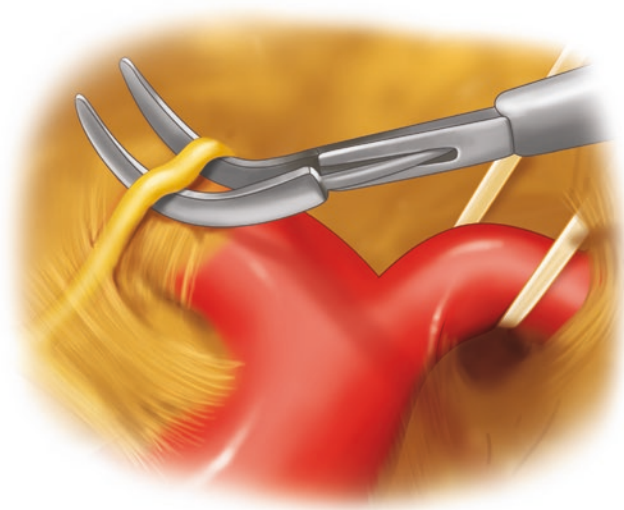

Fig. 4.2 Dissect and retract the left vagus nerve with a vessel loop while identifying and avoiding the phrenic nerve

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P. Ferrada, R. Ferrada (eds.), *Atlas of Trauma*, https://doi.org/10.1007/978-3-030-26871-8_4

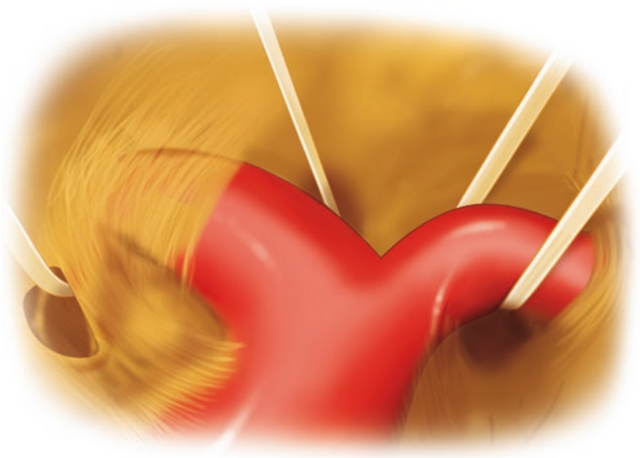

Fig. 4.3 Being careful not to enter the hematoma, dissect the space between the left subclavian and common carotid arteries, and then circumferentially around the proximal aorta at this level. Blunt finger dissection is often required. Avoid injury to the pulmonary artery, which lies just inferior to the aortic arch. Place an umbilical tape around the aorta for proximal control

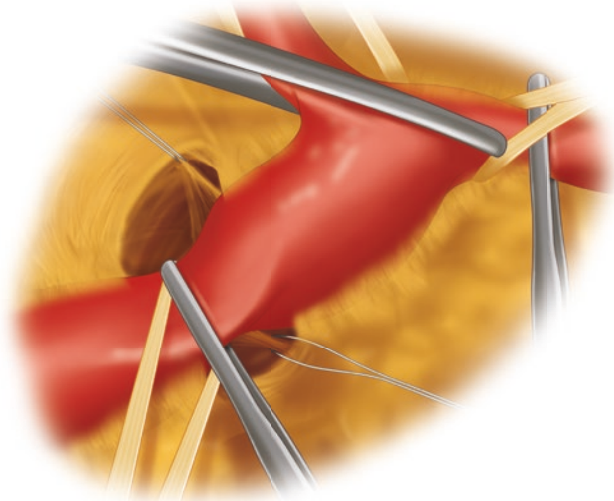

Fig. 4.5 Cross clamp the proximal aorta, left subclavian artery, and descending aorta at the sites dissected. Have anesthesiologist keep track of cross-clamp time

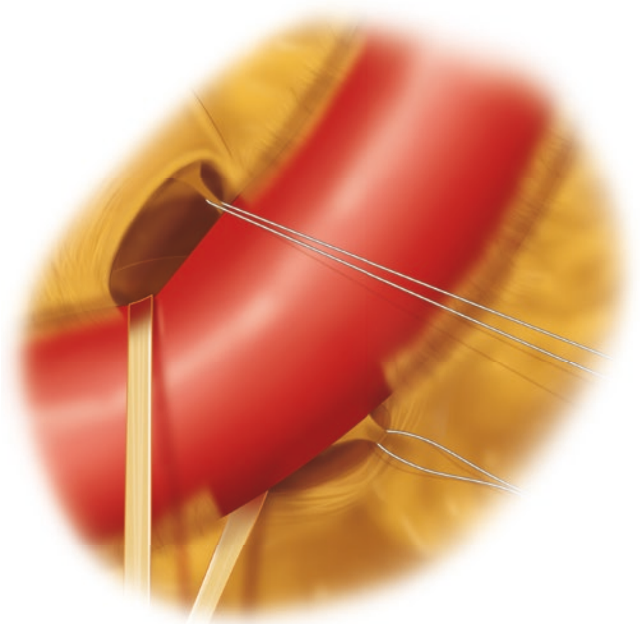

Fig. 4.4 Circumferentially dissect and control the descending aorta with umbilical tape, distal to the hematoma. Loop the intervening intercostal arteries with 2-0 silk ligatures

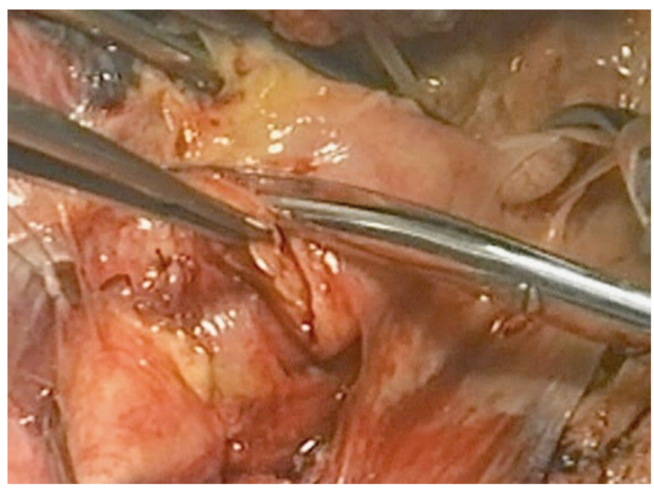

Fig. 4.6 Rapidly open the pleura over the mediastinal hematoma and evaluate the rupture. Excise the injured aorta and trim the anterior wall as necessary. Control back-bleeding from intercostal arteries as needed with suture ligature. Walking the aortic arch clamp proximally may gain more stump length for suturing, if needed

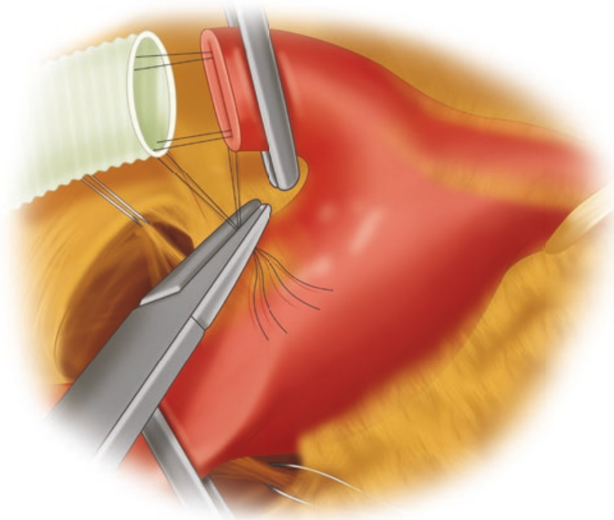

Fig. 4.7 Utilize woven Dacron or PTFE for the graft, anastomosing with 3-0 polypropylene suture on SH needle, beginning along the posterior wall of the proximal stump, "parachuting" placed suture to distribute tension evenly along the suture line. Exercise caution to avoid injury to the esophagus, which is just postero-medial to the aorta

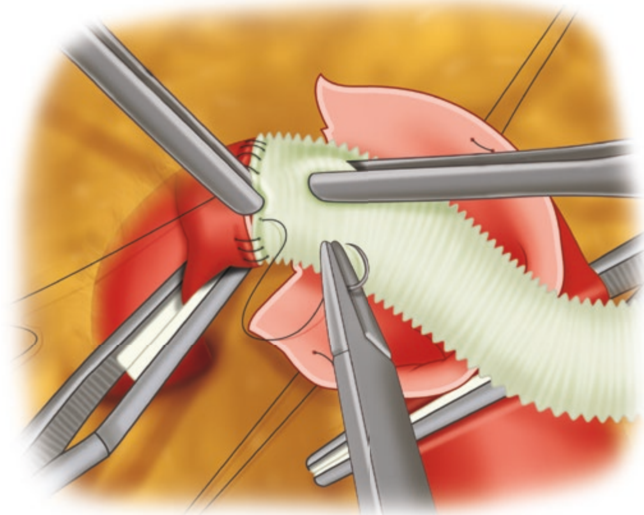

Fig. 4.9 Measure and cut the graft to appropriate length, then suture the distal anastomosis. Announce completion of the distal anastomosis 10 minutes in advance for benefit of anesthesia personnel. Administration of extra fluids before the unclamping could prevent hypotension, one of the causes of postoperative paraplegia. Vent air prior to tying the final suture by partially releasing clamps proximally and distally

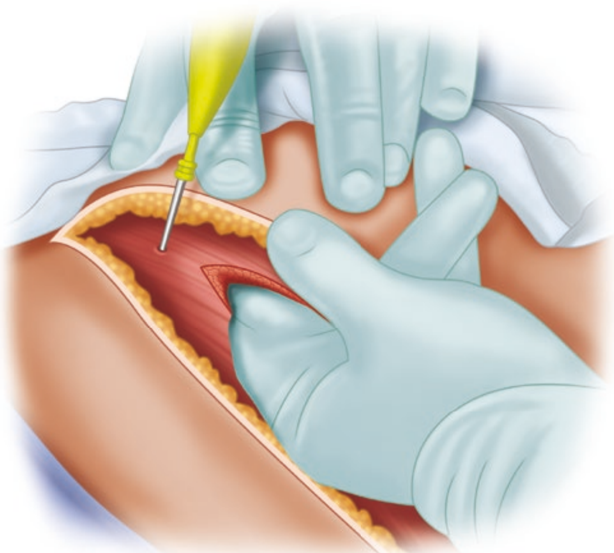

Fig. 4.8 Once the proximal anastomosis is completed, check the posterior wall. Partially unclamp the aorta for a moment, and reinforce any anastomotic leaks with pledgeted 4-0 polypropylene sutures, as needed

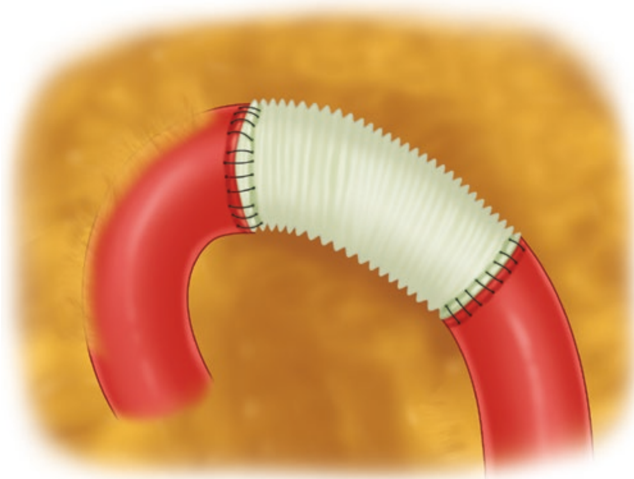

Fig. 4.10 Remove the clamps from the distal aorta and subclavian artery, then very slowly release and remove proximal aortic clamp. Release the ties on the intercostal vessels. Inspect the anastomosis carefully and reinforce as needed with pledgeted 4-0 polypropylene suture. Attempt to cover the graft with mediastinal pleura, place chest tubes so they do not lie near the graft, and close the thoracotomy incision

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Surgical Stabilization of Rib Fractures: Indications and Technique

5

Babak Sarani

Rib fractures are present in approximately 10% of patients and flail chest, defined as three or more ribs fractured at two points. This trauma is present in 3–5% of patients admitted to a trauma center [1, 2]. Six or more rib fractures and flail chest are strongly associated with respiratory failure, need for prolonged hospitalization, and death. The Eastern Association for the Surgery of Trauma (EAST) practice management guidelines for the treatment of flail chest support the use of surgical stabilization of rib fractures (SSRF) in patients who cannot be liberated from mechanical ventilation despite use of a multimodality pain regimen. In this group, SSRF has been shown to significantly reduce the need for and duration of mechanical ventilation, need for tracheostomy, risk of developing pneumonia, and death. As such, it is imperative that trauma surgeons be well versed in this technique.

This chapter will cover indications for SSRF, technique, and emphasize how to avoid pitfalls. This chapter will not discuss SSRF for non-union or malunion cases.

Indications Surgical Stabilization of Rib Fractures

The purpose of SSRF is mainly to control pain in order to allow the patient to mobilize, cough, and breathe deeply to prevent pneumonia. However, this is indicated only in patients who have actual or impending respiratory failure despite a multimodality regimen to control pain, including use of regional analgesia. In this population, respiratory failure is defined as the need for mechanical ventilation. A less common indication for SSRF is chest wall instability causing inability to ventilate and therefore need for mechanical ventilation. Hypoxemia is generally not considered to be an indication for SSRF if it is due a lung parenchymal source, such as pulmonary contusion, but may be an indication for SSRF if it is due to hypoventilation resulting from pain or chest wall instability. The role of SSRF in patients who have respiratory failure in the absence of flail chest is not known. Even less proven is the role of SSRF in patients who have neither flail chest nor respiratory failure but who do have severe pain precluding their ability to mobilize and carry out pulmonary hygiene. Lastly, there are conflicting reports on the long-term benefits of early SSRF in terms of pain relief. When indicated, timing to SSRF should be kept as brief as possible to decrease the need for mechanical ventilation and risk of pneumonia [3].

Localization of Rib Fractures

Chest x-ray and rib x-ray series lack sensitivity that is sufficient to adequately diagnose all rib fractures. Two-dimensional (2D) chest CT scan is the imaging modality of choice to diagnose rib fractures as well as to determine their characteristics [4]. Three-dimensional (3D) reconstruction CT scan is now ubiquitous and may be helpful in operative planning, but 3D imaging remains inferior to 2D CT imaging for the diagnosis of rib fractures [5].

Precisely localizing a displaced rib fracture is difficult. Obese body habitus lowers the utility of physical exam, and the scapula can mask fractures above the sixth rib. Moreover, the curvature of the chest wall makes measurement based on known landmarks, such as the spinous process or sternum, on the CT scan inaccurate. Lastly, CT scans are obtained with the patient in the supine position and the arms either at the side or above the patient's head. However, as noted below, patients are commonly placed in a decubitus position or prone for SSRF. This makes extrapolation from the CT scan problematic in terms of knowing precisely where to make an incision.

Video-assisted thoracoscopic surgery (VATS) can be used to determine the location of rib fractures. However, this

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P. Ferrada, R. Ferrada (eds.), *Atlas of Trauma*, https://doi.org/10.1007/978-3-030-26871-8_5

necessitates single lung ventilation, which the patient may not be able to tolerate, and the fracture segments are not as readily obvious as one would want (Fig. 5.1). Moreover, there is only one rib plating system that is approved for implantation from a VATS approach.

Most recently, Novarad Inc. (American Fork, Utah) has developed OpenSight™, a novel technology that allows a CT scan to be overlaid onto a patient, thereby allowing the surgeon to see both the patient as well as the CT scan simultaneously (Fig. 5.2). Although the efficacy of this novel technology has yet to be studied and proven, it may be revolutionary in allowing the surgeon to precisely localize the site of a fracture and minimize the length of incision needed to repair it.

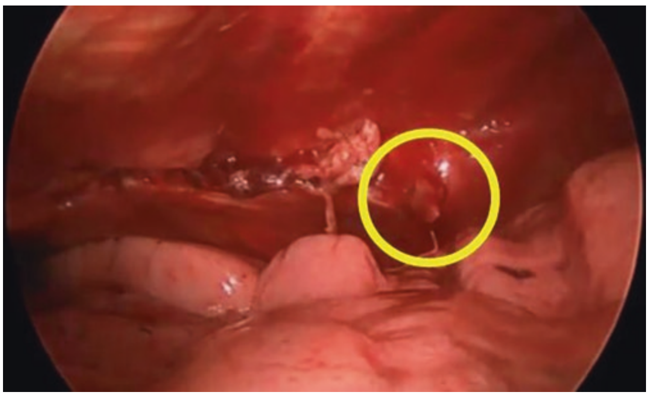

Fig. 5.1 VATS view of a broken rib (circle)

SSRF Technique

The technique of SSRF can broadly be broken down into three steps: (1) intraoperative localization of each fracture line; (2) reduction of the fracture; and (3) stabilization of the fracture via implantation of a titanium plate/screw system. Although the process of implantation of the hardware differs among the various product vendors, there are currently three general approaches: (1) implantation of anterior plates; (2) implantation of U-plates; and (3) implantation of intrathoracic plates. Each of these will be discussed individually. There have been no head-to-head studies comparing outcomes between these systems. Lastly, the decision to drain the pleural space is surgeon-dependent, based on the probability of violation of the pleural space and the need for drainage of fluid, be it blood or effusion, from the pleural space.

Implantation of anterior plates requires elevation of periosteal soft tissue from the anterior aspect of the rib for

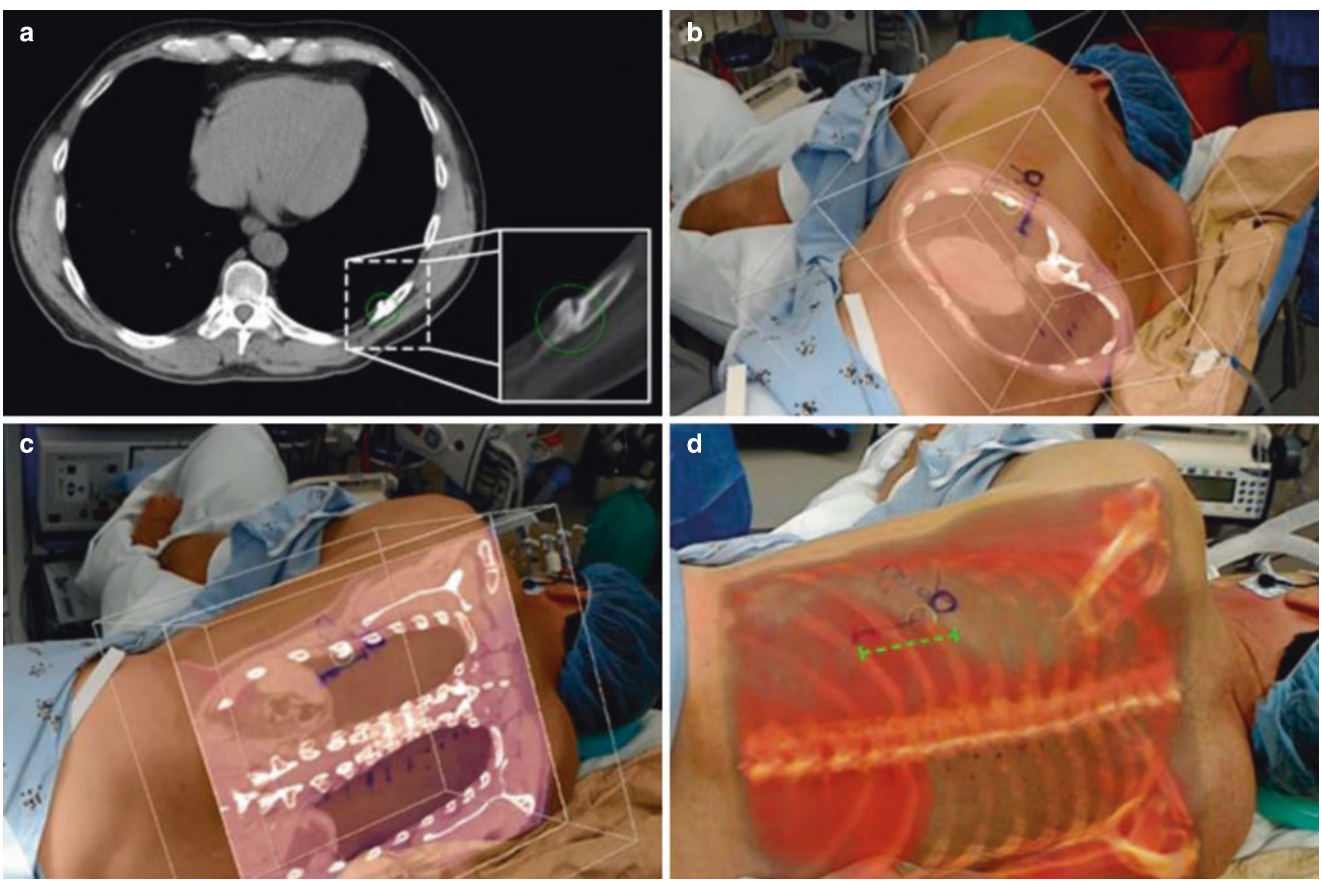

Fig. 5.2 Intraoperative holographic depiction of a CT scan using the OpenSight™ System

approximately 4–5 cm on each side of the fracture line in order to obtain at least three points of fixation on each side of the fracture line. Depending on the system being used, there may be a need to measure the thickness of the rib if the intent is to secure the plate using bicortical locking screws (i.e., screws that are locked to the plate but pierce the posterior cortex of the rib as well). This is not necessary when using a screw system that is unicortical. In this system, the screws are placed at an angle, thereby making it less likely that they will pull out, and theoretically obviating the need for fixation to the posterior cortex (Fig. 5.3).

Implantation of U-plates requires elevation of periosteal soft tissue along the superior aspect of the rib where the U-brackets will serve as hinges over the rib (Fig. 5.4). Because the screws holding these plates are locked to the back portion of the U-hinge (plate-anterior cortex-posterior cortex-plate), these plates require fixation at two points on each side of the fracture line. This means that less exposure is needed as compared to anterior plates. The system self-measures the thickness of the rib to determine the length of screw needed. However, there is a higher incidence of pleural space violation given that the plates are situated partly behind the rib.

Intrathoracic plates require VATS to identify the site of each fracture. A small incision is then made overlying this area and a drill guide is used to make a hole and introduce a

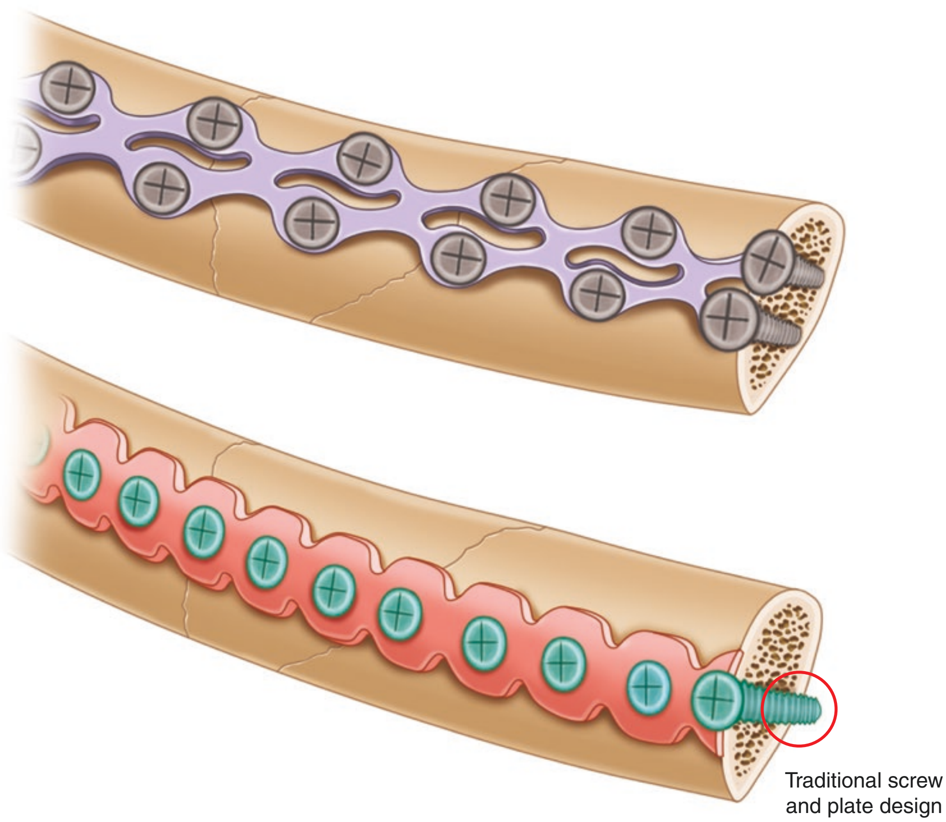

Fig. 5.3 Comparison of bicortical and unicortical fixation. The top figure shows unicortical screws inserted at an angle. The bottom figure shows screws that are inserted 90 degrees to the rib and are fixed to both the anterior and posterior cortex

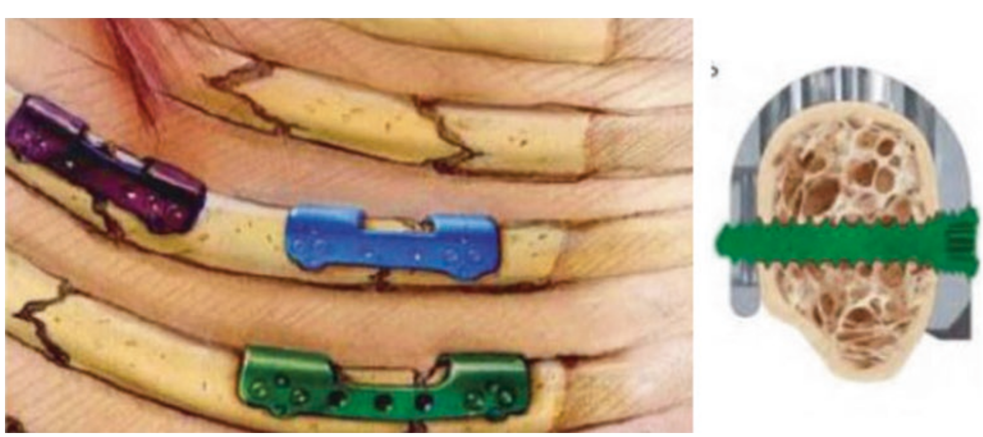

Fig. 5.4 Front and side view of U-plates. Note that this plate has a locking screw that is secured to the back of the plate

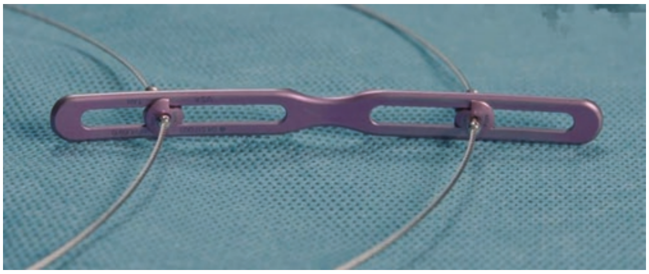

Fig. 5.5 Intrathoracic plating system with guidewires in place

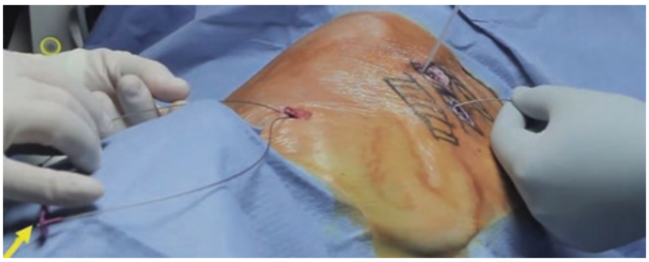

Fig. 5.6 Picture showing an intrathoracic plate being inserted into the pleural space. Note that the guidewires have been placed through the ribs and are externalized, thereby allowing the surgeon to pull the plate into the chest and position it along the undersurface of the rib

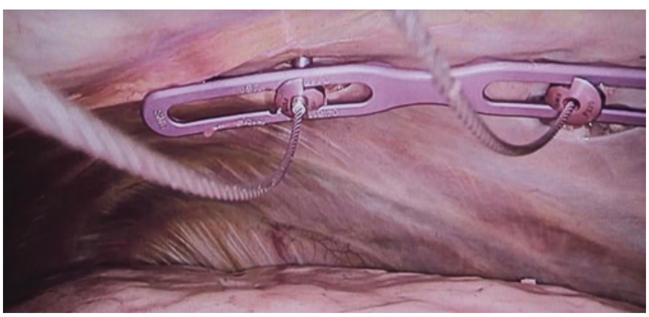

Fig. 5.7 In situ image of an intrathoracic plate with guidewires still attached. The guidewires are removed once the plate is secured in place from the outside

guide across the rib. The plate, which has two guidewires affixed to it, is introduced via the trocar site into the chest. The guidewire is pulled up across the previously drilled hole in the rib and the plate itself is used to reduce the fracture. The plate is then secured to the rib via a screw-and-nut system from the outside of the chest wall, and the guidewire is removed (Figs. 5.5, 5.6, and 5.7).

SSRF Pitfalls

Surgical Incision

If the surgical incision is made horizontally, there will be greater ability to reduce and fix fracture segments that are along the same rib, as is the case in a flail chest. However, there will be less ability to fix multiple ribs without elevating myocutaneous flaps, which increase the risk of postoperative seroma and infection. Additionally, it may be more beneficial to make two separate incisions than one large incision for fracture segments that are far apart as in, for example, a flail chest where one fracture segment is posterior and the other is in the mid-axillary line.

Iatrogenic Injury

Ribs have a thin cortex and therefore will not tolerate significant torque or stress. One cannot use a screw as a lever to reduce a severely displaced fracture. Similarly, excessive force to reduce a fracture can result in an iatrogenic fracture elsewhere on the rib. Bone clamps, a right-angle clamp, or the surgeon's finger can be used to reduce each fracture. The exception to this is the intrathoracic plating system, which uses the plate itself to reduce the fracture.

Dissection should be kept away from the inferior/posterior aspect of the rib as the neurovascular bundle is situated in a groove under the rib. When reducing the fracture, soft tissue should be kept intact along the inferior aspect of the rib so that bone clamps do not crush this bundle.

Devascularization of the Fracture

Excessive elevation of the periosteum or over-zealous use of cautery to clear the soft tissue in the area of the fracture can cause devascularization of the bone and result in non-union of the fracture. Only the immediate area where the plate will be secured should be cleared of soft tissue. The remainder of the periosteum should be kept intact.

Hardware Failure

Plates used in SSRF are not designed to span a large gap, such as may be seen in cases with severely comminuted fractures. The recurrent movement of the chest wall will result in metal fatigue and plate fracture if plates are not supported over bone. Thus, in instances where there is more than a 2-cm gap, bone graft or bone matrix is needed to provide support and allow healing of the fracture line.

In addition, the anchoring screws on plates can pull out if they are placed under tension. Thus, it is important that plates be contoured based on the curvature of the chest wall so they can lay in a tension-free fashion. Theoretically, the risk of screw migration is lowest with U-plates because the screws are fixed to the back of the plate itself, and the risk is highest with unicortical fixation systems. Similarly, risk of screw migration is higher in patients with osteopenia, where either unicortical or bicortical fixation is apt to fail due to poor bone quality.

The risk of screw migration is lessened when plates are implanted over the mid-body of each rib, which is the thickest portion of the rib (Figs. 5.8 and 5.9). Anterior plates that are positioned crooked over the rib or are off-center are more prone to fail. This is less of a concern with the U-plates, which are designed to screw into the mid-body of each rib if they are appropriately seated over the top of the rib (Figs. 5.4, 5.10, and 5.11).

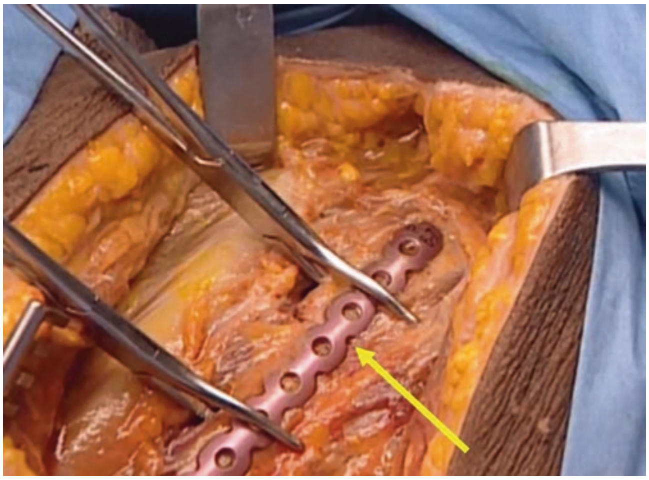

Fig. 5.8 Anterior plate centered on the rib. Note the fracture line denoted by the arrow. Also note that there are three points of fixation on each side of the fracture line

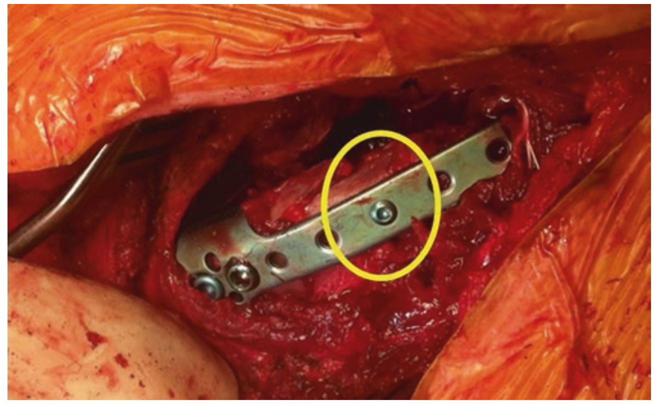

Fig. 5.10 U-Plate system in situ. Note the brackets that are hinged over the rib thereby centering the plate itself onto the rib. Also note the two points of fixation at the anchor as well as a center "intermediate" screw that stabilizes the free-floating segment of the fractured rib (circle)

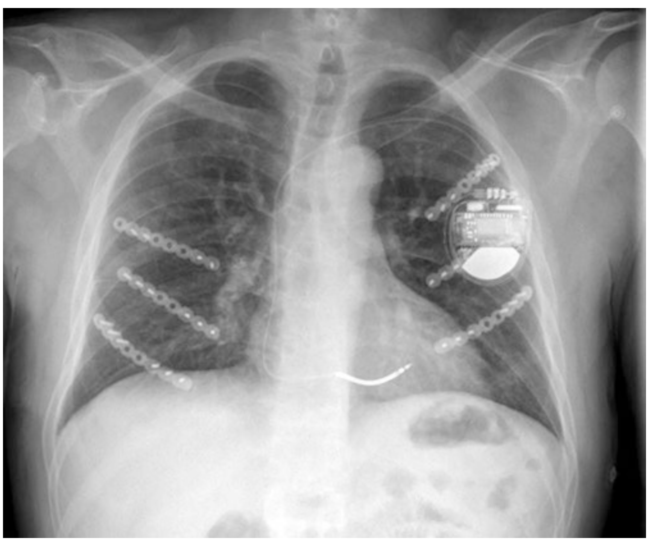

Fig. 5.9 AP chest x-ray showing anterior plates in situ

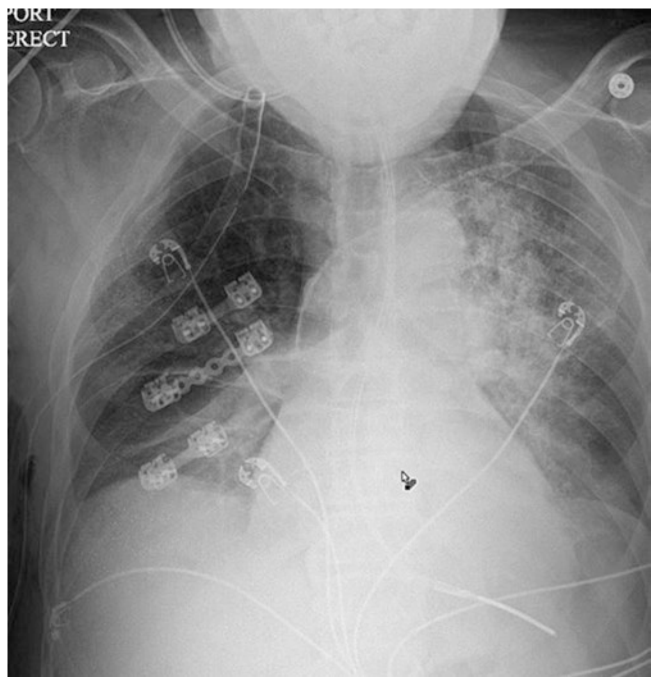

Fig. 5.11 AP chest x-ray showing U-plates in situ

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Abdominal Exposures and Bowel Anastomosis for Trauma

6

Levi Procter and Paula Ferrada

Traumatic injuries to the abdominal cavity are not uncommon trauma. Traumatic injuries requiring surgery mandate a consistent and reproducible entry into the abdominal cavity. This chapter will provide a sound and reproducible approach to the abdomen.

Laparotomy Incision

Exposure to the abdominal contents is most readily accomplished through a midline laparotomy and is the recommend approach in the setting of trauma [1]. The incision spans the xiphoid process to the pubic symphysis. As described by Hirschberg et al. [2], the scalpel should be used to cut through the skin and subcutaneous tissue down to the linea alba in one swipe. The surgeon should continue to sharply divide the linea alba while carefully sparing the peritoneum, allowing it to bulge throughout the entire length of the incision without entering the peritoneal cavity. This allows the surgeon to quickly gauge if there is massive bleeding in the abdomen because the peritoneum will bulge outward and allow one to see blood pooling or distending the peritoneum. The surgeon can then prepare the surgical and anesthesia team for the next steps involved with dealing with massive intra-abdominal hemorrhage.

The peritoneum should then be opened sharply with Metzenbaum or curved mayo scissors to avoid thermal and/or electrical injury to the underlying viscera. Electrocautery doesn't work if the tip of the device is drowning in blood. The surgeon can bluntly open the peritoneum with their fingers throughout without injury to the viscera. If the peritoneum isn't exposed along the entire predicted incision length, it can be very difficult to open the abdomen quickly and safely without large amounts of bleeding. Finally, a sharp injury to the viscera is often easier to identify and more reliably repaired through standard techniques, whereas thermal injury can go unrecognized and tissue healing, even with repair, is hard to predict (Fig. 6.1).

Once the linea alba has been sharply opened from xiphoid to the pubic symphysis, the falciform ligament should be ligated with silk ties and sharply divided. This lessens the degree of liver capsular injury when retractors are used on the costal margin. Various retractors can be used to expose the abdominal cavity. Whether to use hand-held retractors (e.g., Richardson) or self-retaining retractors (e.g., Balfour, Bookwalter, Thompson) depends on the patient's needs and is at the discretion of the of the surgeon.

Intra-abdominal Esophageal Exposure

The intra-abdominal esophagus can be difficult to expose, and the difficulty increases with patients who have a higher body mass index.

The surgeon will be afforded better exposure through the use of self-retaining retractor systems. Once the self-retaining retractor system is in place, ask for the patient to be placed into reverse Trendelenburg. This will allow the viscera to move caudal to allow for better exposure. If possible, have the anesthesia providers place an orogastric or nasogastric tube. This allows for palpation of the esophagus in relation to the aorta and/or spinal column.

Use of the non-dominant hand can retract the stomach inferio-laterally to the patient's left. Gross visual inspection in this region in the setting of trauma can provide several clues, including bleeding, hematoma, and enteric contents to assist with the identification of an injury of the intra-abdominal esophagus. If this doesn't identify suspicion for injury and surgical dissection is warranted, then we would

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P. Ferrada, R. Ferrada (eds.), *Atlas of Trauma*, https://doi.org/10.1007/978-3-030-26871-8_6

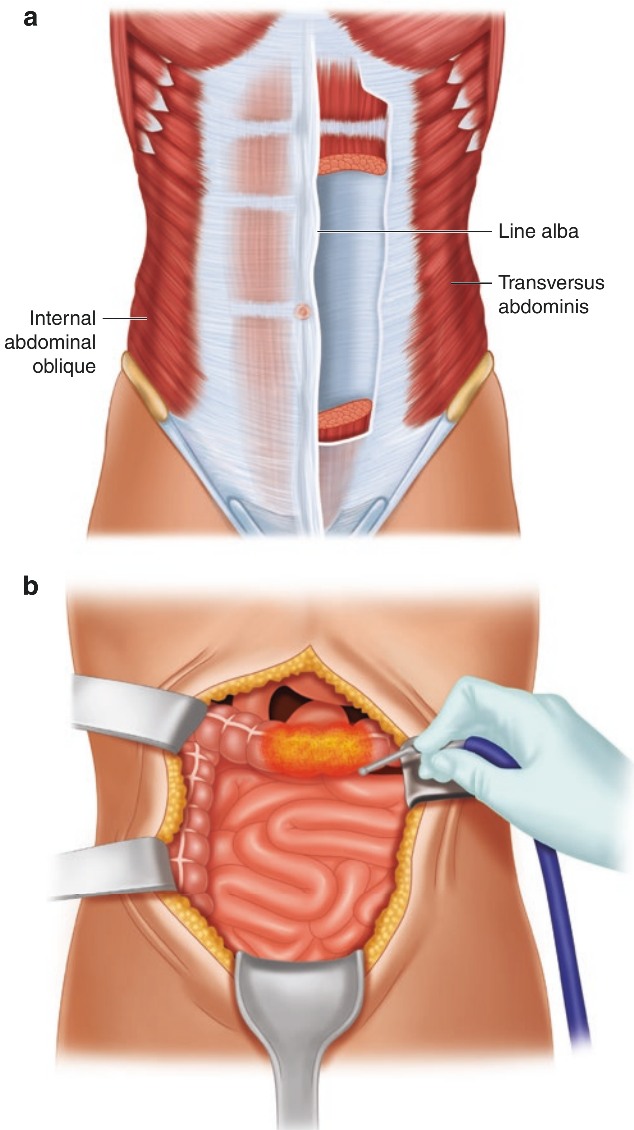

Fig. 6.1 Line alba (**a**) and generous incision (**b**) for laparotomy

proceed with sharply incising the pars flaccida and continuing cranially into the phreno-esophageal ligament. Once around the esophagus in this region a large silicone tube (e.g., Penrose) or an umbilical tape can be encircled around the intra-abdominal esophagus to serve as a retractor. It is not uncommon for the surgeon to need to divide the short gastric vessels high on the greater curve of the stomach to provide complete exposure. Meticulous hemostasis and careful traction is required here to lessen bleeding from the short gastric vessels and splenic injury. The short gastric vessels should be taken between ties and/or clips and divided sharply (Fig. 6.2).

If an esophageal injury is identified, the surgeon must consider the time from injury, degree of contamination, velocity of the missile if a penetrating mechanism, and the patient's physiology. Standard principles of repair should focus on a two-layer reapproximation of healthy, well-perfused tissue, minimal-to-no tension on the repair, wide drainage, and distal feeding access.

Low-velocity penetrating injuries that are less than 50% of the circumference of the esophagus can be repaired primarily. Opening the muscularis to identify the full extent of the mucosal injury is paramount to any esophageal repair. Then the mucosal injury should be repaired with absorbable suture; either interrupted or running is appropriate. The outer muscularis can be closed in numerous ways, but we recommend a slowly absorbable monofilament suture such as polydioxanone in an interrupted fashion (Fig. 6.3).

To achieve a tension-free repair the surgeon may have to mobilize the intra-thoracic esophagus. This plane should be largely loose areolar tissue and often bloodless plane. Gentle finger dissection can often achieve this, but sponges applied to graspers or Kittners can also be utilized. Avoid cautery here to prevent inadvertent thermal injury to the esophagus. The surgeon must also be cautious not to violate the thoracic pleura and the aortic perforators to the esophagus. Excellent retraction is required in this region and an additional experienced surgeon can provide time-saving assistance. Once the repair is done the surgeon should consider placement of a nasogastric tube, intra-abdominal drains, and the need for distal feeding access if the repair were to fail (e.g., feeding jejunostomy).

Exposure of the Stomach

The stomach is readily exposed through a midline laparotomy. The stomach is rarely injured from a blunt mechanism and is most commonly injured in penetrating trauma. Typically, the stomach can be thoroughly evaluated in the supine position; some cases, however, may require reverse Trendelenburg to increase visualization. Irrespective of the method of injury, the stomach should be thoroughly evaluated. The anterior portions of the stomach are often readily evaluated with hand traction and gross visualization. Posterior stomach exposure is most readily accomplished by opening the lesser sac. This is most readily accomplished on the left lateral aspect of the greater curvature of the stomach between the stomach and colon. The gastrocolic omentum can be elevated between forceps or the surgeon's hands to identify a very thin peritoneal window. This can be opened bluntly, sharply, or with energy. There should be minimal

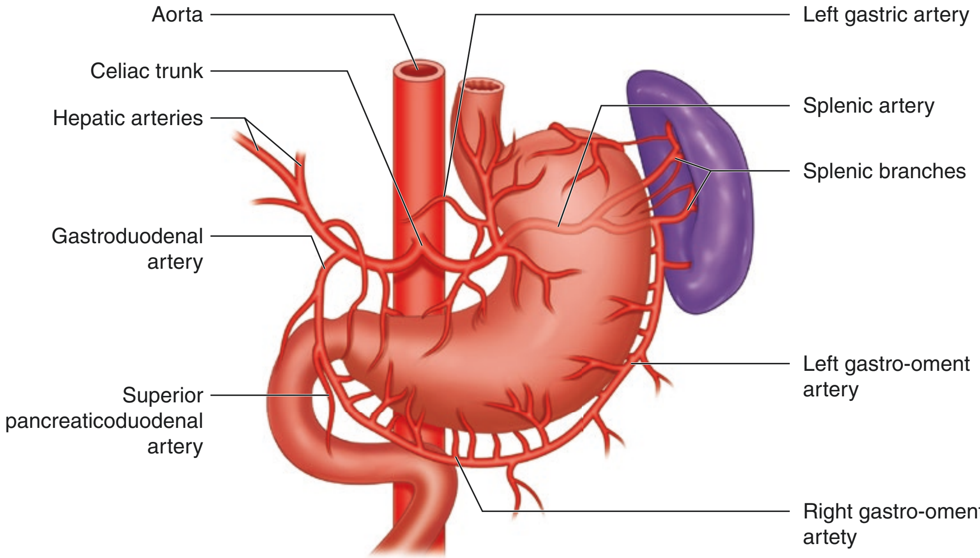

Fig. 6.2 Intra-abdominal esophagus

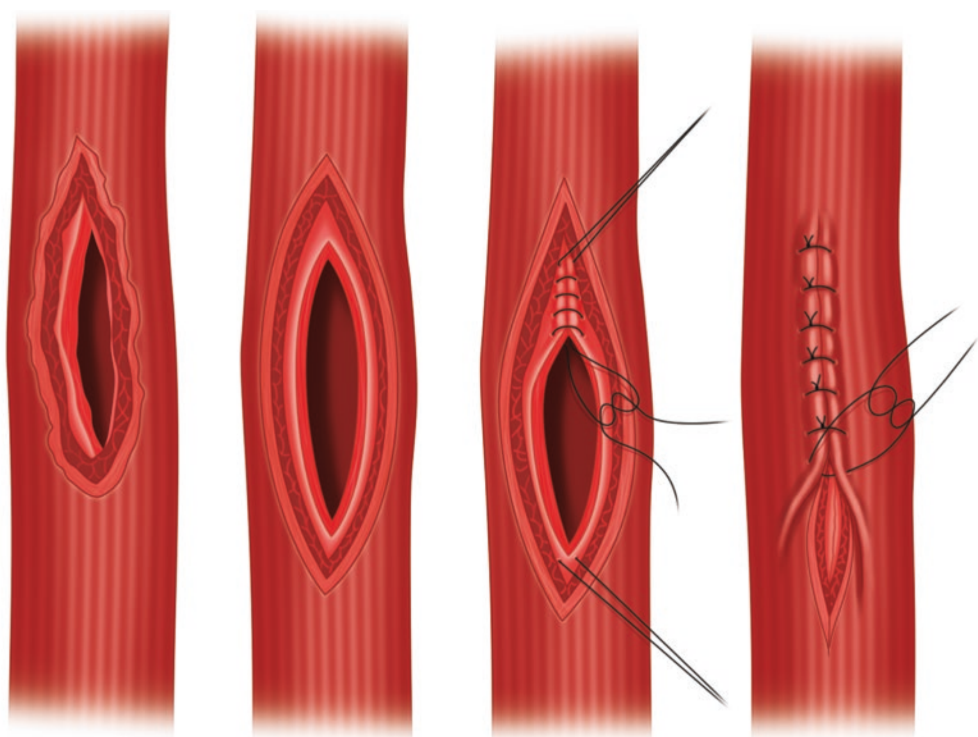

Fig. 6.3 Esophageal repair

bleeding. If bleeding or large vessels are encountered it is likely that the transverse colon mesentery is being entered. The more lateral (to the patient's left) that the surgeon begins this entry in the gastrocolic omentum, the easier it is. The planes fuse together as you move toward the midline and patient's right.

Once in the lesser sac, the surgeon can identify the posterior wall of the stomach and the body and tail of the pancreas. Penetrating trauma from missiles (gunshot wounds) will often have two apertures a viscus or a tangential injury. If an aperture is identified, the surgeon must explore the entire stomach for a second aperture.

Injuries to the stomach that are less than 50% of the stomach can often be repaired primarily. Standard surgical principles apply, including: debridement of devitalized tissues and tension free repairs. Holes in the stomach can be repaired primarily in one or two layers with permanent or absorbable suture. These injuries can also be wedge-resected with intestinal stapling devices. Tangential injuries can be repair in a similar fashion.

Once the repair is completed, attention should be given to a nasogastric tube for gastric decompression and, depending on the severity of the injury, consideration for durable feeding access through a naso-enteral feeding tube or a feeding jejunostomy. Finally, placement of drains can be considered.

If the antrum of the stomach is destroyed or not amenable to standard repair techniques, then antrectomy should be considered. The stomach should be divided distal to the pylorus and several centimeters proximal to the injury with stapling devices. The surgeon can then choose reconstruction based on mobility of the stomach to provide a tension-free Billroth I reconstruction versus a Billroth II reconstruction. If a Billroth II reconstruction is chosen, we recommend a posterior gastrojejunostomy in a two-layer handsewn fashion. Outer layers with interrupted 3-0 silk sutures and the inner layer with a running, slowly absorbable monofilament suture with conversion to Connell. Stapling devices can be utilized with great success; however, the surgeon must take in to account the discrepant bowel thicknesses and staple heights as well as predictable anastomotic edema postoperatively.

Pyloric Exclusion

Pyloric exclusion can be considered for rare and destructive injuries of the duodenum and pancreas [3–6]. The goal behind pyloric exclusion is to prevent enzymatic activation on pancreatic enzyme by inhibiting gastric enzymes from entering the duodenum, as well as decreasing the overall volume of enteric contents entering the duodenum from the stomach, which can be over 1500 ml/day. Pyloric exclusion is a highly morbid procedure that exposes the patient to many potential complications.

The stomach is opened on the greater curvature of the stomach in a longitudinal fashion. The pylorus is manually palpated and grasped with Allis clamps and delivered through the gastrotomy. The pylorus is closed with a running absorbable, monofilament suture (e.g., polydioxanone) with a large needle in a running forward-to-backward fashion, and tied.

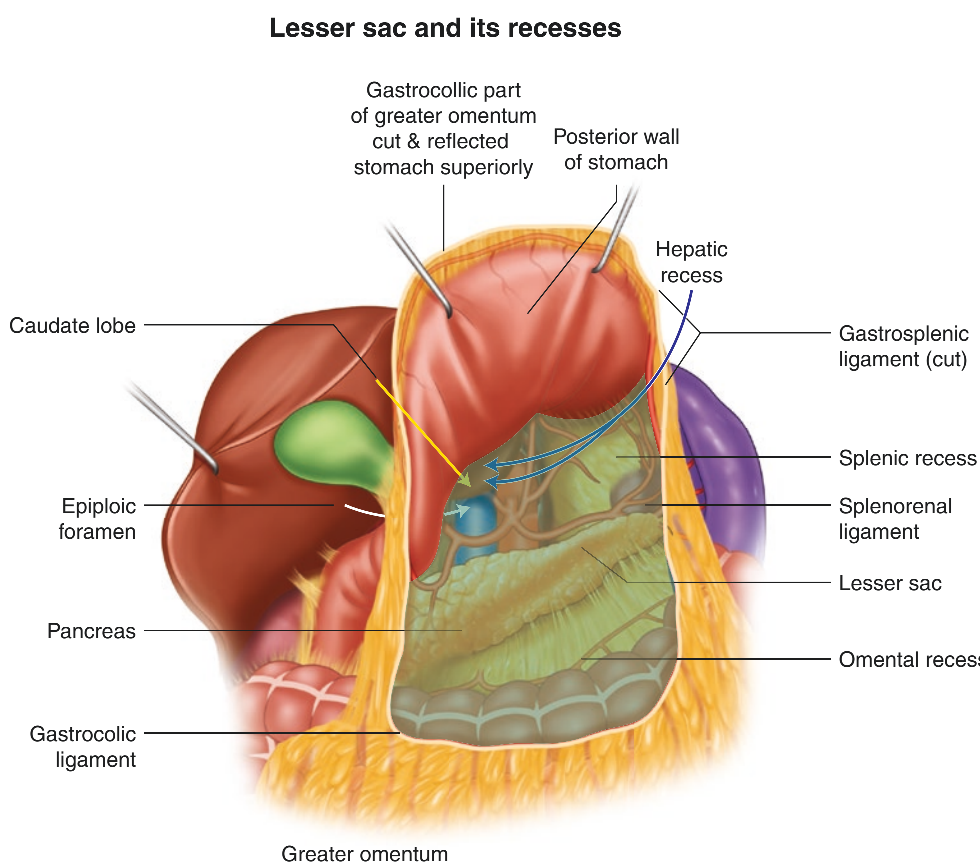

Fig. 6.4 How to expose the posterior stomach

Transverse anastomosis (TA) stapling devices can be used but are discouraged. There are reports of stapling devices being inadvertently applied to the duodenum instead of the pylorus, which is profoundly problematic for the patient because the duodenum will not recanalize after being stapled closed. The natural history of a pyloric exclusion is that the pylorus muscle pulls the suture or stapling apart and therefore becomes patent again. The muscle can be of varying thickness, which can make application of the stapler and staple height selection difficult and create a high risk for failure. There are patients in whom the pylorus may not reopen and can require endoscopic cutting of the suture to allow restoration of the pyloric conduit.

The secondary components to the pyloric exclusion can vary and often depend on the patient's injury, disease burden, and surgeon experience. It is important to point out that gastrojejunostomy can be ulcerogenic, and that the majority of the duodenal injuries can be repaired primarily if other injuries are not prohibitive of the repair.

I will place a gastrostomy tube lateral and superior to the closed gastrotomy, a distal feeding jejunostomy, and a retrograde duodenostomy tube placed through a proximal enterotomy from the feeding jejunostomy. I will use a pediatric nasogastric tube as my retrograde duodenostomy tube to allow better draining of the duodenum. However, all types of tubes have been utilized successfully (red rubber catheters, etc.) so the choices are largely based on the surgeon's preference and experience. Wide drainage of the repaired duodenum is recommended. Lastly, one can consider a t-tube placed in the common bile duct with concomitant cholecystectomy to increase biliary diversion. This is often not necessary, however, and further increases patient morbidity.

Small Bowel Anastomoses

There is little clinical evidence to demonstrate superiority of either a handsewn or stapled small bowel anastomosis in the setting of trauma and/or emergency general surgery operations [7]. The decision should be centered on the patient, the clinical scenario, and the surgeon's experience. A small bowel that is very friable and edematous, however, should be considered for handsewn anastomoses secondary to the surgeon's ability to control for tension, bite size, etc. Single-layer or two-layer handsewn anastomoses are also largely without clinical difference and should be based on the surgeon's expertise. The fundamentals for anastomosis should be well-perfused bowel, tension-free and anastomosed between the anti-mesenteric borders of the two limbs of the small bowel. This is the application to the stapled anastomoses.

If handsewn is chosen, an isoperistaltic orientation is employed. The two ends of bowel are oriented longitudinally along their anti-mesenteric borders. 3-0 silk sutures are applied in a Lembert fashion, flanking the region where the enterotomies will be made. An inner row of 3-0 silk sutures in a Lembert fashion are placed 4–5 mm away from proposed enterotomy sites. A 5–6 cm enterotomy will often be sufficient, and the bowel is scored longitudinally with cautery. An enterotomy is made along the anti-mesenteric border and extended along the scored length, full-thickness, on both limbs of bowel. A 3-0 double-armed monofilament slowly absorbable suture is used. In the middle of the enterotomies, this 3-0 suture is passed through both layers, getting a small purchase of the submucosa and healthy bite of the remaining bowel wall. The suture is tied leaving equal lengths of suture. The suture is run toward each end of the enterotomy until running is too difficult. Then the surgeon converts to a Connell stitch for the remaining closure. Before tying the suture at the completion of the inner layer, the surgeon can use the tip of a tonsil to gently probe the suture line to make sure there are no gaps. If gaps exist, the suture can be pulled out and redone proximal to the area of concern, or interrupted suture can be placed with care not to back wall the anastomosis. After tying, the outer layer of 3-0 silks in a Lembert fashion is applied.

A stapled enteroenterostomy is far faster and reproducible. For speed, a functional end-to-end side-to-side stapled anastomosis is the easiest choice. The bowel is divided with a slight dog ear away from the mesentery. The dog-ear portions are grasped with an Allis clamp, and this corner of bowel is sharply removed with curved Mayo scissors. The GIA stapler, at least 50–75 mm in length, is inserted into the lumens of the bowel. The bowel ends are pulled into the full length of the stapler and oriented so the stapler surfaces on the anti-mesenteric borders. The stapler is closed and allowed to rest to confirm correct placement (nothing should be trapped in the stapler, including mesentery or other viscera) on the anti-mesenteric borders and to allow the edema to equilibrate. The stapler is fired as appropriate per the manufacturer's guidelines. As the stapler is removed, careful attention should be paid to the staple line intraluminally to look for appropriate staple formation and bleeding from the staple line. If bleeding is observed, the staple line bleeding should be grasped with an Allis clamp and everted through the enterotomy and controlled with suture. Avoid cautery at all costs. The remaining common enterotomy is grasped with three Allis clamps and the enterotomy is closed with a TA stapler (60 mm is often sufficient). This common enterotomy can also be closed in a hand-sewn fashion based on surgeon preference and experience. A GIA stapler can be used to close the common enterotomy; however, the surgeon must consider greater

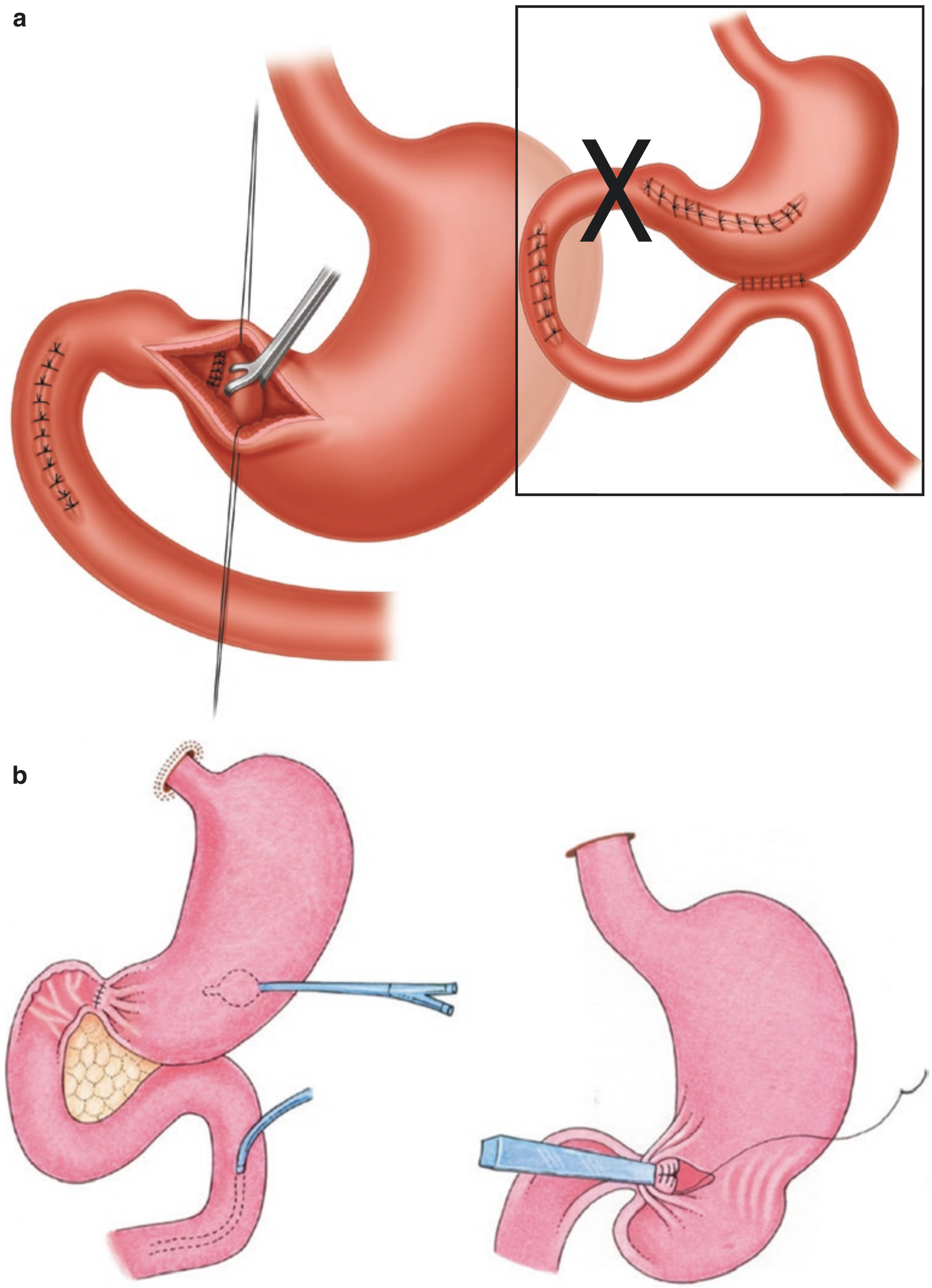

Fig. 6.5 Pyloric exclusion. (**a**) With gastrojejunostomy. (**b**) Pyloric exclusion without gastrojejunostomy requires a way to empty the stomach. In this case the empty is made through a Foley catheter, avoiding the gastrojejunostomy. Enclosed are the figures (PE1, PE2)

narrowing of the common enterotomy portion of the anastomosis and therefore should consider a longer common channel staple fire(ing) if a GIA is to be used for the closure of the common enterostomy.

The decision to close the mesenteric defect is left to the surgeon. The advantage of closing the mesenteric defect lowers the likelihood of internal hernia, but closure increases risks of bleeding and ligation of blood supply to the bowel. This can be avoided by incorporating only the peritoneum with the closure of the mesentery (Figs. 6.6 and 6.7).

Colorectal Anastomoses

Colorectal anastomoses require the same fundamentals for all anastomoses (adequate blood supply and minimal-to-no tension). The blood supply of the colon and rectum is less robust than that of the small bowel; colorectal anastomeses therefore present a higher risk of anastomotic failures.

Colocolostomy can be stapled or handsewn. Isoperistaltic anastomoses visually appear more appropriate; however,

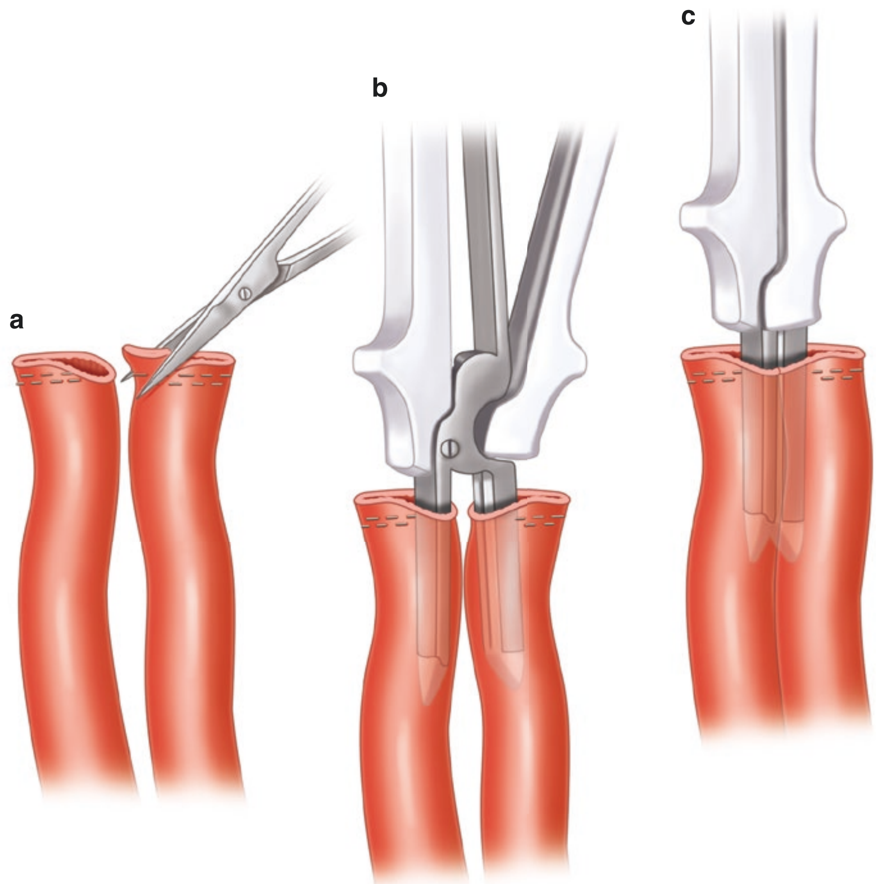

Fig. 6.6 (**a**–**c**) Stapled anastomosis

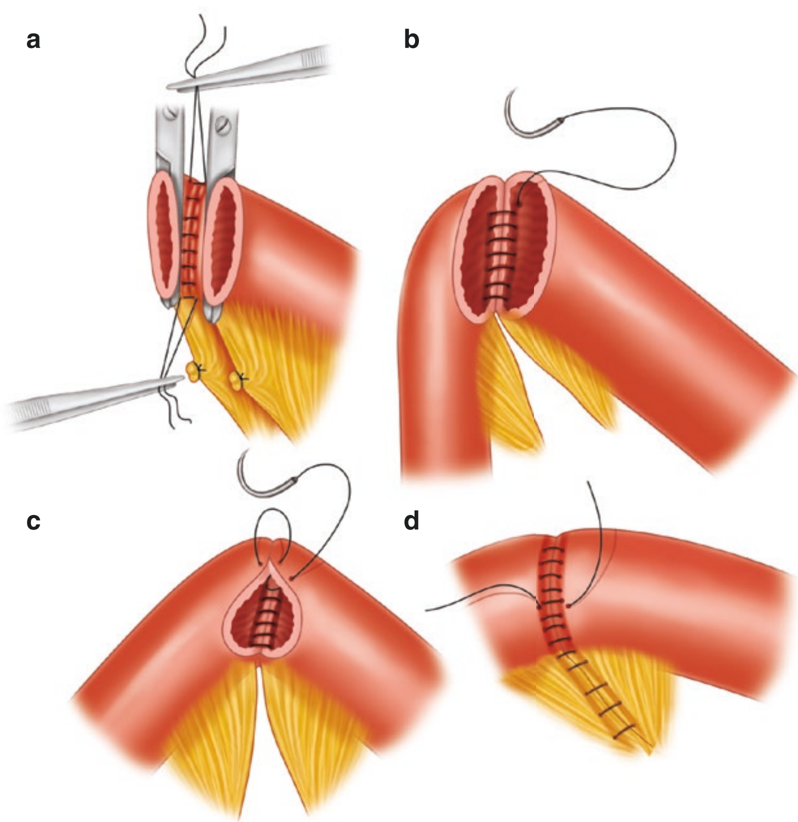

Fig. 6.7 (**a**–**d**) Hand-sewn anastomoses

functional end-to-end side-to-side procedures are done liberally without a clinical detriment.

Colorectal anastomoses, however, often require the use of an end-to-end anastomotic (EEA) stapling device. These have allowed for consistent, reproducible anastomoses. Often the patient should be in lithotomy to aid with passage of the EEA via the anus; however, intra-abdominal use of the EEA is successful also. If a standard EEA is to be applied in lithotomy position, the EEA is chosen with a size in mind, often no smaller than 28 mm, and inserted carefully into the anus and guided into the rectal stump without injuring or perforating the rectum. If there is difficulty in passage of the EEA, consider serial dilation with EEA sizers, and if this isn't successful, often the rectum needs to be mobilized more to decrease tension of the sacrum so the EEA can pass. The anvil of the EEA stapler is placed in the proximal colon after a purse string is created in the end of the proximal colon colostomy. The purse-string suture is tied down to secure the anvil. The spike is deployed through the middle of the rectal stump staple line to fully expose the spike and its collar. The anvil is connected to the spike and a click should be appreciated. The EEA is closed as delineated by the manufacturer, paying attention to ensure that the colon is appropriately oriented (prevent twisting of the colon) and that no other structures are incorporated into the anastomosis (bladder, vagina, bowel, ureter, etc.). The stapler is then fired, and the EEA is removed. The surgeon should check for two intact colorectal anastomotic rings and then perform a leak test. If a leak is identified it should be repaired with a suture and leak-tested for success and to confirm that is has a very low threshold for a diverting loop ileostomy.

If the EEA is to be used from an abdominal approach as described by Baker [8], the anvil is placed in the rectum after a purse string is placed in the rectum (end or side of bowel wall). The EEA can be inserted through the end of the proximal colon to allow the spike to come through the antimesenteric border of the colon to complete the anastomoses and GIA closure of the common colostomy. If there is not enough colon length to perform this, then a proximal longitudinal colotomy several centimeters from the end of the proximal colon is made. The EEA is inserted through the proximal colotomy and advanced to the end of the open colon. A purse string is placed here and tied around the fully deployed spike, and the EEA anastomosis is created. Anastomotic rings are inspected for integrity and the proximal colostomy is closed, often in a transverse fashion, with a TA stapler, or is hand-sewn.

Handsewn isoperistaltic two-layered colorectal anastomoses and end-to-end anastomoses can also be done, but are far more difficult and are beyond the scope of this chapter. Consultation with surgeons experienced in handsewn colorectal anastomoses would be wise if this is needed (Figs. 6.8 and 6.9).

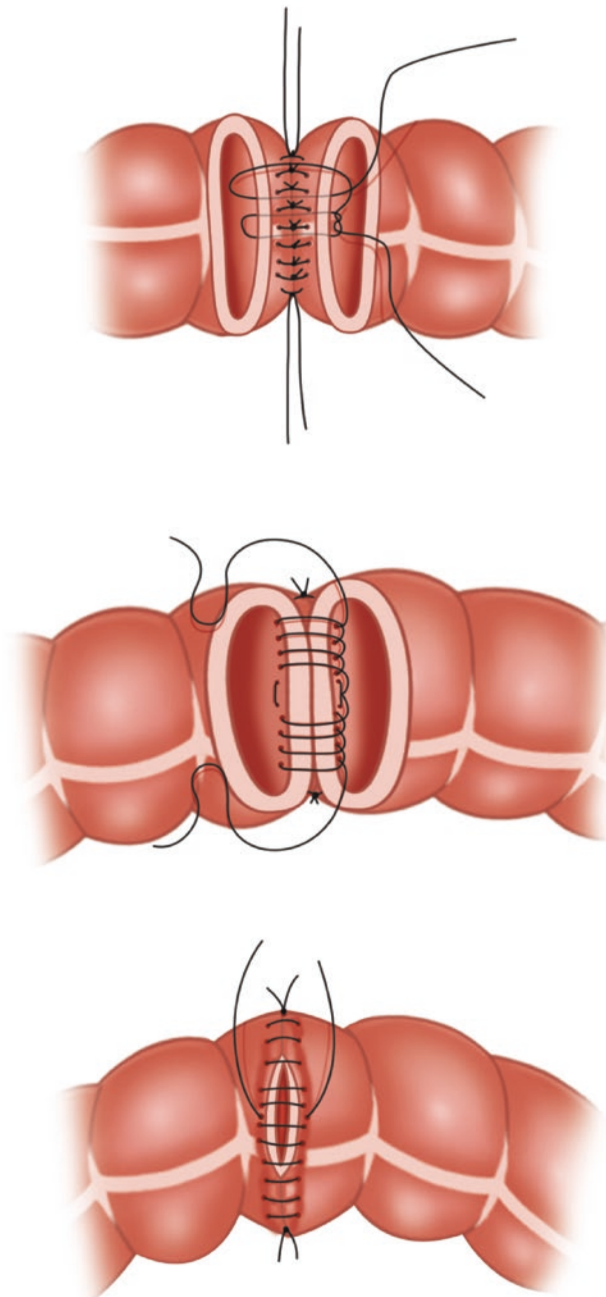

Fig. 6.8 Hand-sewn colorectal anastomosis

Retroperitoneal Exposures

In order to reach the retroperitoneal great vessels, expose the back wall of the colon or get access to the kidney. These exposures are essential.

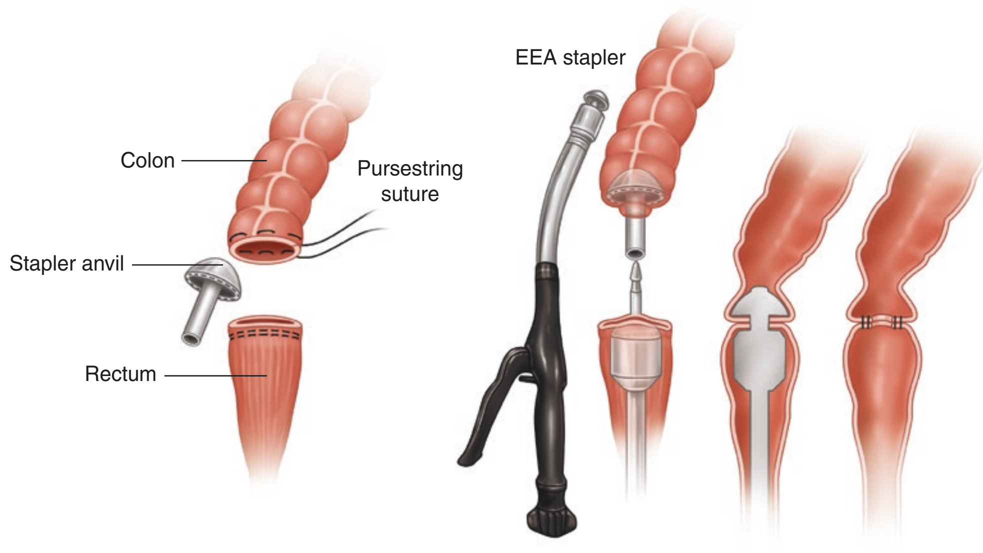

Fig. 6.9 Stapled anastomosis

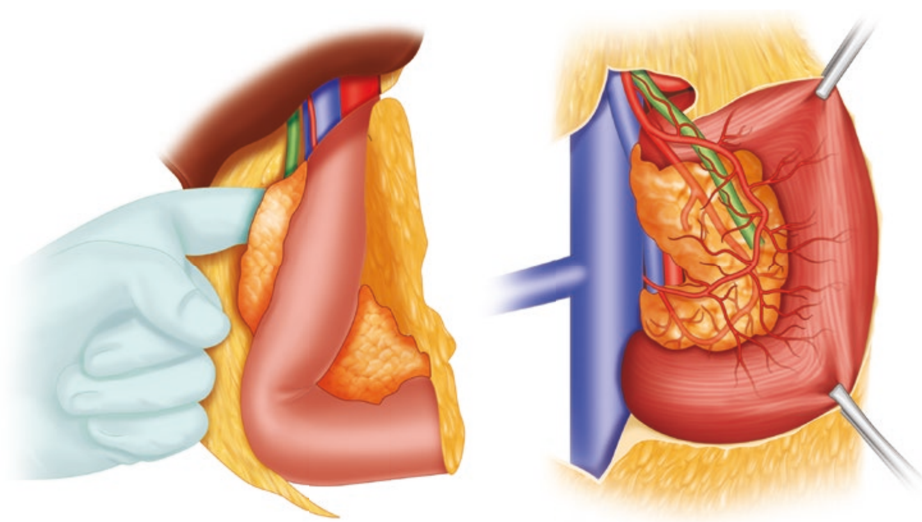

Fig. 6.10 Kocher maneuver

Kocher Maneuver and Right-Sided Medial Visceral Rotation

Start with a full Kocher maneuver by mobilizing the duodenal loop and head of the pancreas from the common bile duct superiorly to the superior mesenteric vein inferiorly. This exposes the second part of the duodenum. Extend the incision in the posterior peritoneum along the white line of Toldt, and mobilize the right colon. Separate the small bowel mesentery from the posterior peritoneum. This will allow you to move the small bowel and right colon out of the abdomen and onto the patient's anterior chest, exposing the entire inframesocolic retroperitoneum (Figs. 6.10 and 6.11).

Left-Sided Medial Visceral Rotation

Start the maneuver by mobilizing the lowermost descending colon. Incising the white line of Toldt allows the surgeon to dissect behind the left colon and rapidly mobilize it from below toward the splenic flexure. Continuing the blunt dissection in an upward and medial direction in the same avascular plane immediately anterior to the muscles of the posterior abdominal wall allows the surgeon to gradually rotate the left kidney, spleen, pancreas, and stomach medially and expose the entire length of the abdominal aorta all the way up to the diaphragmatic hiatus. In most situations requiring this maneuver, a large

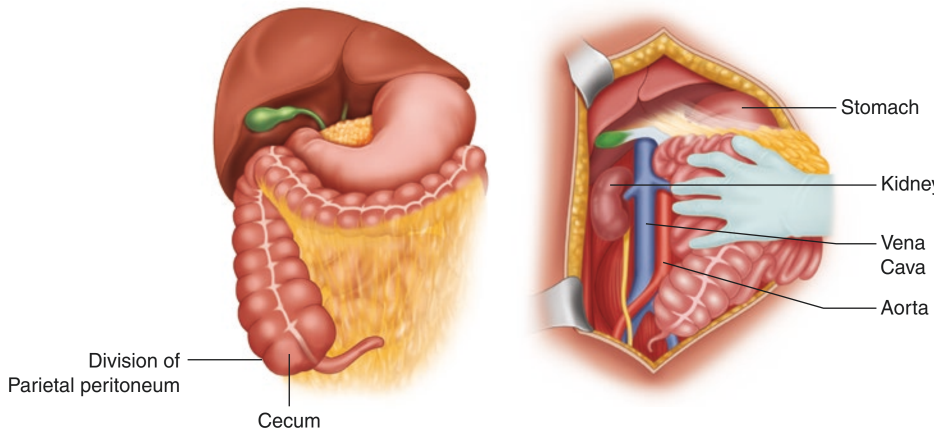

Fig. 6.11 Right medial visceral rotation

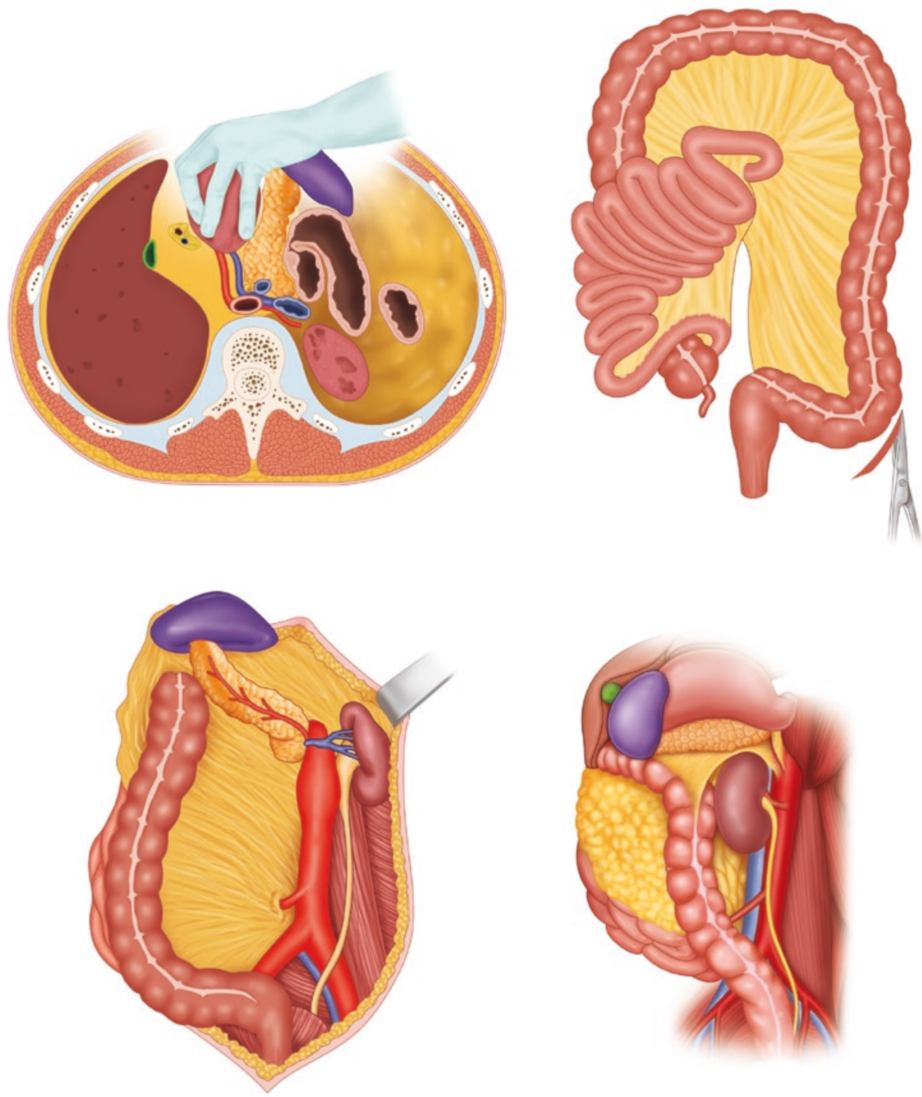

Fig. 6.12 Left medial visceral rotation

supramesocolic retroperitoneal hematoma greatly facilitates the dissection by lifting the peritoneal organs off the posterior abdominal wall. You can achieve proximal control of the supraceliac aorta immediately below the diaphragm. Another option is to incise the left diaphragmatic crus laterally, bluntly dissect around the aorta, and clamp it in the lower chest through the incised hole in the diaphragm (Fig. 6.12).

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7 Liver and Spleen

Roberto C. Castillo and Paula Ferrada

This chapter delves into the management of the most commonly injured solid intraabdominal organs. The liver and spleen are both highly vascular solid organs in which injuries span the spectrum from minor lacerations to major injuries requiring skilled operative intervention for hemorrhage control. Common operative techniques for hemorrhage control including packing maneuvers, vascular control, hepatorrhaphy, splenorrhaphy, and resection. These are essential skills in the management of hepatic and splenic trauma patients.

Liver

The Liver is often cited as the most commonly injured intraabdominal organ in trauma. The range of injuries extends from minor insults resulting in spontaneous cessation of hemorrhage or requiring minimal nonoperative intervention to major trauma requiring drastic operative and nonoperative interventions. Hemodynamically stable patients who have initially been treated nonoperatively may still require some manner of intervention, whether operative or via angiography and embolization. Liver trauma in hemodynamically unstable patients requires operative intervention. The management of major hepatic trauma has advanced to include a wide array of operative and nonoperative interventions. This multimodal approach has been shown to improve and optimize patient outcomes [1].

Liver Anatomy (Fig. 7.1)

Anatomical familiarization of the liver is essential for effective management of minor and complex liver injuries. Ligamentous attachments from the liver to the abdominal wall include the falciform ligament, coronary ligaments, and triangular ligaments. Complete mobilization of the liver requires division of these attachments.

The liver itself is divided into two lobes along a sagittal plane from the inferior vena cava (IVC) through the gallbladder fossa known as Cantlie's line. The liver is further divided into eight segments based on each segment's vascular supply from branches of the portal vein. Segments II–IV make up the left lobe of the liver and segments V–VIII form the right lobe of the liver. Segment I is also known as the caudate lobe, which receives blood supply from both main branches of the portal vein and has hepatic veins that drain directly to the IVC.

Vascular outflow from the liver is via hepatic vein branches that form the right, middle, and left hepatic veins. These veins drain directly to the IVC with relatively short extrahepatic segments. The middle hepatic vein will often join the left hepatic vein before draining into the IVC. There

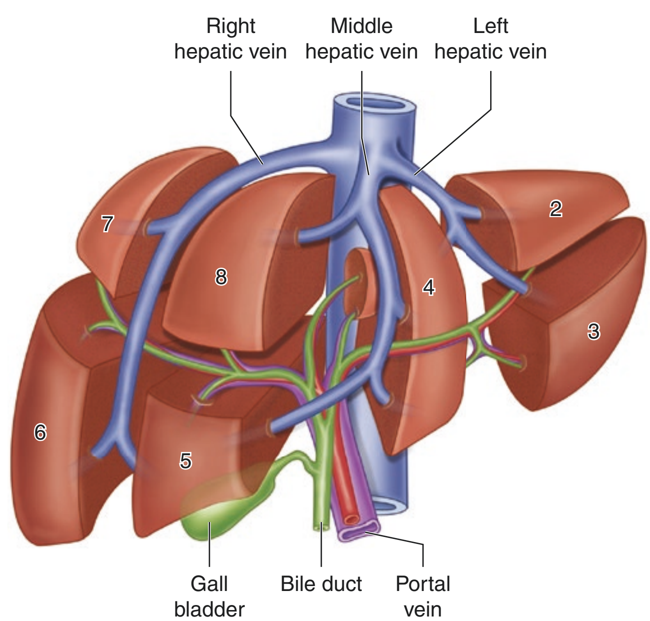

Fig. 7.1 Liver anatomy

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P. Ferrada, R. Ferrada (eds.), *Atlas of Trauma*, https://doi.org/10.1007/978-3-030-26871-8_7

are also a number of small hepatic veins draining the lower portion of the liver; these drain directly to the retrohepatic IVC, which may become clinically significant in hepatic trauma.

Vascular inflow to the liver is via the portal vein, which supplies 75% of hepatic blood flow. The remainder of the inflow is from the common hepatic artery. Frequent variations to be aware of include: a right hepatic artery originating from the superior mesenteric artery (SMA) and a left hepatic artery originating from the left gastric artery.

Manual Compression and Hepatic Packing (Fig. 7.2)

Upon initial entry into the abdominal cavity, control of hemorrhage can be temporarily achieved by manually compressing the injured liver with laparotomy pads. This temporary control of hemorrhage allows the anesthesia team to "catch up" in the resuscitation of the patient before embarking on more definitive means of hemorrhage control or repair.

Initial hepatic packing can be achieved by placing laparotomy pads above the liver, ensuring that packing is done above the dome of the liver and as posterior as possible. Another set of laparotomy pads are placed below the liver in an effort to sandwich the liver and provide temporary hemostatic control with compression. Division of the falciform ligament allows for optimal superior packing and later evaluation of the superior and lateral lobes of the liver.

In the event of more severe hepatic trauma, further mobilization of the liver is needed to provide more direct manual compression to control hemorrhage by realigning the liver parenchyma to its normal anatomic position. This mobilization is accomplished by dividing the right and left triangular ligaments. The freely mobilized liver can then be optimally manually compressed by pushing left and right lobes together with the surgeon's or assistant's hands. The liver can also be compressed posteriorly and superiorly to tamponade any posterior hepatic bleeding.

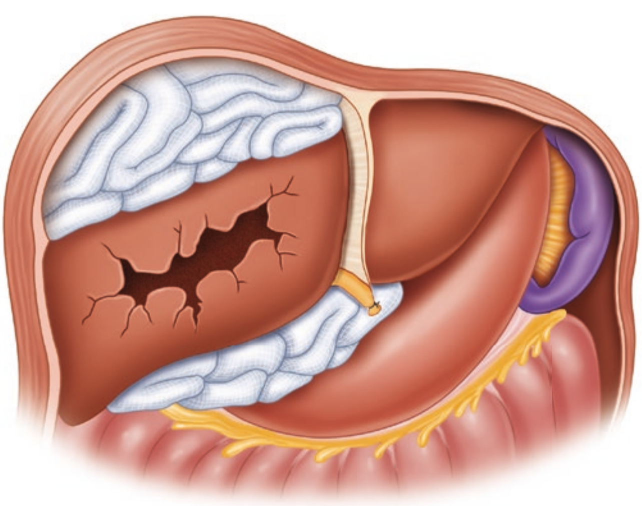

Fig. 7.2 Manual compression and hepatic packing

Other techniques for hepatic compression include the use of absorbable mesh to circumferentially wrap around the liver. The goal is to create a tamponade effect by restoring the liver to its normal anatomical state. This technique is best utilized on burst injuries in which the parenchymal edges are still viable.

Caution should be taken if hematomas are noted in either ligament, as hepatic vein or caval injuries may be present. In cases of retrohepatic venous injuries, division of the triangular ligaments and mobilization of the liver may negate the tamponade effect provided by hepatic compression and release further sites of uncontrolled hemorrhage.

Finger Fracture and Direct Suture Ligation (Fig. 7.3)

Higher grade or deeper hepatic lacerations may not respond to manual compression alone. Superficial laceration may be amenable to hemostatic control with direct suturing to approximate the liver parenchyma. Utilization of a large blunt tip 0-chromic suture is preferred in order to avoid tearing Glisson's capsule when reapproximating the tissue. However, this technique is not advised in deeper hepatic laceration, because blindly suturing these lacerations may injure intrahepatic bile ducts and vasculature and cause larger areas of hepatic necrosis from ischemia, intrahepatic hematomas, or hemobilia.

In cases of more severe lacerations, direct ligation of larger bleeding hepatic artery or portal vein branches is necessary for hemostatic control. This is accomplished by gently separating the edges of the fractured liver to expose the depth of the wound. Any visible injured or bleeding vessels can be ligated at this time. Careful dissection through the liver parenchyma can be accomplished via finger fracture technique to identify injured vessels. These vessels can then be ligated via suture ties or clips.

Resection (Fig. 7.4)

Major hepatic trauma can often result in friable or partially devascularized tissue at the liver periphery or within a hepatic laceration. Non-anatomic resection of the devascularized tissue can be accomplished by various techniques. Devitalized tissue can be removed by finger fracturing through the hepatic parenchyma, ligating vasculature to the tissue, and using electrocautery to resect. Liver clamps can also be applied to

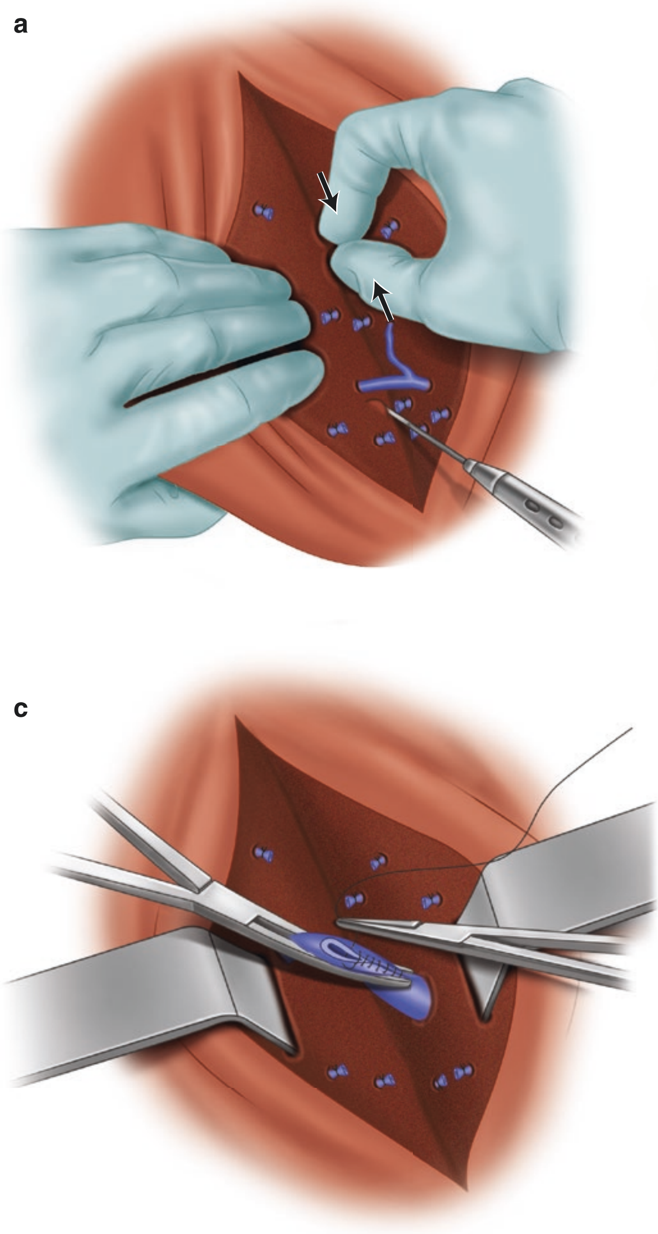

Fig. 7.3 Finger fracture and direct suture ligation

either side of the injured tissue that requires resection. Mattress sutures can be applied for hemostasis prior to resection of the tissue. The use of linear stapling devices offers a more expedient option for resection of devitalized liver.

Additional electrocautery or argon beam can be utilized to cauterize oozing from the remaining liver edges. Once major bleeding has been controlled, a pedicle flap of viable omentum can be placed within a deep liver laceration to provide further hemostasis and protect against bile leakage from unidentified injuries to minor bile duct branches.

Balloon Tamponade (Fig. 7.5)

In the case of a penetrating hepatic injury, bleeding from the penetrating tract within the liver can be difficult to access and visualize. Internal tamponade of bleeding from a penetrating tract can be achieved via balloon tamponade with a red rubber catheter or a Foley and Penrose drain. Holes are cut in the red rubber catheter and a Penrose drain is slipped over the catheter tied at each end. The holes cut in the catheter then serve to inflate the Penrose drain like a balloon. This is inserted into the penetrating tract and inflated to serve

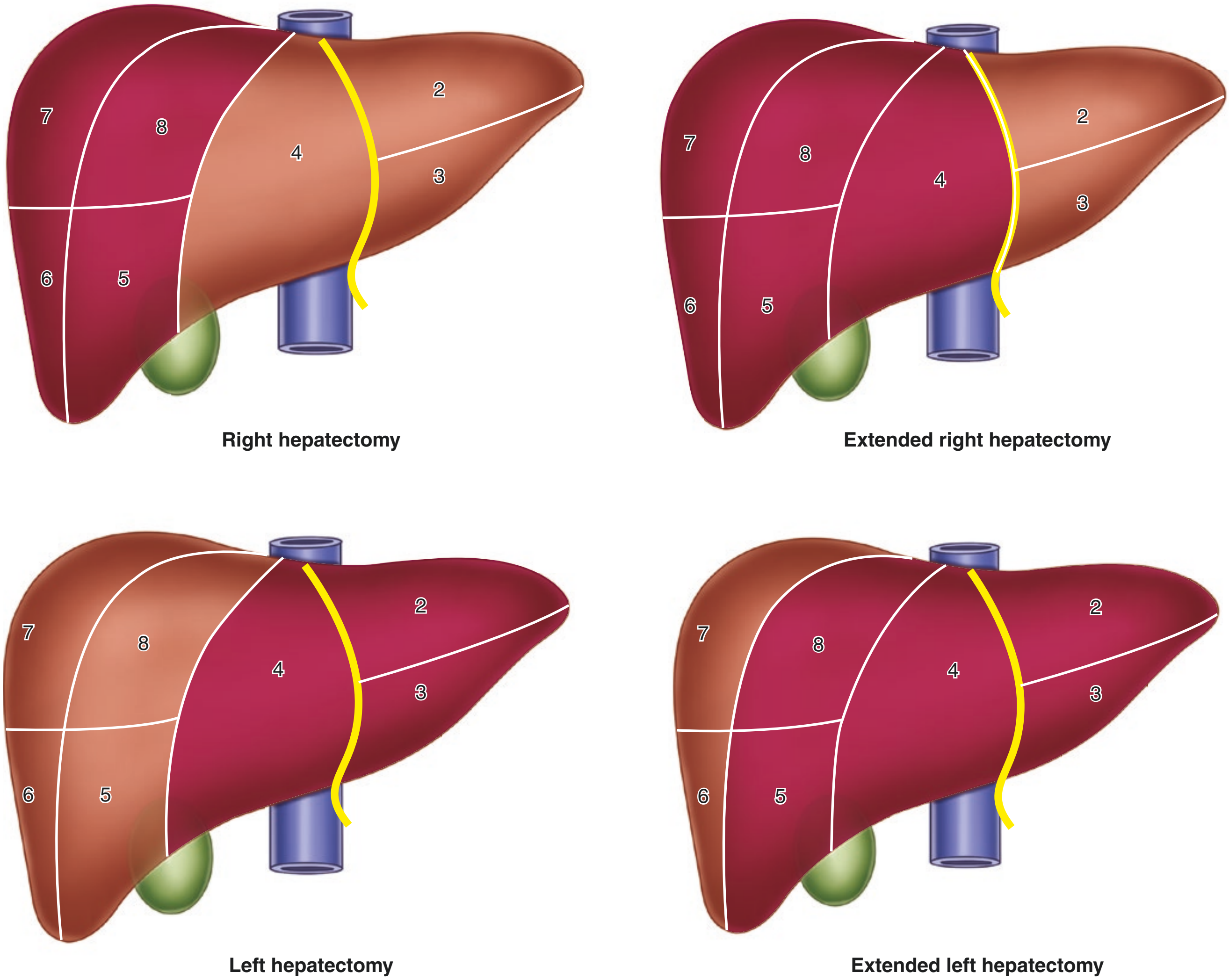

Fig. 7.4 Resection

as an internal tamponade device. Once in the optimal position, the device can be left in place for 24–48 hours and re-evaluated upon return to the operating room.

Vascular Control (Fig. 7.6)

When hemorrhage control cannot be achieved with hemostatic agents or compression/packing, occlusion of the portal triad can effectively reduce bleeding from the liver and provide time to identify and provide a more definitive method of hemorrhage control. The Pringle maneuver is achieved by encircling the portal triad initially with a finger through the epiploic foramen and then clamping with a vascular clamp or Rummel tourniquet. Warm hepatic ischemia can be tolerated from 30 to 60 minutes [2, 3].

If further bleeding is noted after vascular inflow occlusion via the Pringle maneuver, then retrograde bleeding from the retrohepatic inferior vena cava or portal veins must be suspected. In the evident of major retrohepatic venous injury, the infrahepatic and suprahepatic inferior vena cava and portal triad can be occluded to achieve hepatic vascular isolation. Atriocaval shunts to shunt blood from the inferior vena cava to the heart and bypass the liver were first described by Schrock and colleagues in 1968 [4]. These shunts have been associated with overall high mortality rates.

Extrahepatic Biliary Injury

The gallbladder is the most commonly injured component of the extrahepatic biliary system. In these cases, an operative cholecystectomy is the optimal procedure. Operative management of injury to the common bile duct is dictated by the extent of the injury and the patient's clinical state. In a damage-control operation, injury to the extrahepatic biliary

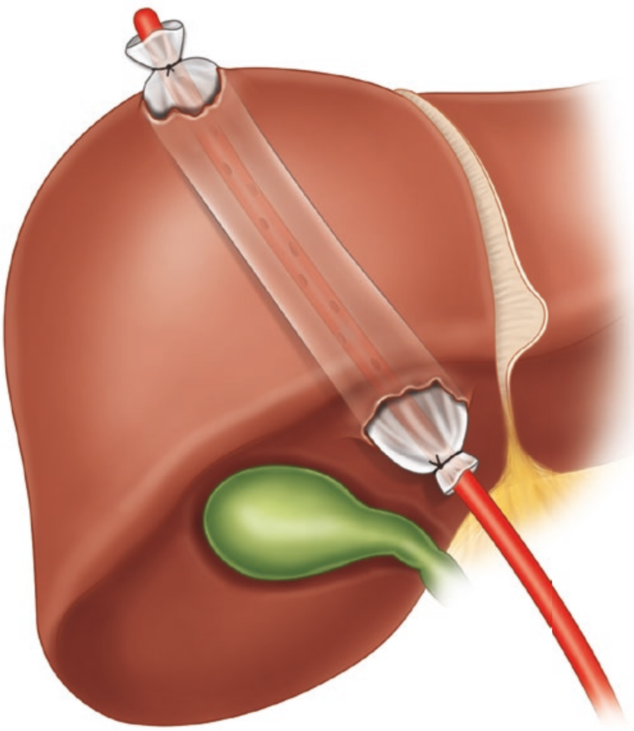

Fig. 7.5 Balloon tamponade

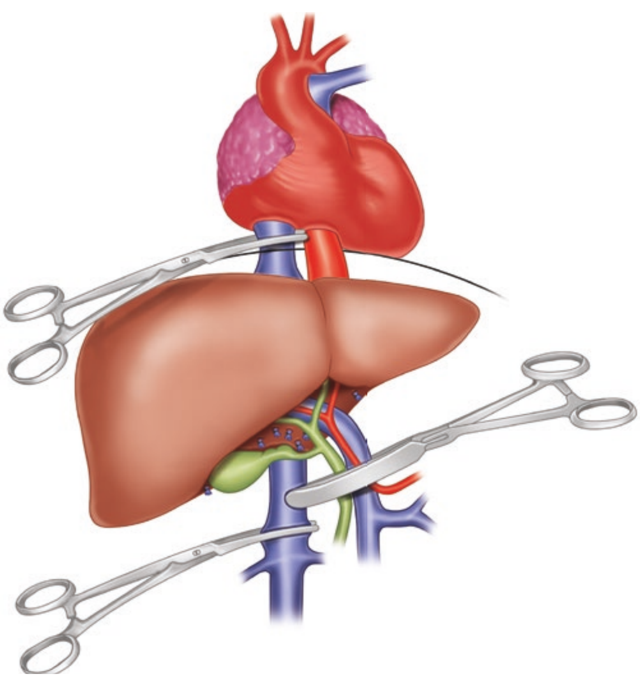

Fig. 7.6 Vascular control

tree can be managed with wide external drainage of the area. Wide external drainage of near-total or total transections of the extrahepatic biliary ducts can serve as a temporary solution in order to optimize the patient for future definitive repair with a Roux-en-Y hepaticojejunostomy. If an injury is seen and noted to be a partial transection (<50% of the circumference), then it can be repaired primarily with an absorbable monofilament suture. If possible, a repair over a T-tube through a separate choledochotomy can decompress and drain the biliary system and provide an avenue for future imaging and intervention if necessary.

Complications

Patients with severe hepatic injuries may suffer from significant complications ranging from delayed bleeding, hepatic abscess, bile leak, biloma, hemobilia, and hepatic necrosis. Delayed bleeding can present itself in any patient initially managed nonoperatively. These patients can be subsequently managed with angioembolization or operative intervention as detailed above.

Hepatic abscesses or bilomas secondary to biliary leaks from damaged biliary ducts complicate cases of liver trauma with a frequency of 0.5–21% [1, 5, 6]. Hepatic abscesses or bilomas can be drained percutaneously or operatively. Endoscopic retrograde cholangiopancreatography (ERCP) with sphincterotomy and biliary stent placement have proven a useful tool in managing biliary leaks from liver trauma [7].

Hepatic necrosis is another complication that may occur after operative intervention for hemorrhage control or angioembolization. The reported rate of hepatic necrosis after embolization is as high as 40%. Early operative debridement is crucial because acute liver failure or septic sequelae can occur if management is delayed [8, 9].

Although a rare complication, hemobilia may present days or weeks after hepatic injury. Patients with hemobilia will classically present with the triad of right-upper-quadrant pain, jaundice, and upper gastrointestinal bleeding. Early diagnosis is critical to the management of this complication, as life-threatening bleeding can occur. Treatment is accomplished with angiography and embolization.

Spleen

The spleen is a commonly injured organ in both blunt and penetrating trauma. Its anatomical position and the manner in which it attaches to the abdominal wall and other structures make it prone to injury from neighboring structures (i.e., ribs) and from forces inflicted on the body in blunt trauma.

Anatomy (Fig. 7.7)

One of the main functions of the spleen is to act as a filter and remove pathogens and aged cells from the bloodstream. In

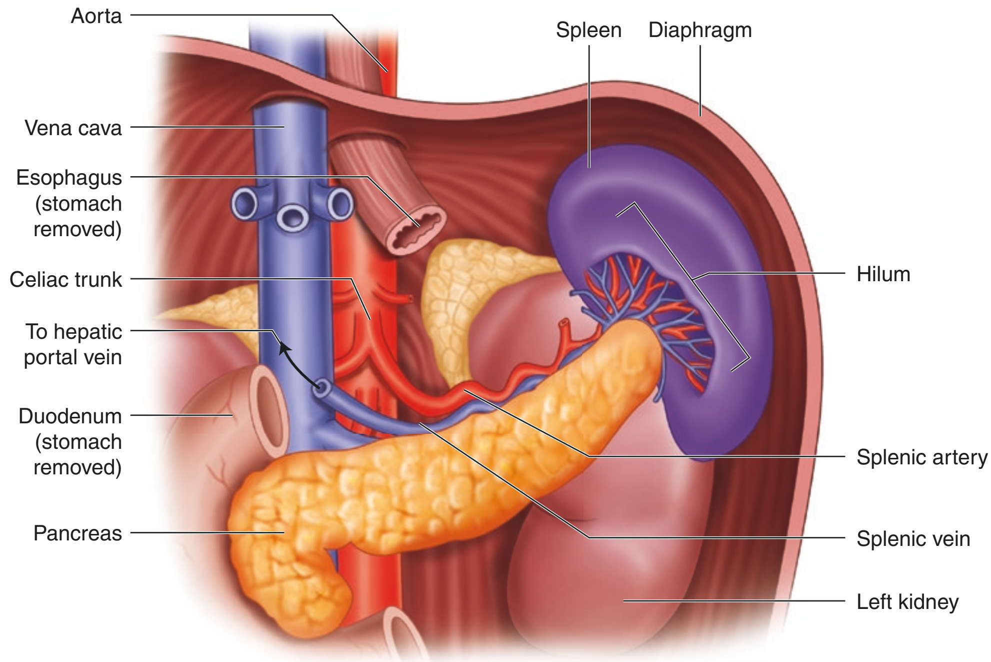

Fig. 7.7 Spleen anatomy

order to accomplish this, the spleen itself is a highly vascular organ. Its main blood supply is from the splenic artery, which receives about 5% of the cardiac output per day. The splenic artery follows a tortuous course and runs along the superior border of the pancreas. Before entering the spleen, the splenic artery branches into smaller vessels at the hilum. There is variability in how many branches and how proximal or distal the branching occurs.

The spleen is attached to neighboring structures by the gastrosplenic, splenocolic, splenorenal, and splenophrenic ligaments. These must all be taken down in order to mobilize the spleen for either splenorrhaphy or splenectomy.

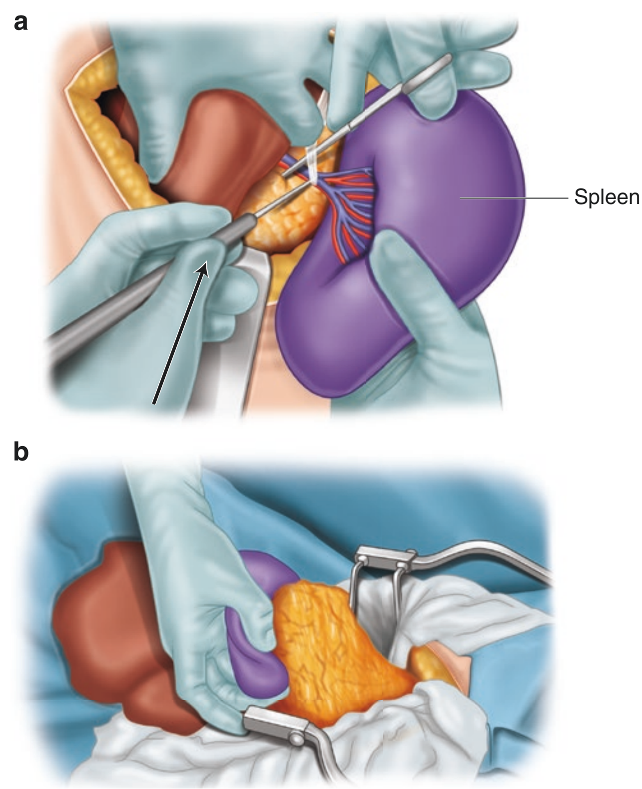

Fig. 7.8 Splenectomy

Splenectomy (Fig. 7.8)

Historically, most splenic injuries have been managed with splenectomy. Nonoperative management of splenic injury has proven to succeed in certain patient populations. Angiography and embolization have contributed to the success of nonoperative management. In the hemodynamically stable patient, nonoperative management has success rates of 78–98% [10]. Factors such as patient age, greater Injury Severity Score, and greater splenic injury grade have been shown to be prognostic factors for failure in nonoperative management of splenic injury [11]. For patients who are hemodynamically unstable, however, the standard is still operative splenectomy.

Once the abdomen is entered, it is critical for the spleen to be fully mobilized to properly evaluate the extent of injury. This is accomplished by using the nondominant hand to retract the spleen midline. Laparotomy pads are then placed posterior to the spleen to elevate it into the operative field. It is important to establish the avascular plane posterior to the spleen and the tail of the pancreas, and above the kidney. The ligamentous attachments between the spleen and neighboring structures can then be taken down with electrocautery, a tissue-sealing device, or blunt/sharp dissection. Division of the gastrosplenic and splenocolic ligament should be done with manual ligation, electrocautery, or a tissue-sealing device, as these are vascular attachments.

As the spleen is fully mobilized, the splenic hilum can be palpated and clamped for vascular control. Ligation of the splenic vessels at the hilum can be accomplished by serially clamping and dividing the vessel branches at the hilum. Alternatively, the vessels can be ligated with a linear stapling device with a vascular load. It is important to stay close to the spleen when ligating the vessels at the hilum in order to avoid iatrogenic injury to the pancreatic tail.

Splenorrhaphy

The decision between splenectomy and spleen-preserving splenorrhaphy should take into account variables such as patient age, extent of injury to the spleen, and the patient's overall trauma burden and clinical status. Long-term consequences of splenectomy are increased risk of infections by encapsulated bacteria and overwhelming post-splenectomy infection/sepsis. Therefore, spleen-preserving techniques maybe preferred in certain populations such as pediatric patients.

Lower-grade splenic injuries, such as superficial laceration or capsule tears, can often be managed with manual compression, application of hemostatic agents, or electrocautery. Higher-grade injuries may require other techniques for splenorrhaphy. Obstacles to suture repair of a splenic laceration are based in the inability of the splenic capsule and parenchyma to hold sutures well. Therefore, a monofilament suture that can slide through the capsule and parenchyma without tearing it is preferred. Teflon pledgets or even omentum are utilized to bolster and provide further support to the stitch. Ultimately, the splenic laceration is repaired with a monofilament suture in a horizontal mattress stitch with a bolster in place.

In the event that a high-grade splenic injury is isolated to one of the poles, a partial splenectomy can be achieved by sharply excising the devitalized tissue or utilizing a linear stapling device. Hemostasis of the remaining splenic tissue can be accomplished via approximation of the splenic parenchyma and capsule with monofilament sutures bolstered by Teflon pledgets. If a linear stapling device is used, hemostatic agents or electrocautery are available for further hemostasis. The staple line can also be reinforced with sutures and pledgets.

The spleen itself can be wrapped with an absorbable vicryl mesh bag with underlying hemostatic agents or suture repairs in order to provide another element of compression to provide hemostatic control. However, if hemorrhage control is unable to be achieved with various spleen-preserving techniques, a complete splenectomy remains the definitive treatment.

Complications

The major long-term complication of splenectomy is an increased risk of infection from encapsulated organisms. In more severe cases, these infections can result in overwhelming post-splenectomy infection (OPSI). OPSI itself carries a mortality rate of 40–70%. The greatest incidence of OPSI is within the first few years post-splenectomy and within the pediatric population, but the risk is lifelong. However, the overall risk is <0.5% [12, 13]. For this reason, post-splenectomy vaccines against common encapsulated organisms such as *Haemophilus influenzae*, *Streptococcus pneumoniae*, and meningococcus are given to splenectomy patients.

Postoperative bleeding complications can occur from bleeding short gastric arteries, the splenic bed, or from the splenic parenchyma after splenorrhaphy. Iatrogenic injury to surrounding structures is possible as well. Injury to the greater curvature of the stomach can occur when taking down the gastrosplenic ligament and during ligation of the short gastric arteries. Injury to the pancreatic tail can occur secondary to its proximity to the splenic hilum. The sequalae of pancreatic injury or leak can have devastating effects on the postoperative phase of the patient. Therefore, if a pancreatic injury is suspected, a drain is left at the operative site.

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Vena Cava Injury

8

Ricardo Ferrada and Paula Ferrada

Mortality from vena cava injury is high both in pre-hospital and in-hospital settings. This is due to hypovolemia. Injuries to the vena cava can cause rapid exsanguination. For this reason, it is most important to maintain hemodynamic stability. Before opening the hematoma, the patient must have several intravenous lines and blood must be available, preferably inside the operating room.

Frequently, however, the diagnosis of vena cava injury is made during laparotomy. The classic view for the surgeon is a retroperitoneal hematoma in the right flank, behind the mesentery or the duodenum (Fig. 8.1). The best way to access the periduodenal, periportal hematoma is the Kocher maneuver, which entails medial rotation of the head of the pancreas and duodenum. As with any vascular technique, the key is proximal and distal control. It is wiser to start the dissection far from the suspected injury. Most surgeons prefer to start dissection on the iliac area, and to perform a temporal occlusion on the iliac and cava veins. It is easier to isolate the injury first before getting into the hematoma since active bleeding and trauma can distort anatomy and increase the technical difficulty of the repair.

It is safer and better to start the dissection near to the iliac vein, not in the hepatic flexure of the colon. By using this maneuver, the vena cava can be accessed and controlled inferiorly. After the cecum is lifted, the vein is dissected, and the dissection can be made closer to the hematoma without opening it (Fig. 8.2). Opening the hematoma will cause bleeding, which in turn makes it much more difficulty to identify the blood loss point.

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As pointed out earlier, the most important step is to ensure the best possible hemodynamic stability before opening the hematoma. Once opened, the blood loss can produce sudden deterioration followed by death. For this reason, when vena cava injury is suspected, the key is to postpone opening the hematoma until the dissection is closer. Instead, a balanced resuscitation before entering the zone of danger is pivotal.

Clamping the inferior vena cava results in ingurgitation of the collaterals, which in turn fills the veins and makes the dissection more difficult. However, 100% occlusion is almost never necessary at this moment. The low pressure in the cava vein allows control of bleeding control to be achieved by a gentle fingertip (Fig. 8.2e) or by application of gauze or sponge sticks to the vein (Fig. 8.3a, b). Once dissected, the vein can be controlled by applying a Satinsky clamp lateral to the injury (Fig. 8.4).

Posterior injury can be repaired through the anterior hole or by twisting the vein under proximal and distal control. If necessary, the anterior hole can be enlarged (Fig. 8.5a, b).

The cava vein has a number of lumbar collaterals. If possible, these should be ligated and divided. They are small, but bleeding makes visualization much more difficult for the surgeon. The IVC can be ligated with almost no immediate consequences. However, ingurgitation of collaterals follows soon after ligation, and important bleeding from small vessels can be seen. For this reason, is wiser to avoid interruption or ligation if possible. When local destruction makes this difficult, however, it is wiser to ligate (Fig. 8.6).

In summary, prognosis and mortality improve when the surgeon recognizes his or her own limitations. Once the IVC injury is suspected, the most important issue is to ask for help and preserve stability.

P. Ferrada, R. Ferrada (eds.), *Atlas of Trauma*, https://doi.org/10.1007/978-3-030-26871-8_8

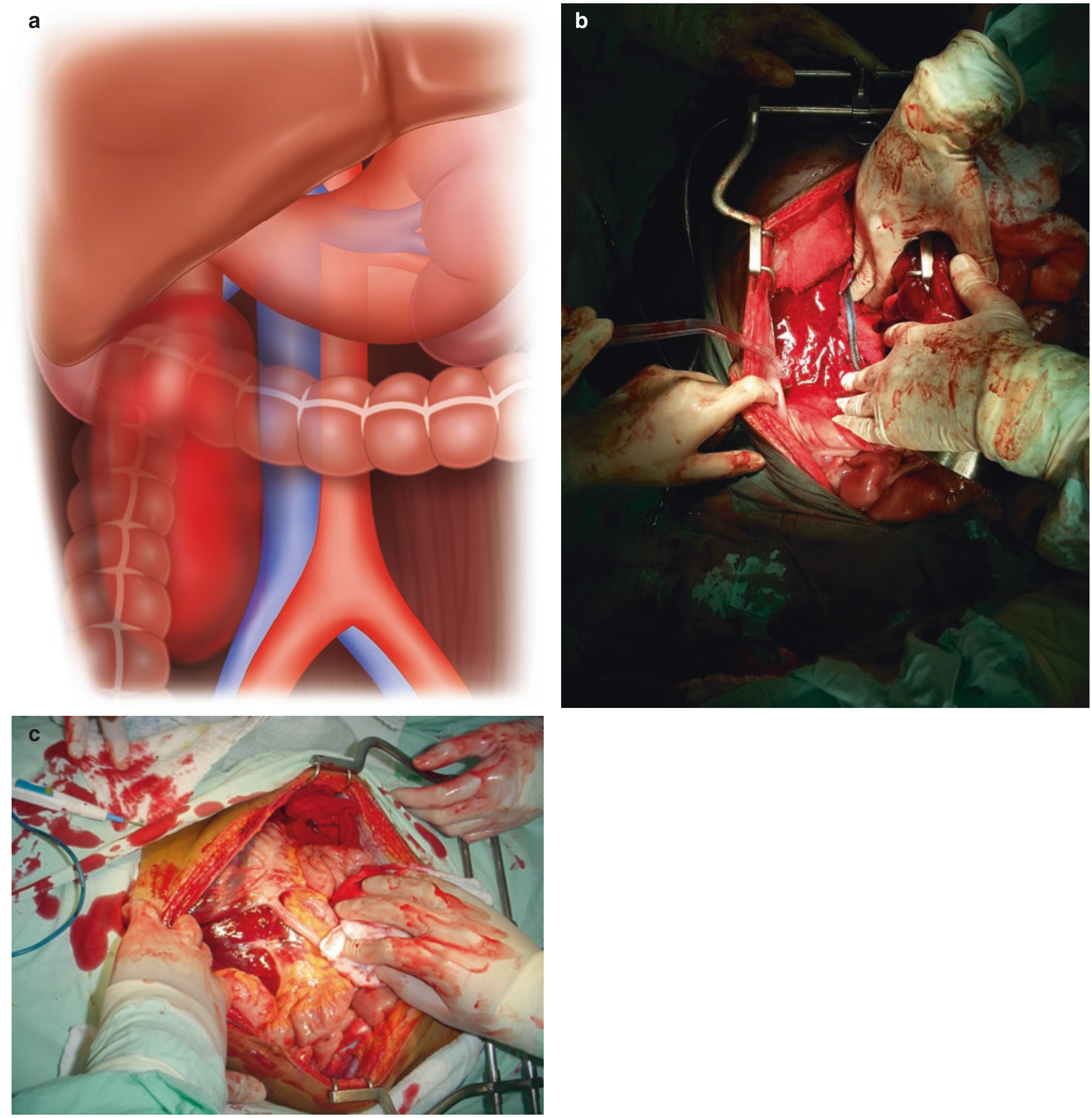

Fig. 8.1 (**a**–**c**) Hematoma

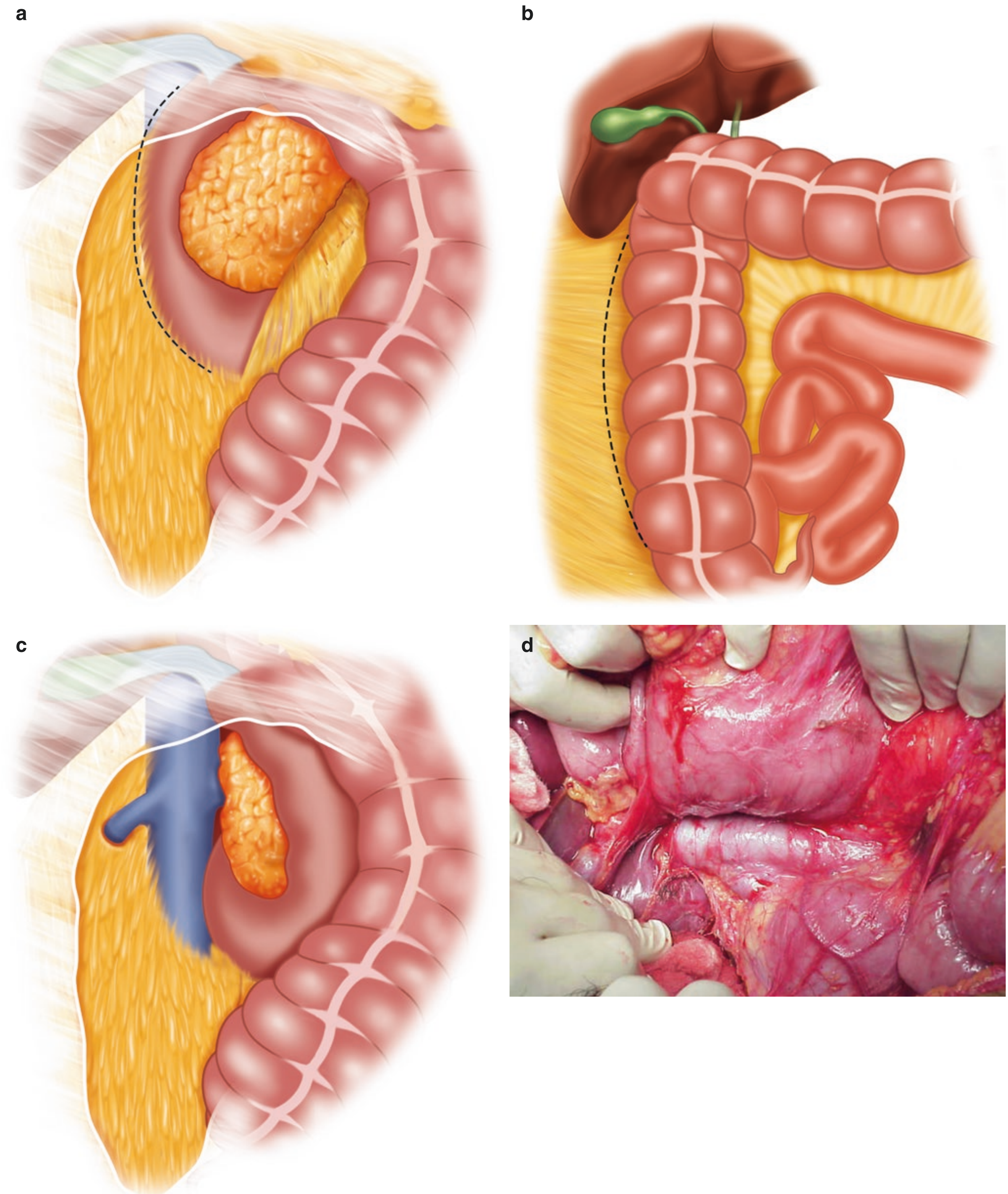

Fig. 8.2 (**a**–**d**) Kocher. (**e**) Low pressure in the cava vein allows bleeding control, which can be achieved by a gentle fingertip

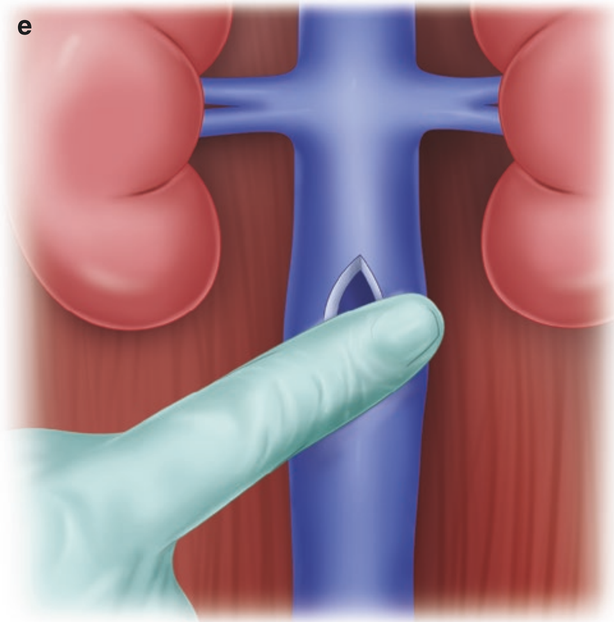

Fig. 8.2 (continued)

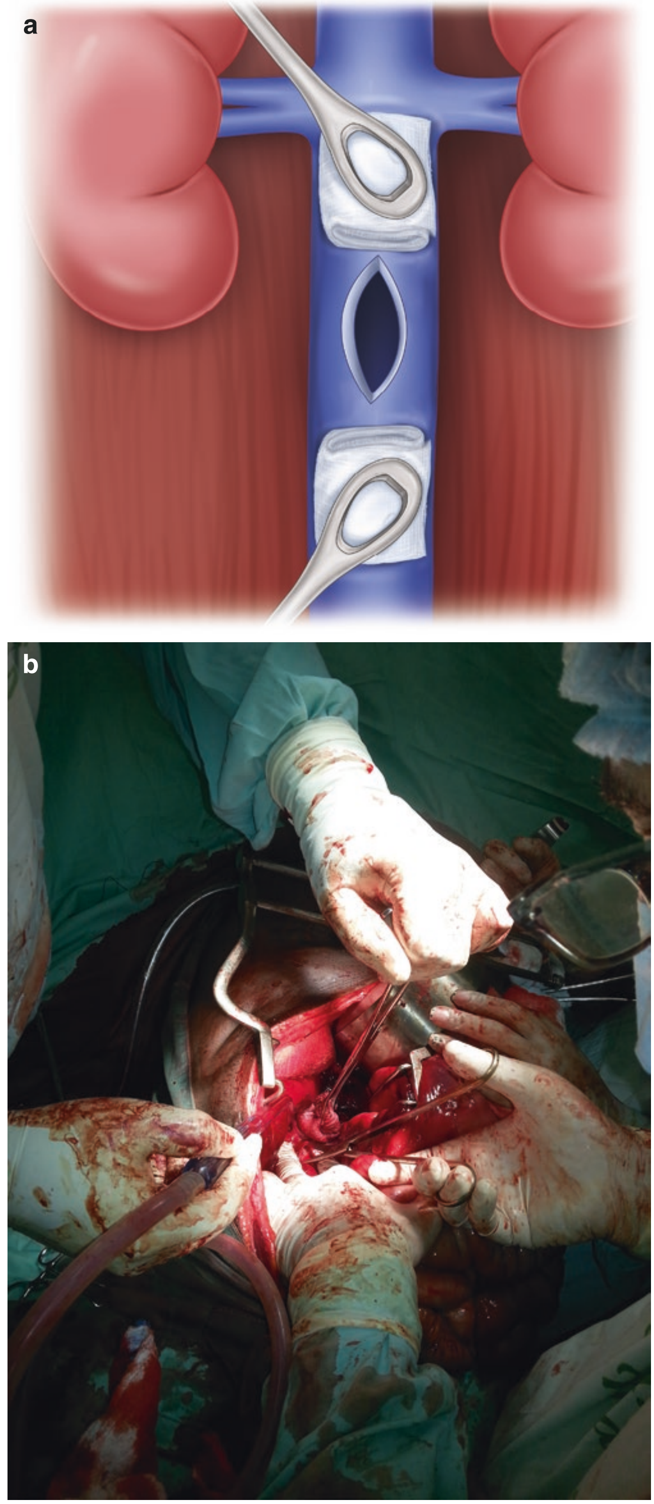

Fig. 8.3 (**a**) and (**b**) Sponges

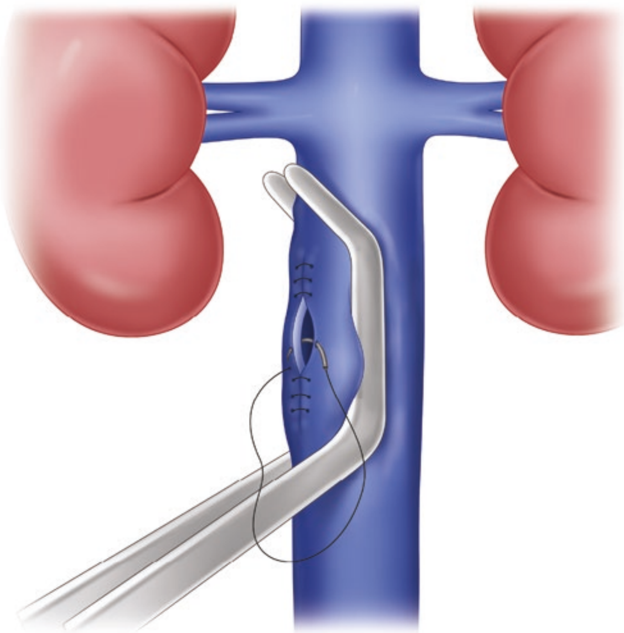

Fig. 8.4 Clamp lateral to the injury

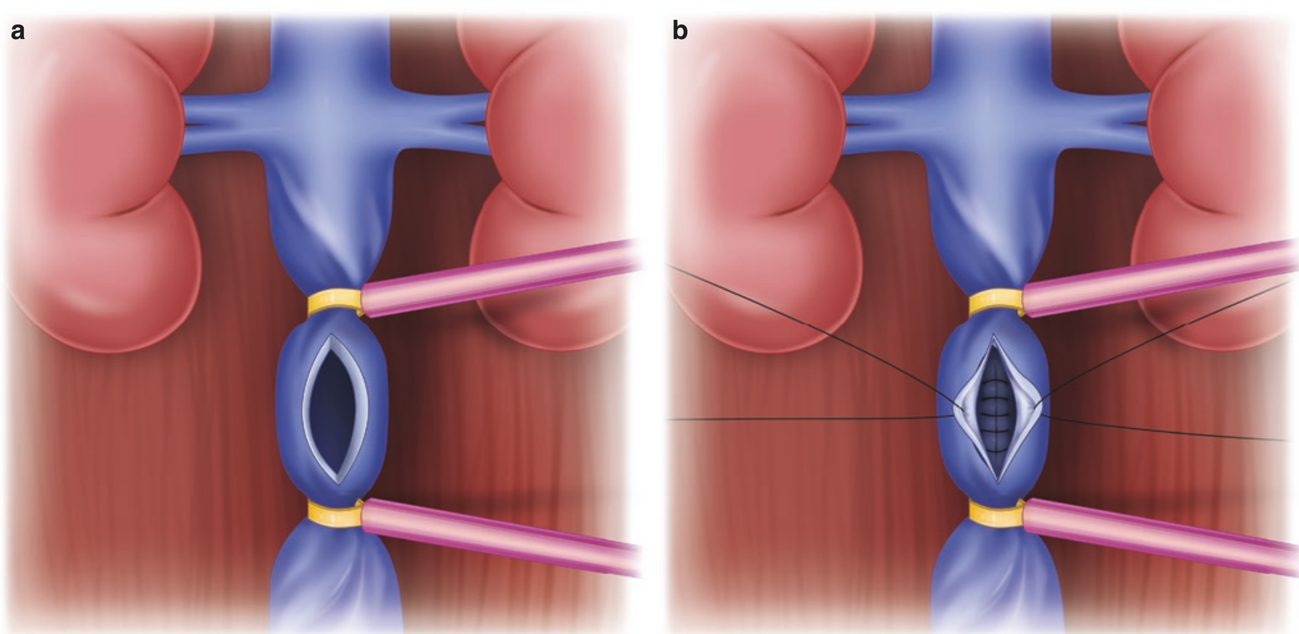

Fig. 8.5 (**a**) and (**b**) Posterior injury can be repaired through the anterior hole or by twisting the vein under proximal and distal control. If necessary, the anterior hole can be enlarged

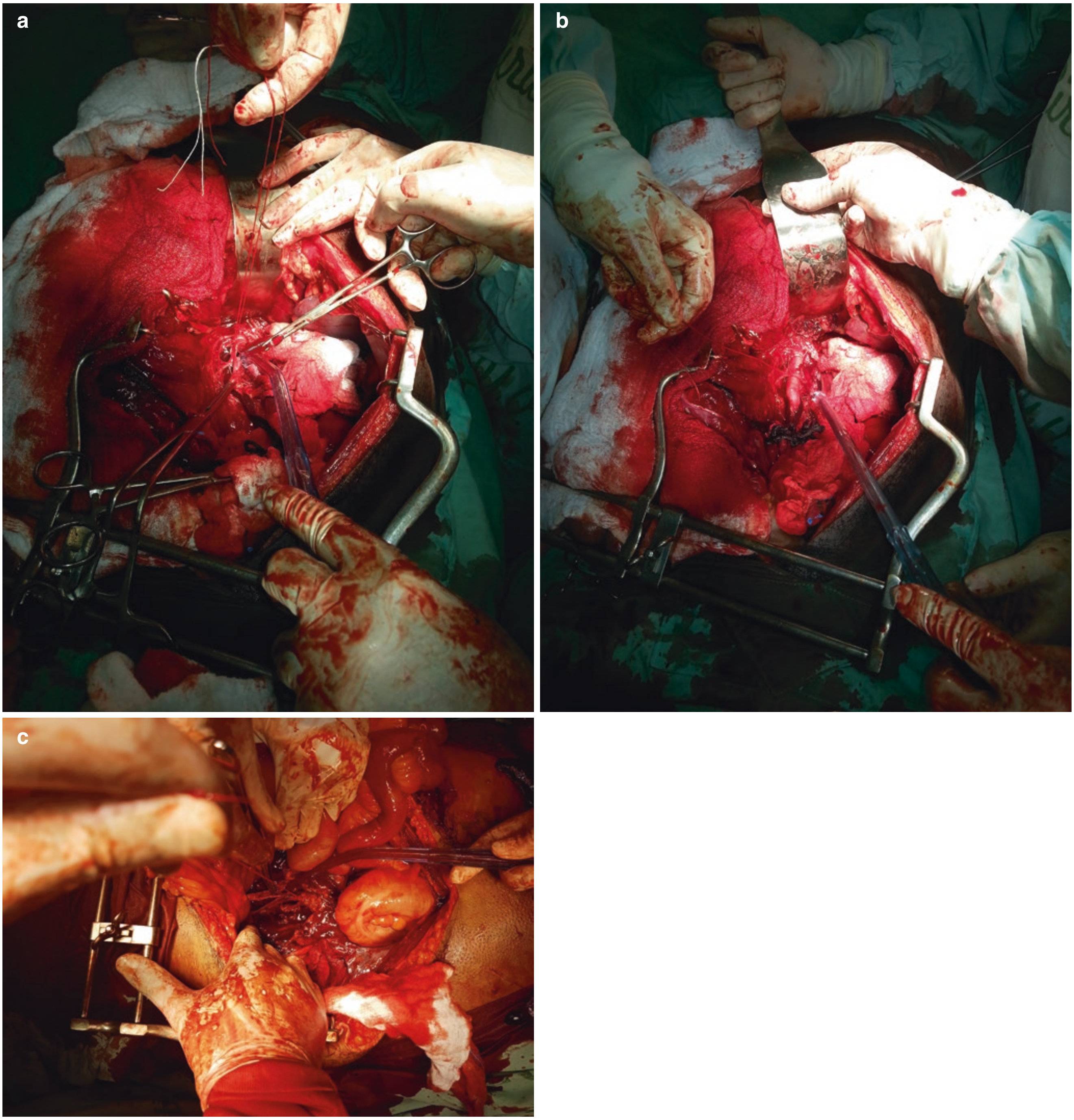

Fig. 8.6 (**a**) and (**b**) Shunt. (**c**) Destruction

Suggested Reading

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Genitourinary Operations in Trauma

9

Asanthi Ratnasekera and Paula Ferrada

Introduction

Genitourinary injuries are infrequent consequences of trauma, but may carry significant morbidity and mortality if not treated and recognized promptly. Genitourinary injuries are seen about 1–5% of all traumas, with 80% of injuries related to the kidney. The majority of genitourinary injuries are related to blunt trauma. While controversies exist on the management of various genitourinary trauma using nonoperative management, we hope to guide the surgeon on the operative management of genitourinary trauma when encountered.

Renal Injury

Renal Anatomy

Understanding renal anatomy is important to the diagnosis and operative management of renal injuries. The kidneys are located in the retroperitoneum and are covered by Gerota's Fascia. Gerota's fascia is a thick fibrous capsule that overlies the kidneys, allowing tamponade of bleeding and containment of urinary leaks in the retroperitoneum. The diaphragm covers the upper poles of the kidney posteriorly. The kidneys lie on the psoas muscle and are bounded laterally by the quadratus lumborum muscle.

The right kidney is bounded medially by the lateral portion of the duodenum. The hepatic flexure is anterior to the lower pole of the right kidney.

The left kidney is bounded superiorly by the pancreatic tail and inferiorly by the splenic flexure of the colon.

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After entering Gerota's fascia, the renal vein lies the most anterior, followed by the renal artery and the renal pelvis.

The right renal vein is shorter than the left renal vein and directly drains into the IVC. The left renal vein is longer and courses underneath the superior mesenteric artery. The gonadal vein, lumbar veins, and the left adrenal vein drain into the left renal vein. The length of the renal vein allows for the left renal vein to be divided close to the IVC if needed (Fig. 9.1).

Each renal artery has five branches: the apical, superior, middle, lower, and posterior branches. Approximately 25% of kidneys receive accessory arterial supply directly from the aorta.

AAST grading of Renal Injury (Fig. 9.2)

Nephrectomy

Indications

- Unstable patient with the kidney being the source of hemorrhage
- Failed attempts at partial nephrectomy
- Extensive injury to the kidney where repair is not warranted
- Avulsion injuries to the renovascular pedicle
- Avulsion of the fornices seen more commonly in pediatric population

Technique

1. Patient position: standard trauma laparotomy position—supine with both arms abducted to 90 degrees.
2. Prep patient from mandible to thighs above the knee as in a standard trauma laparotomy fashion.
3. Standard laparotomy incision with use of self-retaining abdominal retractor, such as a Bookwalter.

P. Ferrada, R. Ferrada (eds.), *Atlas of Trauma*, https://doi.org/10.1007/978-3-030-26871-8_9

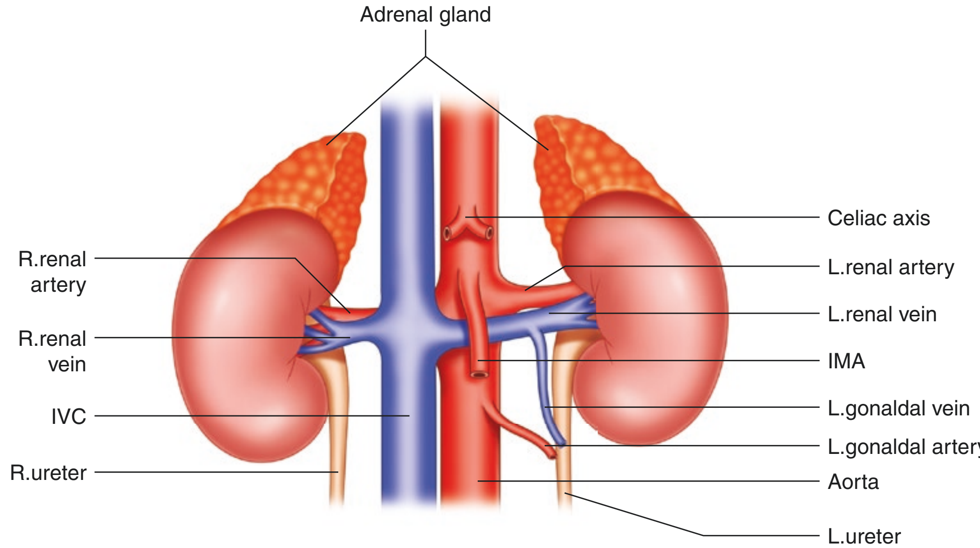
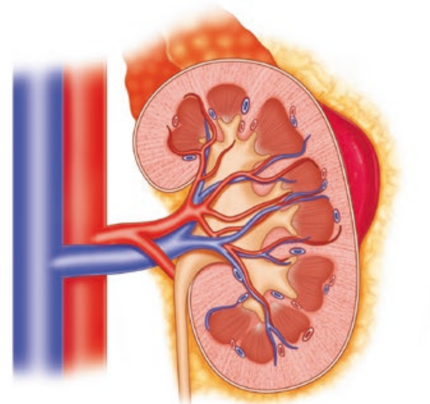


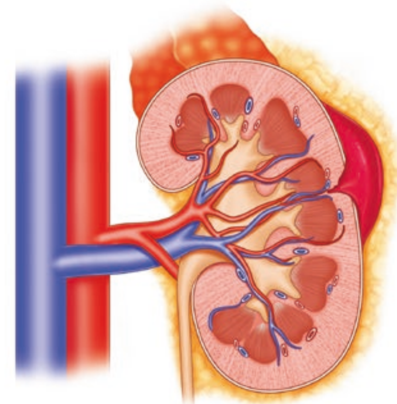
Fig. 9.1 Renal vascular anatomy

4. Proximal renal vascular control increases the chance of kidney salvage. In an unstable patient, however, this may not be feasible. Clinicians have debated the proximal renal vascular control method gaining higher likelihood of kidney salvage.
5. It is important to determine the presence and functionality of the contralateral kidney, whether by Focused Assessment with Sonography in Trauma (FAST) exam or by CT scan to look at architectural anatomy of the kidney prior to nephrectomy. In the unstable hemorrhaging patient this may not be accomplished other than by direct visualization to confirm the presence of the contralateral kidney.
6. Proximal renal vascular control (Fig. 9.3)
   (a) The transverse colon is retracted cephalad.
   (b) The small bowel is gathered in a moist towel and retracted to the right upper quadrant and packed away with a broad malleable retractor.
   (c) The root of the mesentery and Ligament of Treitz is identified.
   (d) The retroperitoneum is incised lateral to the aorta medial to the inferior mesenteric vein. The incision is carried superiorly on the aorta until the renal vessels are identified.
   (e) The renal vein and artery are dissected, and vessel loops placed around the vessels.
7. Exposure of the kidneys require medial visceral rotation.
   (a) Left kidney
      (i) Perform Mattox maneuver to expose the left kidney.
      (ii) Incise along white line of Toldt and reflect the left colon medially.
      (iii) Make a generous incision on the Gerota's Fascia anteriorly. Use blunt and sharp dissection to deliver the kidney out of the retroperitoneum.
   (b) Right kidney
      (i) Perform Cattell-Braasch maneuver to expose right kidney
      (ii) Incise the retroperitoneum lateral to the third portion of the duodenum to perform Kocher maneuver to get better access to the right renal vessels.
8. The renal vein and renal artery are separately ligated using 0 silk ties near the hilum to avoid the potential for developing an arteriovenous fistula. Consider oversewing the short right renal vein with a continuous 3-0 Prolene suture.
9. Ligate the ureter near the kidney using 2-0 silk suture.
10. Ligate the left gonadal if necessary.
11. Identify any accessory arterial vessels from the aorta and ligate using silk suture.

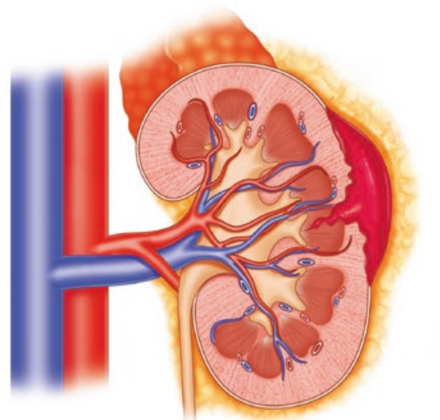
Fig. 9.2 AAST Renal Injury Grading



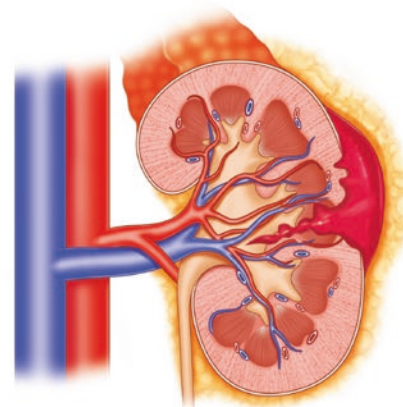
I. Contusion Microscopic or gross hematuria, urologic studies normal
Hematoma Subcapsular, nonexpanding without parenchymal laceration



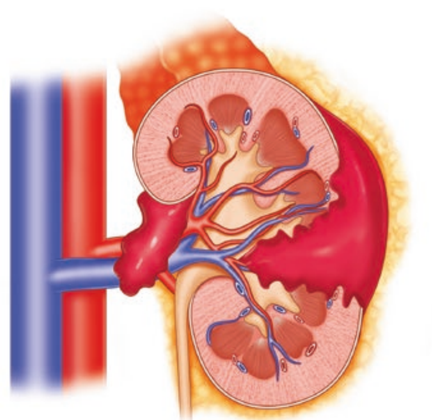
II. Hematoma Nonexpanding perirenal hematoma confined to renal retroperitoneum
Laceration <1.0 cm parenchymal depth of renal cortex without urinary extravasation



III. Laceration <1.0 cm parenchymal depth of renal cortex without collecting system involvement



IV. Laceration Parenchymal laceration extending through renal cortex, medulla, and collecting system Vascular Main renal artery or vein injury with contained hemorrhage



V. Laceration Completely shattered kidney Vascular Avulsion of renal hilum which devascularizes kidney

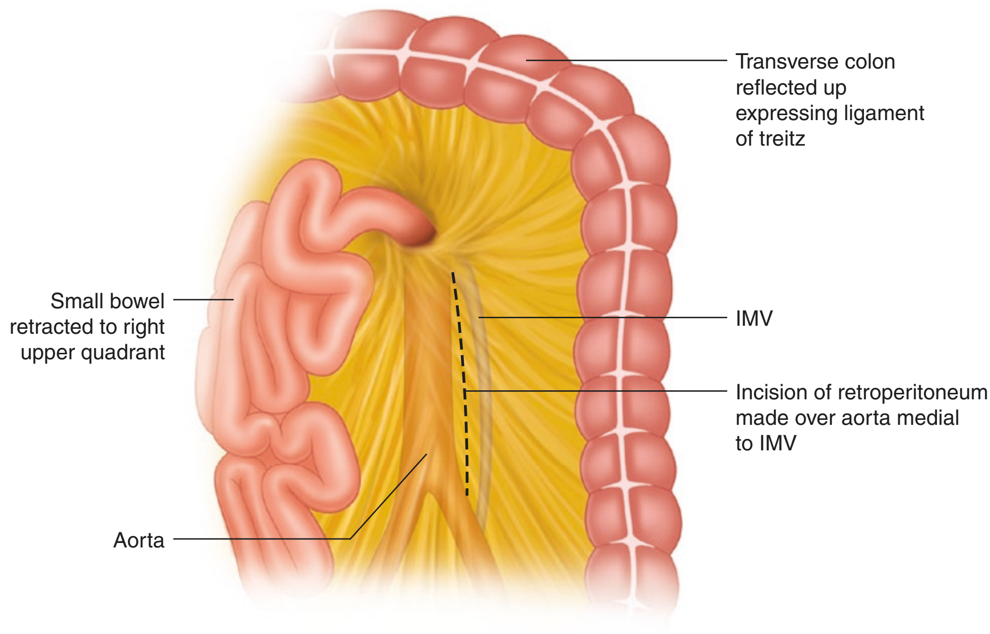


Fig. 9.3 The incision of the retroperitoneum to obtain renal vascular control. Medial to the IMV and just lateral to the aorta

Complications and Management

- Need for dialysis due to complications of renal failure and other organ dysfunction in patients with high injury severity scores.
- Retroperitoneal abscess: treated with percutaneous drainage and antibiotics.
- Arteriovenous fistula or renal artery pseudoaneurysm: may be treated with interventional radiology embolization and close radiologic monitoring.
- Mortality related to concurrent injuries.

Partial Nephrectomy/Renorrhaphy

Indications

- During laparotomy for intra-abdominal injuries an expanding retroperitoneal (Zone 2)
- Hematoma may be identified requiring renal exploration
- Hemodynamically stable patient
- Renal cortical disruption

Technique

1. Patient position: standard trauma laparotomy position—supine with both arms abducted to 90 degrees. A Foley catheter must be placed.
2. Prep patient from mandible to thighs above the knee as in a standard trauma laparotomy fashion.
3. Standard laparotomy incision with use of self-retaining abdominal retractor, such as a Bookwalter.
4. If there is an expanding Zone 2 retroperitoneal hematoma suspicious for kidney injury, hemorrhage is controlled by gaining proximal vascular control of the renal vessels as described above.
5. Medial visceral rotation as described above (see section "Technique", no. 7).
6. Incision over Gerota's Fascia anteriorly and exposing kidney.
7. Evacuate the hematoma. If there is cortical disruption, carefully evacuate the hematoma underneath the renal capsule and attempt to preserve the renal capsule.
8. Identify any injured collecting system. Suture ligate with 4-0 absorbable suture. Using absorbable suture prevents renal calculi formation along the suture. Collecting duct system repairs needs to be watertight to prevent future urinoma and urine extravasation.
9. Sharply excise devitalized tissue.
10. Control any parenchymal bleeding with 3-0 or 4-0 absorbable suture. Topical hemostatic agents may be used to obtain hemostasis.
11. Pledgeted sutures may be used to close the defect, if small (Fig. 9.4).
12. Polar cortical disruptions can be managed with a guillotine approach by transecting renal parenchyma down to healthy bleeding tissue (Fig. 9.5).
13. If the renal capsule can be preserved, close the renal capsule over the parenchyma using 3-0 Vicryl suture in a running fashion, with or without the aid of pledgets.

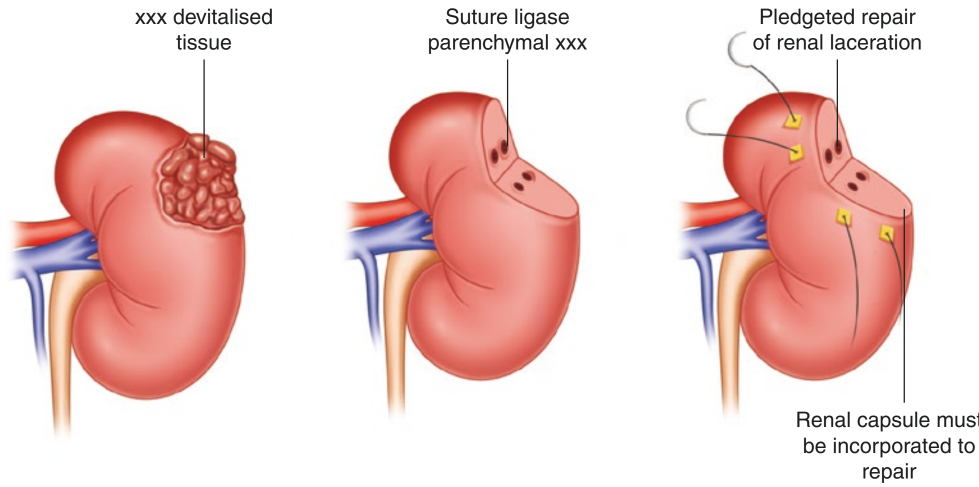


Fig. 9.4 Renorrhaphy, pledgeted Renorrhaphy

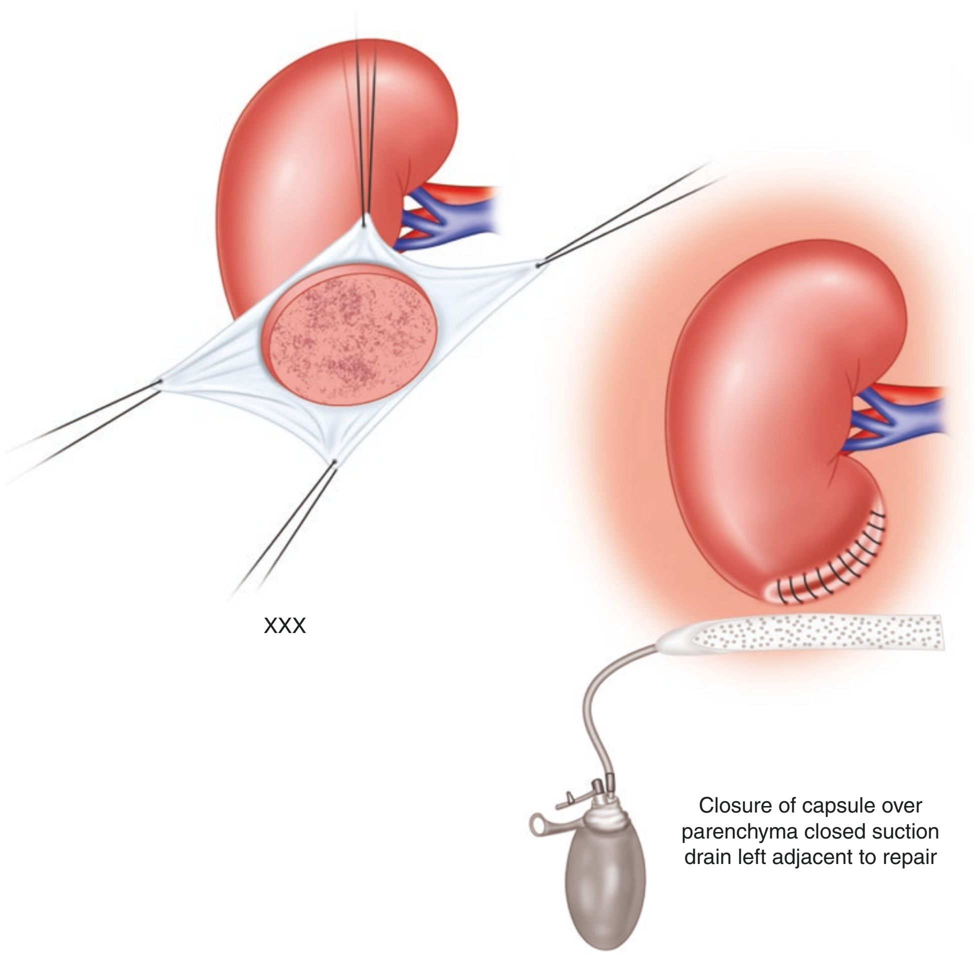


Fig. 9.5 Partial Nephrectomy. Guillotine of lower pole of kidney with preservation of renal capsule. Renal capsule closed with a running suture

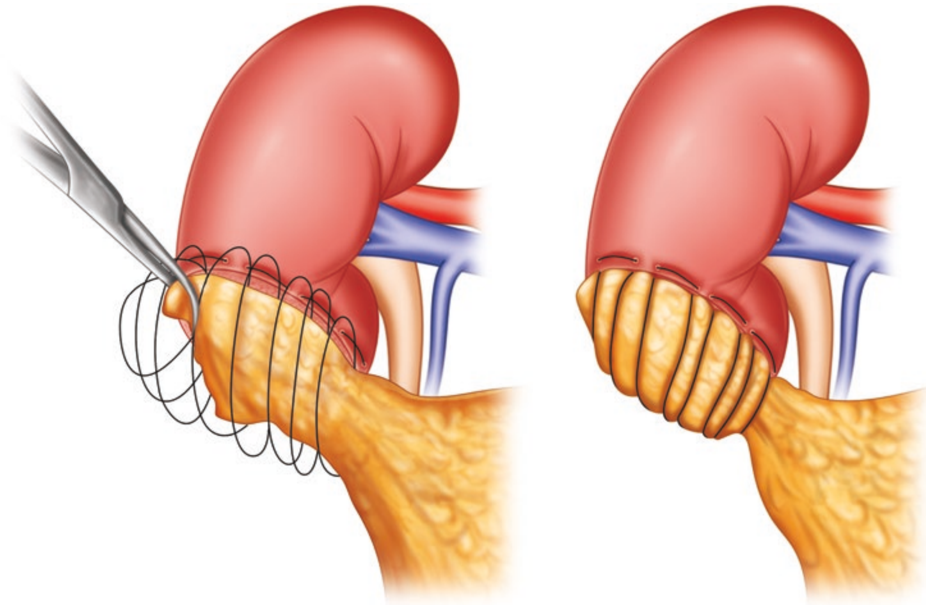


Fig. 9.6 Omental Flap closure of Guillotined kidney. If the defect is large and renal capsule is unable to be preserved, and omental flap can be mobilized for closure of defect

14. If the renal capsule is disrupted, an omental flap can be used and sutured to healthy renal capsule using 3-0 Vicryl suture. If omentum is not available, Gelfoam or fibrin sealant may be used. Do not attempt to close the capsule over a large parenchymal defect, as that will cause further tearing and bleeding (Fig. 9.6).
15. A closed suction drain is left next to the kidney.
16. If there is concern regarding the repair of the collecting system, consider a placement of nephrostomy or an internal JJ stent.

Complications and Management

- Need for dialysis due to complications of renal failure and other organ dysfunction in patients with high injury severity scores.
- Retroperitoneal abscess: treated with percutaneous drainage and antibiotics.
- Urinoma or urine extravasation from repair: will need percutaneous drainage of urinoma and nephrostomy or internal ureteral stent for diversion of urine.
- During debridement of the renal parenchyma, renal capsule is compromised: will need to preserve as much healthy renal capsule as possible. Buttress large defects with omentum or fibrin sealant as described above.
- Renovascular injury causing renal artery thrombosis: will need interventional radiology for endoluminal stenting and thrombectomy.
- Goldblatt Kidney Phenomenon: post-injury hypertension or secondary hypertension is treated medically with antihypertensives. If medical management fails, the patient will need a delayed nephrectomy.
- Arteriovenous fistula or renal artery pseudoaneurysm: may be treated with interventional radiology embolization and close radiologic monitoring.

Ureteral Injuries

Ureteral Anatomy

Ureteral injury should be promptly diagnosed and treated to prevent acute renal failure, sepsis from urine leaks, and death. In penetrating trauma with retroperitoneal hematomas in Zone 2, the retroperitoneum must be explored to rule out ureteral injuries. The approach to ureteral injury depends on the location of the injury. The ureter is anatomically divided into three areas: the proximal, mid, and distal ureter.

The proximal ureter is above the iliac bifurcation. The mid ureter is between the iliac bifurcation and pelvis. The distal ureter is located below the internal iliac artery.

The proximal ureter receives its blood supply directly from the renal arteries. The mid ureter receives blood supply from the branches of the aorta, the common iliac, and gonadal arteries. The nutrient branches course medially when entering the ureter. The distal ureter receives blood supply from the branches of the internal iliac artery. These nutrient branches course laterally into the ureter.

The ureter courses inferiorly from the kidneys in the retroperitoneum. The gonadal vessels cross over the ureter proximally. The genitofemoral nerve courses behind the ureter on top of the psoas muscle. At the pelvic brim the ureter crosses over the common iliac vessels near the bifurcation. The ureter then dives into the pelvis. In females it courses posterior to the ovary and courses next to the uterine vessels. In males the ureter runs parallel to the inferior hypogastric plexus and artery to the vas deferens before entering the bladder.

The ureter runs obliquely into the bladder wall and is encased in the muscular layer of Waldeyer, which joins the detrusor muscle.

Ureteral Repair

In damage control conditions where the patient is not hemodynamically stable for a ureteral reconstruction, a stent can be placed into the proximal ureter, into the kidney, and brought out through the abdominal wall and secured into the abdominal wall.

The proximal and distal ends of the ureter can also be ligated and marked with suture for a second-look operation for reconstruction. A nephrostomy for the kidney may not be needed if a second-look operation is planned for 48–72 hours postoperatively.

Ureteroureterostomy

Indications

- Proximal to mid ureteral injury
- Hemodynamically stable patient with control of hemorrhage

Technique

1. Patient position: standard trauma laparotomy position—supine with both arms abducted to 90 degrees. A Foley catheter must be placed.
2. Prep patient from mandible to thighs above the knee as in a standard trauma laparotomy fashion.
3. Standard laparotomy incision with use of self-retaining abdominal retractor, such as a Bookwalter.
4. Medial visceral rotation as described above (see section "Technique", no. 7).
5. Identify the ureter and examine the extent of the injury.
6. Do not skeletonize the ureter to devitalize it.
7. Mobilize the ureter to allow for tension-free anastomosis.
8. Spatulate the ends of the ureter to prevent stenosis of the anastomosis (Fig. 9.7).
9. Place 4-0 or 5-0 absorbable suture at the corner of each end of the ureter.
10. Place indwelling double J stent into proximal and distal ureter.

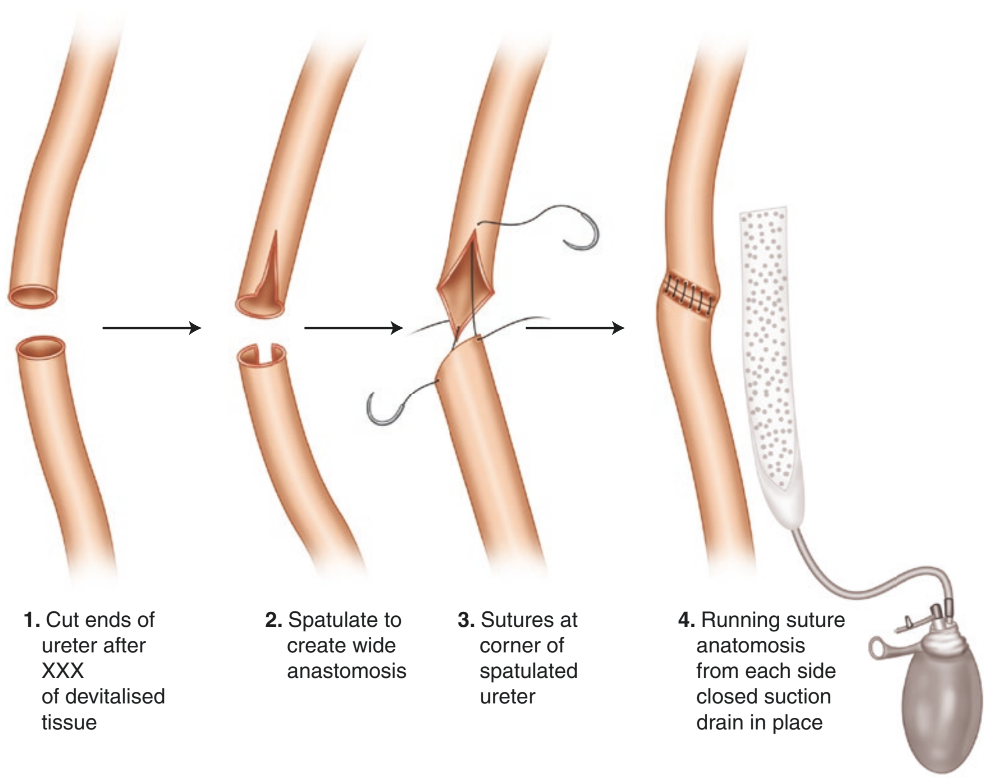


Fig. 9.7 Ureteroureterostomy Spatulating the urether

11. Perform tension-free anastomosis with running 4-0 or 5-0 absorbable Vicryl or PDS suture from the corners of the spatulated ureter edges.
12. Place drain at the anastomosis.
13. An omental flap may be used to cover the ureteral anastomosis.

Psoas Hitch

Indications

- Mid to distal ureter injury
- Inability to perform a direct ureteroureterostomy without tension
- Ureteral defect of 5–8 cm

Technique

1. Patient position: standard trauma laparotomy position—supine with both arms abducted to 90 degrees. A Foley catheter must be placed.
2. Prep patient from mandible to thighs above the knee as in a standard trauma laparotomy fashion.
3. Standard laparotomy incision with use of self-retaining abdominal retractor, such as a Bookwalter.
4. Medial visceral rotation as described above (see section "Technique", no. 7).
5. Identify the ureter and examine the extent of the injury.
6. Do not skeletonize the ureter to devitalize it.
7. Mobilize the ureter to allow for tension-free anastomosis and place a stay suture at the end of the proximal ureter.
8. The distal ureter is transected and ligated at the level of the bladder.
9. The bladder is filled with 300–350 cc of saline through the Foley catheter.
10. The peritoneum is dissected off the bladder.
11. The median and medial umbilical ligaments are divided to allow mobilization of the bladder.
12. Two stay sutures are placed on the bladder 4–5 cm apart and an oblique incision is made between the two stay sutures (Fig. 9.8).
13. The index finger is placed inside the bladder to raise the bladder to the psoas muscle above the level of the common iliac artery.
14. Two-to-three interrupted absorbable sutures (PDS) are placed through the tendon of the psoas muscle and through the bladder, avoiding the mucosa. These sutures are left without tying with clamps placed on each suture. Be careful to avoid injury of the genitofemoral nerve on the psoas muscle (Fig. 9.9).
15. Using a Metzenbaum scissor, a submucosal plane is created below the mucosa and above the detrusor muscle. Stay sutures are placed at either side of the entrance of the tunnel.
16. The tunnel should be approximately 4–5 cm in length. The tunnel width should be confirmed by adequate dilation with the Metzenbaum scissors. At the end of the tunnel, the bladder mucosa is excised (Fig. 9.10).
17. A clamp is inserted through the tunnel toward the ureter and the ureter is grabbed by its stay suture and pulled through the tunnel.

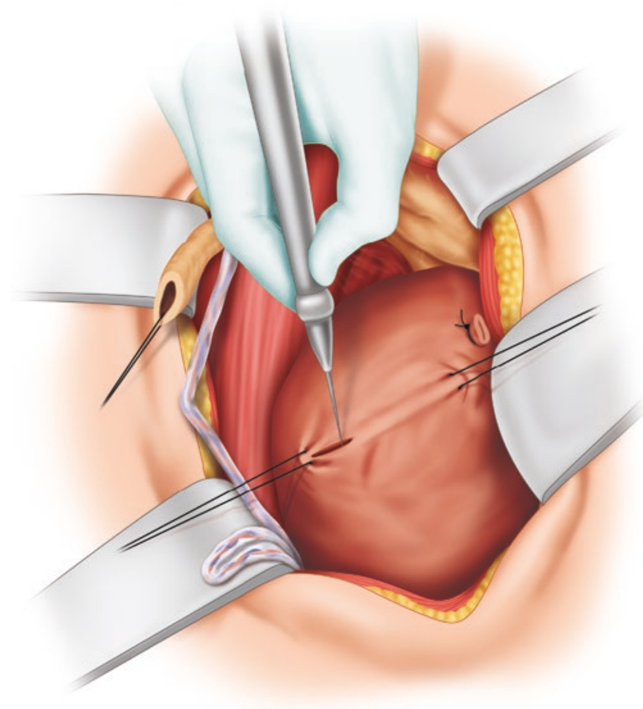


Fig. 9.8 Psoas Hitch. Bladder incised between two stay sutures

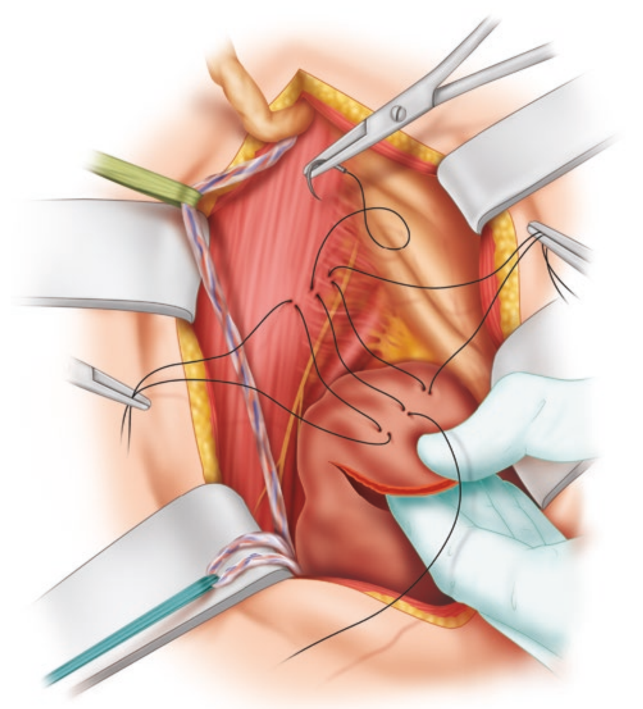


Fig. 9.9 The bladder flap is sutured to the psoas tendon with three interrupted sutures

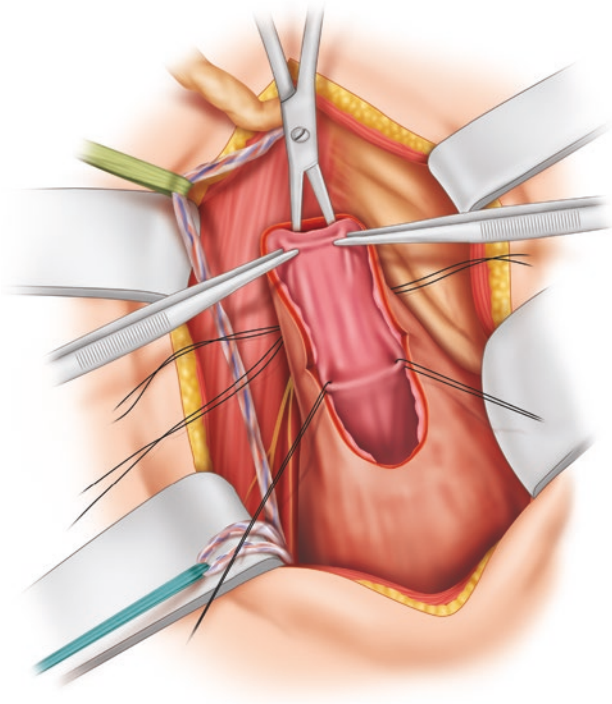


Fig. 9.10 Creation of the submucosal plane with Metzenbaum scissors

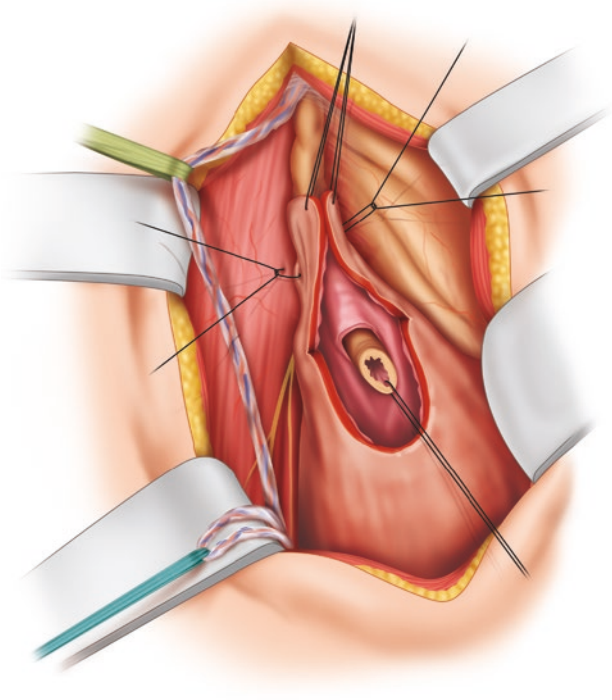


Fig. 9.11 The proximal end of the ureter with stay suture is pulled through the submucosal tunnel using the stay suture. The entrance of the tunnel is sutured to the psoas tendon on either side

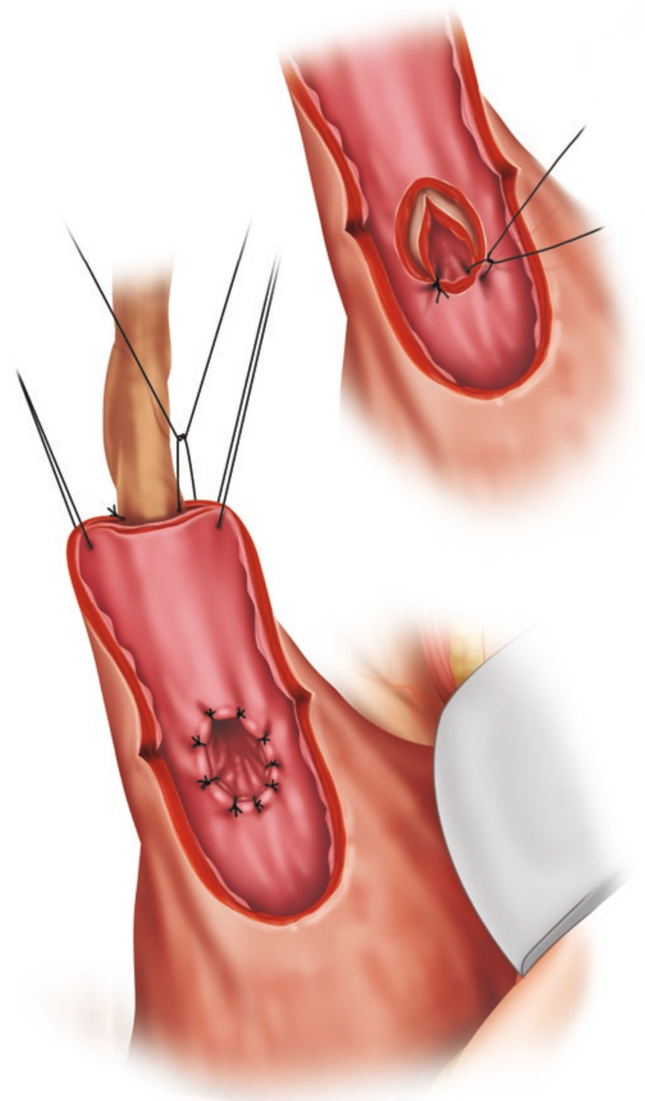


Fig. 9.12 The end of the ureter is spatulated. Ureter to bladder mucosal interrupted sutures are placed

18. The ureter is brought through the opening of the bladder mucosa (Fig. 9.11).
19. The ureteral edge is spatulated. Two stay sutures are placed through the bladder mucosa, detrusor muscle, and the ureter wall using 5-0 or 6-0 monofilament absorbable suture.
20. At the entrance of the tunnel, the adventitia of the ureter is anchored to the detrusor muscle using 5-0 or 6-0 monofilament absorbable suture (Fig. 9.12).
21. The rest of the ureteral orifice to the bladder is completed using 5-0 or 6-0 absorbable monofilament suture, suturing the bladder mucosa to the ureteral wall in an interrupted fashion.
22. The sutures to the psoas muscle are now tied down.
23. A ureteral stent is placed through the neo-orifice of the ureter into the bladder.

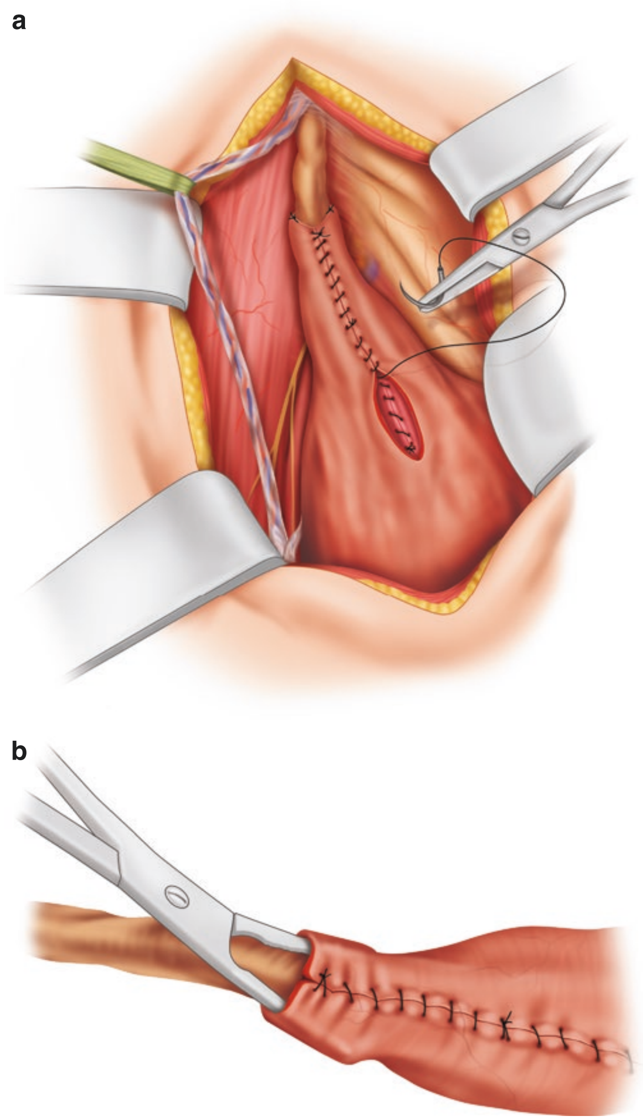


Fig. 9.13 Ureteral stent place into the bladder through neoureterocystostomy. The bladder is closed in two layers

24. The bladder is closed in two layers using 2-0 or 3-0 monofilament absorbable suture. This to avoid formation of calculi with non-absorbable suture for the mucosal layer and then the detrusor muscle layer (Fig. 9.13).
25. Closed suction drains are placed around the neoureterocystostomy.

Boari Bladder Flap

Indications

- Distal ureteral injury
- Inability to perform tension-free anastomosis with psoas hitch and ureteric defects greater than 6–8 cm in length.

Technique

1. Patient position: standard trauma laparotomy position—supine with both arms abducted to 90 degrees. A Foley catheter must be placed.
2. Prep patient from mandible to thighs above the knee as in a standard trauma laparotomy fashion.
3. Standard laparotomy incision with use of self-retaining abdominal retractor, such as a Bookwalter.
4. Medial visceral rotation as described above (see section "Technique", no. 7).
5. Identify the ureter and examine the extent of the injury.
6. Do not skeletonize the ureter to devitalize it.
7. Mobilize the ureter to allow for tension-free anastomosis and place a stay suture at the end of the proximal ureter.
8. The distal ureter is transected and ligated at the level of the bladder.
9. The bladder is filled with 300–350 cc of saline through the Foley catheter.
10. The peritoneum is dissected off the bladder.
11. The median and medial umbilical ligaments are divided to allow mobilization of the bladder.
12. Two stay sutures are placed on the bladder 4–5 cm apart, and a rhomboid-shaped incision is made over the bladder with a broad base (Fig. 9.14).

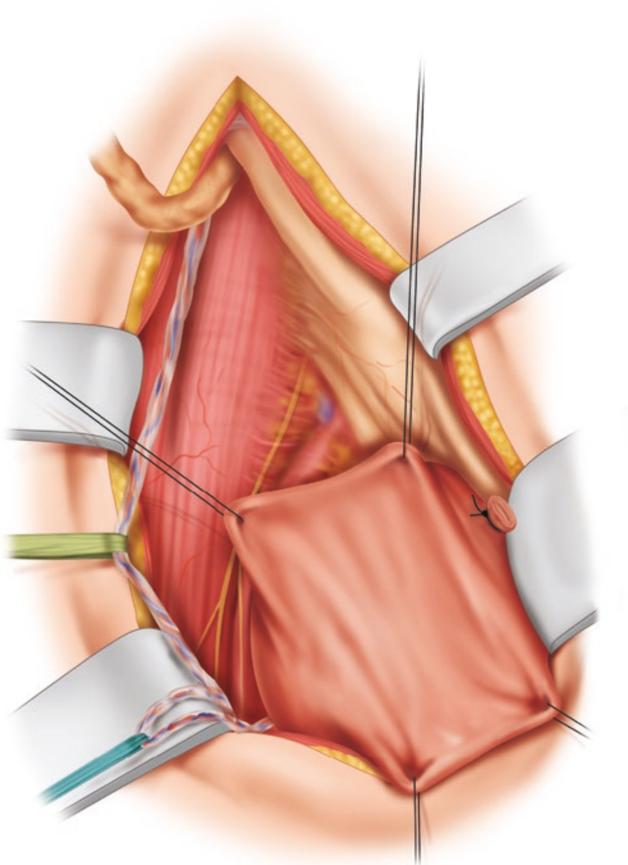


Fig. 9.14 Boari Flap. Stay sutures placed. A rhomboid incision made on the bladder wall

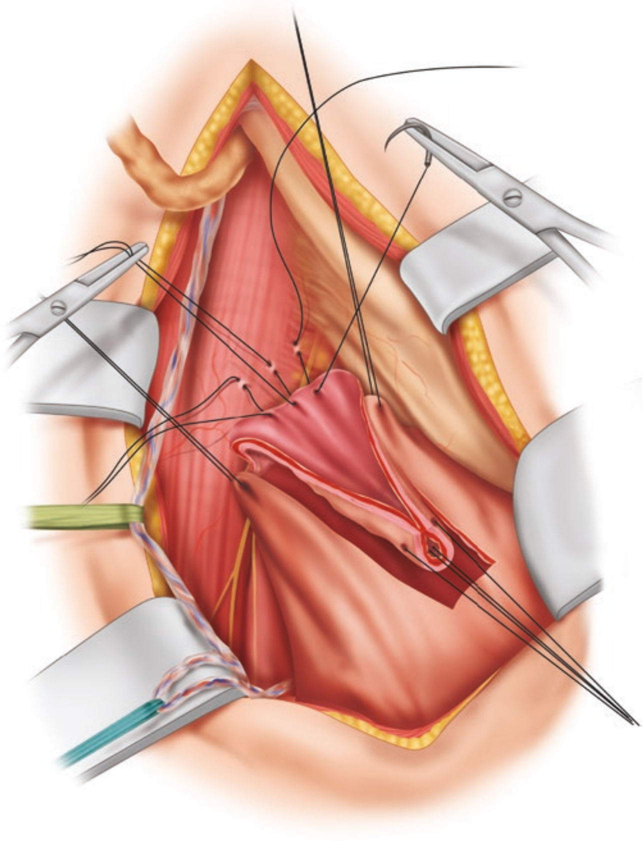


Fig. 9.15 Bladder flap is sutured to the psoas tendon. Submucosal plane and tunnel created

13. The bladder flap is fixed to the tendon of the psoas using 3-0 monofilament absorbable suture in an interrupted fashion.
14. The stay sutures are tied down to the psoas tendon.
15. A submucosal plane is created using Metzenbaum scissor below the mucosa and above the detrusor muscle. Stay sutures are placed at either side of the entrance of the tunnel.
16. The tunnel should be approximately 4–5 cm in length. The tunnel width should be confirmed by adequate dilation with the Metzenbaum scissors (Fig. 9.15).
17. A clamp is inserted through the tunnel toward the ureter and the ureter is grabbed by its stay suture and pulled through the tunnel.
18. The ureter is brought through the opening of the bladder.
19. The ureteral edge is spatulated. Two stay sutures are placed through the bladder mucosa, detrusor muscle, and the ureter wall using 5-0 or 6-0 monofilament absorbable suture.
20. At the entrance of the tunnel, the adventitia of the ureter is anchored to the detrusor muscle using 5-0 or 6-0 monofilament absorbable suture (Fig. 9.16).
21. The rest of the ureteral orifice to the bladder is completed using 5-0 or 6-0 absorbable monofilament suture, suturing the bladder mucosa to the ureteral wall in an interrupted fashion.
22. A ureteral stent is placed through the neo-orifice of the ureter into the bladder.
23. The bladder is closed in two layers using 2-0 or 3-0 monofilament absorbable suture for the mucosal layer and then the detrusor muscle layer.
24. Closed suction drains are placed around the neoureterocystostomy.
25. Internal stents should be maintained for 4–6 weeks postoperatively and removed endoscopically after a CT urography or retrograde pyelogram.

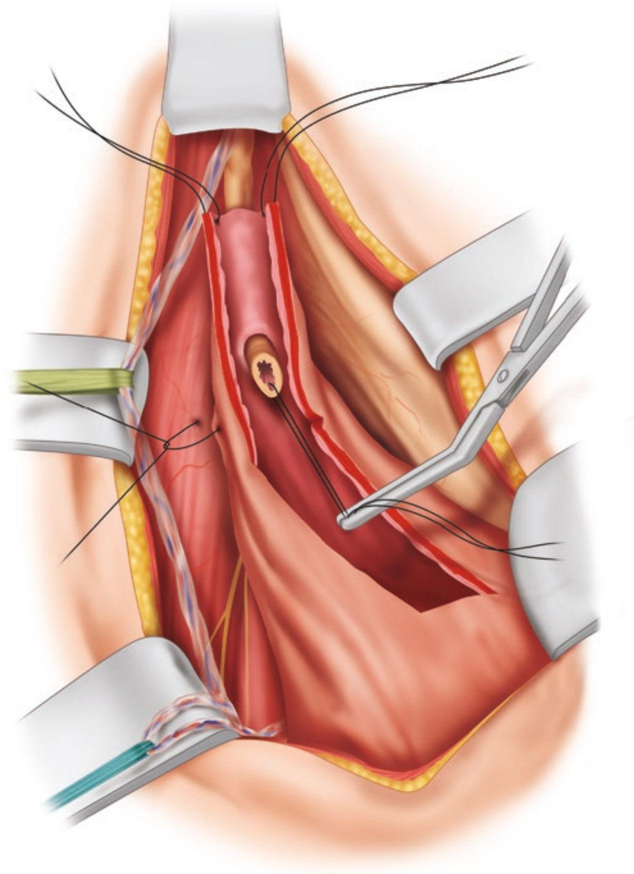


Fig. 9.16 The proximal ureter advanced through tunnel using stay suture at the proximal end. Stay sutures to the psoas tendon tied down

Complications and Management

- Urinoma or urine leak: treated with drainage and maintaining stenting of the anastomosis.
- Anastomotic stricture if ends of the ureters are not spatulated: will need endoscopic balloon dilation or reconstruction or revision of the ureter.
- Ischemia of the anastomosis due to extensive ureteral skeletonization and dissection and stricture: may need revision of ureteral anastomosis.

Bladder Repair

Indications

- Intraperitoneal bladder injuries from trauma
- Select blunt extraperitoneal rupture
- All-penetrating injury to the bladder

Technique

1. Patient position: standard trauma laparotomy position—supine with both arms abducted to 90 degrees. A Foley catheter must be placed.
2. Prep patient from mandible to thighs above the knee as in a standard trauma laparotomy fashion.
3. Consider prepping genitalia into the sterile field so that a Foley catheter may be manipulated during surgery.
4. Standard laparotomy incision with use of self-retaining abdominal retractor, such as a Bookwalter.
5. Most likely the bladder injury is located in the dome of the bladder. If there is penetrating injury, the peritoneal surface of the bladder is examined and anterior cystostomy is created to enter the bladder.
6. The interior of the bladder should be palpated and examined for clear efflux from both ureteral orifices at the trigone of the bladder. An extension of the laceration may be needed to perform this.
7. The devitalized tissue from the edges of the laceration is debrided.
8. Foley catheter should be placed for bladder drainage.
9. The laceration should be repaired in two layers.
10. 3-0 or 4-0 absorbable suture is used to repair in the inner layer in a running or running locking fashion for hemostasis and hydrostasis.
11. The outer layer is closed in a lambert fashion using 2-0 or 3-0 absorbable suture (Fig. 9.17)
12. A closed suction drain is placed.
13. Test the closure by instilling 200–300 cc of sterile saline through the existing Foley catheter.
14. The Foley catheter is maintained for 7–10 days. Depending on the complexity of repair, consider a cystogram prior to removal of the Foley catheter.
15. Drains may be removed when output is minimal.

Complications and Management

- Missed injuries during the first exploration of the bladder.
- Missed ureteral injuries from not seeing clear efflux from the ureteral orifices: will need a CT urogram to evaluate for ureteral injury.
- Persistent urine leak at 7–10 days: consider maintaining Foley catheter drainage for another 7–10 days and repeating cystogram.

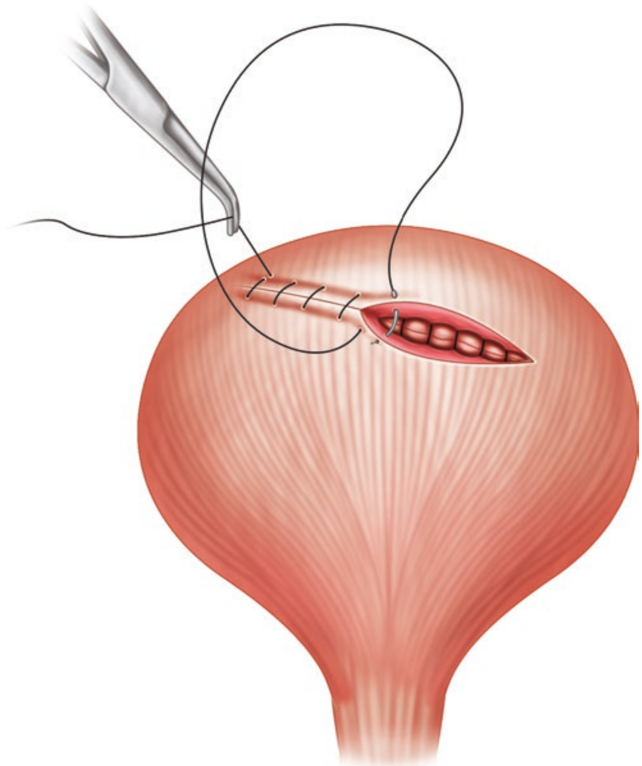


Fig. 9.17 The bladder is repaired in two continuous layers

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10 Vascular Exposures in the Upper Extremities

Ana Milena Del Valle and Juan Carlos Herrera

Introduction

Owing to technological advances and lessons learned in modern wars, vascular trauma management has undergone multiple changes. Despite this, acute traumatic hemorrhage remains responsible for 90% of military and 40% of civilian deaths, with vascular injuries of the extremities being the most frequent. According to the Western Trauma Association (WTA), peripheral vascular trauma is defined as injury to the axillobrachial axis and its branches in the upper extremity, or trauma of the femoral-popliteal axis and its collaterals in the lower limb. Forty to 75% of these injuries are secondary to penetrating trauma, mainly gunshot, while blunt trauma occurs in approximately 5–25% of cases. In the upper extremity, brachial artery has the highest incidence of injury. When we confront vascular trauma, physical examination will lead us to its management and treatment, which will be informed by the hemodynamic stability of the patient and the presence of hard or soft signs. In the asymptomatic patient, physical examination and the ankle-brachial index (ABI) or ankle-brachial pressure index (ABPI) will allow a triage management. Currently, the gold standard study for vascular injuries is the Computed Tomography Angiography (CTA). The findings of this test will lead to the type of treatment to be performed, from medical management of vasospasm to endovascular and classic techniques of open surgery.

The principles of definitive vascular repair include adequate exposure of the traumatized area, proximal and distal control of the injury, debridement, Fogarty catheter to clear the vessel clots, heparin for local use and repair of the lesion through a arteriorrhaphy, primary anastomosis and graft interposition. Ignoring the principles of vascular repair can lead to serious consequences for both limb and patient, resulting in amputation or even death.

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Vascular Exposure of the Upper Extremity

Axillary Artery Injury

Surgical Anatomy

The axillary artery is the direct continuation of the subclavian artery. It starts from the lateral border of the first rib to the lateral border of the teres major muscle and continues on as the brachial artery. The axillary artery is divided into three portions by the pectoralis minor muscle: medial, posterior, and lateral to the muscle. The medial portion extends from the lateral edge of the first rib to the medial border of the pectoralis minor muscle, and it is covered bythe clavipectoral fascia and the clavicular head of the pectoralis major muscle. In this portion, it has a single branch, the supreme thoracic artery. The posterior portion lies beneath the pectoralis minor muscle, where it gives rise the two most important branches: the thoracoacromial and the lateral thoracic artery. In this portion, the cords of brachial plexus surround the axillary artery. The lateral portion runs from the lateral border of the pectoralis minor to the lateral border of the teres major. This portion has three branches: the subcapsular, the lateral humeral circumflex, and the medial circumflex arteries. It also has three major nerves, the median, ulnar, and radial, that surround the distal portion. The median and ulnar nerves accompany the brachial artery, and the radial nerve lies posterior and passes around the humerus. The axillary vein is the first structure in the axillary sheath, and it runs anterior and inferior to the artery and becomes the subclavian vein. The cephalic vein runs through the deltopectoral groove, and it joins the axillary vein.

P. Ferrada, R. Ferrada (eds.), *Atlas of Trauma*, https://doi.org/10.1007/978-3-030-26871-8_10

Vascular Exposure

The patient is positioned in the supine position with the arm abducted 30 degrees. Sterile skin preparation should include neck, chest, and both sides of the groin (Figs. 10.1, 10.2, 10.3, and 10.4).

Vascular Repair

Axillary artery injury requires prompt diagnosis and treatment. Blind clamping can lead to a devastating injury. 5000 units of a heparin bolus are used if the vascular trauma is an isolated injury. Once the hemorrhage is controlled, the injured end of the artery should be debrided to the level of normal arterial wall. Fogarty balloon catheters must be passed proximally and distally to clear the thrombus and ensure adequate flow. The local heparinized saline is flushed into the artery proximally and distally. The vascular injury may be repaired with running or interrupted sutures or primary anastomosis. If the injury cannot be repaired by primary anastomosis, it is necessary to perform an interposition graft. The optimal graft is autologous greater saphenous vein harvested from an uninjured leg. A synthetic graft is an acceptable second choice. A vein patch can be used to close the arterial injury. Temporary shunts are used for damage control until definitive repair is achieved. The venous laceration should always be adequately controlled and treated. All muscle sections should be repaired with absorbable suture.

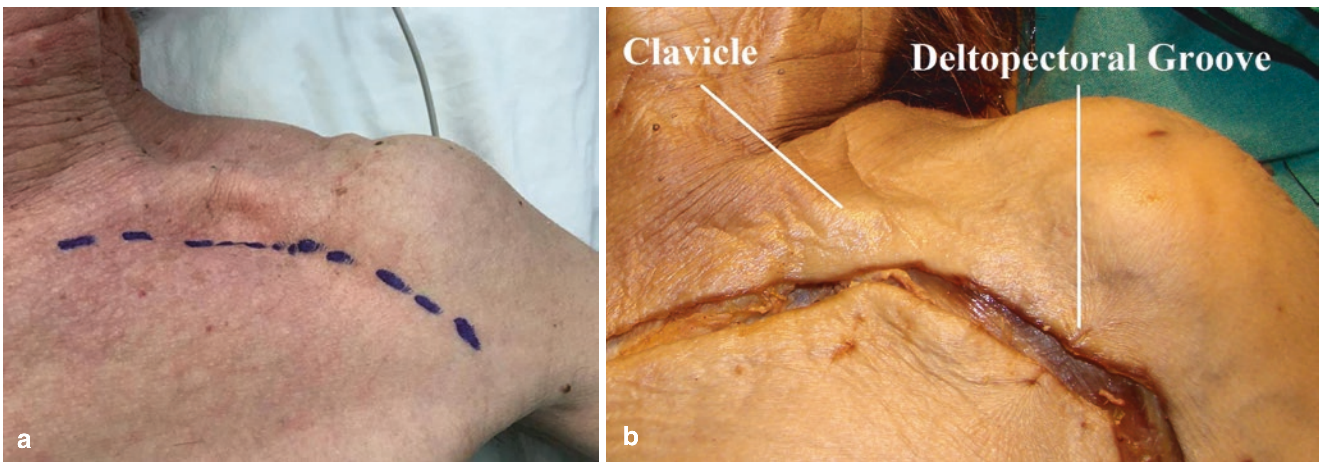

Fig. 10.1 (**a**) and (**b**) The axillary artery can be exposed through skin incision 2 cm below to the midpoint of the clavicle, following the curve into the deltopectoral groove for 5–7 cm. If necessary, the clavicle should be divided

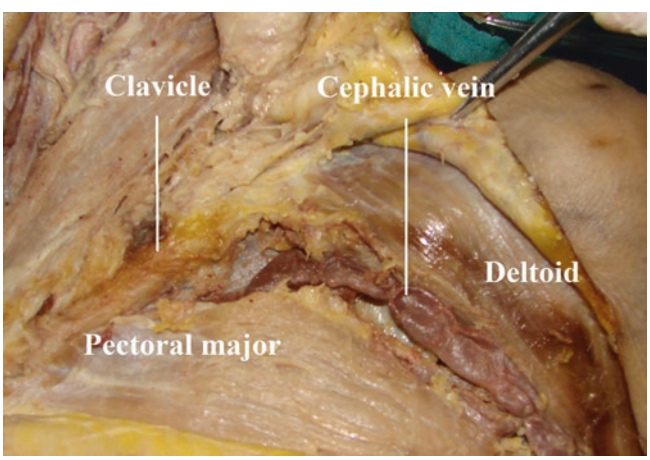

Fig. 10.2 Incision through deltopectoral groove. The intermuscular groove between the pectoralis major and deltoid muscles is separated. The deltoid muscle is retracted laterally, and the pectoralis major muscle is retracted medially. The cephalic vein is mobilized from the deltoid muscle. The vein can be ligated

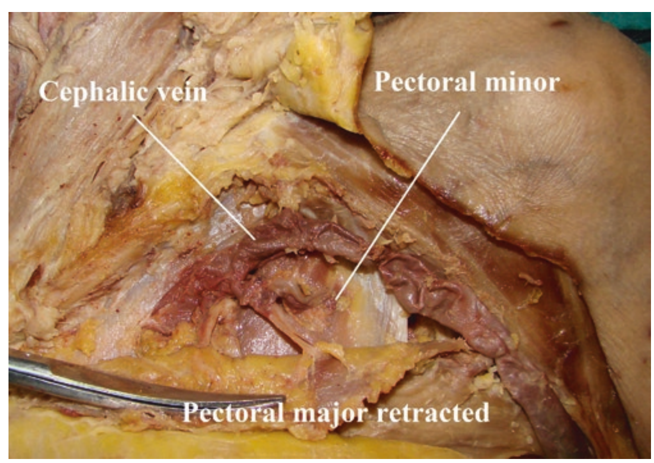

Fig. 10.3 The pectoralis major muscle is exposed. The pectoralis major tendon is divided 2–3 cm by the humerus insertion. The pectoralis minor muscle is below the pectoralis major muscle

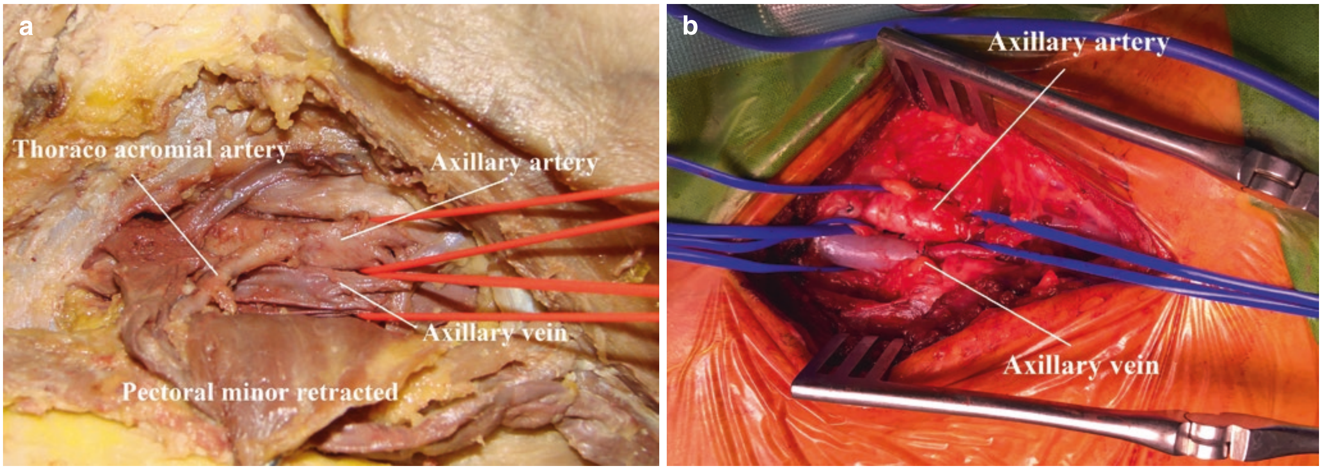

Fig. 10.4 (**a**) and (**b**) The pectoralis minor tendon muscle is divided near the coracoid process. Nerves should be protected. After sectioning the pectoralis minor, the neurovascular bundle is exposed. For free-tension mobilization of the axillary artery, the lateral thoracic artery (located on the inferior surface of axillary artery) is ligated. The vascular control of the axillary vessels is achieved by silastic vessel loop

Brachial Artery Injury

Surgical Anatomy

The brachial artery is the direct continuation of the axillary artery. This artery extends from the lower border of the teres major muscle to the antecubital fossa, where it bifurcates into ulnar and radial arteries, below the elbow. The axillary artery lies in the groove between the biceps and triceps muscles. The proximal portion of the brachial artery runs medial to the humerus, and, distally, it crosses anterior to this bone. The profunda brachial artery (or deep brachial artery) arises on the posteromedial surface of the brachial artery, distally to the border of the teres major muscle, and the radial nerve accompanies it. The brachial artery is usually accompanied by two veins. In the upper half of the arm, the ulnar nerve is posterior to the artery, and in the middle half it lies behind the medial epicondyle. The basilic vein lies in the subcutaneous tissue from the antecubital fossa to the mid arm, where it penetrates the fascia to join one of the brachial veins. The cephalic vein runs superficially and enters the deltopectoral groove to drain into the junction of the brachial and axillary veins. The brachial artery lies next to the median nerve.

Vascular Exposure

The patient is placed in the supine position with the injured arm abducted 90 degrees with the palm facing up. Skin preparation includes hand, arm, axilla, neck, chest, and bilateral groins for vein harvest (Figs. 10.5 and 10.6).

The incision is deepened through subcutaneous tissue. The basilic vein runs in this level, which can be retracted laterally for its protection. The arterial exposure requires superior retraction of the biceps and inferior retraction of the triceps muscle. The ulnar nerve is protected with inferior retraction of the triceps muscle (Figs. 10.7, 10.8, and 10.9).

Fig. 10.5 Skin longitudinal incision in the groove between the biceps and triceps brachial muscles, on the medial aspect of the arm. The incision can be extended to increase proximal or distal exposure

Fig. 10.6 (**a**) If the distal brachial artery is injured, the original incision can be extended distally, across the antecubital fossa, toward the radium by an S-shaped incision. This incision is performed to prevent wound contracture. (**b**) If the proximal brachial artery is injured and more exposure is necessary, the original incision can be extended to the deltopectoral groove for proximal vascular control at the axillary artery level. (**c**), If the brachial artery bifurcation is injured, an S-shaped incision allows trifurcation vascular control

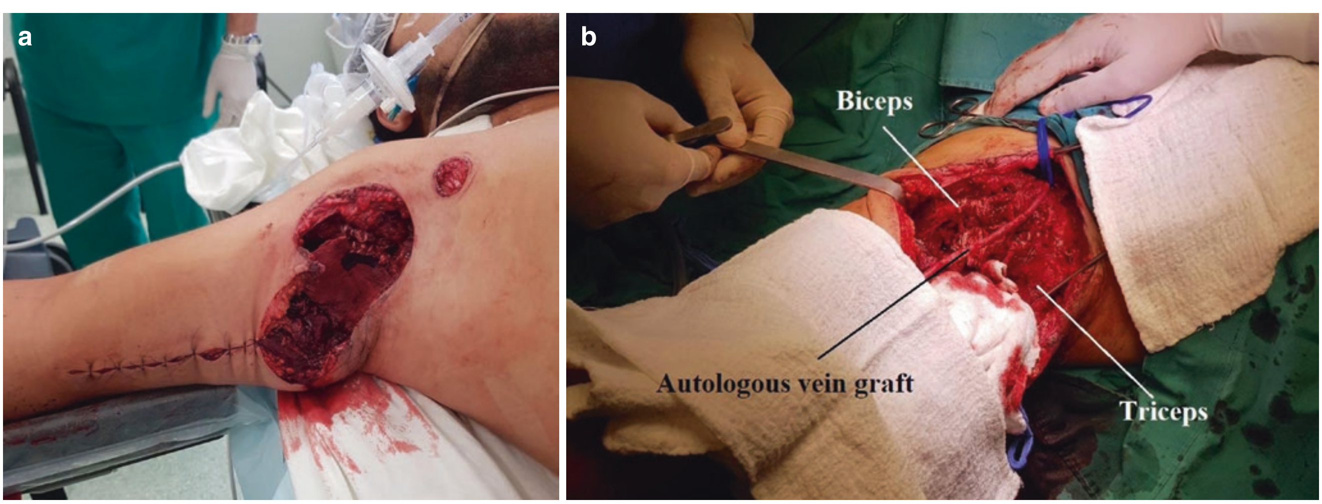

Fig. 10.7 (**a**) Stab wound injury on the left arm. (**b**) The vascular exposure was performed through a longitudinal incision in the medial aspect of the arm. The arterial injury was repaired with an end-to-end anastomosis

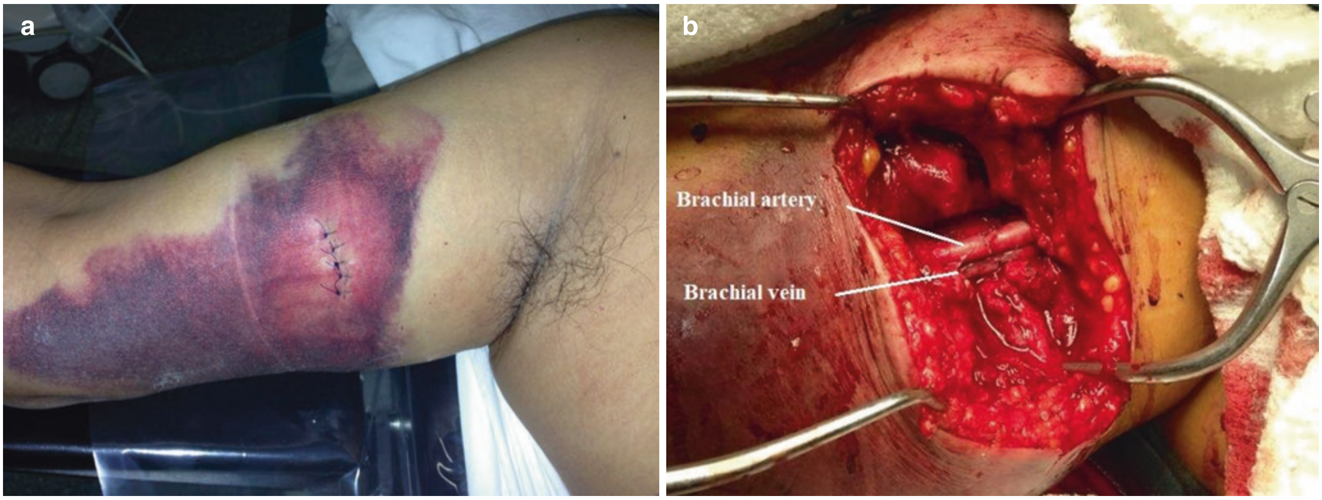

Fig. 10.8 (**a**) Gunshot wound (GSW) in the right arm with complete section of the brachial artery. (**b**) The vascular approach was performed between biceps and triceps brachial bellies with exposed neurovascular bundle. The vascular injury was managed by debriding the arterial wall injury. A 3F Fogarty catheter was passed by proximally and distally to clear vessel clot. The heparin solution (5000 U in 100 mL saline solution) is used for local flushing. After, to achieve an adequate blood flow, the vascular reconstruction is performed. In this case, for brachial artery repair it was necessary reverse the autologous greater saphenous vein. The anastomosis is performed using monofilament 6-0 polypropylene

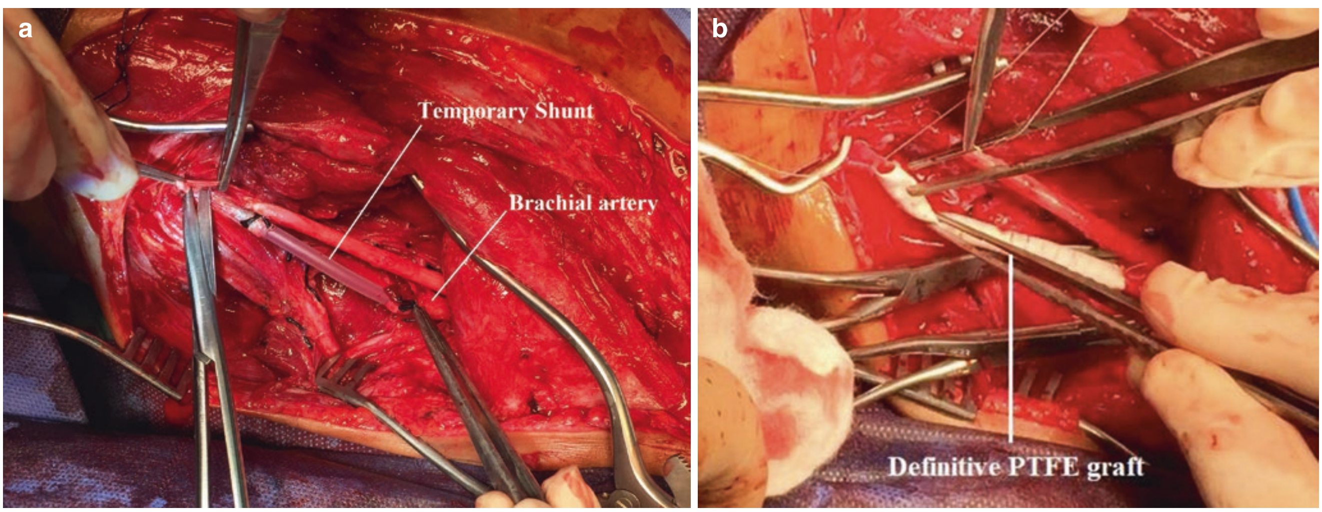

Fig. 10.9 (**a**) If the arm presents a severe traumatic injury, the restoration of the distal flow is imperative. This is achieved by the temporary shunt. It is used in damage control surgery and allows delayed definitive reconstruction. The shunt should be placed in a straight line with enough remaining tissue to place 2-0 silk tie at each end. The vessel debridement must not be performed until definitive repair, because the ties cause intimal damage and wall artery injury. (**b**) For definitive repair, the shunt is removed and the vascular repair is made. In this case, it was performed with interposition of Gorotex graft. The anastomosis was performed using 6-0 Gorotex suture

Radial and Ulnar Arteries Injuries

Surgical Anatomy

The brachial artery bifurcates in the antecubital fossa into radial and ulnar artery, underlying the bicipital aponeurosis. The radial artery extends through the forearm from antecubital fossa to the wrist, gradually takes a lateral direction, and arises under brachioradialis muscle, continuing between brachioradialis and the flexor carpi radialis muscles. The distal portion of the radial artery is superficial, running between the flexor pollicis longus and the lateral border of the radius, entering the hand behind the flexor retinaculum. The radial artery bifurcates into the recurrent radial artery and the superficial palmar branch.

The ulnar artery is a branch of the brachial artery. It is the dominant artery of the hand in 60% of cases. This artery extends through the forearm from the antecubital fossa to the wrist. In the proximal third of the forearm, the radial artery has a deeper position, and it is covered by three muscles. At the distal portion of the forearm, this artery is more superficial and emerges between the tendon of the flexor digitorum superficialis and flexor carpi ulnaris, where it is only covered by skin and fascia. The ulnar artery ends in the superficial palmar arch. The median nerve runs medial to the ulnar artery, crosses in front the artery and takes a lateral position.

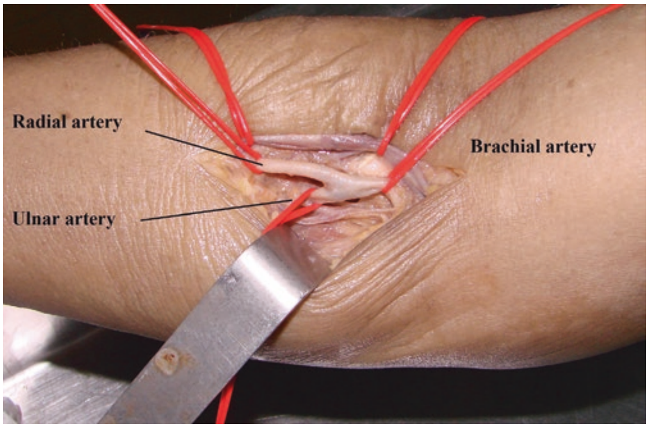

Fig. 10.10 The S-shaped incision in the antecubital fossa allows vascular control of the brachial bifurcation (distal brachial artery, radial, and ulnar arteries). In this case, the radial artery was injured by a stab wound, evolving with a secondary compartment syndrome. Extensive fasciotomy was necessary, and the artery repair was performed with lateral arteriorrhaphy

Vascular Exposure: Radial Artery

The patient is placed in the supine position with the injured arm abducted 90 degrees with the palm facing up (Fig. 10.10).

In the proximal and middle thirds of the forearm, the radial artery is exposed through a longitudinal incision on the lateral aspect of the forearm, on the medial edge of brachioradialis muscle (Fig. 10.11).

Distal approach of radial artery is achieved by an incision directly over the radial pulse.

Vascular Exposure: Ulnar Artery

The patient is placed in the supine position with the injured arm abducted 90 degrees with the palm facing up (Figs. 10.12 and 10.13).

Vascular Repair

The radial and ulnar arteries are vessels that often develop vasospasm. For this reason, their repair can be difficult. Simple arterial ligation is allowed if the contralateral artery is permeable (Fig. 10.14).

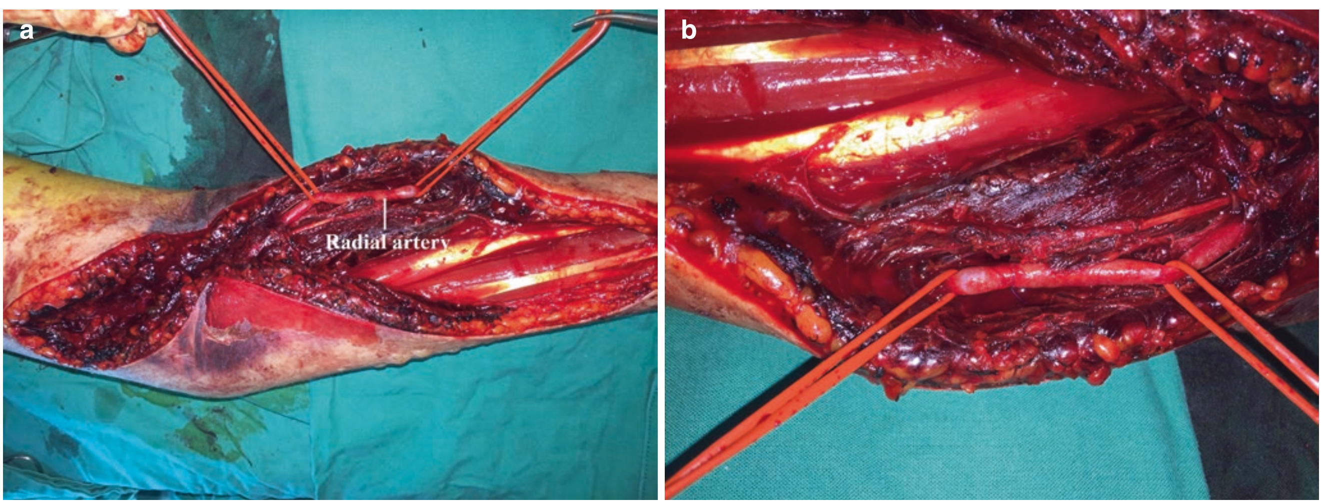

Fig. 10.11 (**a**) and (**b**) The artery is totally exposed through an extensive longitudinal incision, from the midpoint of the antecubital crease to the styloid process of the radius, corresponding the medial edge of the brachioradialis muscle and the lateral retraction, exposing the neurovascular bundle

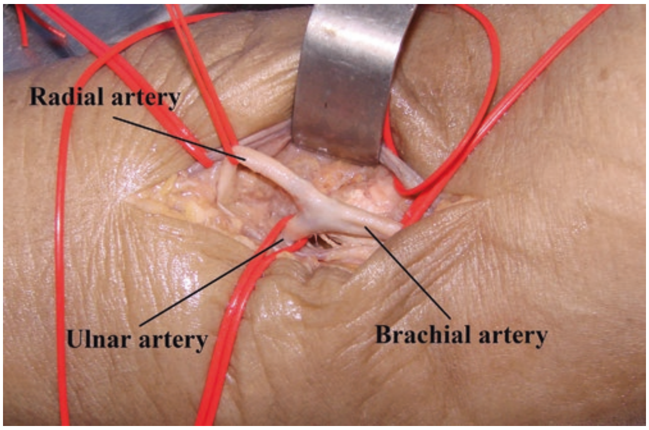

Fig. 10.12 The proximal portion of the ulnar artery is exposed through an S-shaped incision in the antecubital fossa. Exposure of the middle part of the artery is achieved by an incision over medial volar aspect the forearm

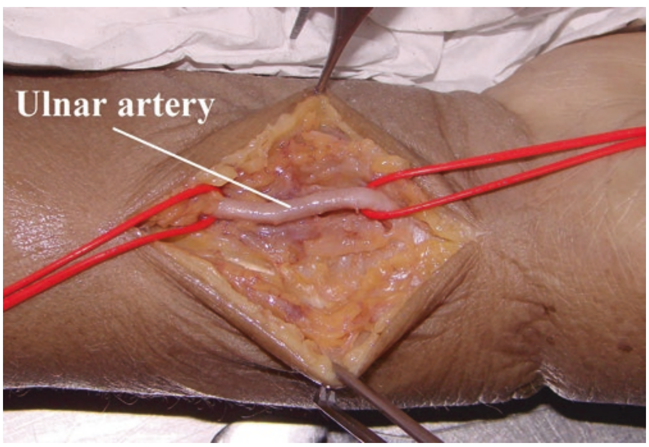

Fig. 10.13 A distal, the ulnar artery courses just beneath the antebrachial fascia. It is exposed through a longitudinal incision placed medial to the flexor carpi ulnaris muscle

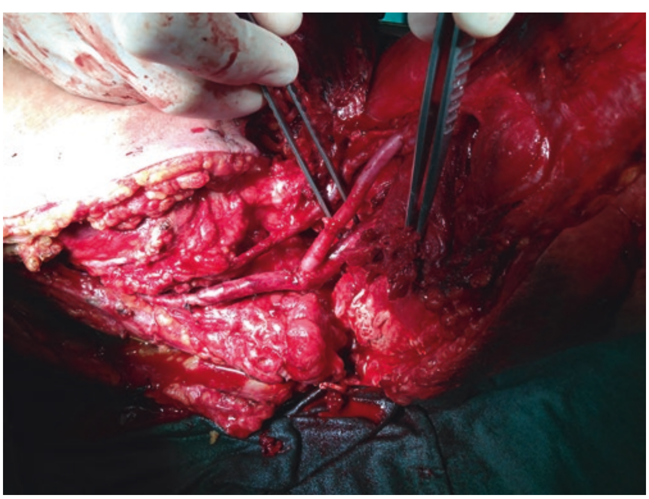

Fig. 10.14 Blunt injury with secondary elbow destruction repaired with reverse saphena vein interposition. The anastomosis bypass was performed from the distal brachial artery to radial artery. Anastomosis was performed using monofilament 6-0 polypropylene. The fracture was managed with external fixation

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11 Vascular Exposures in the Lower Extremities

Ana Milena Del Valle and Juan Carlos Herrera

Introduction

Injury is the leading cause of mortality among people aged 15–44 years. Motor vehicle collisions account for the largest number of traumatic deaths. Hemorrhage is present in 15–25% of admissions in the civilian setting. Hemorrhage that is the secondary disruption of arterial or venous structures in the limbs is classified as compressible hemorrhage. This occurs in accessible sites, and for this reason the first therapeutic maneuver is to compress the site of bleeding with pressure dressing or use a tourniquet to slow the flow of blood. The femoral artery is the most frequently injured vessel in the lower extremities (50–60% of cases). Vascular repair is a systematized process with well-defined stages. These stages must follow the classical principles of vascular reconstruction mentioned in the previous chapter. The surgeon must know the different ways of approaching the vascular structures of the extremities, the techniques of definitive vascular repair, and the techniques of temporary repair such as the vascular shunt. When repairing vascular trauma, anatomical knowledge and vascular techniques are essential; however, the surgeon's craftiness and improvisation are essential to face the unexpected difficulties of this type of trauma.

Femoral Artery Injury

Surgical Anatomy

The continuation of the external iliac artery is the common femoral artery; this artery extends from the inguinal ligament to adductor hiatus at Hunter's canal. It lies just medial to the midpoint of the inguinal ligament. The common femoral artery enters the femoral triangle of Scarpa accompanied by the femoral vein and nerve. The femoral vein is medial to the artery. The Scarpa's triangle is limited above by the inguinal ligament, medially by the adductor longus muscle, and laterally by the sartorius muscle. The greater saphenous vein runs medially on the surface of the thigh, draining into the femoral vein about 3–4 cm below the inguinal ligament. The length of the common femoral artery is 4 cm, and it bifurcates into the deep and superficial femoral artery. The deep femoral artery emerges posterolaterally and supplies blood to the thigh. The superficial femoral artery joins the femoral vein through the adductor's canal. This canal is bounded by sartorius muscle in its anteromedial wall, by the vastus medialis laterally, and by the adductor longus and adductor magnus in its posterior wall.

Vascular Exposure

Common Femoral Artery

The patient is placed in the supine position. Sterile skin preparation should extend from the lower abdomen to the knee, and both legs should be prepared.

The femoral vessels are exposed by vertical incision in the middle of the inguinal ligament between the anterior superior iliac spine and the pubic tubercle. If more exposure is necessary, the original incision can be extended over the inguinal ligament by sectioning it or by a retroperitoneal approach through a parallel incision with medial extension to 2 cm above inguinal ligament. The peritoneal envelope is elevated from lateral to medial, and the iliac vessels are exposed (Fig. 11.1).

Superficial Femoral Artery

The patient is placed in the supine position. Sterile skin preparation should extend from the lower abdomen to the knee, and both legs should be prepared.

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P. Ferrada, R. Ferrada (eds.), *Atlas of Trauma*, https://doi.org/10.1007/978-3-030-26871-8_11

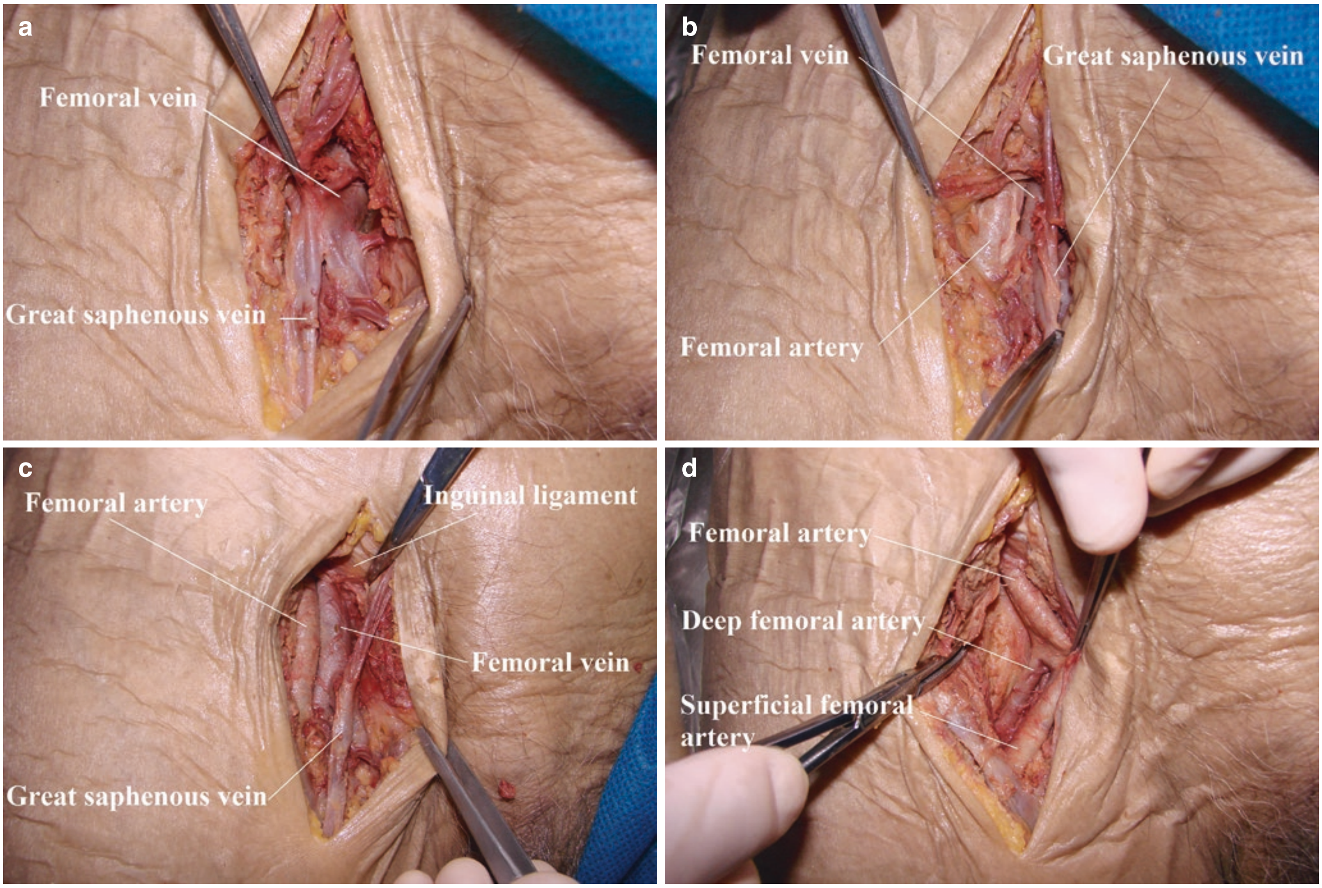

Fig. 11.1 (**a**) After skin is open, the incision is deepened to the subcutaneous tissue protecting greater saphenous vein. (**b**) and (**c**) The deep fascia is dissected and femoral sheet is open, exposing the neurovascular bundle: artery, vein, and femoral nerve. (**d**) For vascular control of the femoral bifurcation, it is necessary to control proximal and distal flow by silastic vessel loops for the superficial and deep femoral artery

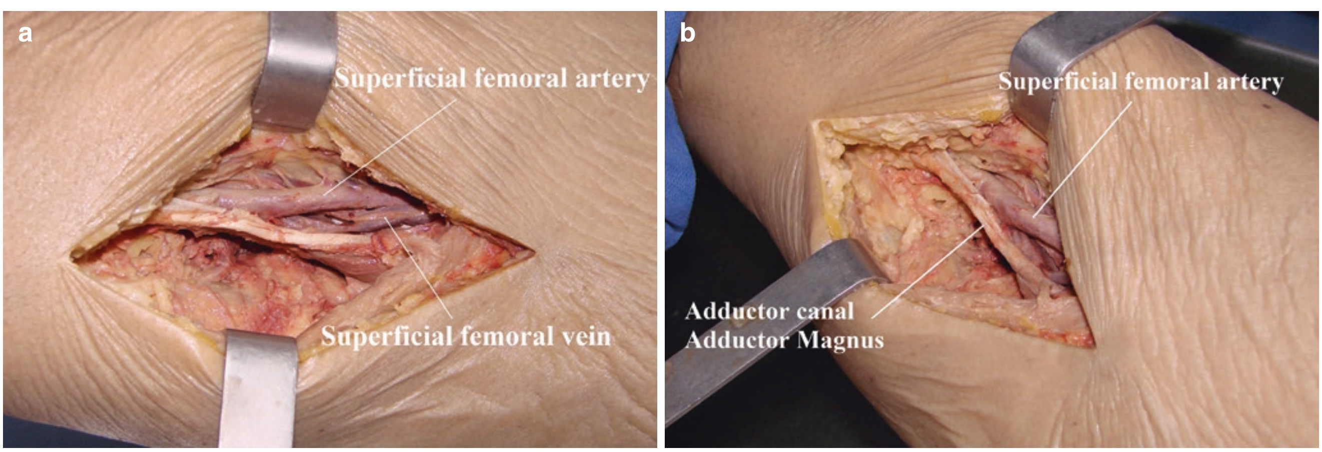

Fig. 11.2 (**a**) and (**b**) The superficial femoral artery is exposed via a longitudinal incision on the medial aspect of the thigh, always protecting the saphenous vein. When opening the superficial fascia, the sartorius and vastus medialis muscles are exposed, and with the retraction of the sartorius and vastus medialis muscles laterally and the adductor longus medially, the adductor's canal is displayed. The canal section exposes the neurovascular

Deep Femoral Artery

The patient is placed in the supine position. Sterile skin preparation should extend from the lower abdomen to the knee, and both legs should be prepared. The exposure of the deep femoral artery to the level of the second perforating branch requires division of the adductor longus muscle. The best exposure of the deep femoral artery is achieved for division of the adductor longus insertion on the linea aspera (femur).

Vascular Repair

Ligation of the common femoral artery and superficial femoral artery results in ischemia and limb loss. For this reason, the distal flow must be recovered with definitive vascular repair or temporary shunt. The deep femoral artery and the femoral vein can be ligated without any issues.

For vascular repair, it is necessary to ensure vascular control of proximal and distal flow with double passing silastic vessel loops around the vessel; the injured vessel wall should be debrided and a Fogarty catheter should be used proximally and distally in the artery for removing clots and ensuring adequate flow. The heparinized solution (5000 U in 100 mL of Saline solution) is flushed locally. The vascular repair is performed with arteriorrhaphy, anastomosis, vein patch, interposition of autogenous reverse saphenous vein, or prosthetic graft. At the end of arterial repair check that ether is a palpable pulse (Figs. 11.3, 11.4, and 11.5).

When a trauma occurs in the femoral bifurcation, vascular repair is performed by joining distal segments of the superficial femoral and deep femoral arteries. This creates a common trunk that allows for vascular repair. The temporary shunt is used to maintain distal flow to the injured leg in damage-control surgery. Routine prophylactic fasciotomies are not indicated.

Fig. 11.3 (**a**) and (**b**) Groin stab wound (GSW) with common femoral vein section. The vein was repaired by primary anastomosis performed by using monofilament 5-0 polypropylene

Popliteal Artery Injury

Surgical Anatomy

The popliteal artery is the direct continuation of the superficial femoral artery. This artery extends from adductor hiatus, entering the popliteal fossa passing between the femoral condyle to the lower border of the popliteus muscle, posterior to the knee joint. The popliteal artery bifurcates below the knee into the anterior tibial artery and tibioperoneal trunk. At 2–3 cm from the trunk, the fibular artery emerges. The tibioperoneal trunk continues in the posterior tibial artery. The popliteal fossa is behind the knee and is limited superiomedially by semimembranosus and semitendinosus muscles, superolaterally by biceps femoris, and the lateral and medial head of gastrocnemius muscles are the limits of the lateral and medial inferior border. The popliteal vessels are surrounded by firm connective tissue; the small fat of the popliteal fossa facilitates surgical mobilization. The popliteal vein and tibial nerve are more superficial than the popliteal artery. The popliteal artery gives rise to the genicular branches that perfuse the knee joint.

Exposure and Vascular Repair

The popliteal artery can be exposed by two approaches, medial and posterior.

Fig. 11.4 (**a**) and (**b**) Groin stab wound with extensive tight destruction. The superficial femoral artery was sectioned. It was repaired using reverse autologous saphenous vein interposition. The saphenous vein was harvested to contralateral groin

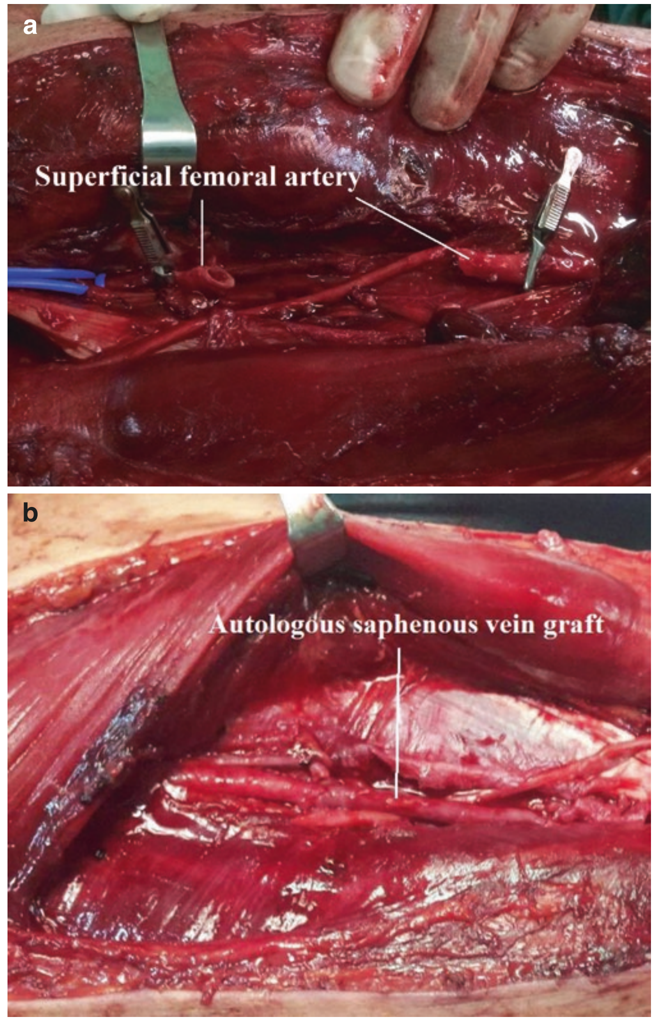

Fig. 11.5 (**a**) Groin stab wound with injury in the middle of the superficial femoral artery. (**b**) The artery was repaired using reverse autologous saphenous vein interposition

Medial Approach

The patient is placed in the supine position with the injured leg externally rotated and knee flexed 30 degrees and supported with a bump. Skin preparation of both lower extremities is indicated.

The exposure of the entire popliteal artery is performed with an incision that starts 1 cm posterior to the femur, between the sartorius and vastus medialis muscles, passing the knee until 1 cm posterior to the tibia. All junctions of posteromedial muscles are sectioned (semitendinosus and semimembranosus muscles). The union to medial head gastrocnemius muscle is sectioned too.

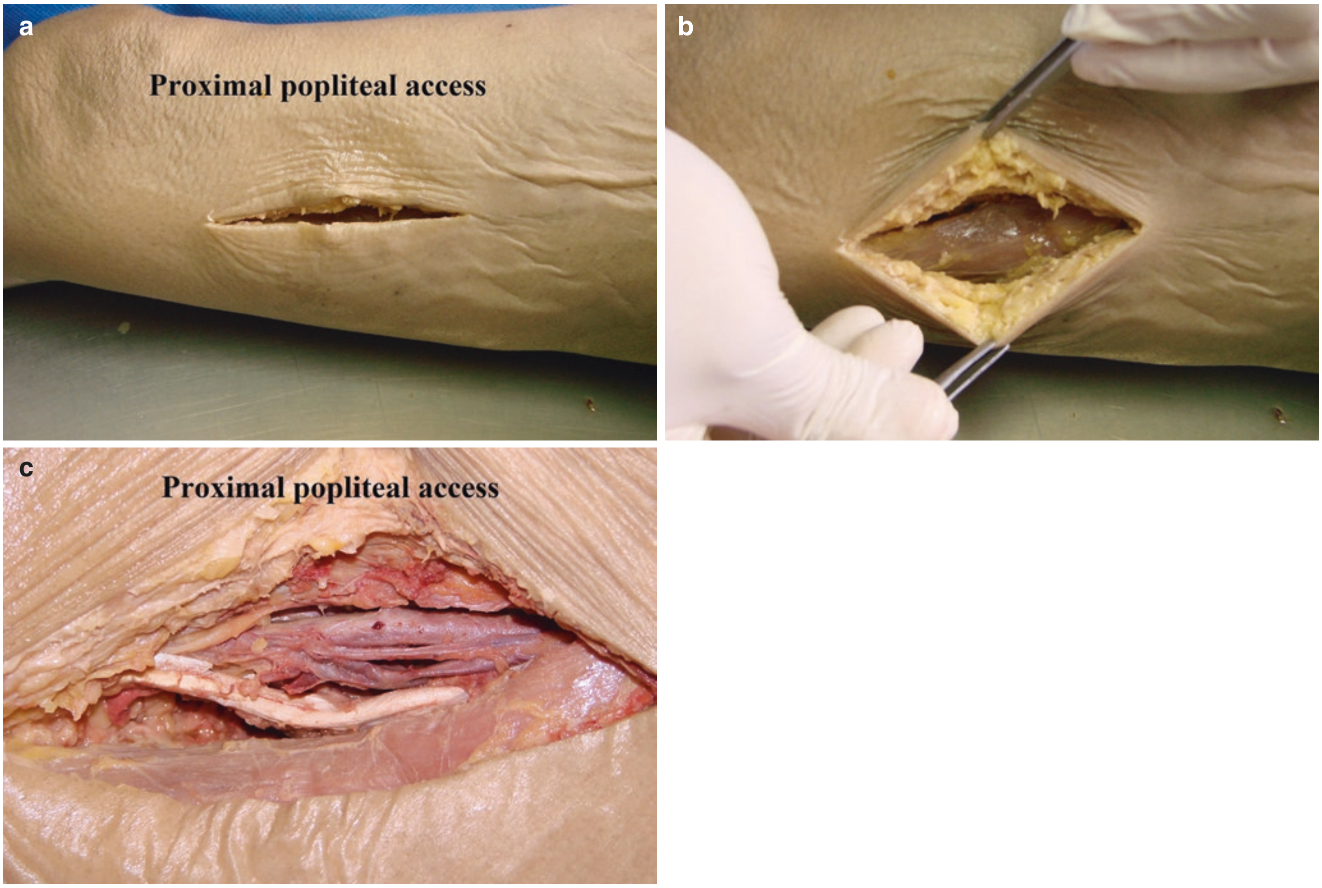

Fig. 11.6 (**a**–**c**) The supragenicular incision allows proximal vascular control of the popliteal artery. It is performed on the medial aspect of the thigh, 1 cm posterior to the femur between the sartorius and vastus medialis muscles, and when opening the deep fascia, the fat tissue and the popliteal vessels are palpated under the distal shaft of the femur

The most frequent approach is supra and infragenicular incision, which allows proximal and distal vascular control without dissecting knee ligaments (Figs. 11.6 and 11.7).

The easiest way to perform medial repair of the popliteal artery is to exclude the injured segment between ligatures and perform a interposition of autogenous reverse saphenous vein.

Prosthesis graft is used only in specific situations. Examples include extensive bilateral lower extremity injuries, inadequate saphenous size, and previous saphenous vein harvest for cardiac surgery. In these cases, a synthetic graft is an acceptable second choice (Fig. 11.8).

Vascular trauma of the popliteal artery is associated with a high incidence of loss of limb; for this reason is essential to maintain distal blood flow, because occlusion or ligature of the popliteal artery results in amputation in 75% of cases. If the vascular injury is associated with a fracture, a vascular shunt reestablishes the blood flow. After that, fixation of the fracture should be performed. During the dissection of popliteal vessels, it is necessary to protect the saphenous vein. If popliteal vein ligation is performed, the saphenous vein will allow adequate venous drainage to the extremity.

Posterior Approach

The patient is placed in the prone position. An important difficulty with posterior approach is that with the patient in the prone position, harvesting the greater saphenous vein requires repositioning of the patient (Figs. 11.9, 11.10, and 11.11).

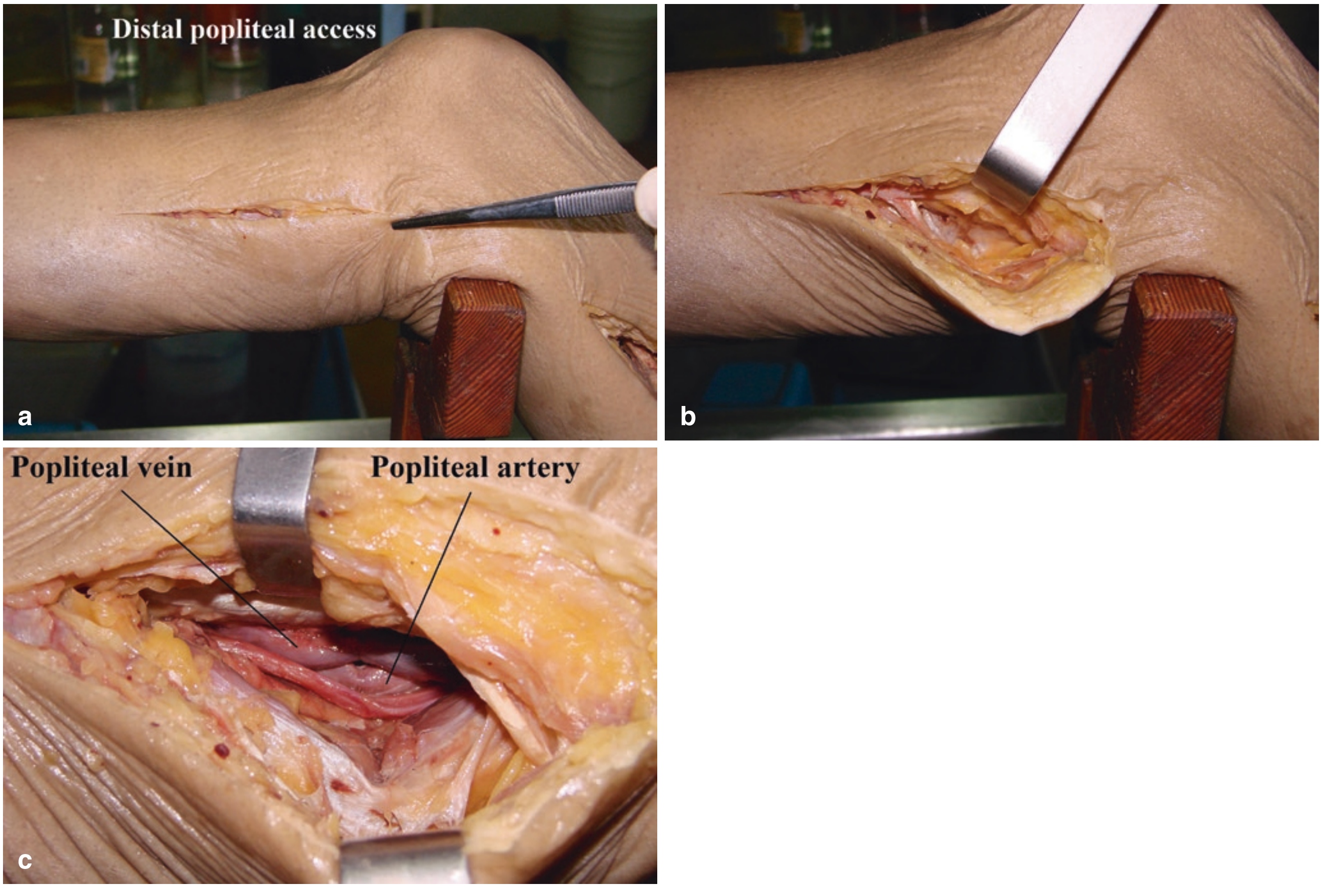

Fig. 11.7 (**a**) and (**b**) The distal vascular control is made through infragenicular incision to 1 cm posterior to the tibia. (**c**) Section of the deep fascia exposes fat tissue of popliteal fossa and neurovascular bundle: the nerve and popliteal vessel. The first structure is the popliteal vein, which is anterior to the popliteal artery

Tibial Vessels Injury

Surgical Anatomy

The tibial vessels are:

- **Tibioperoneal trunk**: The greatest terminal branch of popliteal artery, the tibioperoneal trunk measures from 0–5 cm and bifurcates into the peroneal artery laterally and into the posterior tibial artery medially. The trunk runs on the tibialis posterior muscle, and it is covered by the gastrocnemius and soleus muscles. The trunk is accompanied by the tibial nerve below the arch of the soleus muscle.
- **Posterior tibial artery**: This artery descends in the posterior compartment and the proximal portion runs on the posterior tibialis muscle. It is covered by the gastrocnemius and soleus muscles. At its end, the posterior tibial neurovascular bundle runs posterior to the ankle, among the tendons of the deep leg muscles (the tibialis posterior and flexor digitorum longus muscles), and beneath the flexor retinaculum. The posterior tibial artery ends by medial and lateral plantar arteries. This artery is accompanied by a posterior tibial nerve.
- **Peroneal artery**: This artery descends laterally toward the fibula. The proximal portion lies on the posterior tibialis muscle. The distal third runs behind the belly of the flexor hallucis longus muscle. Finally, the peroneal artery terminates as a perforating branch through the distal interosseous membrane.
- **Anterior tibial artery**: As the terminal branch of the popliteal artery, the anterior tibial artery passes through the interosseous membrane into the anterior compartment, and its proximal portion lies between the tibialis anterior and extensor digitorum longus muscles. Its distal portion descends between the tibialis anterior and extensor hallucis longus muscles. It arises lower down, covered only by skin, fascia, and the extensor reticulum. The anterior tibial artery becomes the dorsalis pedis artery between the first and second metatarsals. The anterior tibial artery is accompanied by the deep peroneal nerve.

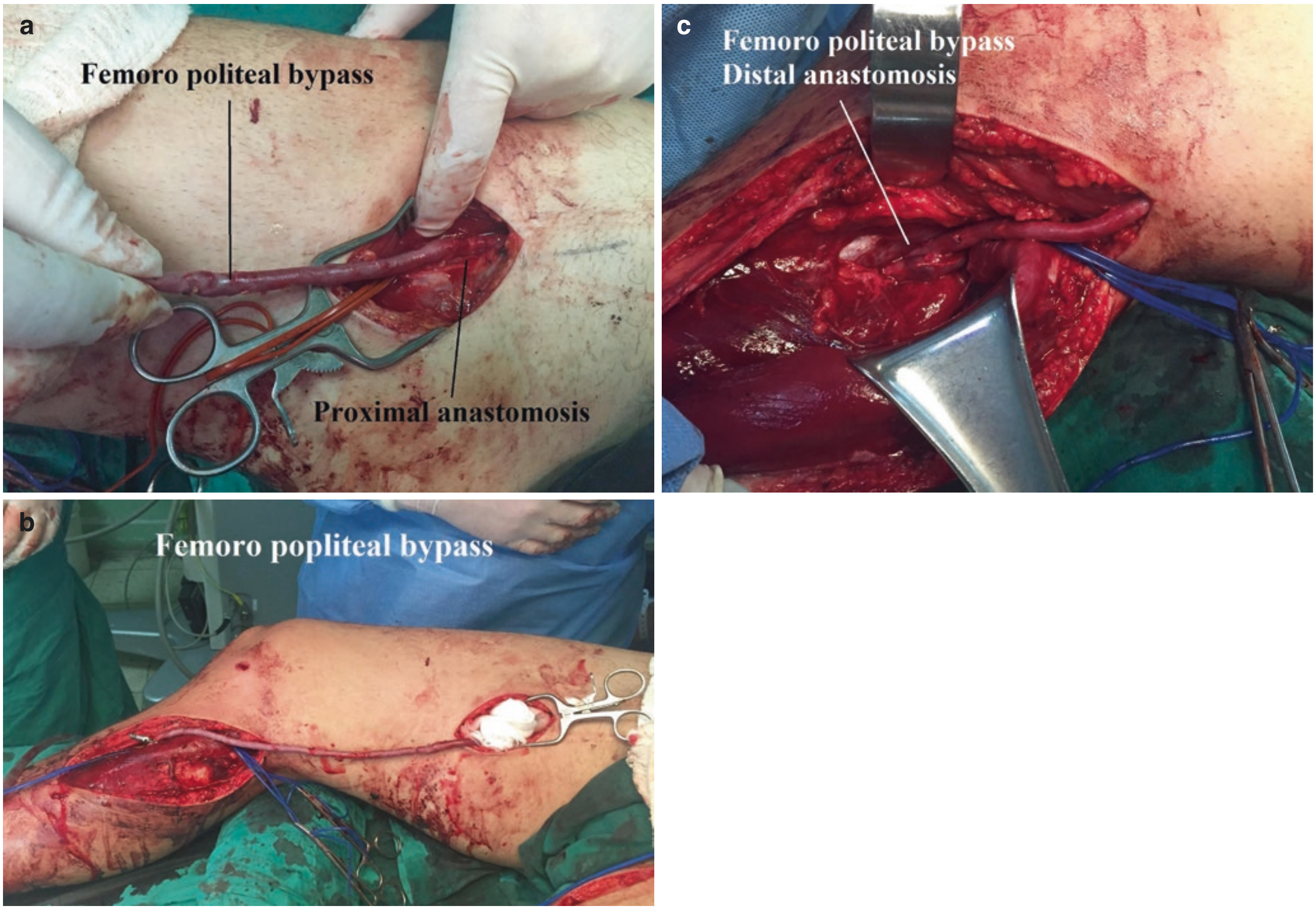

Fig. 11.8 (**a**–**c**) The extensive popliteal injury is repaired with reverse saphenous vein interposition. The vascular approach is performed through supra and infragenicular incision. The proximal anastomosis is performed and the autologous graft to the infrageniculate popliteal artery is passed through the adductor canal, then it is tunneled posterior to the knee between the femoral condyles. The distal anastomosis is performed in the infrageniculate popliteal artery. The anastomoses are performed using monofilament 5-0 or 6-0 polypropylene. The key in this repair is to avoid kinking when the knee is flexed

Exposure and Vascular Repair

The patient is placed in the dorsal decubitus positing and both limbs are prepared before surgery.

Tibioperoneal Trunk Exposure (Figs. 11.12 and 11.13)

This approach exposes the distal portion of the popliteal artery.

The incision is deepened, the medial head gastrocnemius is divided, and the trunk is exposed penetrating the soleus muscle.

Posterior Tibial Artery Exposure: Proximal Approach

The proximal portion of the posterior tibial artery is exposed by an extension of the infrageniculate approach through a medial incision, which is made 2 cm behind the posterior border of the tibia and extended distally for 10–15 cm.

Posterior Tibial Artery Exposure: Distal Approach (Figs. 11.14 and 11.15)

(**a**–**c**) The distal portion of the posterior tibial artery emerging under the soleus and gastrocnemius muscles. It lies more superficially covered by skin, subcutaneous tissue, and fascia. The posterior tibial artery at the ankle is exposed by medial incision to the calcaneus tendon.

The posterior tibial artery is used for bypass distal anastomosis.

Anterior Tibial Artery Exposure (Figs. 11.16, 11.17, and 11.18)

The anterior tibial artery is exposed through the longitudinal lateral incision between the tibia and fibula.

Intermuscular septum is divided between tibialis anterior as extensor hallucis muscles are divided.

The artery is observed with lateral retraction of the extensor hallucis longus. The distal portion of the artery lies more superficial.

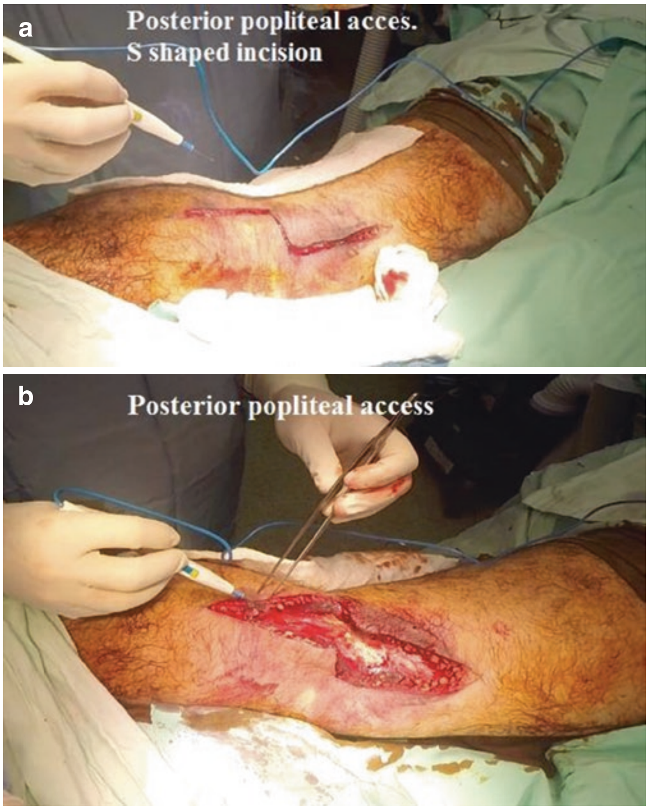

Fig. 11.9 (**a**) and (**b**) The posterior exposure is done through a Lazy S-shaped incision in the posterior aspect of the knee. The incision deepens between the medial and lateral head of the gastrocnemius muscle, respecting tibial nerves and the popliteal vein

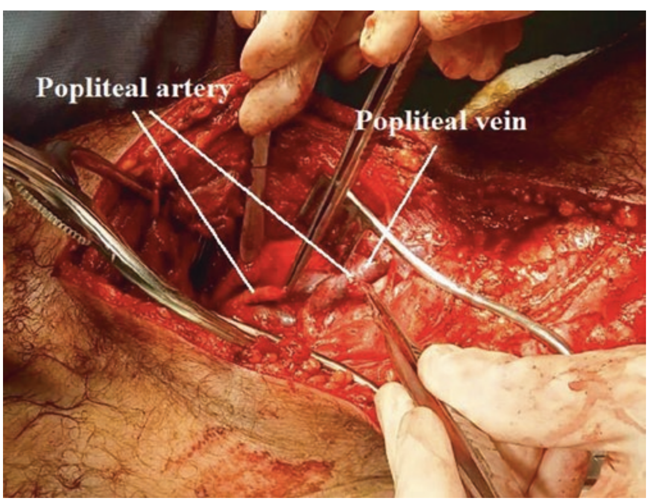

Fig. 11.10 Popliteal artery dissection with proximal and distal vascular control

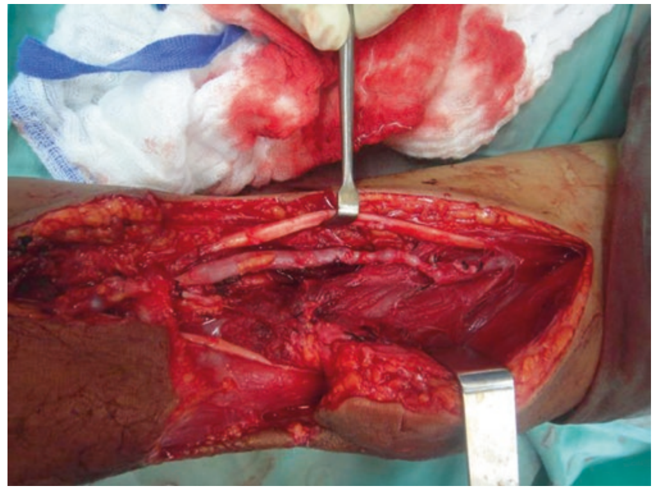

Fig. 11.11 The vascular repair can be performed by arteriorrhaphy, end-to-end anastomosis and interposition of autologous or prosthesis graft. In this case, the repair was achieved with reverse autologous saphenous vein

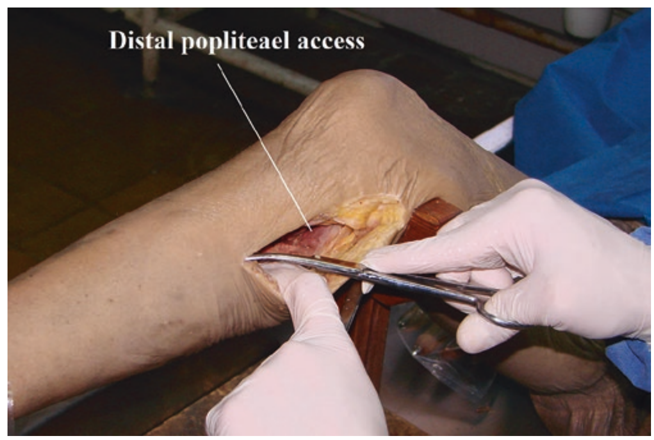

Fig. 11.12 This approach exposes the distal portion of the popliteal artery

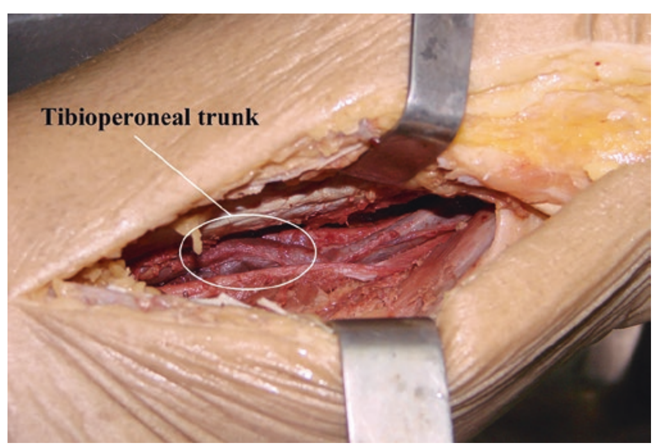

Fig. 11.13 The incision is deepened, the medial head gastrocnemius is divided, and the trunk is exposed penetrating the soleus muscle

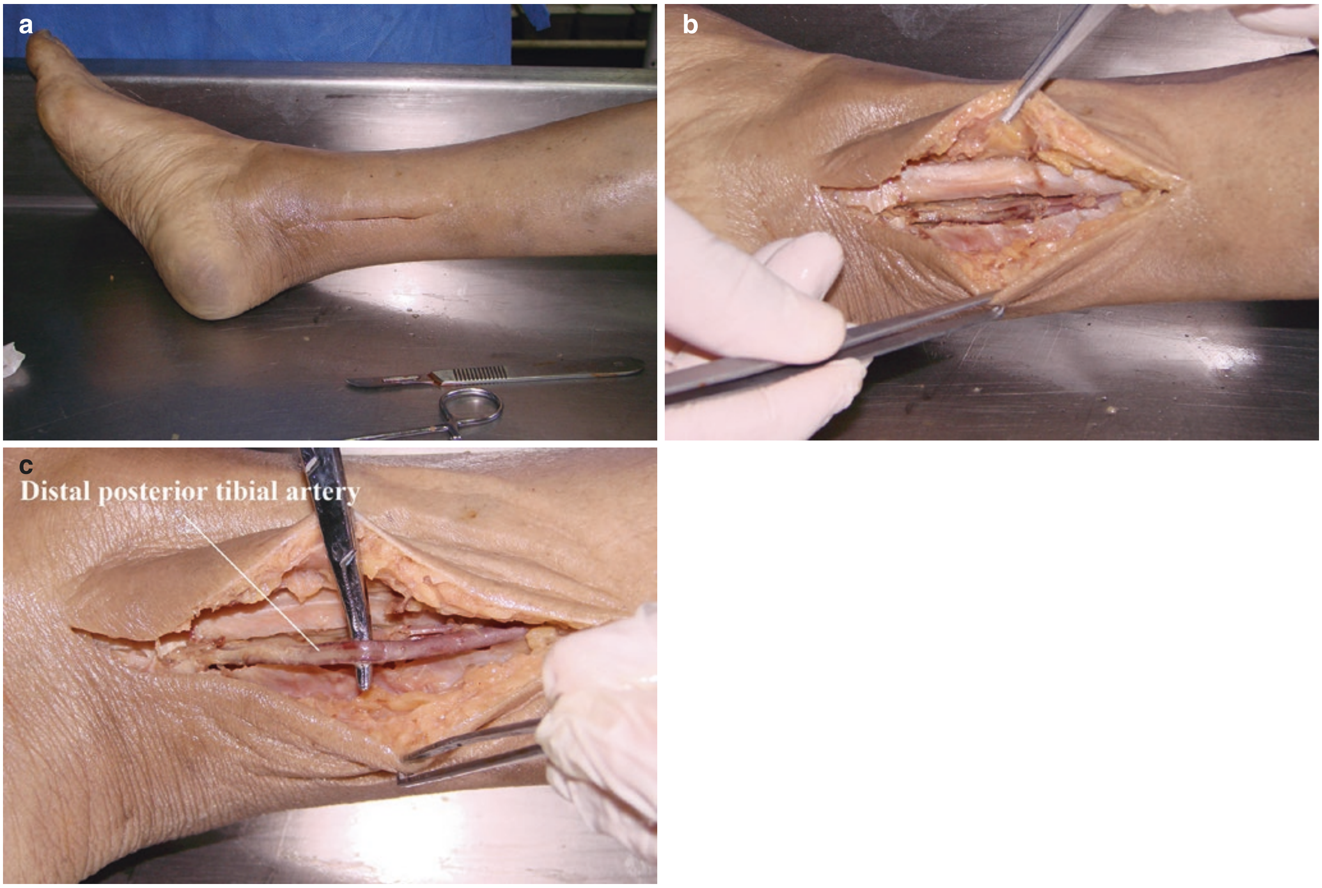

Fig. 11.14 (**a**–**c**) The distal portion of the posterior tibial artery emerging under the soleus and gastrocnemius muscles. It lies more superficially covered by skin, subcutaneous tissue, and fascia. The posterior tibial artery at the ankle is exposed by medial incision to the calcaneus tendon

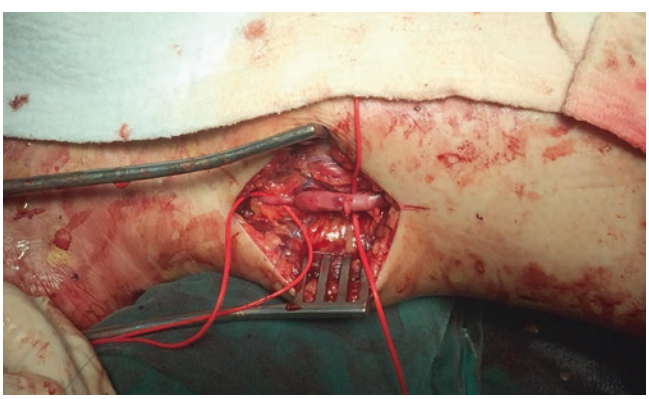

Fig. 11.15 The posterior tibial artery is used for bypass distal anastomosis

Fig. 11.16 The anterior tibial artery is exposed through the longitudinal lateral incision between the tibia and fibula

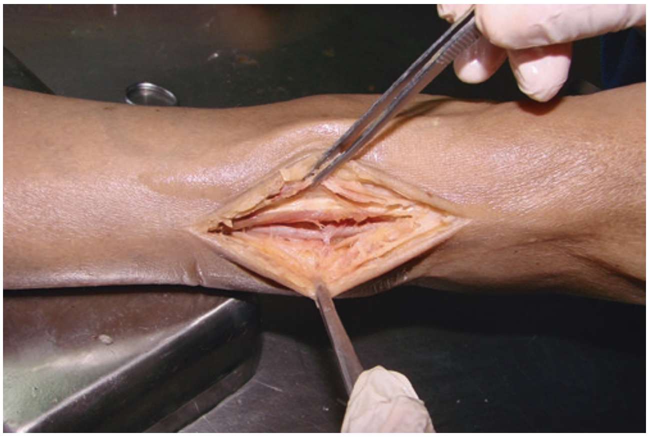

Fig. 11.17 Intermuscular septum is divided between tibialis anterior as extensor hallucis muscles are divided

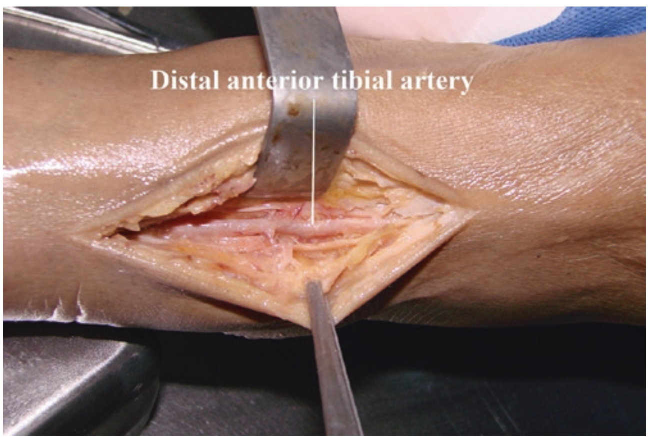

Fig. 11.18 The artery is observed with lateral retraction of the extensor hallucis longus. The distal portion of the artery lies more superficial

Peroneal Artery Exposure

This artery is exposed by vertical incision behind the posterior border of the tibia, and the tibial fiber of the soleus muscle are separated. The incision is deepened until the peroneal artery is exposed.

Vascular repair depends on the accessibility and artery cover; usually the posterior tibial artery is repaired. The peroneal artery and anterior tibial artery are tied.

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12 Lower Extremity Fasciotomy: Indications and Technique

Matthew K. George and Rahul J. Anand

The competent trauma surgeon must be familiar with lower extremity fasciotomy. This operation becomes necessary in patients who are suffering from and who are at risk for developing a compartment syndrome (CS)—a surgical emergency. CS is the result of the pressure within a muscle compartment exceeding that of the perfusion pressure, which subsequently causes ischemia of the muscles and nerves contained within. The overall rate of fasciotomy after extremity injury is 2.8%. Proper knowledge of the pertinent anatomy of the thigh and leg are essential in order to avoid complications. The consequences of missing an indicated adequate lower extremity fasciotomy can be limb- or even life-threatening. There are also medico-legal consequences to this. This chapter will cover indications for lower extremity thigh and leg fasciotomy, technique, and emphasize how to avoid pitfalls.

Indications for Lower Extremity Fasciotomy

The development of a CS is a function of lower extremity anatomy. The thigh and leg are divided into distinct muscle compartments bounded by fascial layers. The trauma/acute care surgeon is often faced with a CS that occurs from traumatic injury to a major artery or vein, crush injury, or hemorrhage into a compartment. Any mechanism that causes increased pressure within a compartment increases the risk of developing a CS. Reperfusion injury, venous outflow obstruction, prolonged immobility, and exertion can all cause ischemia and produce a CS.

Predictive factors that increase risk of requiring a lower extremity fasciotomy are young males sustaining penetrating trauma, blood transfusion requirements, open fractures, knee dislocation, and vascular injury. Before one can intervene on lower extremity CS, the diagnosis must first be made.

Diagnosis of Lower Extremity Compartment Syndrome

The clinician must have a high index of suspicion that the patient is experiencing an acute CS. History, physical exam, and mechanism of injury all contribute to the diagnosis. The classic signs of acute CS include the "6 Ps": pain, paresthesia, poikilothermia, pallor, paralysis, and pulselessness. The most common physical exam finding that must alert the clinician to CS is exquisite pain on passive motion of the extremity and a tense compartment on physical exam. Pain out of proportion to injury that is not responsive to pain medication or reduction of a fracture suggest a CS. Paresthesia distal to the compartment in question is an early sign of CS developing, especially the loss of two-point discrimination. Pulselessness tends to be a later finding—and, to prevent limb- or life-threatening consequences from ensuing, the astute clinician should not wait for this to happen to make the diagnosis.

There are certain circumstances and populations in which history and physical exam may be unreliable. These special populations include unconscious, impaired, and pediatric patients. In these populations, a compartment pressure may be measured to gain objective data to seal the diagnosis of CS. Commercially available devices such as the Stryker needle (Fig. 12.1) can be used to measure pressure within a given compartment. If this device is not available, a needle connected to an arterial line transducer can also be used to make a measurement. Compartment pressure is measured by directly inserting the needle into the muscle compartment (Fig. 12.2), starting with the compartment that is most concerning. Ideally, all compartments in the thigh or leg should be measured. This is sometimes difficult, however, if the compartment of concern is the deep posterior compartment. Traditionally, the threshold at

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P. Ferrada, R. Ferrada (eds.), *Atlas of Trauma*, https://doi.org/10.1007/978-3-030-26871-8_12

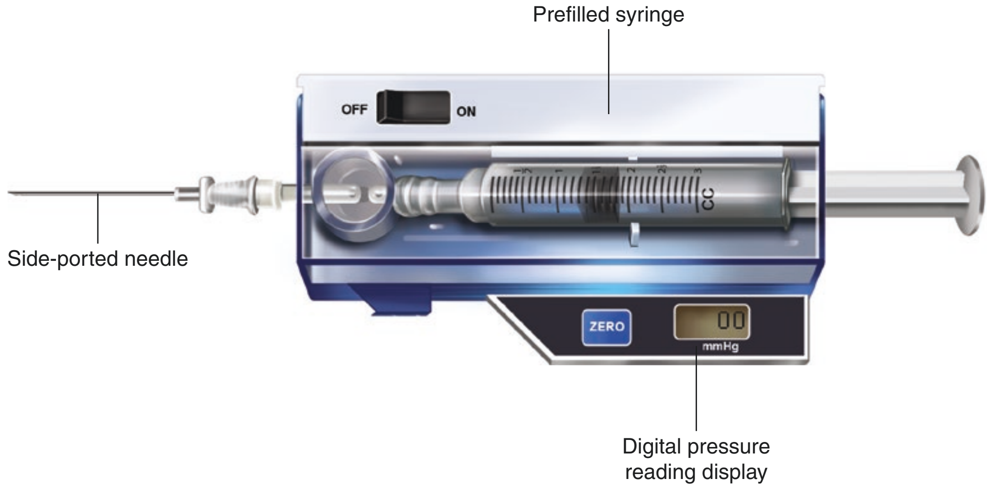


Fig. 12.1 Stryker Manometer for measuring compartment pressure

Fig. 12.2 Using a Stryker Manometer to measure a compartment pressure. Air bubbles are evacuated from the saline-filled syringe. The apparatus is held at a 45-degree angle and zeroed. The tip of the needle is inserted in to the compartment at the same angle, and 0.3 mL of saline is injected slowly. The reading should now display compartment pressure

which to perform fasciotomy has been an absolute compartment pressure of 30 mmHg, but this is an area of controversy. Another method is to use the "Delta-P" method. If the compartment pressure is within 30 mmHg of the diastolic blood pressure, suspicion is higher for a CS, and fasciotomy should be entertained.

When CS is identified, serum chemistries and creatinine kinase (CK) level should be checked. CK levels can be elevated in the setting of muscle injury. Muscle injury can cause kidney injury from rhabdomyolysis, which can lead to hyperkalemia and should be treated if warranted.

In patients at risk for CS in whom fasciotomy is not performed, serial exams must be performed, as CS is a dynamic process. Patients in whom prophylactic fasciotomy should be undertaken include those with limb ischemia over 6 hours, combined arterial and venous traumatic injuries to an extremity, phlegmasia cerulea dolens, tense compartment after crush injury, tense compartment after fracture, or obtunded patients with tense compartments.

Leg Fasciotomy Technique

The leg has four compartments. These include the anterior, lateral, superficial posterior, and deep posterior compartments. Before proceeding with a leg fasciotomy, the surgeon must have a thorough understanding of the anatomy (Fig. 12.3). The standard operation used to perform the fasciotomy is a two-incision technique. Through lateral and medial incisions, all four compartments can be released. A single-incision technique has been described for leg fasciotomy. In the setting of acute CS, we do not recommend this procedure.

First, the leg should be circumferentially prepped out and draped from the inguinal crease down to the feet. Next, identify and mark bony landmarks. At the superior aspect of the leg, mark the tibial tuberosity anteriorly and the fibular head laterally. At the inferior aspect, mark the medial and lateral malleolus.

The most common compartment involved with CS is the lateral compartment, so one begins decompression with the lateral incision. An incision is made about 2 finger breadths lateral to the tibia or about 1 fingerbreadth anterior to the fibula (Fig. 12.4). This craniocaudal incision extends from 3 fingerbreadths below fibular head to 3 fingerbreadths above the lateral malleolus. The incision is extended using cautery through the subcutaneous fat to the level of the fascia. Skin flaps of about 3 cm are raised in each direction. Once completed, the intermuscular fascial septum between the anterior and lateral compartments are identified.

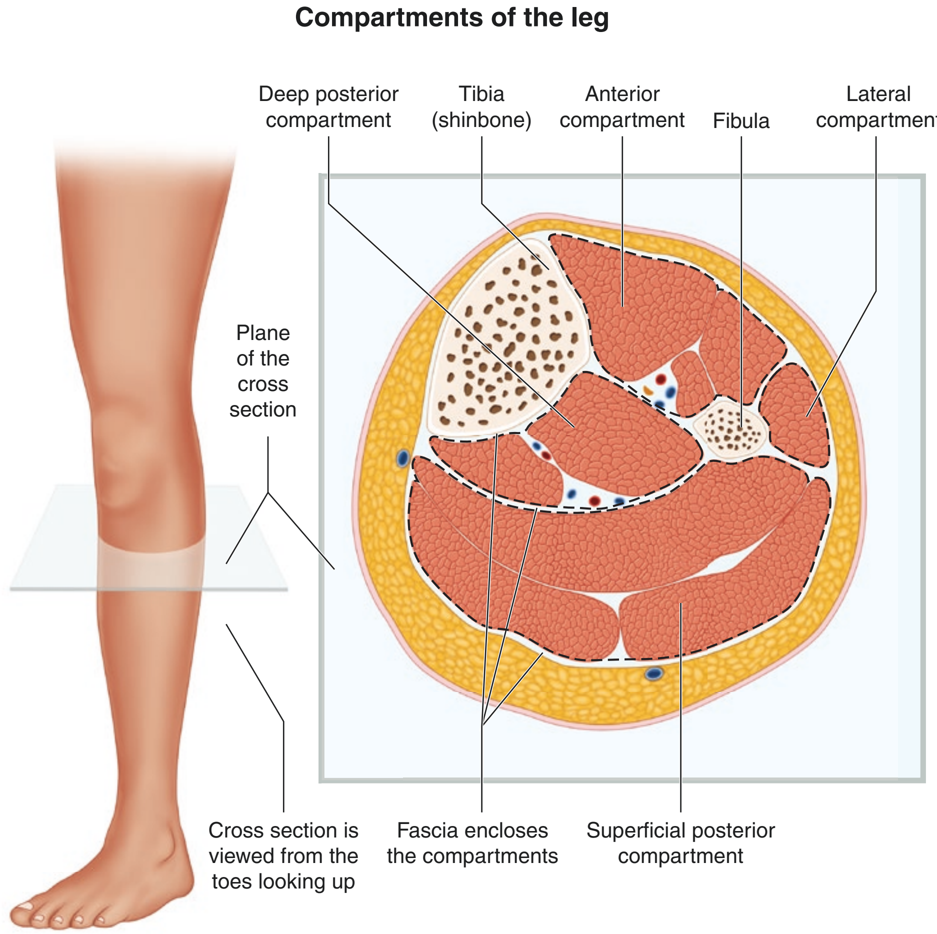


Fig. 12.3 Cross-section of leg showing anatomy of the four compartments of the leg

The lateral compartment is incised and then decompressed using Metzenbaum scissors. A single jaw of the scissor is inserted into the compartment and the scissors are pushed along the line of incision to cut the fascia superiorly and inferiorly. Bulging muscle indicates CS. Tips of the scissor should be pointed away from the intermuscular septum to avoid damage to the peroneal nerve. Next, a second lateral incision should be made on the anterior compartment fascia to decompress the anterior compartment in a similar fashion to the lateral compartment using Metzenbaum scissors. Some authors have advocated for connecting the two fascial incisions across the intermuscular septum to form an "H" type incision (Fig. 12.5).

Attention is now turned to the medial incision to decompress the superficial posterior and deep posterior compartments. An incision is made about 1 thumb breadth posterior to the tibia (see Fig. 12.4). This craniocaudal incision extends from 3 fingerbreadths below tibial tuberosity to 3 fingerbreadths above the medial malleolus. While extending the skin incision through the subcutaneous tissue, the surgeon should be careful not to damage the greater saphenous vein. The fascia of the superficial posterior compartment is now encountered and is decompressed via a longitudinal incision along the gastrocnemius fascia. Once this compartment is decompressed, the soleus muscle is identified and separated from the underside of the tibia. This maneuver exposes the fascia overlying the tibialis posterior and one enters the deep posterior compartment, which may also be confirmed by identifying the posterior tibial neurovascular bundle. The soleus muscle is essentially "stripped" from the back of the tibia bluntly to expose the deep posterior compartment (Fig. 12.6).

An important step to this procedure is assess the viability of the muscle. All muscle that is seen and appears dead and does not contract with stimulation (Bovie electrocautery can be used) should be debrided so that the metabolites do not get disseminated within the patient.

Leg Fasciotomy Pitfalls

The astute surgeon needs to be aware of certain pitfalls during leg fasciotomy. Incomplete fasciotomy has an incidence of 12% and can be a devastating complication. In a patient

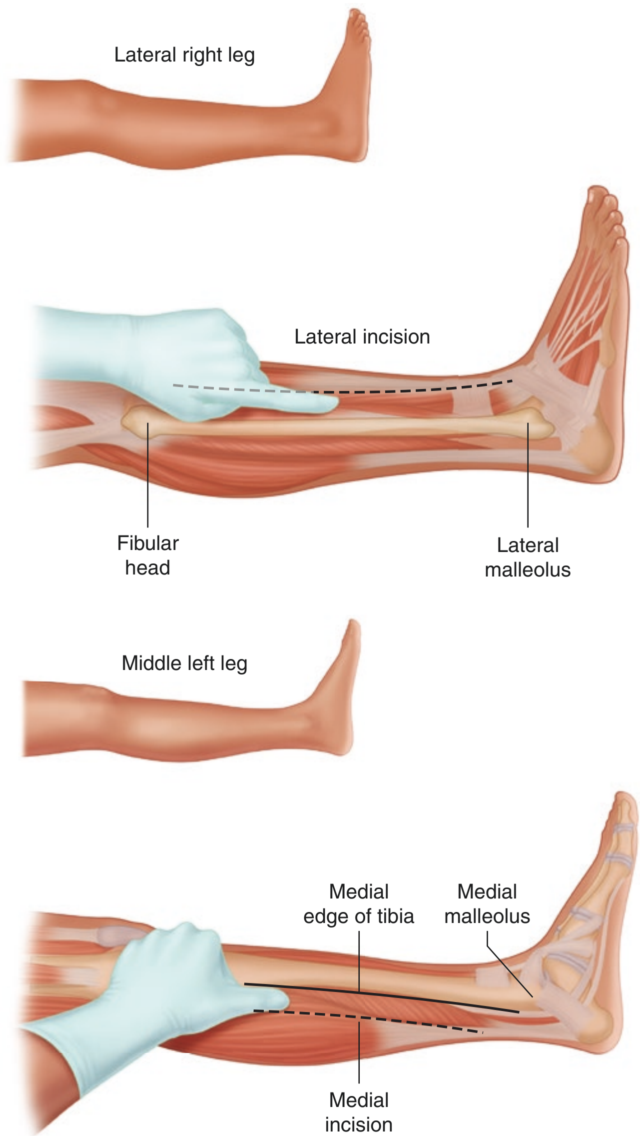


Fig. 12.4 Recommended skin incisions for leg fasciotomy. Lateral Incision is made 1 finger breadth anterior to fibula. The medial skin incision is made 1 thumb breadth posterior to tibia

with acute leg CS, leg swelling may make identification of landmarks difficult. It is not hard to "miss" the anterior compartment in this situation. Identification of the intermuscular septum and use of a "H"-type incision to decompress the lateral and anterior compartments through two parallel incisions lessens the chance of this happening (see Fig. 12.5). The other commonly "missed" compartment is the deep posterior compartment. "Stripping" the soleus from the back of the tibial completely minimizes this (see Fig. 12.6). "Missed" compartments should be considered in any patients with ongoing rhabdomyolysis after a supposedly complete fasciotomy. Incomplete fasciotomy can also result if the incisions are not long enough. Ideally, fasciotomy incisions should be between 12 and 20 cm in length.

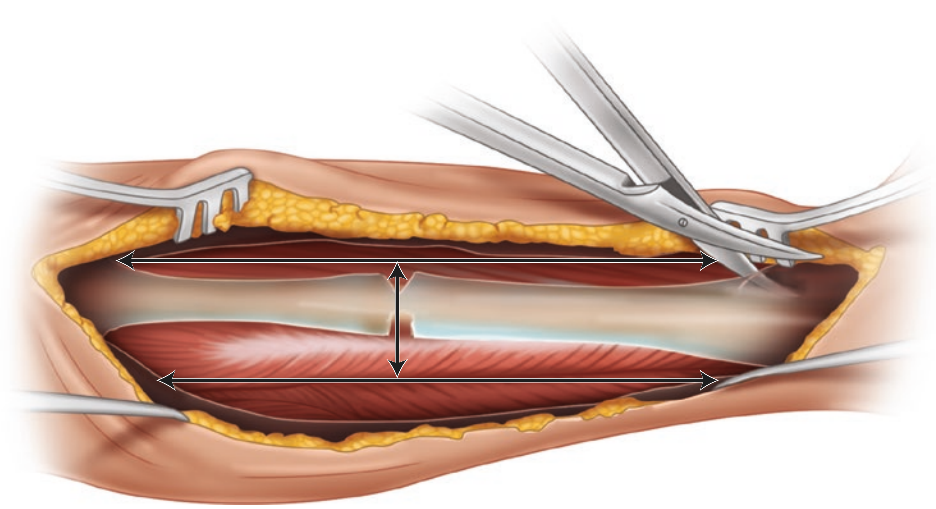
Proper placement of the incisions for leg fasciotomy is of utmost importance. A common mistake is for one to place the lateral incision too far laterally. Doing this results in an inability to successfully identify the intermuscular septum or release the anterior compartment without making large skin flaps. Placing the lateral incision anterior to the fibula helps to avoid this.

Again, with the lateral leg fasciotomy, care should be taken to preserve the terminal branch of the deep peroneal nerve. This is located adjacent to the intermuscular septum that separates the anterior and lateral compartments. For this reason, fasciotomy incisions on the anterior and lateral compartments should be performed 1 cm from the intermuscular septum.

Thigh Fasciotomy Technique

The majority of thigh CS occurs from blunt trauma with a high association of concomitant femur fractures. Thigh CS can also develop from penetrating injury. There are three main compartments in the thigh, which include the anterior, posterior, and medial compartments (Fig. 12.7). Components of the anterior compartment include the quadriceps muscles

Fig. 12.5 Completed lateral leg fasciotomy. Both the anterior and lateral compartments have been released through parallel incisions. The intermuscular septum has been divided creating an "H"-type incision



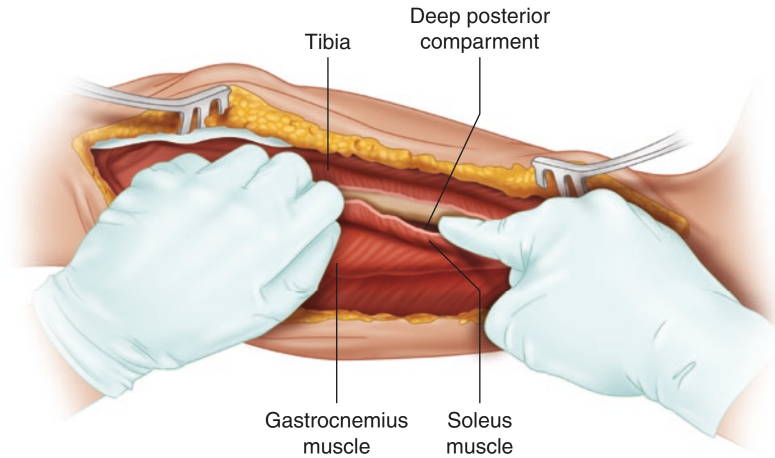


Fig. 12.6 Medial leg fasciotomy. To enter the deep posterior compartment, soleus fibers are stripped from the posterior tibia

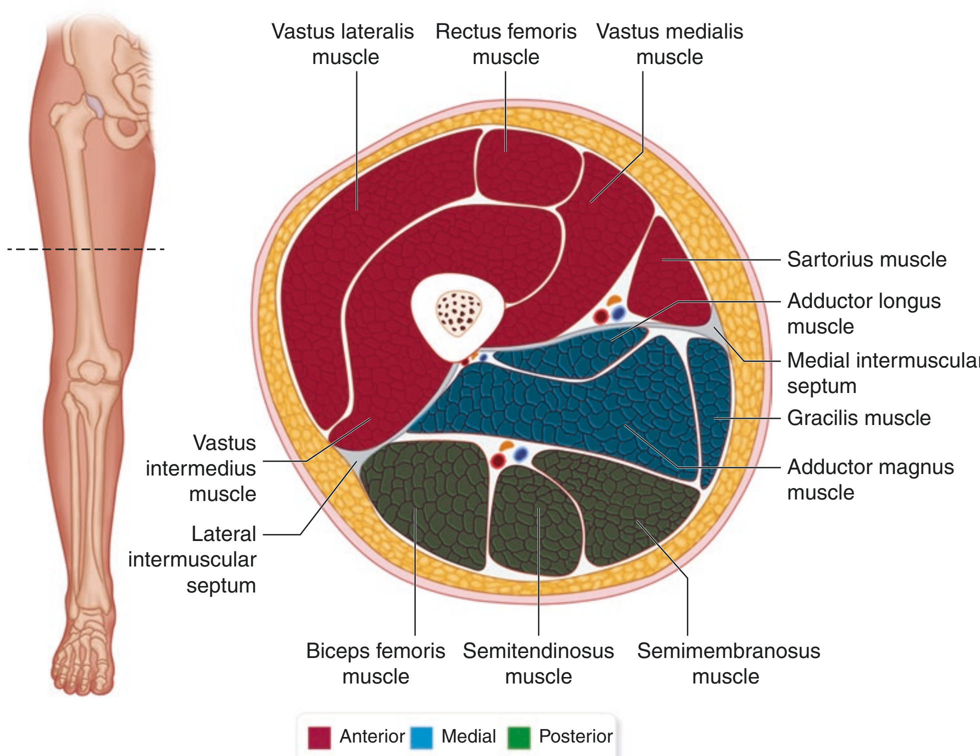


Fig. 12.7 Cross-section of thigh showing anatomy of thigh compartments. The lateral intermuscular septum separates the lateral and anterior thigh compartments

and the sartorius, which are innervated by the femoral nerve. Posterior compartment components include biceps femoris, semimembranosus, and semitendinosus muscles. Medial compartment components include the pectineus, obturator externus, gracilis, and adductor muscles. The medial compartment rarely needs decompression, so a thigh fasciotomy is approached from a lateral incision. The lateral incision therefore serves to decompress the anterior and posterior compartments.

Thigh fasciotomy is performed through a lateral technique (Fig. 12.8). The patient is placed in a supine position and prepped from the iliac crest to the knee joint. An incision is planned from the greater trochanter toward the lateral epicondyle of the femur. An incision is made, and dissection is com-

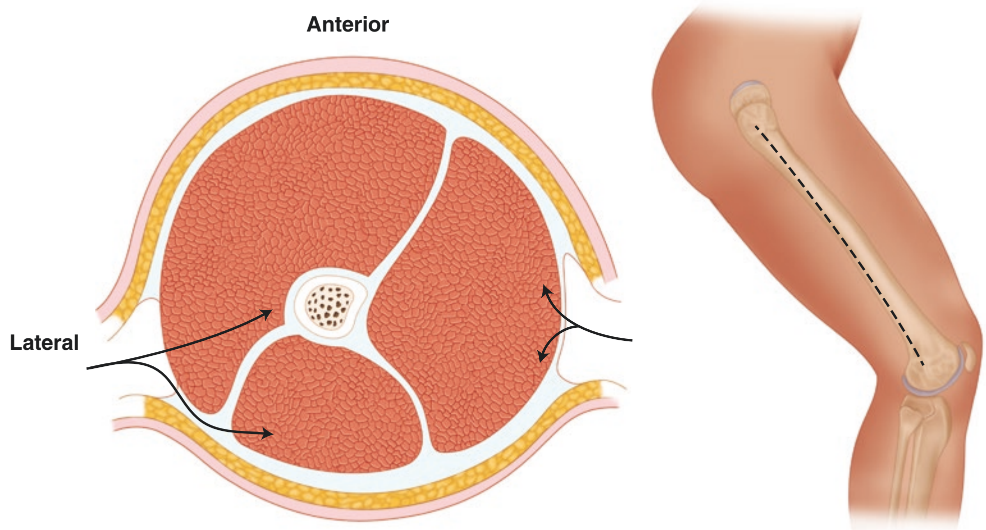


Fig. 12.8 Lateral incision on thigh serves to decompress anterior and lateral compartments. Medial incision decompresses medial compartment. Recommended incision for lateral thigh fasciotomy is from the greater trochanter towards the lateral epicondyle of the femur

pleted through the skin and subcutaneous tissue until the iliotibial band is encountered. The band is incised in a longitudinal fashion, which exposes the fascia of the vastus lateralis. The fascia is incised and may be elongated in the craniocaudal direction with Metzenbaum scissors. The anterior compartment is now decompressed. Identifying the vastus lateralis and retracting it medially exposes the lateral intermuscular septum. The intermuscular septum is incised with a knife and then opened cranially and caudally with Metzenbaum scissors to decompress the posterior compartment. If needed, the medial compartment can be decompressed with a medial incision and dissection through the subcutaneous tissues to the adductor fascia (see Fig. 12.8), incising the fascia and releasing the medial compartment. Missed thigh CS has a significant mortality, which has been shown to be as high as 47%, although this has been attributed to polytrauma and infections contracted by patients. Functional and sensory deficits as well as poor knee flexion are known complications.

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13 Resuscitative Endovascular Balloon for Occlusion of the Aorta (REBOA) and Other Endovascular Techniques

Megan Brenner and Elizabeth R. Benjamin

Introduction

Resuscitative endovascular balloon for occlusion of the aorta (REBOA) is a minimally invasive method of aortic occlusion. The catheter is introduced through a sheath in the right or left common femoral artery. A balloon in then inserted through the sheath to the desired location along the thoracic or abdominal aorta (Fig. 13.1).

The balloon can be inflated in zone I (the descending aorta from the left subclavian artery to the diaphragmatic hiatus), effectively occluding blood flow below the level of the diaphragm, or in zone III (the abdominal aorta from below the renal arteries to above the aortic bifurcation), occluding blood flow to the lower body, including the pelvis and perineum (Fig. 13.2).

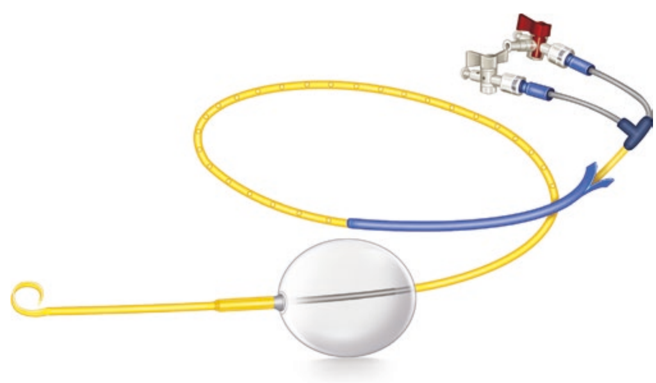

Fig. 13.1 There are several commercially available catheters for endovascular occlusion of the aorta. Pictured is the ER-REBOA catheter (Prytime Medical) with an arterial and balloon port, measurement markings, and an atraumatic tip for insertion

Indications

The indications for REBOA placement remain controversial. REBOA is indicated for truncal hemorrhage that cannot be controlled by a tourniquet, junction devices, or manual pressure. Due to distal ischemia, REBOA is considered a bridge to definitive treatment and should be only temporarily deployed and followed immediately with an intervention to treat the underlying hemorrhagic source.

Thoracic trauma is considered a relative contraindication to REBOA placement, and as such, a chest X-ray is recommended prior to deployment.

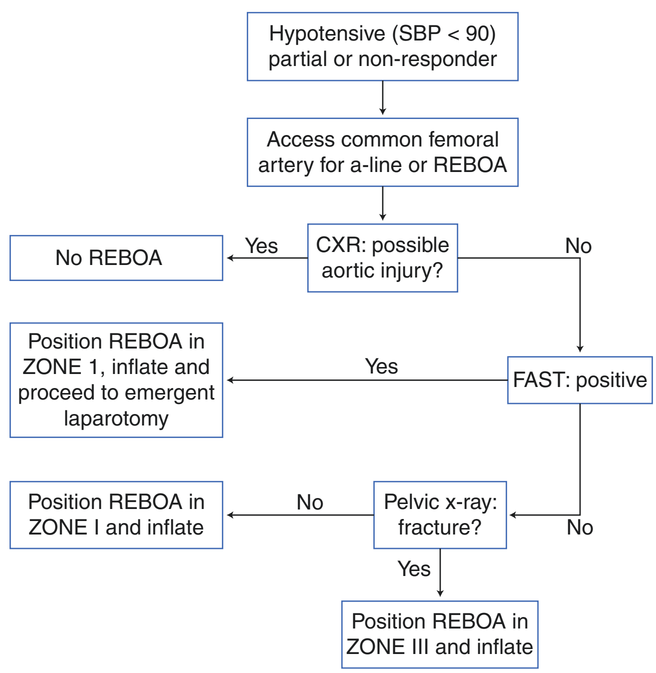

Fig. 13.2 Algorithm for REBOA placement. Zone I is between the left subclavian and celiac arteries. Zone III is between the lowest renal artery and the aortic bifurcation

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P. Ferrada, R. Ferrada (eds.), *Atlas of Trauma*, https://doi.org/10.1007/978-3-030-26871-8_13

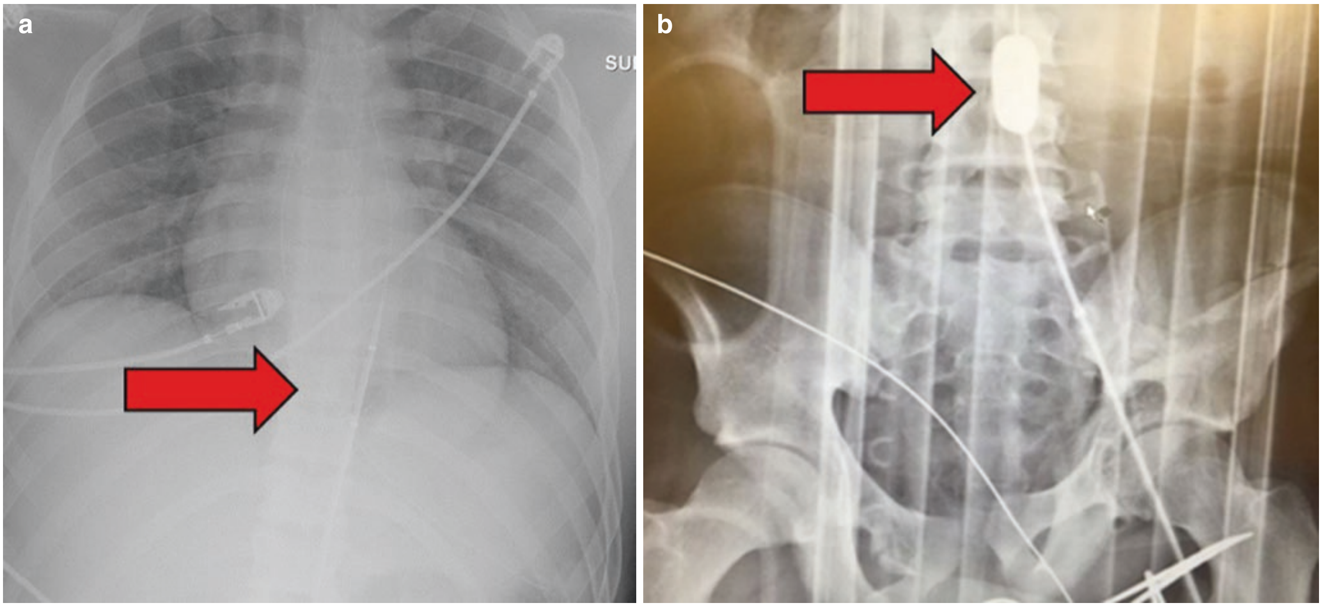

Fig. 13.3 (**a**) REBOA placement at Zone I: the descending thoracic aorta below the level of the left subclavian. (**b**) REBOA placement at Zone III: just above the aortic bifurcation

Zone I occlusion is considered in patients with severe hypotension or arrest due to hemorrhage in the abdomen or pelvis. Ideal occlusion times in Zone I are less than 20–30 minutes.

Zone III occlusion is considered in patients with severe hypotension due to hemorrhage in the pelvis or perineum and can support longer occlusion times (Fig. 13.3).

Procedure

Preparation and Access

The bilateral groins should be prepped and draped in the standard sterile fashion. If ultrasound is available, the common femoral artery can be accessed using ultrasound guidance and a micropuncture kit (Fig. 13.4).

It is imperative to access the artery well above the bifurcation and below the inguinal ligament in order to avoid injury to the superficial femoral artery and resultant limb ischemia, as well as accumulation of retroperitoneal hematoma due to iatrogenic iliac injury. If ultrasound is not available, open groin exploration and direct visualization of the femoral artery are appropriate (Fig. 13.5).

In some cases, a hybrid approach with skin incision and ultrasound localization is effective, especially in the severely hypotensive patient with poorly palpable pulses.

Once the common femoral artery is accessed, an introducer sheath is placed. Sheath size is dependent upon the commercially available REBOA catheter available at the institution. For example, the low-profile ER-REBOA used for the procedure below is introduced via a 7F sheath, while several other catheters require a larger sheath for access.

Catheter Deployment

The following steps are specific to the ER-REBOA catheter (Prytime Medical). For other commercially available catheters, modify the below procedure accordingly.

Dependent upon desired landing zone, the approximate catheter insertion length is estimated based on external landmarks. The arterial port is flushed with saline and emptied of any air bubbles. The orange peel-away sheath is advanced in a corkscrew fashion over the catheter balloon and P-tip (Fig. 13.6). The orange peel-away sheath is inserted less than 1 cm into the arterial sheath and the REBOA catheter is advanced into the arterial lumen. Once the balloon has passed the sheath valve, the orange peel-away is divided and removed while the REBOA catheter is advanced to the desired position. Once in place, X-ray or fluoroscopy is used to guide and confirm precise positioning (Fig. 13.7). The catheter can be attached to a standard arterial line setup to allow blood pressure monitoring above the level of the balloon. The balloon is then inflated to the desired volume to achieve aortic occlusion. Inflation volume is guided by tactile feedback, imaging (Fig. 13.7), and blood pressure monitoring above the level of the balloon. Make sure to secure the catheter at the desired level (Fig. 13.8) before, during, and after inflation, as it has a tendency to migrate out. The time of balloon inflation and deflation should be meticulously recorded.

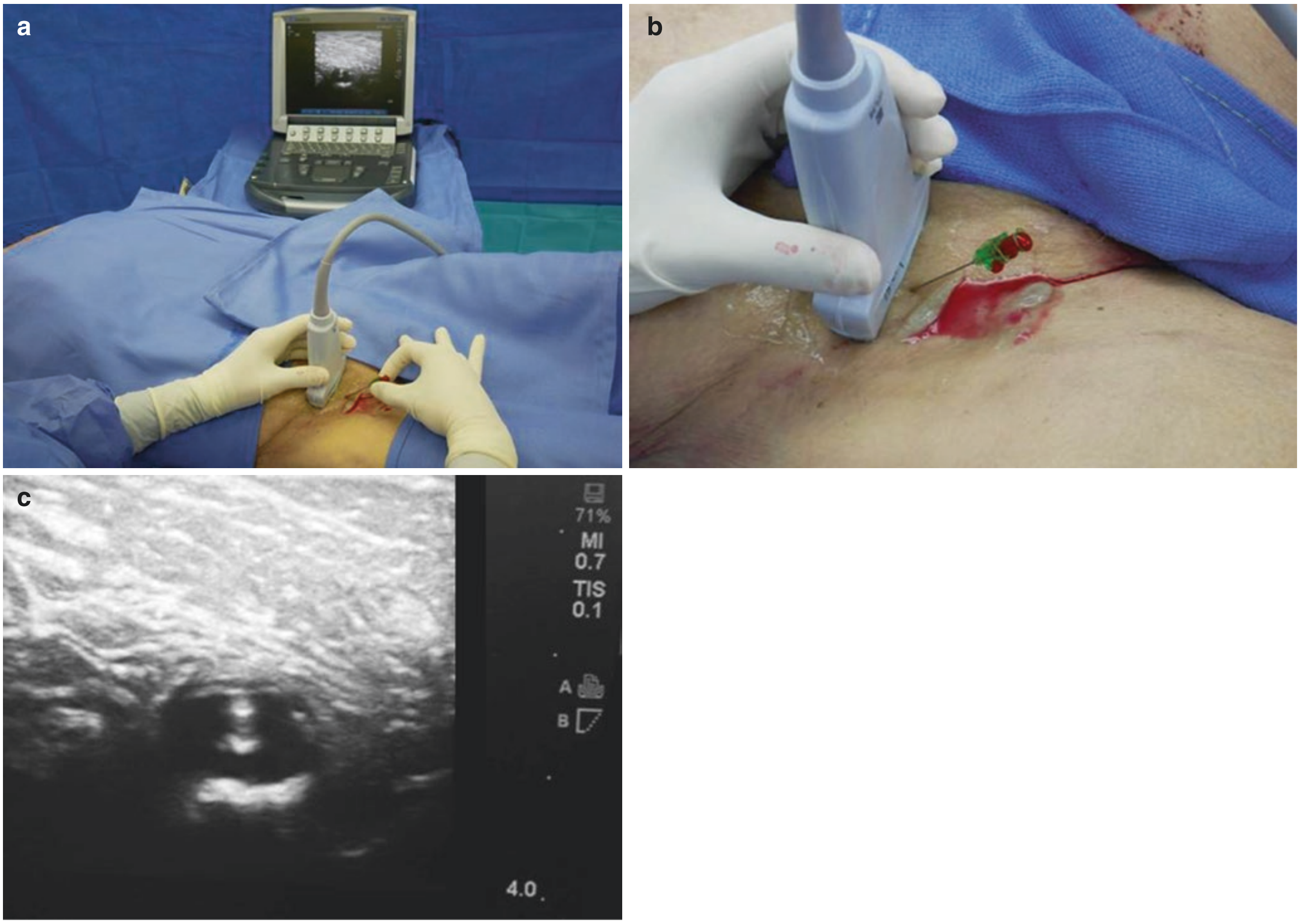

Fig. 13.4 (**a–c**) Ultrasound of the groin can be used to identify the common femoral artery and vein as well as the inguinal ligament and arterial bifurcation. Once the artery is accessed, ultrasound can be used to confirm placement in the artery

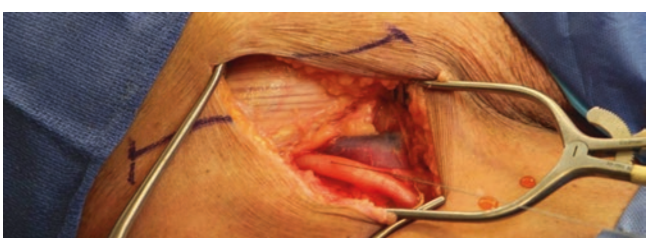

Fig. 13.5 Open groin exposure is a common method of accessing the common femoral artery, especially in hypotensive patients

Catheter and Sheath Removal

The REBOA balloon should be deflated at the earliest possible time. The risk of ischemic complications is directly related to the duration of aortic occlusion. To remove the catheter, fully deflate the balloon slowly to ensure complete collapse. The catheter should be removed in one continuous movement. Once the catheter is removed, attention should be turned to the timing of sheath removal. If at all possible, remove the sheath at the time of catheter removal. This will minimize catheter-related complications including thrombosis, distal embolization, and resultant ischemia. If the patient is coagulopathic, the provider may wish to perform an open exploration and arterial repair at the time of sheath removal or temporarily delay removal. Prior to sheath removal, the side port should be aspirated to confirm that no clot is present at the sheath tip.

All patients should receive a femoral artery ultrasound to assess flow and rule out pseudoaneurysm approximately 24 hours after sheath removal.

Complications

REBOA complications can be divided into several categories including complications of access, balloon deployment, and catheter and sheath removal. All REBOA programs should have an established rapport and agreement with a surgical group, most commonly vascular surgeons, that is comfortable addressing the potential complications of catheter placement. Local complications at the level of the artery can include arterial dissection, transection, thrombosis, and distal embolization.

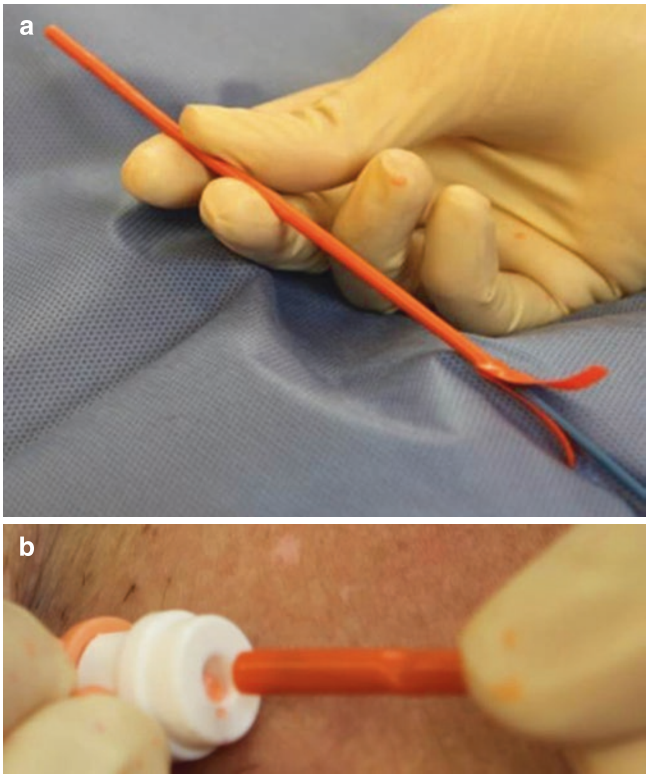

Fig. 13.6 (**a**) and (**b**) The orange peel-away sheath is advanced over the balloon and P-tip of the catheter using a corkscrew motion. This is then inserted less than 1 cm into the arterial sheath and the REBOA catheter is advanced

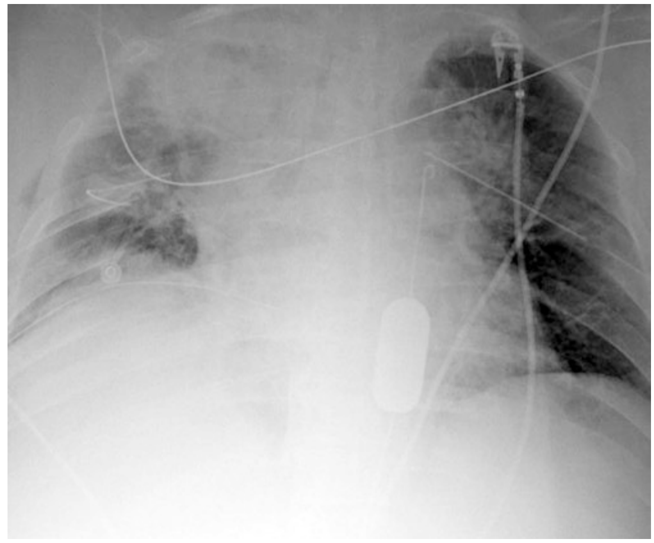

Fig. 13.7 REBOA balloon inflated in Zone I above the level of the diaphragm. Note the vertical position above the diaphragm and the gentle sloping of the balloon indicating adequate but not over-inflation

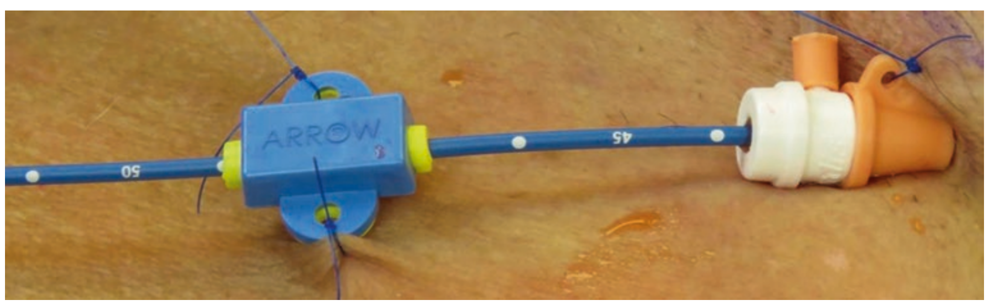

Fig. 13.8 The REBOA catheter must be carefully secured once positioned to avoid migration

Partial Occlusion

Although REBOA is traditionally described as binary with occlusion or deflation, as technology improves and providers become more comfortable with the device, partial occlusion is becoming more popular. With partial occlusion, the balloon volume is titrated to blood pressure and slowly deflated over time, allowing the body to equilibrate during reperfusion.

Summary

REBOA is a promising technology for temporary occlusion of the aorta and resuscitation after abdominal and/or pelvic hemorrhage. Deployment in zone I is standard for patients in extremis when information is limited. If hemorrhage is isolated to the pelvis and perineum, zone III occlusion can be a more appropriate targeted therapy. It is important to deflate the catheter and remove both the catheter and sheath at the earliest possible convenience. REBOA is highly effective at improving targeted perfusion and can be a life-saving procedure.

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