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CHAPTER 7.13

Trauma Surgery

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(Print pagebreak 714)

Initial Assessment and Airway Management for Trauma Surgery

Initial Assessment

The Advanced Trauma Life-Support System (ATLS), developed by the American College of Surgeons Committee on Trauma, represents the best current approach to the severely injured patient. The sequence of management includes: (a) primary survey and initial resuscitation, (b) evaluation of initial treatment and continued resuscitation, and (c) secondary survey with definitive management.

In the primary survey, attempt to identify and treat immediate life-threatening conditions by following the ABCs: **airway control,** with cervical spine precautions; assisted **breathing** or mechanical ventilation; and support of the **circulation** via volume resuscitation and tamponade of external bleeding. After alveolar ventilation is ensured, the next priority is to optimize O_2 delivery by maximizing cardiovascular performance. Hypovolemia is the most likely etiology of postinjury shock; therefore, fluid resuscitation should be initiated via two large-bore iv cannulas placed in the antecubital veins. Any external source of bleeding should be controlled with manual compression. When vascular collapse precludes peripheral percutaneous access, femoral vein cannulation in the groin or saphenous vein cutdown at the ankle are preferred alternatives. ECG monitoring, serial vital signs, rapid physical examination, temperature reading, and initiation of flow sheet complete the primary survey. Then evaluate the patient's response to fluid resuscitation and, if crystalloid volume exceeds 50 mL/kg, give type-specific or O negative blood. If shock persists despite fluid resuscitation, consider ongoing hemorrhage, tension pneumothorax, or cardiac tamponade. Ongoing hemorrhage should be treated operatively without delay to attempt correction of vital signs. Tension pneumothorax should be vented immediately through a needle inserted into the second interspace in the midclavicular line, followed by chest tube placement. Cardiac tamponade will require operative decompression.

Management of Airway

Airway obstruction, inadequate ventilation, hypoxemia, abnormal mental status, and cardiovascular instability are the usual indications for airway intervention. The three commonly accepted methods of airway control are: **orotracheal intubation, blind nasotracheal intubation,** and **cricothyrotomy**.

Oraltracheal intubation, with the use of appropriate neuromuscular blockade and the Sellick maneuver cricoid pressure, is the preferred choice. The approach is rapid, but at least three people are required to perform it safely in the patient with suspected C-spine injury.

In-line stabilization of the neck has replaced in-line traction as the protective measure. Because a failed intubation may force operative airway intubation, equipment for cricothyrotomy should be immediately accessible. Fiberoptic assistance or other supportive techniques for endotracheal intubation may be used in the stable patient with a difficult airway. Patients in respiratory distress with severe facial or neck trauma or unstable cervical spine injury require a surgical airway. An airway placed in transport should be immediately evaluated for position and changed to a definitive airway when appropriate.

Nasotracheal intubation, used only in spontaneously breathing trauma patients, can be performed without the use of pharmacologic agents or special equipment. It is, however, associated with higher incidence of vomiting and aspiration. In the intoxicated patient with a depressed level of consciousness, the success rate may be as low as 65%. Blind nasal intubation is contraindicated in patients with unstable midface fractures, penetrating neck trauma, or significant neck hematomas.

Cricothyrotomy (Fig. 7.13-1) is the preferred method in adults who require a surgical airway. The important anatomic landmarks of the superior and inferior borders of the thyroid and cricoid cartilages are palpated. The thyroid cartilage is then stabilized, a vertical skin incision is made, and the ETT or tracheostomy tube is rapidly advanced through subcutaneous tissue. The cricothyroid membrane lies very superficially, covered only by the skin and platysma muscle. The cricothyroid membrane is incised transversely with the scalpel. In emergency situations, a standard small-caliber ETT is generally easier to insert than a tracheostomy tube (Fig. 7.13-1B). Cricothyrotomies should be converted to tracheotomies within 72 h after the initial injury, provided the patient's condition permits.

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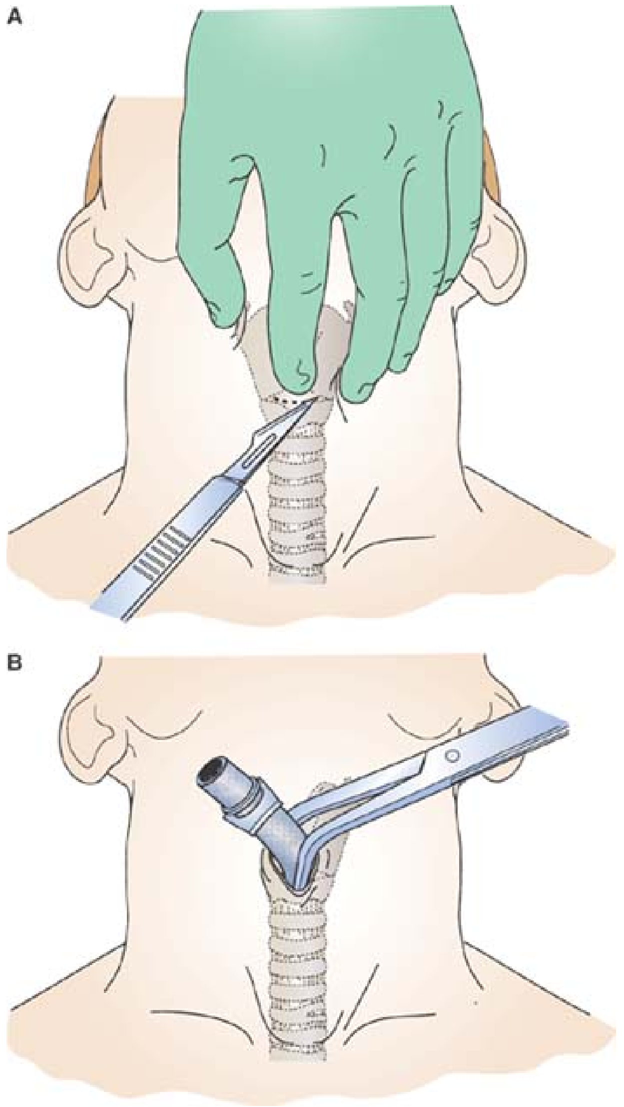

Figure 7.13-1. 1. Cricothyrotomy (vertical skin incision not shown). **(A)** Identification of the cricothyroid membrane by palpation and incision of the membrane transversely. **(B)** Insertion of a tracheostomy tube or ETT through the cricothyroid membrane, which is spread with a tracheal dilator. (Redrawn with permission from Greenfield LJ, Mulholland MW, Oldham KT, et al., eds: *Surgery: Scientific Principles and Practice,* 2nd edition. Lippincott Williams & Wilkins, Philadelphia: 1997.)

A **tracheostomy** is indicated for patients requiring surgical airway in less dramatic situations or if a cricothyrotomy cannot be performed due to direct laryngeal injury. A tracheostomy can be accomplished through the same incision, extended caudally, if laryngeal injury is found (see p. 714). On rare occasions, the injury is in the distal cervical or proximal intrathoracic trachea. In such cases, it may be necessary to intubate the distal end of the airway through the wound. A subsequent median sternotomy may be required to expose the injury. Right thoracotomy provides access to the distal intrathoracic trachea (see Chest Trauma, p. 723).

Usual preop diagnosis: Airway compromise

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Summary of Procedures

Position	Supine
Incision	Midline longitudinal incision in the neck
Unique considerations	The large number of legal claims involving failed intubation suggests that surgical cricothyrotomy remains an underutilized technique.
Antibiotics	Usually not given until clear indications related to the primary injury are apparent.
Surgical time	2 min
EBL	Minimal
Postop care	Mechanical ventilation
Mortality	Related to the primary injury
Morbidity	Cricothyrotomy is more likely to result in airway stricture or damage to more proximal structures in the larynx. On this basis, cricothyrotomy is converted to tracheostomy within 48–72 h of admission if patient's general condition permits.
Pain score	3

Emergency Tube Thoracostomy

Surgical Considerations

Description: In the United States, trauma is the most common cause of death in young people; 25% of these deaths (16,000 per year) are the result of thoracic trauma. Most of these are due to lethal injuries at the scene (e.g., cardiac rupture, free aortic transection). For patients who reach the hospital, proper management is crucial, because many deaths can be prevented. Early deaths are due to airway obstruction, tension pneumothorax, massive hemothorax, flail chest, cardiac tamponade, and open pneumothorax. Later deaths are due to respiratory failure, sepsis, and unrecognized injuries.

Eighty percent of blunt thoracic injuries are caused by motor vehicle collisions (MVCs). Penetrating injuries to the chest are almost as common as blunt trauma. The death rate in hospitalized patients with isolated chest injury is 4–8%; this increases to 10–15% when one other organ system is involved and to 35% if multiple additional organs are injured. Eighty-five percent of chest injuries do not require thoracotomy, and the patient can be managed with relatively simple measures, such as airway control, tube thoracostomy, and pain management. Blunt trauma can induce injury by three distinctive mechanisms: direct blow, deceleration injury, and compression injury. Rib fracture is the most common sign of blunt thoracic trauma. Fracture of the upper ribs (1st–3rd), clavicle, or scapula implies high-energy impact and is associated with a higher likelihood of major vascular injury.

Life-threatening injuries caused by penetrating trauma are distinctly different from those caused by blunt trauma. In penetrating chest injuries, pneumothorax is almost always present and hemothorax is present in 80% of cases. Hypovolemia from intrathoracic hemorrhage is second only to rib fractures as a sequela of thoracic trauma.

Tension pneumothorax may be caused by blunt or penetrating trauma. Venous return to the heart is impaired by the increased intrathoracic pressure and compression of the vena cava → ↓ BP and distended neck veins. Loss of lung volume on the ipsilateral side and subsequent compression of the contralateral side leads to impaired ventilation and hypoxia. The diagnosis of tension pneumothorax is made clinically. The presence of respiratory distress and absent or diminished breath sounds warrant immediate needle decompression (14–16-ga catheter through the 2nd intercostal space, midclavicular line), followed by subsequent tube thoracostomy. Treatment should not be delayed for radiographic confirmation. Because sequelae of thoracic injuries interfere with air exchange, treatment must take high priority, just after securing the airway, obtaining iv access, and beginning fluid resuscitation. In the hemodynamically stable patient, however, suspicion of a pneumothorax should be confirmed by x-ray. On the CXR, a 20% loss of lung dimension corresponds to 50% loss of lung volume. A small, simple pneumothorax (< 10%) with no respiratory compromise may be observed. These patients require close observation in the hospital *(Print pagebreak 717)* and a repeat CXR in 4–6 h. Tube thoracostomy should be performed for a large pneumothorax (> 10%), for patients with respiratory compromise or multiple injuries, or when it is not possible to adequately monitor the patient (e.g., during extended transport).

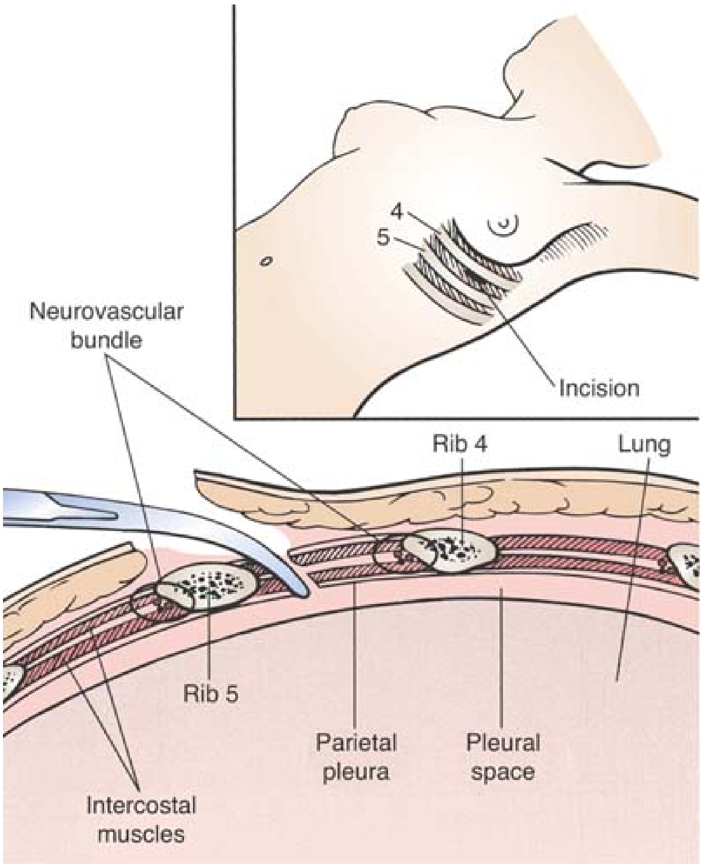

Figure 7.13-2. 2. Tube thoracostomy. Incision through 4th or 5th interspace at anterior axillary line. Forceps are used to tunnel over the superior edge of the rib and to bluntly enter the pleural space.

As much as 40% of the circulating blood volume can accumulate in a **hemothorax**. The most frequent sources of bleeding are the intercostal and internal mammary vessels. Some degree of hemothorax is present in almost every patient with chest injury. A supine CXR may miss up to 1 L of blood. Although an upright CXR is more sensitive, this is generally impractical in a multiple-trauma patient (whose spine often has not been fully evaluated). Following chest tube placement, blood loss > 1200–1500 mL or an ongoing loss of 250 mL/h for 4 h suggest the need for surgical intervention.

Simple pneumothorax without associated hemothorax can be treated with a 20–22 Fr chest tube placed in the 4th intercostal space in the midaxillary line or in the 5th intercostal space in the anterior axillary line. Hemothorax and tension pneumothorax require a large-bore, 38–40 Fr chest tube placed in the midaxillary line through the 5th intercostal space (Fig. 7.13-2). A 20-mL syringe with 1% lidocaine can be used not only to provide local anesthesia, but also to locate the upper edge of the rib in the obese patient. A generous 3-cm incision should be made one interspace below the targeted level. The subcutaneous tissues are dissected bluntly, creating a tunnel that is directed upwards. The pleural space should be entered just above the upper edge of the rib to avoid injury to the intercostal neurovascular bundle, located just below the lower edge of the rib. After the pleural space has been entered bluntly, it should be explored with the operator's finger swept around to ensure proper location and to free potential adhesions. The chest tube should be inserted and advanced in the posterior and superior direction. The tube then should be connected to a suction/collection system under 20 cm of water-negative pressure, preferably through an autotransfusion device. CXR should immediately follow chest tube placement to evaluate decompression and assess for other injuries. If the pleural space still contains blood, another chest tube could be inserted or video-assisted thoracoscopy (VAT) could be considered if major vascular injury is not suspected.

(Print pagebreak 718)

Usual preop diagnosis: Tension pneumothorax; pneumothorax; hemothorax

Summary of Procedures

Position	Supine with arm abducted 90°
Incision	3 cm in interspace below 5th intercostal space in midaxillary line

Special instrumentation	38–40 Fr chest tube should be used in most patients. Small, 20–22 Fr tube reserved for simple pneumothorax in stable patients. Autotransfusion device should be available in ER.
Unique considerations	In tension pneumothorax, a large-bore needle inserted in the 2nd intercostal space of the midclavicular line can relieve tension and save a patient's life.
Antibiotics	Cefazolin 1 g iv
Surgical time	5 min
EBL	Minimal from tube placement. Variable amounts drained out, depending on extent of hemothorax and associated injuries.
Postop care	Chest tube may be removed after at least 48 h, when there is no air leak from lung and < 100–150 mL of fluid drainage per 24 h.
Mortality	Isolated chest injury: 4–8% When one other organ system is involved: 10–15% When two or more organ systems involved: > 35%
Morbidity	Clotted hemothorax Empyema Lung abscess Lung contusion
Pain score	5

Emergency Department Thoracotomy

Surgical Considerations

Description: Rarely, emergency department thoracotomy may offer the only chance of survival in highly selected trauma patients. Its use should be restricted largely to patients who show signs of life in the emergency department (ED) but lose such signs shortly thereafter. The usual indications are: (a) massive exsanguination in the left chest, usually due to cardiac, vascular, or pulmonary injuries and (b) pericardial tamponade. For patients with penetrating cardiac injuries who show signs of life in the ED, survival may be as high as 15%. For blunt trauma in this setting, survival is < 1%, regardless of presentation. With either mechanism, functional survival is almost unprecedented if the patient arrives without vital signs and unreactive pupils.

A **left anterolateral thoracotomy** is the preferred approach since pericardiotomy, open cardiac massage, and aortic occlusion are best achieved by this means. This incision can be extended easily across the sternum and into the right chest to improve exposure and to control massive blood loss and/or air embolism from the right lung. The entire chest is prepped liberally, and left anterolateral thoracotomy is performed rapidly in the 5th intercostal space using a large-blade scalpel. Heavy scissors can be used to quickly divide the intercostal muscles and to cut across the sternum. If pericardial tamponade is encountered, the pericardium is opened longitudinally, anterior to the phrenic nerve. Blood and clot are evacuated and bleeding sites controlled with gentle digital pressure. Large, full-thickness lacerations that extend into the chambers may be controlled by inserting a Foley catheter, inflating the balloon, and pulling it snug against the myocardium. The open end of the Foley can be clamped or used as an infusion line for resuscitation. During ED thoracotomy, placement of clamps on the atria or ventricles should be avoided as they may extend the laceration. Attempts to repair cardiac lacerations should be delayed until resuscitative measures have been completed. In the nonbeating heart, suturing is performed prior to defibrillation. If coronary or systemic air *(Print pagebreak 719)* embolism is present, the appropriate hilum is cross-clamped and air is aspirated from the left ventricle through the elevated apex. Cardiac arrest is an indication for immediate internal massage. The two-hand method is preferred, and internal defibrillation should be instituted. If internal defibrillation does not restore proper cardiac activity, cross-clamping of the aorta will improve coronary perfusion. To cross-clamp the aorta, the left lung is retracted anteriorly and superiorly, and the posterior pleura is dissected under direct vision. Despite proper exposure and an NG tube in the esophagus, cross-clamping the aorta in the ED is difficult.

Usual preop diagnosis: Penetrating chest trauma with cardiac arrest and recent recorded signs of life

Summary of Procedures

Position	Supine
Incision	Left anterolateral thoracotomy. Extension of incision across sternum could be considered for improved exposure.
Special instrumentation	ED thoracotomy tray; internal defibrillator paddles; suction device; Foley catheter; rapid-infusion device; O(-) blood
Unique considerations	Airway should be secured first. NG tube should be placed if possible. Typically, patients are not anesthetized for this procedure.
Antibiotics	Cefazolin 1 g iv
Surgical time	10 min
EBL	1–2 L
Postop care	ICU
Mortality	Blunt trauma: 98% All penetrating chest injuries requiring ED thoracotomy: 85% Penetrating cardiac injury: 50%
Morbidity	Arrhythmias Acute MI
Pain score	10

Exploratory Surgery for Neck Trauma

Surgical Considerations

Description: The cervical region contains a greater variety of vital structures than any other region of the body (Fig. 7.13-3). The cardiovascular, respiratory, digestive, endocrine, and CNS systems are all represented in the neck; injury to any of these can be fatal.

Injuries to the neck may result from blunt or penetrating trauma. In blunt trauma, < 5% of cases will have C-spine injuries. Because the consequences are so grave, however, all patients should be evaluated for C-spine injuries (H&P, x-rays, CT), and full spinal precautions should be maintained until the C-spine is cleared. Blunt airway injuries can be devastating and present significant management difficulties; however, the majority of blunt neck trauma consists of minor soft-tissue injuries that can be managed nonoperatively.

Penetrating neck trauma is defined as penetration of the platysma muscle. For these injuries, the neck is usually divided into three horizontal zones (Fig. 7.13-3, inset). Zone I extends from the sternal notch to the cricoid cartilage. Penetrating injuries in this area are associated with a high mortality. Zone II extends from the cricoid cartilage to the angle of the mandible. Because this is the most exposed region of the neck, injuries can be evaluated and explored relatively easily. Zone III extends from the angle of the mandible to the base of the skull. Because of anatomic constraints, injuries to Zones I and III can be difficult to identify and repair. In patients with a Zone I injury, iv access should be established in the contralateral upper extremity because of the possible injury to the ipsilateral internal jugular vein or subclavian vein.

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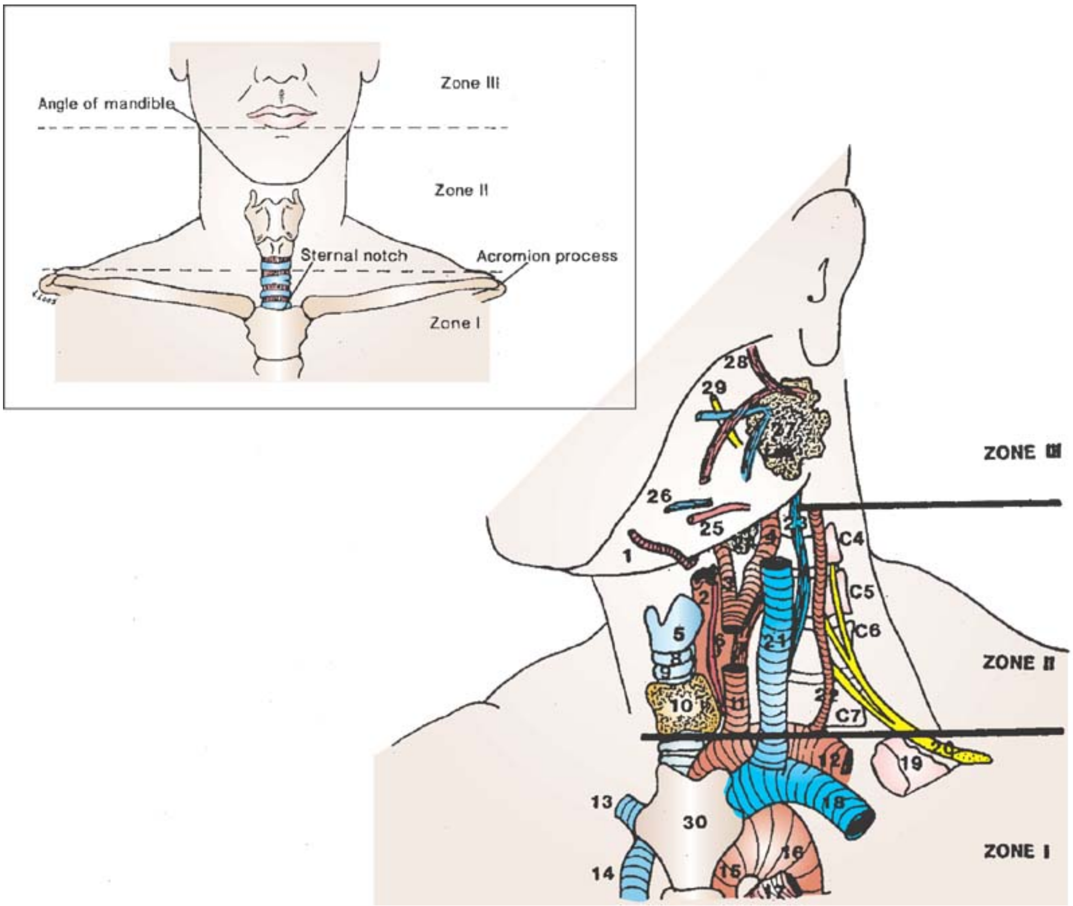

Figure 7.13-3. 3. Cervical structures contained in Zones I, II and III: (1) facial artery; (2) esophagus; (3) internal carotid artery; (4) external carotid artery; (5) thyroid cartilage; (6) sympathetic trunk; (7) vagus nerve; (8) cricothyroid membrane; (9) cricoid cartilage; (10) thyroid cartilage; (11) common carotid artery; (12) subclavian artery; (13) right innominate vein; (14) SVC; (15) ascending aorta; (16) descending aorta; (17) PA; (18) subclavian vein; (19) clavicle; (20) brachial plexus; (21) IJ vein; (22) vertebral artery; (23) phrenic nerve; (24) submandibular gland; (25) lingual artery; (26) hypoglossal nerve; (27) parotid gland and duct; (28) facial nerve and its branches; (29) maxillary artery; (30) sternal manubrium. The thoracic duct is not shown in this figure. (Adapted with permission from Ordog GJ, et al. *J Trauma* 1985; 25:238). (Inset reproduced with permission from Baker RJ, Fischer JE: *Mastery of Surgery*. Lippincott Williams & Wilkins, Philadelphia: 2001.)

Until recently, evaluation and management of stable patients with neck injuries that penetrated the platysma depended on location of injury. Injuries to Zones I and III were evaluated radiographically, whereas injuries to Zone II were indications for mandatory exploration. With the increased availability of CT and arteriography, however, a selective exploration strategy is now favored. Evaluation of the larynx, pharynx, trachea, and esophagus should be performed if Sx are present; however, a penetrating neck wound should never be probed or explored locally, as this may dislodge a clot and precipitate significant hemorrhage or air embolus.

Management of hemodynamically unstable or symptomatic patients with penetrating neck injuries should be limited to applying direct pressure, protecting the airway, establishing iv access, and obtaining a CXR. Exploration and *(Print pagebreak 721)* definitive management of the injury in the OR should follow as soon as possible. In stable patients with penetrating injuries and no indications for exploration, CT is generally the first diagnostic test.

A **median sternotomy incision** may be used for patients with right-neck Zone I injuries or if injuries to the mediastinum involving the innominate artery or right subclavian artery are suspected. Exposure of injuries to the proximal left subclavian artery is extremely difficult via median sternotomy. In this case, a left anterior thoracotomy is preferred. The chest and left arm should be prepped and draped so as to allow arm manipulation.

Usual preop diagnosis: Penetrating neck injury

Summary of Procedures

Position	Supine with head turned away from side of exploration and neck extended. If both sides of neck require exploration, head should be in midposition. It is helpful to clear the C-spine before exploration.
Incision	Sternocleidomastoid anterior border
Unique considerations	Monitor BP and HR carefully during carotid sinus manipulation.
Antibiotics	Cefazolin 1 g iv. If pharyngoesophageal injury: ampicillin 1 g and gentamicin 80 mg iv.
Surgical time	1 h
Closing considerations	Wound requires drainage, especially in Zone I exploration and if esophagus or airway was violated.
EBL	Variable
Postop care	ICU 12–24 h for neurologic and airway monitoring. After carotid injury repair, angiography should be considered.
Mortality	1%
Morbidity	Hemorrhage: acute from injuries; delayed from pseudoaneurysms Airway injury: acute loss of airway; delayed tracheal stenosis Damage to neural or vascular structures Esophageal fistula
Pain score	4

Patient Population Characteristics

Age range	Typically young adult
Etiology	Typically male
Incidence	5–10% of all trauma involves neck structures.
Associated conditions	Intrathoracic injuries; spinal cord injuries; recurrent laryngeal nerve injury; phrenic nerve injuries; thoracic duct injury

Anesthetic Considerations for Neck Trauma Surgery

Preoperative

Patients with neck injuries often present unique challenges for ET intubation. Extensive internal damage may be present despite minimal external signs. High-velocity deceleration events, or “clothesline” injuries, are often associated *(Print pagebreak 722)* with airway compromise. Vascular injuries, particularly involving the carotid artery, can markedly distort internal anatomy and prevent visualization of laryngeal structures or passage of an ETT. Known or suspected C-spine injuries will restrict optimal positioning of the head and neck for laryngoscopy. Facial or dental injuries may impede access for laryngoscopy because of limited mouth opening or the presence of blood in the oropharynx. The use of alternative methods to secure the airway (e.g., fiber optic bronchoscopy) or a surgical approach may be the safest option. Equipment for a surgical airway should be available prior to attempting ET intubation.

Airway	Preop assessment of the airway and nature and extent of the cervical injury is crucial. Stridor and hoarseness may be present with laryngeal injury or compression of the trachea. Assess patient's ability to talk as a part of the airway evaluation. C-spine injury (though not common with penetrating neck injuries) should be evaluated by x-ray or CT scan. Airway injury can be associated with subcutaneous emphysema or pneumothorax. The extent of mouth opening, dental injuries, and any distortion of internal and external structures due to tissue swelling or

	hematoma should be determined before induction. The CXR or CT should be examined carefully for evidence of tracheal deviation compression or pneumothorax. **Tests:** x-ray; CT scan; ABG
Cardiovascular	The patient should be evaluated for the extent of blood loss (BP, HR, capillary refill, peripheral pulse, skin condition). In addition to vascular injuries, associated facial and dental injuries may result in significant occult blood loss accumulated in the stomach. Venous lacerations can allow air embolism.
Neurological	Deficits associated with acute compromise of cerebral arterial blood flow should be evaluated on physical exam. Damage to the recurrent laryngeal nerve can occur, resulting in changes in voice and ↑ aspiration risk. C-spine injuries should be assessed by physical exam (neck pain, neurologic examination) and radiologic studies (lateral C-spine x-rays [including C-7] CT scan, MRI).
Premedication	Full-stomach precautions (see p. B-4).

Intraoperative

Anesthetic technique: GETA

Induction	The induction technique will depend on the associated injuries and physical exam. In the hypovolemic patient, induction doses of STP or propofol should be reduced by 50–75% to minimize ↓↓ BP. Consider etomidate (0.2–0.3 mg/kg) or ketamine (0.5–1 mg/kg iv) as alternative induction agents. A rapid-sequence iv induction with cricoid pressure is usually required. In the presence of a vascular injury, the cough reflex and the BP response to intubation should be suppressed (e.g., remifentanil 1 mcg/kg iv), in addition to induction agents, to prevent expansion of the hematoma. A wide range of ETT sizes (5.0–8.0 mm) should be available. If C-spine injury is suspected, in-line stabilization of the patient's head and neck should be provided by an assistant. In the presence of an unstable C-spine, cricoid pressure should be avoided to prevent further injury. If a difficult intubation is anticipated, fiber optic intubation (see p. B-5) or an awake surgical airway (cricothyrotomy or tracheotomy) should be considered. In patients with penetrating neck injuries; "blind" intubation techniques should be avoided.	
Maintenance	Standard maintenance (p. B-2) is usually appropriate for the normotensive neck-trauma patient. In cases of vascular injury, careful control of BP in the low normal range is advantageous. When nerve testing is anticipated, either no muscle relaxation or a short-acting agent (e.g., mivacurium) should be used.	
Emergence	Postop intubation and mechanical ventilation is prudent in patients with residual neurological deficits or oropharyngeal swelling. BP control at low normal levels and slight elevation of the head of the bed (10–20°) will help to resolve tissue edema. Awake extubation is the goal in patients with minimal distortion of the airway at the conclusion of the procedure.	
Blood and fluid requirements	IV: 14–16 ga × 2 NS/LR @ 4–6 mL/kg/h	Blood transfusion may be necessary with vascular injuries.
Monitoring	Standard monitors (see p. B-1). ± Arterial line	Invasive monitoring may be indicated for patients with major vascular injuries; however, the placement should not delay the start of emergency surgery.
Positioning	and pad pressure points eyes	With suspected or known C-spine injuries, stabilization of the head and neck in the neutral position is required.
Complications	Awareness Hypothermia	

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Postoperative

Complications	Hemorrhage Hematoma Airway compromise	BP control at low normal levels (SNP infusion, labetalol, NTG) and elevation of the head of the bed (10–20°) will help minimize tissue edema and hematoma formation, which could lead to airway compromise.
Pain management	See p. C-1.	
Tests	As indicated.	

Suggested Readings

1. Dutton RP, McCunn M: Anesthesia for trauma. In: *Miller's Anesthesia,* 6th edition, Vol 2. Miller RD, et al., eds. Churchill Livingstone, New York: 2005, 2451–95.

2. Kendall JL, Anglin D, Demetriades D: Penetrating neck trauma. In: *Emerg Med Clin North Am: Contemporary Issues in Trauma.* Eckstein M, Chan D, eds. WB Saunders, Philadelphia: 1998, 85–106.

3. Wisner D, Blaisdell FW: Neck injuries. In: *Scientific American Surgery*, Vol 1. Scientific American, New York: 1998.

Chest Trauma: Pericardial Window, Release of Tamponade, Repair of Cardiac Laceration

Surgical Considerations

Description: Cardiac contusions may occur in patients with blunt chest trauma. The degree of injury varies from localized contusion to cardiac rupture, but most are clinically insignificant if the patient survives to the hospital. Autopsy studies of victims of immediately fatal accidents show that as many as 65% have rupture of one or more cardiac chambers and 45% have pericardial lacerations. Most of the patients with cardiac rupture die at the scene; however, survivors are reported if vital signs are present during transport. Early clinical findings in cardiac contusion are most commonly dysrhythmias, but occasionally patients can develop cardiac failure. The initial ECG in the ED is the most sensitive diagnostic test. The most common abnormalities are atrial arrhythmias and right bundle branch block. Serial cardiac monitoring is indicated only if the initial ECG is abnormal. Serum enzymes are not helpful. Management is symptomatic. Arrhythmias should be treated in the standard fashion and are not a contraindication to surgery. Pericardial lacerations from stab wounds tend to seal and cause tamponade, present in 80–90% of patients with stab wounds to the heart. Accumulation of 150 mL of blood in the pericardium may impair preload and cause shock. **Beck's triad** of distended neck veins, muffled heart sounds, and ↓ BP is present in only 30% of patients with *(Print pagebreak 724)* tamponade. Pulsus paradoxus is even less reliable. The diagnostic test of choice is ultrasound, performed in the ED as part of the focused assessment by sonography for trauma (FAST) exam.

Treatment of penetrating cardiac injuries has gradually changed from initial management by **pericardiocentesis** to prompt **thoracotomy** and **pericardial decompression.** Pericardiocentesis, with ultrasound guidance, may be used to stabilize a patient until sternotomy or thoracotomy can be performed. A subxiphoid pericardial window is an option, but is best performed in the OR.

Gunshot wounds (GSWs) can produce extensive myocardial damage, multiple perforations, and massive bleeding into the pleural space. Hemothorax, shock, and exsanguination occur in nearly all cases of cardiac GSWs. Pericardial tamponade is often absent. Hemodynamically stable patients with penetrating injuries close to the heart should have ECG evaluation in the ED only if equipment is immediately available. The presence of pericardial fluid should be evaluated with a FAST scan. If a hemopericardium is confirmed, blood should be evacuated and injury treated in the OR.

Patients who are stable enough to be transported to the OR have excellent prognosis with reported survival of 97% for stab wounds and 71% for GSWs. In contrast, patients who require ED thoracotomy have only a 15% survival rate for penetrating injuries.

Subxiphoid pericardial window under local or GA: The entire chest is prepped for potential sternotomy. A vertical midline incision is made over the xiphoid process and upper epigastrium. The xiphoid is elevated or excised, allowing access to the pericardiophrenic membrane and anterior mediastinum. The pericardium is opened between two stay sutures and inspected for the presence of blood. If blood is found, definitive repair should follow without delay. With the use of FAST scanning, this operation is rarely indicated as a diagnostic procedure.

Median sternotomy provides excellent exposure to the heart, great vessels, and pulmonary hila. This approach is ideal for anterior injuries and for the unstable patient, but is less well suited for posterior injuries and left subclavian injuries.

Left anterior/anterolateral thoracotomy in the 5th intercostal space can be used in the stable patient or in the newly unstable ED patient with penetrating injury. The pericardium is opened anterior to the phrenic nerve and tamponade is relieved. The bleeding heart is controlled with digital occlusion and the laceration is closed with mattress sutures, with care being taken not to occlude coronary flow. Small coronary branches can be ligated, whereas others should be repaired and may even require CPB.

Usual preop diagnosis: Cardiac laceration

Summary of Procedures

Position	Supine, L arm abducted 90°
Incision	Median sternotomy or left anterior or anterolateral thoracotomy in 5th intercostal space. (See Fig. 7.13-4.) Further exposure may be obtained by transsternal extension into the R chest.
Special instrumentation	Rapid-infusion device; active rewarming system; internal defibrillator
Unique considerations	Massive blood loss is expected upon opening pericardium and during repair of laceration. Large-bore peripheral lower extremity iv and central venous access are recommended for monitoring of volume replacement. A Foley catheter can be used to occlude laceration and as access for infusion. Arrhythmias are common.
Antibiotics	Cefazolin 1 g iv
Surgical time	45 min
Closing considerations	Hypothermia and coagulopathy contribute to mortality.
EBL	1–2 L
Postop care	ICU
Mortality	Without tamponade: 90% With tamponade: 30% Overall: 85%
Morbidity	Pulmonary complications Acute MI Arrhythmias Intracardiac shunts Ventricular aneurysms Valvular lesions Retained foreign bodies
Pain score	8

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Patient Population Characteristics

Age range	Usually young adult
Etiology	GSWs, stab wounds, blunt trauma
Associated conditions	Hemothorax; pneumothorax; great-vessel injury; lung contusion

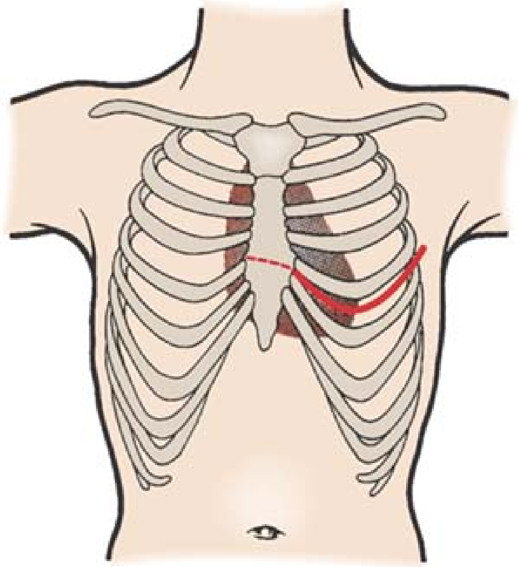

Figure 7.13-4. 4. Incision (dashed/solid line) for ED thoracotomy: made immediately below the nipple, extending from sternum as far laterally as possible. (Reproduced with permission from Baker RJ, Fischer JE: *Mastery of Surgery.* Lippincott Williams & Wilkins, Philadelphia: 2001.)

Anesthetic Considerations

See Anesthetic Considerations for Chest Trauma, p. 729.

Chest Trauma: Repair of Great Vessels

Surgical Considerations

Description: Thoracic great vessel injury accounts for 8–9% of all vascular injuries seen in the trauma center. The subclavian artery and descending thoracic aorta are the vessels injured most often (21% of cases), followed by PA (16%), subclavian vein (13%), vena cava (11%), and innominate artery and pulmonary veins (9%).

(Print pagebreak 726)

Rupture of the thoracic aorta is the most lethal injury following blunt chest trauma and causes up to 50% of fatalities in MVCs. Proposed mechanism of injury is a deceleration force causing flexion or torsion of the aortic arch and subsequent disruption of the aortic wall at the ligamentum arteriosum immediately distal to the left subclavian artery. Survival of the patient depends on retention of the hematoma by the adventitial layer of the aorta. The mechanism of injury and the mediastinal silhouette on CXR are the two most sensitive markers for an injured thoracic aorta. Depressed left mainstem bronchus, apical capping, and a deviated trachea or esophagus (NG tube) seen on CXR may be suggestive of aortic injury. CT angiogram of the chest has high sensitivity and is the preferred modality of evaluation in most trauma centers as a screening test. Arteriography is the gold standard for evaluating aortic injuries and may also allow therapeutic intervention.

Smaller dissections in blunt trauma may be managed in the ICU with tight blood pressure control. Injuries requiring operative intervention are traditionally managed with thoracotomy and graft interposition. Newer endovascular techniques are increasingly used as an adjunct to surgery or for definitive repair. Investigation of these techniques is ongoing.

Ascending aorta: Rupture requires median sternotomy, CPB and repair with a Dacron graft. Penetrating injury to the anterior aspect of the aorta can be repaired primarily; if there is additional posterior injury, CPB is required for successful repair.

Aortic arch: Complete exposure of the great vessels is required; median sternotomy with extension to the neck and division of the innominate vein may be utilized. Complex injuries may require CPB.

Innominate artery, right carotid artery: Approach is via a median sternotomy with right cervical extension and division of the innominate vein, if necessary. Blunt trauma typically involves the proximal innominate artery, in contrast to penetrating trauma, which usually involves the distal portion of the artery near the carotid or subclavian bifurcation. Injuries are repaired using an interposition graft of Dacron or Gore-Tex. Because cerebral perfusion is maintained through the L carotid and subclavian arteries, shunting is not necessary.

Descending thoracic aorta: 97% of patients with great-vessel injury who arrive alive at the hospital will have an injury at the isthmus. Clamping and direct reconstruction are required under temporary bypass shunt or pump-assisted shunt. Posterolateral thoracotomy via the 4th intercostal space is the preferred access. Distal control of the descending aorta is obtained first; then the transverse aortic arch is exposed and umbilical tape is applied between L carotid and L subclavian arteries. Vascular clamps are applied at the proximal aorta, distal aorta, and subclavian artery. Graft interposition is utilized in 85% of the cases. An aortic cross-clamp time of < 30 min minimizes the incidence of paraplegia.

Subclavian artery or vein: Approach is via a cervical extension of the median sternotomy for right-sided injuries. Exposure of injuries to the proximal, left, subclavian artery via median sternotomy is usually inadequate. In patients with such injuries, a high left thoracotomy, often with either a supraclavicular or trap-door incision, is needed. Graft interposition is often necessary.

Pulmonary artery and veins: In major hilar injury, a pneumonectomy may be necessary, despite high mortality. Cross-clamping of the hilum prevents air embolus and hemorrhage. Simultaneous cross-clamping of the vessels and bronchus may reduce mortality in those patients requiring pneumonectomy. Fluid administration should be kept to a minimum to prevent right heart failure.

Thoracic vena cava: Intrathoracic IVC injury may cause hemopericardium and tamponade. Repair often is performed through the R atrium. SVC repair often is performed via a lateral venorrhaphy.

Usual preop diagnosis: Thoracic great vessel injury

Summary of Procedures

Position	Supine
Incision	Anterolateral thoracotomy is preferred as it provides access to the descending aorta for cross-clamping, good access to heart, and may be extended across sternum into right chest.
Special instrumentation	Intraop blood recovery device; rapid-infusion device; graft materials for any vessels larger than 5 mm. CPB may be necessary.
Unique considerations	Use of vasodilators (SNP) prevents cardiac strain during cross-clamping of the aorta. Large amount of fluid is required to prevent hypotension after clamp removal.
Antibiotics	Cefazolin 1 g iv
Surgical time	1–3 h
EBL	≥ 1–2 L
Postop care	ICU. Careful hemodynamic monitoring is critical since underlying pulmonary contusion may be worsened by inappropriate fluid administration. PA catheter may be necessary to optimize hemodynamic parameters, particularly in older patients. Coagulation studies must be carefully monitored and corrected with appropriate blood products.
Mortality	In general, mortality is associated with multisystem trauma and usually 2° concomitant head injury, infection, respiratory insufficiency, and renal insufficiency. Pulmonary artery or vein, suprahepatic IVC, or SVC injury: > 70% Ascending thoracic aorta, aortic arch (in patients with stable vital signs on arrival): 50% Blunt injury to the descending thoracic aorta: 5–25% Subclavian artery injury: 5%
Morbidity	Paraplegia: 8% (with descending aortic injuries)
Pain score	10

Patient Population Characteristics

Age range	Typically young adult
Incidence	Thoracic great vessel injury accounts for 8–9% of all vascular injuries seen in the trauma center.
Etiology	Blunt trauma from MVC; penetrating trauma from stab wounds or GSWs
Associated conditions	Pneumothorax; hemothorax; head injury

Anesthetic Considerations

See Anesthetic Considerations for Chest Trauma, p. 729.

Chest Trauma: Pneumonectomy, Lobectomy, Repair of Tracheobronchial Injury

Surgical Considerations

Description: Penetrating injuries to the chest can be divided into high- and low-velocity injuries. All stab wounds are classified as low-velocity injuries. GSWs may be considered low- or high-velocity injuries, depending on energy of the bullet. The majority of GSWs seen in the ED are low-velocity; however, higher velocity injuries are being seen with increased frequency. The extent of tissue destruction in high-velocity injuries is related to blast effect, tumbling, and fragmentation of the missile, as well as secondary missiles, such as bone fragments. Patients with such injuries are more likely to require thoracotomy and pulmonary resection. In general, pulmonary resection is required in 1% of stab wounds and 2% of GSWs. The indications for early operation are continued shock, prolonged bleeding, a larger air leak with inability to oxygenate or ventilate the patient, and suspected concomitant injuries to the vital intrathoracic structures. In most patients with stab wounds or low-velocity GSWs, bleeding from the lung tissue stops spontaneously after evacuation of the hemothorax and re-expansion of the lung. Only 5–10% of such patients will require thoracotomy to control bleeding as compared to a thoracotomy rate of 70% for high-velocity injuries. Pulmonary contusion is a frequent sequela of GSWs or blunt trauma to the chest. Pulmonary contusion occurs in *(Print pagebreak 727)* 75% of patients with flail chest but also can occur following blunt trauma without rib fracture. Alveolar rupture with fluid transudation and extravasation of blood are early findings.

The incidence of tracheobronchial injuries reported in the autopsy series from MVC is 1%. Mechanisms of injury include rapid deceleration, direct blow, or sudden increase of intratracheal pressure against a closed glottis. The most common injury is transverse rupture, occurring in 74%, followed by longitudinal rupture in 18%, and complex in the remaining 8%. Approximately 80% of cases with tracheal rupture occur within 2.5 cm of the carina. Patients with injury to the airway may present with severe dyspnea and with massive subcutaneous emphysema. About 90% of these patients will have an abnormal CXR, showing pneumothorax, pneumomediastinum, subcutaneous emphysema, or pleural effusion.

Tracheobronchoscopy should be performed in all patients with suspected tracheobronchial injuries to establish the diagnosis and plan operative treatment.

Parenchymal lacerations are repaired by the simplest method available to stop bleeding or air leak. If pulmonary resection is required, formal segmental resection is not necessary. A stapling device should be used to preserve as much lung tissue as possible.

Anatomic pulmonary resections are indicated when bronchial injury repair is not feasible or may lead to complete lobar collapse. **Pneumonectomy** may be required for major hilar injuries but is associated with a mortality rate of 75%. **Primary repair of tracheobronchial injuries** should be performed as soon as possible. Transverse rupture may require the placement of a sterile tracheal tube into the distal trachea through the operative field. After posterior sutures are placed, an orotracheal tube is advanced beyond the area of injury. **Main-stem bronchial repair** is performed under one-lung ventilation. High-frequency jet ventilation may be required to maintain oxygenation. Occasionally, total CPB is necessary for repair of complex airway injuries. Before closing, the suture line is pressure-tested and evaluated by fiberoptic bronchoscopy.

Usual preop diagnosis: Tracheobronchial injury; penetrating/blunt chest trauma

Summary of Procedures

Position	Supine, with neck extended for proximal tracheal injury, or lateral decubitus
Incision	Transverse cervical for almost all proximal tracheal injuries Right posterolateral thoracotomy in 5th intercostal space for thoracic trachea and right bronchial wounds. Left posterolateral thoracotomy for L bronchial injury
Special instrumentation	Fiber optic bronchoscope, intrabronchial tube, jet ventilator/oscillator
Unique considerations	In patients with lobar resection or after pneumonectomy, PEEP may result in bronchopleural fistula
Antibiotics	Cefazolin 1 g iv
Surgical time	2–3 h
EBL	Variable
Postop care	ICU (typically)
Mortality	Pneumonectomy for trauma: 75% Penetrating tracheobronchial injuries: 15%
Morbidity	Bronchopleural fistula: 10% Empyema: 5% Hemothorax: 2–5% Pneumothorax ARDS (depends on extent of injuries)
Pain score	Cervical approach: 5–7 Thoracic approach: 8–10

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Anesthetic Considerations for Chest Trauma Surgery

Blunt and penetrating chest trauma may present as hemopericardium, hemo/pneumothorax, blunt cardiac injury, airway injuries, pulmonary contusion with or without associated flail-chest syndrome, and diaphragmatic injury. Hemopericardium may rapidly progress to pericardial tamponade, requiring immediate pericardiocentesis or pericardial window, followed by surgical exploration and repair of the cardiac or vascular laceration. These patients typically present in shock (↓↓ BP) with distended neck veins (↑↑ venous pressure) and distant heart sounds (Beck's triad) without evidence of tension pneumothorax. Hemothorax may present as respiratory failure, shock and absent breath sounds over the affected hemithorax. Blunt cardiac trauma may present with findings ranging from isolated ECG changes to cardiac rupture. The right ventricle and interventricular septum are most commonly affected. Arrhythmias and ventricular dysfunction are frequently observed. Intrathoracic tracheobronchial injuries are less frequent than upper airway injuries, although they are associated with a high mortality and usually require operative intervention. Pulmonary contusion often presents with hypoxia and tachypnea; hemoptysis may also be present. Large flail-chest defects may require mechanical ventilation. VATS has emerged as the leading diagnostic tool for detection of diaphragmatic injury. Preoperatively, and particularly during the induction of GA, the patient's intravascular volume must be expanded and myocardial contractility, HR, and SVR maintained. Inotropes and antiarrhythmic drugs may be required if hemodynamic instability occurs and does not respond to iv fluid administration. CPB is usually not required.

Preoperative

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Respiratory	Associated injuries, such as hemothorax and/or pneumothorax, may be present, requiring thoracostomy tube placement. Fractures of the first or second rib should prompt a detailed search for associated intrathoracic injuries. A widened mediastinum, apical pleural capping, or fracture of the first or second rib often occurs with injury to the great vessels. Multiple rib fractures are often associated with pulmonary contusions, which may not be apparent on the initial CXR, but can progressively impair oxygenation. With tamponade, spontaneous respiration is preferred over PPV (→↓ venous return + ↓ CO). Significant intrathoracic tracheobronchial disruption may require rigid bronchoscopy or a surgical airway. **Tests:** CXR (PA +lateral views). Upright inspiratory films best delineate chest structures; expiratory films enhance visualization of pneumothorax, but are difficult to obtain in multiple-trauma patients; ABG; Chest CT if the patient's condition permits.
Cardiovascular	BP and HR should be followed and responses to fluid resuscitation noted. With adequate resuscitation, the EJ veins should appear full. CO can be significantly reduced despite normal BP measurements. Pulsus paradoxus may be present, with decreases in SBP of 10–12 mmHg during inspiration. Preop, intravascular volume should be restored, especially in the setting of suspected severe RV dysfunction, and myocardial contractility supported with inotropes as necessary. Correction of metabolic acidosis with iv bicarbonate may be indicated (e.g., 1 mEq/kg, then ABG). Myocardial contusion also can occur and can be associated with atrial or ventricular arrhythmias, RBBB, and RV failure, because the right heart is substernal and most directly involved in blunt trauma to the sternum. Supportive therapy with antiarrhythmics (e.g., lidocaine 1–2 mg/min) and inotropes (dopamine or epinephrine) may be required. Electrolyte abnormalities should be corrected. Substantial intravascular access should be obtained, with strong consideration given to the need for invasive monitoring (arterial line, CVP, etc.). **Tests:** ABG, serial ECGs with myocardial contusion. FAST-scan is the test of choice for detection of pericardial effusions. TTE or TEE may definitively diagnose cardiac tamponade, significant hemothorax and major aortic injuries.
Neurological	↓ BP and ↓ CO may compromise cerebral perfusion. Associated head injury also can contribute to alterations in mental status. Pupil size and reactivity should be noted. Glasgow Coma Scale score ≥ 8 indicates significant brain injury.
Musculoskeletal	Known or suspected C-spine fractures require intubation precautions, with laryngoscopy performed while an assistant provides in-line stabilization of the patient's head in the neutral position. **Tests:** Lateral C-spine x-rays, including C-7; CT; MRI

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Intraoperative

***Anesthetic technique:** GETA with full-stomach precautions (see p. B-4). **NB:** In the patient with an unstable C-spine, cricoid pressure (10 lb) may cause spinal cord injury, and consideration should be given to the establishment of a surgical airway under local anesthesia.

GETA is required for exploration through a median sternotomy or left thoracotomy. In the latter case, a DLT or BB is desirable. If a difficult airway is anticipated, a single-

Induction	lumen ETT may be placed initially with a DLT placed with an airway exchange catheter. Rapid-sequence induction with ketamine (0.5–2.0 mg/kg) and succinylcholine is attractive because higher doses of ketamine are usually associated with ↑ HR, ↑ BP and ↑ CO. Careful consideration should be given to the catecholamine-depleted trauma patient, in whom the direct myocardial depressant effects of ketamine may be unmasked. Etomidate (0.2–0.6 mg/kg) is a useful alternative for patients with head injuries. Inotropic agents (ephedrine, dopamine, epinephrine) should be immediately available to treat ↓ BP. Agents which tend to decrease SVR, such as inhalational anesthetics and narcotics, should be introduced with caution. The potential for sudden and substantial blood loss exists and PRBCs (cross-matched, type-specific or O neg) should be available in the OR prior to induction.	
Maintenance	Initially, low-dose inhalational agents and low-dose narcotics may be used, as tolerated. ↓ BP may require dopamine infusion (1–10 mcg/kg/min). Muscle relaxation and PPV are used. N_2O should be avoided if there will be a need for one-lung ventilation or there is associated pulmonary contusion. If the patient is hypotensive and acidotic, scopolamine (0.2–0.4 mg iv) will ↓ risk of recall. As cardiac and vascular injuries are repaired, BP and CO often will improve, permitting increased depth of anesthesia and decreased inotropic support. Indicators of improved tissue perfusion should be followed, such as resolution of lactic acidosis, central or mixed venous oxygen saturation, and improved urine output.	
Emergence	Trauma patients often require prolonged intubation; however, hemodynamically stable patients with limited injuries may be extubated awake. Patients who received significant blood replacement (> 50% of blood volume), those requiring inotropic support, intoxicated patients and those with head injuries should remain intubated and mechanically ventilated postop. Consideration for continued mechanical ventilation should be given to those patients with large pulmonary contusions and/or flail-chest segments.	
Blood and fluid requirements	Be prepared for large blood loss. IV: 14 ga × 2 Fluid warmer Rapid-infusion device Airway humidifier T&C PRBCs	Large blood losses occur occasionally, depending on the severity of the injury. Crystalloid and/or blood products should be infused to maintain BP and CVP (full jugular veins).
Monitoring	Standard monitors (see p. B-1). Arterial line CVP ± PA catheter	ECG should be observed for changes associated with myocardial contusion (atrial/ventricular dysrhythmias, RBBB, ST-T wave changes). CVP monitoring can be useful in guiding fluid management. With release of tamponade, CVP rapidly drops toward normal, and CO and BP will markedly improve.
	± TEE	Will provide excellent monitor of LVEDV and SVR, as well as RVSP.
Positioning	and pad pressure points eyes ± C-spine: neutral position	Axillary roll, if lateral decubitus position; chest roll if median sternotomy.
Complications	Hypothermia	Hypothermia → dysrhythmias + ↓ CO → acidosis. Rx: warm OR, warm iv fluids, humidify gases, and use patient warming devices.
	Awareness	May be unavoidable in unstable patients. Rx: Consider scopolamine 0.2–0.4 mg iv.
	Renal failure	Usually 2° ↓ renal perfusion (prerenal). Rx: Restore CO with volume and inotropes.
	Coagulopathy	Most commonly 2° dilutional thrombocytopenia. DIC may require replacement therapy with Plts, FFP and cryoprecipitate. Massive transfusion may

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		benefit from a 1:1 ratio of PRBC to FFP. Maintain nl Ca^{++} (1.05–1.3 mM/L).

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Postoperative

Complications	Hypotension Arrhythmias	Cardiogenic shock may be 2° prolonged ↓ BP or cardiac contusion. Neurogenic shock may be seen with associated spinal cord injuries. Hemodynamic instability with atrial/ventricular dysrhythmias may occur. Treatment with inotropic infusions (dopamine 5–10 mcg/kg/min or epinephrine 50–200 ng/kg/min) and antiarrhythmics.
	Hypothermia	Active warming of iv fluids and warming blanket should be continued in ICU or PACU if hypothermia persists. If neurologic injury is present, consideration should be given to mild hypothermia.
	ARDS	Interstitial and alveolar edema → progressively worsening pulmonary function requiring prolonged mechanical ventilation. Institution of lung protective ventilation strategies should be considered.
	Coagulopathy Renal failure	Based on clinical assessment and laboratory data (PT, Plt count, fibrinogen); transfusion of Plts, FFP, and/or cryoprecipitate may be indicated.
	VTE	See p. B-7.
Pain management	PCA (p. C-3) or parenteral narcotics Epidural (p. C-2)	Epidural infusions of narcotic and/or low dose local anesthetics can be effective in patients without coagulopathy. Continuous epidural anesthesia will also be beneficial in the setting of multiple rib fractures.

Abdominal Trauma: Damage Control

Surgical Considerations

Description: The incidence of abdominal injuries requiring laparotomy approaches 25% for penetrating and 5–8% for blunt abdominal trauma. In blunt trauma, liver and spleen injuries occur with an incidence of 50%. In penetrating trauma, the most common injuries are small bowel (29%), liver (28%), colon (23%), and stomach (13%). Many preventable deaths in trauma patients are related to shock from unrecognized intraabdominal hemorrhage caused by solid organ injury.

Victims of severe multisystem trauma are particularly susceptible to development of a fatal coagulopathic state 2° hypothermia, acidosis, dilution, and consumption. Replacement of two or more blood volumes with NS or PRBCs will decrease the level of coagulation factors to 15%. Because of delays in obtaining coagulation profile results, coagulation factors should be replaced empirically in the setting of a large transfusion requirement (e.g., 1 U FFP/1.5 U PRBC). Metabolic acidosis affects both the circulatory system and coagulation, → ↓ CO and triggering DIC. *(Print pagebreak 732)* Chances of salvaging a patient with pH < 7.0 approach zero. To stop this self-perpetuating downward cycle, the concept of “Damage Control” has evolved. This involves rapid laparotomy to control hemorrhage and GI spillage, followed by temporary closure of the abdomen and subsequent exploration after the patient has been warmed and stabilized. With the use of this technique, 40% of critically injured patients can be saved from otherwise fatal injuries.

With the patient on a heated operating table, the patient is prepped from the thighs to the neck and draped, and the abdomen is entered through a midline incision. This critical moment can be associated with significant blood loss and may require rapid blood transfusion. Four-quadrant packing with laparotomy pads is performed in the abdominal cavity, and manual compression of the subdiaphragmatic aorta may be instituted if packing alone does not control the hemorrhage. If necessary, the operation is stopped and blood/fluid resuscitation is performed. After consultation with the anesthesiologist, the surgeon proceeds with the sequential unpacking of each of the four quadrants and identifying injuries. Vascular injuries are controlled with clamping and ligation or shunting, bowel injuries are stapled across, but no attempt is made for primary repair. Liver and retroperitoneal injuries are controlled with packing alone. When damage control is performed, the abdomen is closed with a running skin suture, if appropriate; otherwise, a temporary vacuum dressing is used. PIP should be monitored during closure, as patients may develop abdominal compartment syndrome (↑↑ intra-abdominal pressure → ↑ PIP, ↓ UO, normal filling pressures). The patient is then transported to ICU and actively warmed and resuscitated. Reoperation should be performed at 24–48 h when the patient is rewarmed and acidosis and coagulopathy have resolved. Definitive repair of the injured organs should be completed.

Usual preop diagnosis: Intra-abdominal trauma and hemorrhage

Summary of Procedures

Position	Supine
Incision	Midline abdominal
Special instrumentation	Fluid-warming, rapid-infusion device
Unique considerations	Autotransfusion device (e.g., Cell Saver) may be of use if no contamination of abdominal cavity.
Antibiotics	Cefotetan 1 g iv
Surgical time	45–90 min
Closing considerations	Even temporary closure may not be possible because of severe bowel edema. A silo made from a plastic iv bag may be used to cover the bowel. Monitor PIP and UO during abdominal wall closure, because abdominal compartment syndrome may develop.
EBL	Average transfusion requirement: 12 L crystalloids, 20 U PRBCs, 10–15 U FFP, 6 U Plts
Postop care	ICU; patient remains intubated. Active rewarming is of primary importance.
Mortality	70%
Morbidity	Intraabdominal abscesses: 30% Fistulas: 10%
Pain score	10

Patient Population Characteristics

Age range	Typically young adult
Male:Female	9:1
Incidence	25% for penetrating and 5% for blunt abdominal trauma
Etiology	MVC; penetrating injury (e.g., GSW or stab wound)
Associated conditions	Chest trauma; closed head trauma; pelvic fracture

(Print pagebreak 733)

Anesthetic Considerations

See Anesthetic Considerations for Abdominal Trauma Surgery, p. 737.

Abdominal Trauma: Hepatic and Splenic Injuries

Surgical Considerations

Description: The liver is the most commonly injured organ in patients with penetrating trauma, while the spleen is the most commonly injured organ with blunt trauma. Approximately 30% of all patients requiring laparotomy for trauma will have hepatic injuries. The majority of injuries can be managed nonoperatively unless other injuries mandate laparotomy. Thus, most liver injuries that require operation are complex (grades IV-V), with large blood loss and high mortality (up to 30%).

Several maneuvers can be used to facilitate **repair of liver injuries: Manual compression** temporarily controls bleeding and allows time for volume resuscitation. **Portal triad occlusion** (**Pringle maneuver**) (Fig. 7.13-5) decreases blood loss and identifies the patient who might benefit from selective hepatic artery ligation. Perihepatic *(Print pagebreak 734)* packing and planned reexploration is a life-saving maneuver and should be used early for patients with severe injuries, before they become hypothermic, coagulopathic, and acidotic. Extensive liver mobilization, parenchymal disruption (i.e., finger fracturing), and atriocaval shunts are rarely indicated. Hepatic angiogram and embolization in the immediate or early postop phase may be very useful for patients with severe injuries. At reexploration, intrahepatic omental packing may be used for obliterating dead space. Closed suction drains should be used in all patients.

Figure 7.13-5. 5. Pringle maneuver compression of the portal triad structures with a noncrushing vascular clamp for hepatic inflow control. (Reproduced with permission from Greenfield LJ, Mulholland MW, Oldham KT, et al., eds: *Surgery: Scientific Principles and Practice,* 3rd edition. Lippincott Williams & Wilkins, Philadelphia: 2001.)

Portal triad (portal vein, hepatic artery, common bile duct) injuries, although rare, are associated with extremely high mortality. Isolated portal vein injuries are associated with a 70% mortality. The portal vein should be repaired if possible; however, ligation can be tolerated. Careful volume resuscitation should follow portal vein ligation to avoid ↓ BP 2° fluid sequestration in the splanchnic bed. Simple ligation of the hepatic artery, preferably proximal to the gastroduodenal artery, is recommended for most major hepatic artery injuries. Shock and transfusion-related coagulopathy occurring in the immediate postop period are responsible for 80% of the deaths in liver injury patients. Control of hemorrhage remains the critical component in the successful management of liver injuries.

More than 90% of splenic injuries are caused by blunt trauma. Approximately 75–80% of these patients can be managed nonoperatively. Of the remaining patients, most will require splenectomy, because usually only grade IV (active intraperitoneal bleeding) or V (shattered/avulsed injuries) require operation. Massive bleeding from the LUQ is probably caused by splenic injury. For severe injuries, the spleen is delivered into the wound by blunt dissection. The spleen is removed by cross-clamping the hilum and dividing the short gastric vessels. The LUQ is packed and reinspected for hemostasis once better resuscitation is provided. The splenic salvage rate in the pediatric population approaches 90%.

In a patient with massive **intraabdominal hemorrhage**, sudden cardiovascular collapse is predictable when the abdomen is opened. Laparotomy with manual compression of the aorta at the aortic hiatus is recommended. Access for subsequent aortic clamping is rapidly obtained by blunt finger dissection of the lesser sac. After removing all clots and free blood, four-quadrant packing is used to control bleeding. Significant liver bleeding should be controlled with manual compression, the Pringle maneuver, and perihepatic packing.

Usual preop diagnosis: Hepatic injury; splenic injury

Summary of Procedures

Position	Supine
Incision	Midline abdominal
Special instrumentation	Active rewarming device; Cell Saver
Unique considerations	Most emergency laparotomies require close cooperation between anesthesiologist and surgeon. The procedure may need to be interrupted for fluid or blood resuscitation if patient becomes hypotensive. The entire chest and abdomen, including both groins, need to be accessible to the surgeon; ECG electrodes are placed preferably on the patient's back.
Antibiotics	Cefazolin 1 g iv
Surgical time	1–2 h
Closing considerations	After massive fluid resuscitation, concern over compartment syndrome may preclude primary fascial closure. The abdomen may be left open for later closure.
EBL	2–10 L (transfusion requirement 6–20 U)
Postop care	ICU: shock and coagulopathy management; monitoring for possible rebleeding and abdominal compartment syndrome.
Mortality	Liver: 10% Spleen: 10% (usually due to associated injuries)
Morbidity	Liver: perihepatic abscess: 10% Spleen: septic complications: 7%
Pain score	8–10

(Print pagebreak 735)

Patient Population Characteristics

Age range	Any age
Male:Female	3:1
Incidence	Liver: 30% of patients requiring laparotomy for trauma Spleen: 10% of patients requiring laparotomy for trauma
Etiology	Liver: penetrating wound (80%) with gunshot wounds responsible for 60% and stab wounds for 40% Spleen: blunt trauma (90%), mostly due to MVC
Associated conditions	Liver: isolated hepatic injury (30%); injury to one or two other organs (50%), with diaphragm, major vascular structures, stomach, lung, and colon being most common.

Anesthetic Considerations

See Anesthetic Conditions for Abdominal Trauma Surgery, p. 737.

Abdominal Trauma: Vascular Injuries

Surgical Considerations

Description: Penetrating trauma is the most common cause of abdominal vascular injuries: IVC/hepatic veins, 36%; celiac/mesenteric vessels, 30%; iliac vessels, 11%; and aorta, portal/splenic, and renal vessels, each 5%. Patients with gunshot wounds to the abdomen have 25% incidence of major vascular injury; however, only 10% of patients with penetrating stab wounds will have vascular injuries. Patients sustaining blunt abdominal trauma who require laparotomy have a 5–10% incidence of vascular injury.

Initial resuscitation of the patient with abdominal vascular injuries depends on the patient's condition. Multiple large-bore catheters should be inserted in the upper extremities or, if necessary, central venous access should be obtained. Because of the probable intraabdominal venous injury, lower-extremity venous access is not indicated. Blood replacement during resuscitation is done preferably with type-specific blood. It is a good practice to have 2 U of O neg blood available immediately in the ED in case there is no time for a limited cross-match. Efforts to limit hypothermia should start as soon as the patient arrives (use of warmed fluids and high-flow blood warmers and covering the patient with warm blankets or a forced-air warming blanket).

Injuries to the abdominal vessels can be grouped into four regions, which require different surgical approaches:

Midline supramesocolic hemorrhage or hematoma (superior to the transverse mesocolon) is usually 2° injury to the suprarenal aorta, celiac axis, proximal superior mesenteric artery, or proximal renal artery. Proximal aortic control should be obtained at the hiatus by either aortic compression or manually by entering the lesser sac and digitally splitting the muscle fibers of the crura. Once this is done, direct access to the vessels is achieved through medial visceral rotation of all left-sided viscera. Injuries to the aorta are then repaired directly or with the appropriate graft. An injured celiac axis probably can be ligated safely if the remaining visceral vessels are intact. Superior mesenteric artery injuries must be repaired, usually with a jump graft. Repair of the superior mesenteric vein is preferred, but the vein may be ligated if complex injuries are present. These patients require substantial fluid resuscitation postop and are at high risk for abdominal compartment syndrome. Injuries to the IVC or right side of the aorta can be exposed by **duodenal mobilization (Kocher maneuver).**

Midline inframesocolic hemorrhage or hematoma results from infrarenal aorta or IVC injury. Exposure is obtained by incising posterior peritoneum in the midline after displacement of the small bowel and cephalic retraction of the transverse mesocolon. A proximal aortic clamp is then placed just below the left renal vein, with a distal clamp near the aortic bifurcation. The defect is repaired primarily, using patch aortoplasty, end-to-end anastomosis, or a *(Print pagebreak 736)* graft. If the aorta is intact and an inframesocolic hematoma seems to be more extensive on the right side, or if there is active bleeding coming through the base of the mesentery, then injury to the IVC should be suspected. Access to the infrahepatic IVC is preferably obtained by mobilization of the R colon and duodenum. Proximal and distal controls are best obtained by either digital compression or two sponge sticks. The injury is then repaired directly. Blind clamping should be avoided, but occasionally, with good exposure, a **Satinsky clamp** can be placed. In young patients with exsanguinating hemorrhage, the infrarenal IVC can be ligated, providing time for appropriate fluid management. These patients require significant fluid postop and will likely have chronic venous insufficiency.

Lateral perirenal hematoma or hemorrhage suggests injury to the renal vessels or kidney. In patients with blunt abdominal trauma who have a negative abdominal CT, IVP, or arteriogram, surgery is not required. A penetrating injury usually requires surgical exploration. Vascular control of the ipsilateral renal artery is obtained before the hematoma is entered. If there is active bleeding from the kidney or overlying retroperitoneum, then the kidney is exposed via a lateral incision, and a vascular clamp is applied to the renal vessel. This usually is followed by nephrectomy (after palpation and a one-shot IVP to verify function of a normal contralateral kidney). If the contralateral kidney is missing or nonfunctional, then back-table salvage surgery and autotransplantation of the injured kidney should be attempted. Only 30–40% of kidneys with arterial injuries can be salvaged.

Lateral pelvic hematoma or hemorrhage indicates injury to the iliac vessels. Pelvic hematoma 2° blunt trauma and pelvic fracture should not be explored. Primary control of bleeding is by angiography/embolization and possibly external fixation of the pelvis. This need should be recognized and arranged early in the resuscitative period. For penetrating injuries, vascular control is obtained at the aortic bifurcation proximally and close to the inguinal ligament distally. The internal iliac artery is best visualized by elevating common and external iliac arteries on vascular tapes. Unilateral internal iliac artery injuries can be ligated. Common or external iliac artery injuries can be repaired or a graft can be inserted. Grafts may be used even in the presence of GI contamination, provided the abdomen is thoroughly irrigated and the retroperitoneum is closed over the graft. A temporary intravascular shunt should be used in patients requiring damage control surgery. Injuries to the iliac veins are treated with lateral venorrhaphy or ligation.

Usual preop diagnosis: Abdominal vascular injury

Summary of Procedures

Position	Supine, with left arm abducted 90°
Incision	Midline abdominal
Special instrumentation	Autotransfusion device (e.g., Cell Saver); thoracotomy tray; aortic compressor
Unique considerations	Prevent heat loss and warm all infusions and irrigation solutions. Ventilator warming should be used for cold patients. For the patient requiring massive transfusion, ratio of 1 U FFP:1.5 U PRBCs useful. After prolonged aortic cross-clamp, prophylactic administration of $NaHCO_2$(1–2 mEq/kg) may be indicated to prevent ‘washout’ acidosis.
Antibiotics	Cefazolin 1 g iv
Surgical time	Variable
Closing considerations	Once vascular injuries are repaired, hepatic injuries are controlled with packing, bowel injuries are closed with staplers, and the abdominal wall is closed temporarily.
EBL	5–10 L
Postop care	ICU; Patients after infrarenal vena cava ligation require volume expansion and prevention of lower extremity venous pooling. Elastic wraps and lower-extremity elevation should be maintained for at least 1 wk. Similarly, after superior mesenteric vein ligation, splanchnic hypervolemia requires vigorous fluid resuscitation and lasts 3 d.
Mortality	Combined injury to the suprarenal aorta and IVC: 100% Aorta: 60% Infrarenal abdominal aorta: 50% Superior mesenteric artery: 40–80% Iliac artery: 40% Iliac vein: 30% Infrarenal vena cava: 30% Superior mesenteric vein: 20% Renal artery: 15%
Morbidity	Abdominal compartment syndrome (↑↑ abdominal pressure → ↑ PIP + ↓ UO) Acute renal failure Intraabdominal infection Fistula
Pain score	8–10

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Patient Population Characteristics

Age range	Typically young adult
Male:Female	Male > female
Incidence	15% of patients with abdominal trauma
Etiology	10% of penetrating stab wounds and 25% of gunshot wounds to the abdomen will cause a major vascular injury.

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Associated conditions	Multiple vascular injuries; hollow viscus perforation; fecal contamination

Anesthetic Considerations for Abdominal Trauma Surgery

Abdominal injuries range from relatively simple penetrating injuries (e.g., a stab wound) to severe blunt trauma (e.g., liver lacerations and pelvic fractures) and are often associated with massive hemorrhage. Head injuries and spinal fractures may complicate management plans. The ability to provide rapid, aggressive volume replacement is often the key to survival. Coagulopathy (DIC) and hypothermia present additional challenges.

Preoperative

Respiratory	Associated injuries, such as hemothorax and/or pneumothorax, may be present, requiring thoracostomy tube placement. A widened mediastinum, apical pleural capping, or fracture of the 1st or 2nd rib often occurs with serious vascular injuries. Multiple rib fractures suggest possible pulmonary contusions, which may not be evident on initial CXR, but can progressively impair oxygenation and ventilation. **Tests:** CXR (PA +lateral views); ABG
Cardiovascular	BP and HR should be followed and responses to fluid resuscitation noted. Tachycardia can maintain an adequate BP with reduced pulse pressure, despite 25–30% loss of blood volume. Attempt to quantify overt blood loss (e.g., scalp lacerations, open fracture sites). Blunt chest trauma (e.g., steering wheel contact) may result in myocardial contusion with various dysrhythmias, most often premature ventricular or atrial complexes. **Tests:** Serial Hct; ECG in patients > 50 yrs of age or with blunt chest trauma.
Neurological	Seek physical evidence of open or closed head injuries, such as palpable depressions of the skull or scalp lacerations, abrasions, or contusions. Pupil size and reactivity should be noted. Intubation in the ER is necessary for patients who are unable to protect their airway, require hyperventilation or are combative and unable to cooperate with medical staff for exam and treatment. In general, any patient with a Glasgow Coma Scale (GCS) ≥ 8 (no spontaneous eye opening, inappropriate or incomprehensible speech and only reflexive motor responses) requires intubation. Motor and/or sensory deficits may reflect spinal cord injury and may be associated with neurogenic (“spinal”) shock, particularly with upper thoracic or cervical cord injuries. **Tests:** C-spine x-rays (lateral view, including C7), is a good screening exam: for altered vertical alignment and unequal disk interspaces. CT scan or MRI of head: for gross asymmetry, hemorrhage, or midline shift.
Musculoskeletal	Known or suspected C-spine injuries require intubation precautions. In urgent cases, intubation without neck extension is achieved with an assistant providing in-line stabilization of the head in the neutral position. If time permits, awake, blind, or fiber optic intubation may be attempted. Basilar skull fractures contraindicate nasal ET or NG tubes. Pelvic and femur fractures may represent sources of significant (> 1000 mL) occult blood loss. **Tests:** Radiographs of C-spine (see above), skull, extremities

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Hematologic	Depending on estimations of prior, ongoing, and anticipated surgical blood losses, preop T&C may be desired. O neg or type-specific blood should be available until the T&C is complete. **Tests:** Serial Hct; T&C; Ca^{+} and K^{+} following massive transfusions.
Laboratory	Other tests as indicated from H&P or suspected injuries, including electrolytes, liver panel, toxicology screen, blood alcohol level.
Premedication	Premedication is rarely useful due to the urgency of the procedures and the need to have an alert, responsive patient for serial evaluations of mental status or abdominal pain. Sedative premedication should be avoided in patients who are hemodynamically unstable and those with probable head injuries. Virtually all patients are considered to have full stomachs, and any compromise of the ability to protect the airway is inappropriate. Na citrate (30 mL po) may be administered to alert patients at risk for aspiration; however, ranitidine and metoclopramide may not reach effective levels in the short interval before induction.

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Intraoperative

Anesthetic technique: GETA with full-stomach precautions (p. B-4)

Induction	Before induction, a variety of laryngoscope blades (e.g., Miller 1 and 2, Mac 3 and 4) and ETTs with stylets (6.0, 7.0, and 8.0 mm) should be ready. LMA may be useful for providing temporary airway control without C-spine manipulation if direct laryngoscopy is difficult. LMA may be used as a conduit for ET intubation (fiber optic or fast-track LMA). A size 7.0 mm ETT will pass through a #4 LMA. Equipment for emergent cricothyrotomy (a 14-ga iv catheter + adapter) and jet ventilation should be in OR. Most often, preoxygenation is followed by a rapid-sequence iv induction with cricoid pressure (Sellick's maneuver) using Propofol (1–2.5 mg/kg) and succinylcholine (1.0–1.5 mg/kg). If hypotension is present or a concern, alternate induction agents (e.g., ketamine 0.5–2.0 mg/kg iv or etomidate 0.1–0.3 mg/kg iv) may be used. Verify any meds already administered in ED and field. Axial head and neck stabilization is necessary if C-spine injury is present or suspected. Some trauma patients are intubated in the ED. Verify ETT placement by auscultation and $ETCO_2$ monitoring. Very low $ETCO_2$ values may be obtained in patients with markedly reduced CO. Ventilation with 100% O_2 and paralysis with muscle relaxant (such as rocuronium or vecuronium) is appropriate. Ongoing fluid resuscitation should be continued during this time. Consider sending lab studies/ABG at this point and ensuring availability of blood products.
Maintenance	Titrate O_2/air, muscle relaxants, narcotics, and volatile agents. Avoid N_2O in the presence of pneumothorax, pneumocephalus, bowel distention, or prolonged procedures. Shorter-acting agents (e.g., volatile agents, remifentanil, rocuronium), carefully titrated, may be preferred in patients with head injuries to facilitate early postop assessment of neurologic status. If ↓ BP precludes use of volatile anesthetics and opiates, consider low-dose scopolamine (0.1–0.3 mg iv) or ketamine (0.25 mg/kg/15–30 min) for amnesia. Use forced-air warming blanket(s) and warmed IV fluids, and consider elevated OR temperatures, and warmed irrigation fluids (surgical field, bladder) to maintain normothermia.
Emergence	Prior to extubation, patient should be awake and able to protect his/her airway, and should be hemodynamically stable and spontaneously ventilating with ease through the ETT. Consider postop mechanical ventilation and ICU care for trauma patients with the following conditions: elderly with rib fractures, significant pulmonary

	compromise/trauma, ongoing acidosis, hemodynamic instability ongoing or anticipated significant fluid and blood product resuscitation, coagulopathies, intoxication or neurological impairment.	
Blood and fluid requirements	Anticipate large blood loss IV: 14–16 ga × 2 or 7–9 Fr × 2 NS/LR variable depending on blood loss Fluid warmers Rapid-infusion device T&C PRBCs, ± other blood products	Large blood losses may have already occurred and continue to occur, depending on the mechanism of injury (e.g., liver lacerations, major vascular injury, pelvic fractures). Determine prior fluid administration in field and ED. Early determination of availability of blood products advised. Crystalloid, colloid and blood products should be given to re-establish euvolemia based injuries, EBL, and clinical assessment, which may include: BP, HR, CVP/PCWP, UO, Hct, ABG, TEE, etc. With massive transfusion, Plts and FFP will be needed. In general, 2–4 U FFP and 6 U of Plts should be transfused after 10 U of PRBCs (1 blood volume in a 70-kg person) have been given. Postop hypothermia is best minimized by warming all iv and irrigating fluids, maintaining OR temperature @ 78–80°F, humidifying inspired gases, and use of forced air and circulating water warming blankets. Frequent assessment of Hct/Hgb, Plts, coags, Ca^{++} and ABG essential in managing significant ongoing hemorrhage and resuscitation.
Monitoring	Standard monitors (see B-1). Urinary catheter	Monitor patient during transport to OR and apply standard monitoring as soon as patient enters the OR.
	± Arterial line	Arterial line useful in unstable patient or when frequent lab sampling anticipated.
	± CVP line ± PA catheter ± TEE	CVP line or PA catheter may be useful if vasoactive infusions needed or if ventricular dysfunction apparent. Placement of additional monitoring should be accomplished without delaying the surgical control of hemorrhage or without interrupting aggressive volume resuscitation.
Positioning	and pad pressure points eyes	If C-spine has not been cleared by both radiographically and clinically, neck should remain immobilized intraop and postop.
Complications	Hypothermia	Preexisting hypothermia common in trauma patient. Measures to manage hypothermia early are key and include: warm OR, use of forced air warming and warm IV fluids.
	Awareness	May be unavoidable in unstable or hypotensive patients. Rx: Consider scopolamine 0.2–0.4 mg iv or midazolam 1–2 mg iv in such situations.
	Coagulopathy	Causes include dilutional, hypothermia and brain injury. Assess status and treat early.
	Aspiration	Assume full stomach; aspiration may have occurred prior to OR
		Sources include trauma or subsequent AW

	Airway trauma	management

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Postoperative

Complications	Hypothermia	Active warming of fluids and blood products and forced-air warming blankets and warm room temperatures should be continued in PACU/ICU if hypothermia persists.
	Atelectasis, V/Q mismatch	Pulmonary compliance may decrease with large volumes of fluid replacement. Pulmonary contusions may aggravate this problem and severely compromise oxygenation and ventilation, requiring high-inspired O_2concentration, high PIP, and PEEP.
	Coagulopathy	Causes include dilutional, hypothermic, brain injury, and development of SIRS/Sepsis.
	VTE	See p. B-7.
Pain management	PCA or parenteral narcotics epidural narcotic (see p. C-3, C-2)	Patients with rib fractures benefit from epidural narcotic and/or low-dose local anesthetic infusions.
Tests	Hb/Hct CXR	PT/PTT, Plt counts, if unexplained bleeding postop Fibrinogen, fibrin split products, if DIC suspected

Pediatric Trauma

Airway and Vascular Access

Description: Children younger than 15 yr are victims in about 25% of all trauma occurring in the United States. This incidence translates to 200,000 hospitalizations and 10,000 deaths annually. Another 10,000–12,000 children sustain permanent impairment as a result of their injuries. According to the National Pediatric Trauma Registry, 40% of all pediatric injuries occur as a result of MVC and 35% are injuries sustained at home. Falls remain the most common cause of severe injury in infants and toddlers, whereas bicycle accidents cause most of the injuries in older pediatric groups. The majority of pediatric injuries that occur are 2° blunt trauma, and infants < 2 yr of age are known to have higher mortality rates for the same level of injury compared to older children.

The same sequence of primary survey, resuscitation, secondary survey, and definitive care should be followed as in adults. Confirmation of a patent airway is the essential first step. The best method for restoring airway patency is the **jaw thrust maneuver** and removal of any debris from the mouth. The most common reason for intubation in the pediatric trauma patient is loss of consciousness or as part of resuscitation from shock. Only 2% of children sustaining trauma will present with complete mechanical obstruction to the airway. In the rare child who presents with acute airway obstruction, **needle cricothyrotomy** is the preferred method of securing the airway until definitive airway control can be achieved. This technique of ventilation uses the principle of jet insufflation as defined in the adult. **Surgical cricothyrotomy** in children results in a high incidence of subglottic stenosis, but it is still a viable option in children > 10 if needle cricothyrotomy fails to be effective.

Because infants are obligatory nasal and diaphragmatic breathers, fractures and soft-tissue injuries that occlude the nostrils may actually obstruct the airway. Because air swallowed by the infant or insufflated into the stomach may cause acute gastric distention and restrict diaphragmatic excursion, the stomach should be decompressed with an OG tube.

Once the airway is secured and breathing is assured, attention should be given to the circulation. In the noncrying child, the SBP should be 80 + their age in years ×2. Children may compensate for as much as 25% of circulating volume blood loss without a change in BP. Poor peripheral perfusion, decreased level of consciousness and ↓ UO are suggestive of hypovolemia. IV access must be obtained rapidly to begin crystalloid resuscitation in any child with impending signs of shock. If the peripheral iv access is difficult to obtain, as is often the case, saphenous vein cutdown at the saphenofemoral junction should be performed. In infants, if iv access cannot be obtained within 2 min, *(Print pagebreak 741)* intraosseous access should be attempted (see below and Fig. 7.13-6). After iv access has been obtained, as many as three boluses of crystalloid, using a volume of 20 mL/kg, can be given. If the hypovolemic shock state has not been reversed after the 2nd bolus, and other causes of shock—such as spinal injury, cardiac tamponade, or pneumothorax—are excluded, blood (10 mL/kg) should be administered without delay.

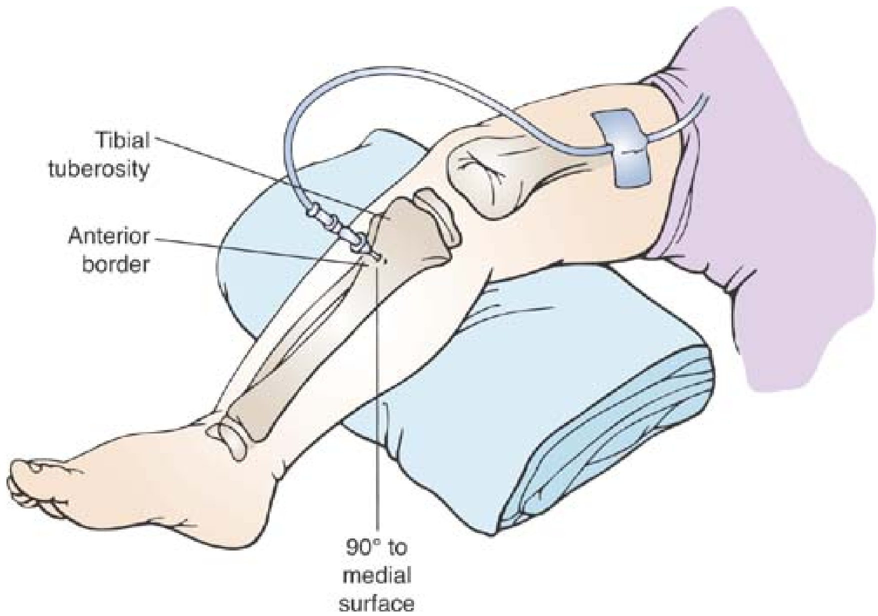

Figure 7.13-6. 6. Intraosseous infusion. (Reproduced with permission from *Textbook of Pediatric Life Support.* American Heart Association, 1994.)

Another important problem in the management of pediatric trauma is related to a high ratio of body surface area to body mass and a lack of substantial subcutaneous tissue. A small infant who is hypothermic may be refractory to therapy; therefore, every attempt should be made to prevent heat loss, and all iv fluids should be warmed.

Needle cricothyrotomy: With the head in neutral position (which may require placement of towels under the shoulders), the neck should be prepped from the jaw to the chest. The neck is protected by in-line immobilization. The cricothyroid membrane should be identified, and the thyroid cartilage immobilized with the surgeon's left hand. The cricothyroid membrane is punctured perpendicularly with a 14–16-ga iv catheter over a needle. The needle is then redirected caudally, the catheter slid off into the trachea, and jet insufflation initiated. Placement of a permanent airway should follow.

Saphenous cutdown: The groin should be prepped and draped and a curvilinear incision made 1–2 cm below and parallel to the inguinal ligament. The saphenous vein is identified at the saphenofemoral junction medial to the femoral artery. Two ligatures are passed underneath; the distal ligature is tied and used to apply tension to the vein. The vein is punctured with a scalpel blade (No. 11) and cut, creating a small flap. Tension applied to the proximal ligature reduces backbleeding during cannulation. A catheter is then introduced, the proximal ligature is tied, and the distal ligature is used to secure the catheter in place.

Intraosseous infusion: After skin preparation, an incision is made 2 cm distal to the tibial tuberosity on the flattened medial aspect of the tibia. An 18–20-ga spinal needle (with obturator) can be used in children < 18 months of age. Older patients may require use of a 13–16 bone marrow biopsy needle. Pressure and rotational motion are applied in a direction perpendicular to the bone until a decrease in resistance is felt. Position of the needle can be confirmed by bone marrow or blood aspiration. This route can be used for rapid fluid infusion and most resuscitation medications can be given this way. Interosseus infusion, however, is only an emergency maneuver and should be used to restore circulating volume to the level that enables more permanent iv access.

Usual preop diagnosis: Airway obstruction; hypovolemic shock; hypovolemic shock with difficult iv access

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Suggested Readings

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