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# Definitive Care Phase: Chest Injuries

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*Part of* "CHAPTER 11 - TRAUMA"

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Chest injuries are common after trauma and are frequently severe. Approximately half of all accident fatalities include some element of chest injury, and approximately one fourth of these deaths can be directly attributed to thoracic injuries. Blunt injuries to the chest, such as from motor vehicle crashes or falls, are more common than those from penetrating trauma, except in some urban areas where penetrating injuries predominate. Among penetrating injuries, stab wounds are in general more common than gunshot wounds.

Most chest injuries can be treated with relatively simple methods, such as tube thoracostomy, appropriate analgesic management, and good pulmonary care (202). However, delay in diagnosis and treatment of severe chest injuries (e.g., tension pneumothorax, aortic transection, rib fractures with pulmonary contusion) is a common cause of preventable death after trauma. An organized structure for understanding chest injuries and their pathophysiology is necessary to guide diagnostic and therapeutic decisions.

## *ANATOMIC CONSIDERATIONS*

For purposes of injury classification, the thorax can be divided into four anatomic zones: (a) the chest wall, (b) the pleural space, (c) the pulmonary parenchyma, and (d) mediastinal structures. Injuries to the chest wall include injuries to the bony thorax and shoulder girdle, as well as soft-tissue injuries. Pleural space injuries include the pneumothorax and hemothorax, in which the potential space between the visceral and parietal pleurae is occupied by either blood or air. Pulmonary parenchymal injuries include contusion, laceration, hematoma, and pneumatocele. Mediastinal injuries involve major vascular structures and the aerodigestive tract. Mediastinal vascular injuries include injuries to the heart, aorta, and great vessels. Aerodigestive injuries include tracheal and bronchial disruptions, traumatic asphyxia, and esophageal injuries.

## *DIAGNOSIS*

### Initial Evaluation

The initial evaluation and treatment of a patient with chest injuries is the same as for any trauma victim. An effective airway is secured, adequacy of breathing is ensured, and circulation is assessed and supported with control of external hemorrhage and establishment of large-bore peripheral venous access. Therapy for potentially life-threatening problems should be initiated immediately.

Whenever possible, a careful history relevant to the chest should be obtained, including details of the mechanism of injury. The speed and direction of impact and the degree of frontal deceleration are important factors in motor vehicle crashes. Aortic transection is associated with severe deceleration injury. Patients not using restraint systems are likely to contact the steering wheel or the dashboard of the car, placing them at an increased risk for chest injuries, such as rib fractures, flail chest, and pulmonary contusion, as well as tracheal or laryngeal injuries.

In patients who sustain penetrating trauma, the characteristics of the wounding instrument are important, but accurate information often is not available. External wounds can be misleading. All information from the patient should be carefully considered, even if the complaints are distant from the perceived trajectory of the injury. Patients with complaints of hoarse voice, dyspnea, throat pain, and dysphagia should be carefully evaluated for injuries to the larynx and the cervical portion of the esophagus. Complaints of dyspnea or pressure in the chest with or without chest wall pain may be indicative of pneumothorax or hemothorax.

The patient's past medical history is also important. A history of pulmonary disease, heart disease, or prior thoracic surgery can alter interpretation of diagnostic studies and affect therapeutic decisions. In addition, a history of medications, allergies, smoking, and the recent ingestion of drugs and alcohol should be obtained.

The physical examination begins with complete exposure of the chest and inspection for signs of contusions, lacerations, or penetrating wounds. These visible signs may give clues to the mechanism of injury. The breathing pattern, its effectiveness in ventilation, and any abnormal motion of the chest wall should be observed. Chest wall splinting and shallow respiration may be noted in patients with rib fractures. Asymmetric chest wall expansion with hyperinflation of one hemithorax is suggestive of tension pneumothorax. Paradoxical motion of a segment of chest wall is diagnostic of flail chest.

The presence of penetrating wounds should be noted, both anteriorly and posteriorly, and marked with metal clips for radiographic reference. In general, these wounds should not be probed. Little if any valuable information is obtained from probing chest wounds, and the maneuver can turn a minor laceration injury into a pneumothorax, requiring a chest tube and longer hospitalization. The location of penetrating injuries, and the likely trajectory of missiles, should modulate the physician's search for mediastinal and pulmonary parenchymal injuries. Penetrating injuries below the nipple line must be presumed to involve the abdominal cavity as well.

The examination of the chest continues with auscultation. The breath sounds should be compared bilaterally for quality and symmetry. Absence of breath sounds on one side is highly suggestive of hemothorax or pneumothorax. Asymmetric hypoventilation may be secondary to splinting from rib fractures, pulmonary contusion, hemothorax or pneumothorax, or main-stem intubation. The presence of rales and rhonchi should alert the clinician to possible intercurrent problems, such as pneumonia or cardiogenic shock from a myocardial infarction.

Gentle but firm palpation of the chest wall demonstrates areas of point tenderness that may be associated with fractures of the ribs, sternum, or clavicles. Areas of referred pain or tenderness should be noted, such as sternal compression causing lateral rib pain in the case of lateral rib fractures. Shoulder pain may be associated with the diaphragmatic irritation of splenic injury (Kehr's sign). The presence of crepitus over the manubrium or in the neck may be an early sign of tracheobronchial injury. Crepitus over the chest wall may be caused by rib fractures or by air in the subcutaneous tissues from a pneumothorax.

Percussion of the chest can also provide valuable information. Hyperresonance should raise suspicion of pneumothorax. This finding is most dramatic with tension pneumothorax, and it may be the most reliable physical sign of tension pneumothorax. Dullness to percussion is suggestive of hemothorax.

## Adjunctive Diagnostic Modalities

The chest radiograph is by far the most important diagnostic study, and it should be obtained early in all patients with significant chest trauma. Standard posteroanterior

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and lateral chest films provide the most accurate information and should be obtained whenever possible. However, because of urgency, concerns about unstable spinal or pelvic injuries, and conflicting priorities, this is rarely possible in the trauma patient. In most patients, 100-cm supine anteroposterior chest radiographs are obtained during the initial evaluation.

Most thoracic injuries can be diagnosed simply from the plain films, making evaluation of chest films a vital skill for the trauma surgeon. A systematic approach to reading chest radiographs is important to ensure that all available information is considered. All chest films should be evaluated for abnormalities of the bony thorax, the soft tissues of the mediastinum, the diaphragm, the pleural space, and the pulmonary parenchyma.

In addition to rib fractures, injuries to the clavicle, scapula, and thoracic spine should be apparent on direct examination of the chest film. A lateral chest film may be necessary to make the diagnosis of sternal fracture, and specific oblique views may increase the diagnostic yield for rib fractures. These special studies are not essential because both rib fracture and sternal fracture are frequently clinical rather than radiographic diagnoses. Presence of significant bony injuries is indicative of major energy transfer to the chest and should raise suspicion of other underlying injuries.

Evaluation of the mediastinum is performed next, looking not only for abnormal widening of the superior mediastinum but for more subtle changes in mediastinal contour. Abnormalities of the aortic contour should raise the suspicion of vascular injury. The presence of air in the mediastinum is suggestive of injury to the esophagus or tracheobronchial tree. The diaphragmatic contours should be sharp and located in normal anatomic position. Poor visualization of a hemidiaphragm may result from traumatic rupture of the diaphragm or from hemothorax. A depressed hemidiaphragm associated with hyperexpansion of the hemithorax suggests tension pneumothorax.

Haziness over one hemithorax on the supine chest radiograph can indicate a hemothorax. Conversely, lucency of one hemithorax should raise suspicion of pneumothorax. Pneumothorax is often confirmed by identification of lung parenchyma collapsed away from the chest wall, but this finding is not always present, especially in patients on positive-pressure ventilation. The radiograph also should be carefully evaluated for lucency in the region of the diaphragm and deepening of the costophrenic sulcus, which are indicative of subpulmonic pneumothorax. The diagnostic accuracy for a suspected pneumothorax may be increased by upright inhalation and exhalation radiographic views.

In patients with potential esophageal injuries, contrast studies should be obtained. The use of a water-soluble contrast agent instead of barium in esophageal evaluation is controversial. The water-soluble medium causes less reaction in the mediastinum if there is an esophageal injury, but it can cause significant pneumonitis if there is a tracheoesophageal fistula. Barium contrast studies give superior mucosal detail in esophageal injuries. It is prudent to begin with water-soluble contrast and proceed with a larger volume of barium for better mucosal detail if no extravasation occurs. In patients who are conscious and alert, the oral contrast should be swallowed under fluoroscopic visualization. In unconscious adult patients, a nasogastric tube is placed just below the pharynx and a 30- to 50-mL bolus of contrast material is injected with enough pressure gently to distend the esophagus while obtaining a plain radiograph.

Angiography is the best study to rule out major injury to the great vessels in the chest in most circumstances, and angiography remains mandatory in most patients at risk for aortic disruption who have abnormal findings on the chest radiograph. Advances in computed tomography (CT) technology have greatly improved the diagnostic accuracy of this modality, and studies suggest that dynamic CT scan of the chest may rival angiography in diagnostic accuracy (203,204) in centers experienced in its use. Dynamic CT scan of the chest is a very useful modality to assess the mediastinum and aortic arch in patients with a negative chest film, where the concern for aortic injury is based on mechanism of injury alone. Transesophageal echocardiography for the evaluation of the aortic arch has been used successfully in some centers (205,206). It is a potential alternative for patients who cannot be transported to the angiography suite because of hemodynamic instability or immediate need for other surgery.

Angiography should be obtained whenever the diagnosis of occult vascular injury in the thoracic cavity is considered. Accurate knowledge of the anatomy of an injury may be essential to planning the correct surgical approach. Patients with penetrating injuries to the thoracic inlet, wounds that cross the midline, or penetrating injuries with trajectories that suggest vascular involvement should undergo angiography if they are hemodynamically stable. Such injuries may present with subtle angiographic findings, and biplanar views are mandatory. Patients with occult vascular injury are at risk for development of massive bleeding during or after angiography, and they must be monitored with great care throughout the procedure.

Video-assisted thoracoscopy is emerging as a potential diagnostic tool for the evaluation of chest trauma. It provides good visualization of mediastinal structures as well as the pleural cavity. The procedure requires general anesthesia and intubation with a double-lumen endotracheal tube to facilitate complete examination, which may limit its usefulness as a screening tool. Video-assisted thoracoscopy is not yet widely used as a diagnostic modality, and experience remains concentrated primarily in centers with an interest in its use.

## *TREATMENT*

### General Considerations

Most injuries to the chest can be successfully managed without surgical intervention. The routine use of tube thoracostomy for treatment of hemothorax and pneumothorax is a cornerstone of therapy. Thoracotomy is most often needed for the control of massive bleeding or bleeding that persists despite tube thoracostomy. Approximately 80% to 85% of patients with hemorrhage in the chest can be treated by tube thoracostomy alone.

Most bleeding in the chest is the result of injuries to the low-pressure pulmonary circulation. Partial or complete collapse of the lung associated with pneumothorax or hemothorax allows small tears or lacerations in the pulmonary parenchyma to continue to bleed. The insertion of a chest tube with subsequent evacuation of the air, blood, and clot allows for reexpansion of the lung and restoration of the normal negative intrathoracic pressure. The reexpanded parenchyma is then apposed against the relatively nondeformable chest wall, leading to tamponade of the low-pressure bleeding. For larger and deeper lacerations, still with relatively low-pressure bleeding from the pulmonary circulation, bleeding can be controlled by the reinflated parenchyma and by the edema in the injured tissue. Tube thoracostomy with full expansion of the lung results in adequate hemostasis in most cases. Persistent bleeding is most commonly a result of injuries to major proximal branches of the pulmonary circulation or to systemic

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arteries, including the intercostal and internal mammary arteries.

The key to successful closed drainage is complete evacuation of blood and clot with full reexpansion of the lung. Patients with ongoing bleeding can form significant clots and are at risk for occlusion of the thoracostomy tube. Therefore, it is vital to use a relatively large tube in patients with hemothorax and to monitor the tube to ensure its continued patency. In most adults, a 36F chest tube is a reasonable choice.

Insertion of a chest tube should be performed as a sterile procedure. After appropriate skin preparation with povidone-iodine solution, local anesthetic is injected, and the chest tube is placed through a skin incision in the fifth or sixth intercostal space, slightly anterior to the mid-axillary line. This relatively cephalad location for the chest tube is chosen to ensure intrathoracic placement of the tube and to avoid injury due to a potentially elevated or ruptured hemidiaphragm. Slightly anterior placement, just behind the body of the pectoralis muscle, is important to minimize risk of injury to the long thoracic nerve. The tube is directed posteriorly to facilitate evacuation of blood from the thorax when the patient is supine. A finger should be inserted through the incision into the thorax before placement of the thoracostomy tube. This digital exploration allows the physician to confirm the thoracic location, assess for the presence of pleural adhesions, feel for viscera (suggesting a ruptured diaphragm), and, possibly, palpate injuries in the diaphragm and pericardium before inserting the chest tube. After insertion, the thoracostomy tube should be placed to closed suction drainage until the air leak is resolved and the output is less than 2 mL/kg (or approximately 150 mL) in a 24-hour period.

The use of prophylactic antibiotics has been shown to decrease infectious complications after tube thoracostomy (207,208). Other data suggest that the risk of major infectious complications, such as empyema, after tube thoracostomy under appropriate sterile technique is low, leading to the conclusion that prophylactic antibiotics are unnecessary (209). The use of prophylactic antibiotics after tube thoracostomy is reasonable, but has not been uniformly adopted.

## Indications for Surgery

### *Chest Wall Injuries*

Most chest wall injuries do not require surgical repair; however, these patients frequently have associated abdominal, orthopedic, or other injuries that do require operative management (210). The open pneumothorax, or sucking chest wound, requires operative débridement and closure. Sternal fractures with significant posterior displacement also require operative repair.

### *Injuries Manifesting in the Pleural Space*

Thoracotomy is indicated for control of ongoing hemorrhage. Pleural space injuries that require operative repair include massive hemothorax with ongoing bleeding, and clotted or caked hemothorax.

### *Parenchymal Injuries*

The cause of hemothorax requiring surgery occasionally is ongoing hemorrhage from lung parenchymal injuries. Deep parenchymal injuries can also produce severe hemoptysis that necessitates thoracotomy. In addition, operative repair is required for injuries to the trachea or major bronchi that exceed approximately one-half the circumference of the airway, or if there are large continuing air leaks that cannot be controlled by insertion of chest tubes.

### *Mediastinal Injuries*

Mediastinal injuries that require surgery include blunt or penetrating cardiac trauma with associated exsanguination, cardiac tamponade, or great vessel injury. Injuries to the thoracic esophagus require thoracotomy and repair.

### *Other Injuries*

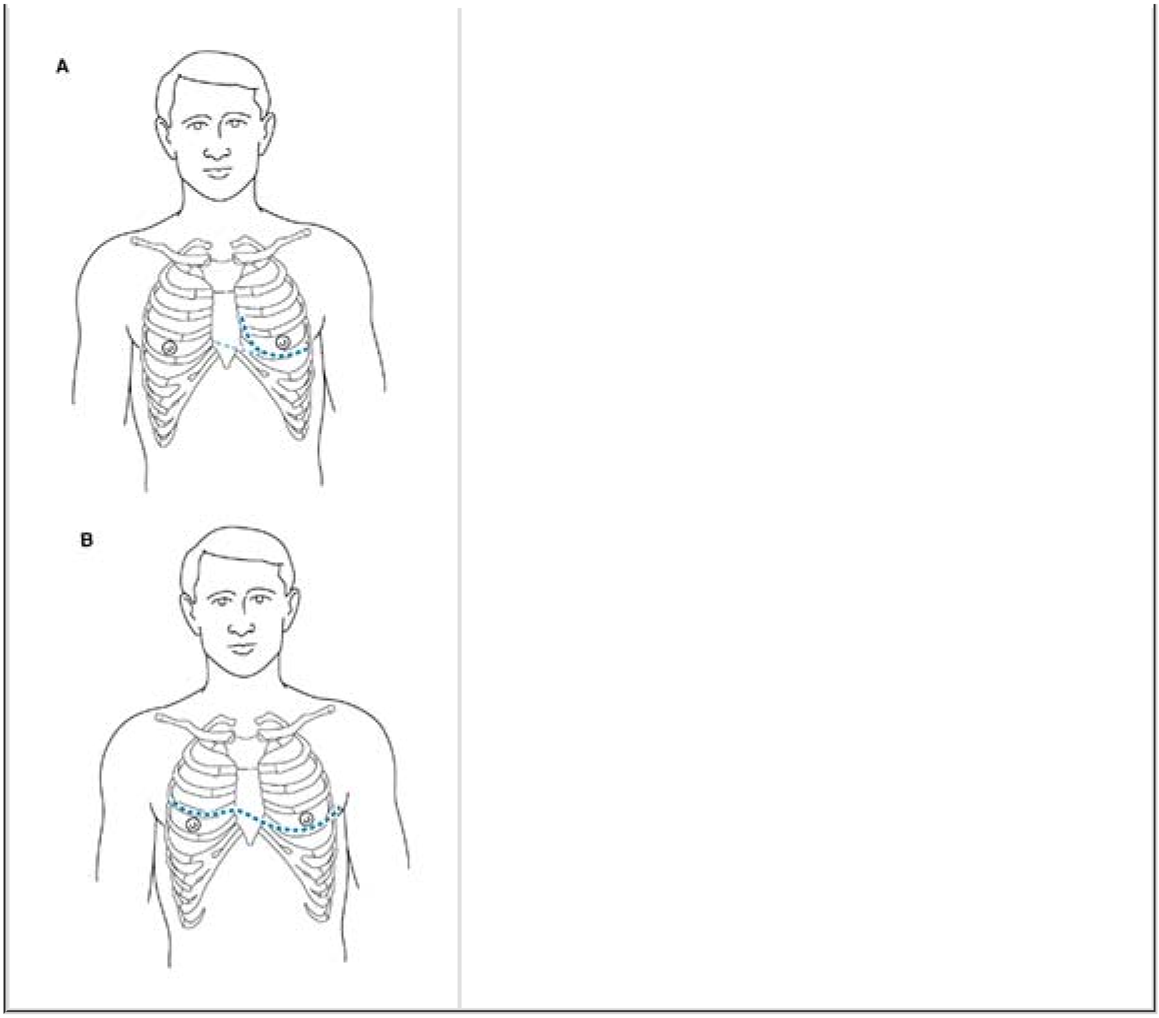
Thoracotomy can be of value in resuscitation of trauma patients with hypovolemia unresponsive to massive volume infusion. Resuscitative thoracotomy also may be indicated in patients with cardiac arrest after penetrating chest trauma, but rarely after blunt trauma.

## General Conduct of Surgery

The choice of position and surgical approach is dictated by the nature of the patient's thoracic injuries, the certainty of diagnosis, and the potential for associated injuries involving other body sites. The standard posterolateral thoracotomy provides optimal exposure to the contents of a particular hemithorax, but the lateral position of the patient makes access to the other side of the chest or the abdomen difficult if not impossible. Therefore, although posterolateral thoracotomy provides the best access, it can be used only in patients who have injuries isolated to a given hemithorax. This determination usually can be made in patients with clearly defined injury and in those who have been under observation for a period before thoracotomy.

In most patients undergoing emergency thoracotomy for chest trauma, an anterolateral approach must be used. The patient remains supine to allow for access to the abdomen and contralateral chest cavity. Exposure through an anterolateral thoracotomy is considerably more difficult but is adequate with proper technique. The ipsilateral side of the body should be elevated to facilitate posterior exposure. The posterior aspect of the incision must extend as far as possible, at least to the border of the latissimus dorsi, and particular care must be taken to follow the curvature of the underlying rib. The mobility of the ribs is limited in the anterolateral approach, and it may be necessary to divide the one or more costal cartilages at the sternum to gain sufficient access. The medial portion of the incision should curve superiorly to facilitate this maneuver (Fig. 11.28A).

***Figure 11.28.*** *(A)* Anterolateral thoracotomy showing correct (dark) and too-transverse (light) incisions. *(B)* A clamshell, or bilateral thoracotomy incision.




The anterolateral thoracotomy incision can be carried transversely across the sternum into the opposite hemithorax to allow exposure to the heart, mediastinum, and structures in the opposite pleural cavity. The sternum can be divided with a sternal saw, a Lebsche knife, or heavy scissors. This bilateral, or clamshell, thoracotomy provides excellent exposure to the heart, mediastinum, and bilateral pulmonary hila (Fig. 11.28B). It is necessary to divide both internal mammary arteries in making this incision, and they must be carefully ligated at the time of closure to prevent recurrent bleeding.

The median sternotomy incision provides excellent exposure to the heart and the great vessels in the anterior mediastinum, but it provides difficult exposure for repair of injuries of the lungs, descending aorta, chest wall, diaphragm, or esophagus. Therefore, like the posterolateral thoracotomy, it can be used only if the patient's injuries can be determined with relative certainty. This is not often the case, and most penetrating injuries to the heart are best approached through a left anterolateral thoracotomy, with extension across the sternum transversely if necessary.

The median sternotomy can be extended into the neck or over the clavicle for exposure of the aortic arch and innominate vessels (Fig. 11.29A). This approach may provide

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the best access to vascular injuries at the thoracic inlet. The median sternotomy combined with the clavicular extension and left anterolateral thoracotomy, the so-called trapdoor incision, can be used for exposure to the entire left thoracic inlet (Fig. 11.29B). Such an incision may be the only way to approach proximal injuries in this difficult area. This exposure should be used only if it is absolutely necessary for control of hemorrhage because it can lead to traction injury of the brachial plexus and disabling long-term sequelae. Care also must be taken to avoid injury to the phrenic nerve on the anterior border of scalenus anterior muscle.

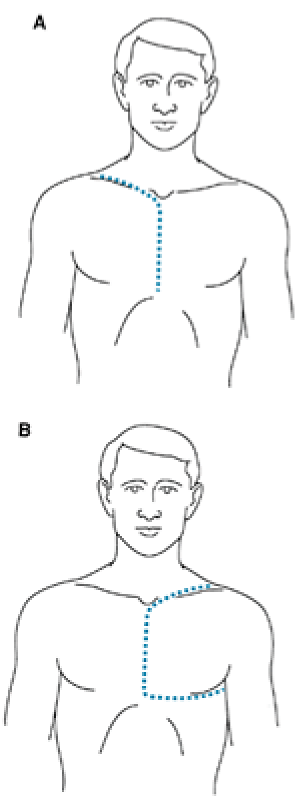


***Figure 11.29.*** Median sternotomy with clavicular extension *(A)* and trapdoor incision *(B)* for exposure of the intrathoracic great vessels.

## Specific Injuries

### *Injuries to the Chest Wall*

#### Rib Fractures.

Rib fractures are the most common injury associated with blunt chest trauma. They can occur directly at the site of force or laterally as a result of significant anteroposterior compression of the chest. The location and area of rib fracture may be indicative of associated injuries. The first rib is protected by the shoulder girdle and clavicle, so fractures of the first rib indicate a significant amount of energy transferred to the torso. First rib fractures have been associated with severe chest and abdominal injuries and with aortic injuries. Posterior rib fractures are also associated with significant energy transfer to the thorax. Fractures of the lower ribs may be associated with intraabdominal injury. A 20% incidence of splenic injury is associated with fractures of ribs 9, 10, and 11 on the left side (211). There is similar association between right lower rib fractures and hepatic parenchymal injuries.

The diagnosis of rib fracture is primarily clinical, and fractures often cannot be seen on routine radiographs. Rib tenderness (either directly or on anteroposterior compression), crepitus over the possible area of fracture, and decreased breath sounds on the side of injury are all suggestive of rib fracture or injury. Specific rib detail films increase the diagnostic yield of chest radiographs, but radiologic confirmation of the diagnosis is not essential (Fig. 11-30). Chest radiographs may demonstrate associated injuries, such as pneumothorax, pulmonary contusion, or hemothorax.

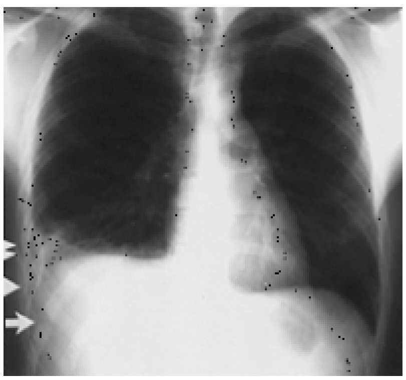

***Figure 11.30.*** Chest radiograph showing multiple rib fractures (ribs 7 to 10). The costophrenic angle is blunted, representing a 400-mL hemothorax.

The treatment of rib fractures is directed primarily at control of their adverse effect on ventilation. Because of the pain associated with chest wall injury, poor inspiratory effort, splinting, and an ineffective cough commonly result. If these are not prevented or appropriately treated, atelectasis and pneumonia ensue. Elderly patients, especially those with preexisting pulmonary disease, are particularly prone to these complications. An assessment of the patient's ventilatory compromise from pain can be made by bedside pulmonary function tests, with primary

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attention to the forced vital capacity and tidal volume. A forced vital capacity of less than 10 mL/kg or a tidal volume of less than 5 to 7 mL/kg is indicative of significant respiratory compromise.

Adequate pain relief and pulmonary care are the primary therapeutic goals. Good analgesia and careful pulmonary care can markedly improve the patient's ventilatory function. The use of intercostal nerve blocks is effective but has been largely supplanted by newer techniques such as patient-controlled analgesia, continuous opioid infusion, and epidural analgesia. Careful use of parenteral opioids, either on a routine basis or through patient-controlled analgesia, suffices in most cases. Epidural techniques are of particular value in elderly patients and in those with underlying pulmonary disease, in whom parenteral opioid use may be limited by respiratory side effects. One study showed that use of epidural opioid produces improvement in pulmonary function superior to that obtained from continuous intravenous administration of narcotic (212). Ventilatory function should be measured both before and after analgesic treatment is begun, and the narcotic dose should be titrated to ventilatory response. The practice of taping fractured ribs is not only ineffective but counterproductive because it can increase the pain from the rib fractures and may further restrict an already compromised ventilatory ability.

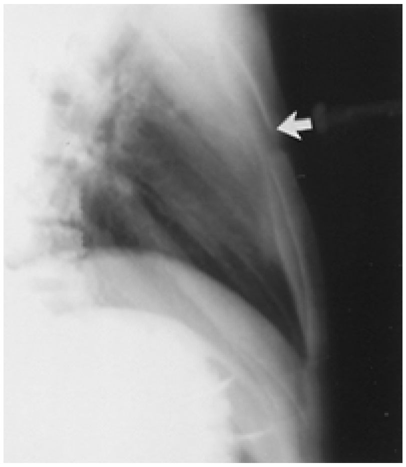
Although epidural and continuous intravenous analgesia appear to be the most effective methods for pain control from rib fractures, not all patients with fractured ribs require hospitalization. Patients who are generally healthy with no underlying medical problems, and who demonstrate good ventilatory function with oral analgesics, may be treated on an outpatient basis with careful follow-up. Patients with a history of smoking, chronic obstructive pulmonary disease, or other pulmonary problems who sustain rib fractures are at increased risk for complications. These patients usually benefit from hospital admission to ensure adequate analgesia and to monitor pulmonary function.

### Sternal Fractures.

Sternal fractures are frequently associated with a significant blow to the anterior chest. The incidence of sternal fractures historically is low, occurring in approximately 5% of patients with severe chest injuries. Sternal fracture has been reported to occur in unrestrained motor vehicle accident victims who strike the steering wheel. The mortality rate associated with sternal fractures in older series has been as high as 25% to 30%, mainly because of other injuries to the chest, such as aortic transection, cardiac contusion or tamponade, or tracheobronchial rupture. More recent studies have suggested a change in the pattern and severity of injuries associated with sternal fracture (213). Major improvements in automobile safety, including collapsible steering columns, interior padding, and passive restraints, have probably contributed to this change. Isolated sternal fracture may result from shoulder belt use, and it does not necessitate hospital admission in the stable patient (214,215,216).

Sternal fractures are usually transverse but can be longitudinal, especially if they are associated with sternal flail chest. Posterior displacement of the fractured sternum can impinge on the heart. The diagnosis of sternal fracture is made by palpation of the sternum if an obvious step-off is present. A lateral chest radiograph can reveal sternal fractures and the degree of posterior displacement (Fig. 11-31). The treatment of sternal fracture is primarily adequate pain relief and pulmonary care, as for rib fractures. If severe displacement is present, operative reduction with fixation of the fracture may be required.

***Figure 11.31.*** Posterior displacement of a sternal fracture *(arrow),* as demonstrated on a lateral chest radiograph.



## Flail Chest.

A flail chest occurs when consecutive ribs are fractured in more than one place, creating a free-floating segment of the chest wall. The free-floating segment can involve the sternum, with separation of the costochondral junction on either side (Fig. 11-32). Flail chest occurs in up to 20% of patients with severe blunt chest injuries.

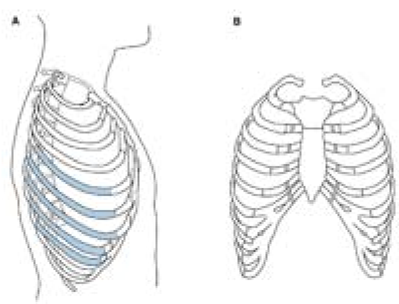


***Figure 11.32.*** *(A)* Right lateral flail chest. *(B)* Sternal flail chest.

Flail chest may result in paradoxical chest wall motion, as the free-floating segment responds to pressure gradients, not to the organized motion of the chest wall during

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breathing. The intact chest wall expands during inspiration, but the negative intrathoracic pressure generated causes the flail segment to move inappropriately inward. On expiration, the flail segment moves outward as the rest of the chest wall moves inward. Historically, it was believed that this paradoxical motion was the cause of the severe ventilatory insufficiency associated with flail chest, and therapeutic efforts were focused on stabilization of the flail segment. Stabilization was attempted with dressings, sandbags, surgical fracture fixation, even towel clips through the chest wall into the rib, attached to the frame of the bed. Mortality rates with these modes of treatment were between 30% and 40% (217).

Our understanding of the pathophysiologic consequences of the flail chest has evolved. The ventilatory impairment is not caused simply by the paradoxical motion of the chest wall but rather by the underlying pulmonary parenchymal injury in combination with the hypoventilation and splinting that result from the pain of multiple contiguous rib fractures. The weak and ineffective ventilatory effort frequently leads to progressive atelectasis and pneumonia. Improved understanding of the pathophysiology of flail chest also has altered the therapeutic focus, with dramatic improvements in survival. The current approach to the patient with flail chest stresses adequate analgesia to prevent the cycle of pain, splinting, and hypoventilation, and early ventilatory support. The need for mechanical ventilation is determined by the degree of pulmonary parenchymal injury and by the inability to achieve adequate pain relief. Using such methods, the mortality rate for flail chest has decreased to approximately 2% in nonventilated patients and approximately 20% in patients requiring mechanical ventilation. Mortality is usually related to severe head injuries, or other associated injuries (218,219,220).

The patient's ventilatory status is assessed at the time of initial presentation. Mechanical problems contributing to respiratory compromise, such as airway obstruction, pneumothorax, or hemothorax, should be treated rapidly. Patients with a flail chest who present with respiratory distress and hypoxemia require immediate endotracheal intubation and mechanical ventilation. If the patient's ventilatory function is initially adequate, aggressive measures to ensure analgesia are undertaken. Epidural techniques are often required, and they should be considered early. The patient is carefully monitored, because the pulmonary injuries commonly progress over the first several hours. Mechanical ventilation should be initiated at the first early signs of impending ventilatory failure, not after the patient is in an advanced state of respiratory compromise.

Vigorous chest physiotherapy and pulmonary care are an integral part of the treatment protocol. Usually, the amount of pain experienced by the patient decreases within 72 hours, and the amount of analgesia required is concomitantly less. These patients are continued on aggressive chest physiotherapy and pulmonary care under careful observation until their pain is well controlled, tidal volume is adequate, and cough has improved. Then they can be weaned gradually from systemic to oral analgesia.

### Open Pneumothorax.

The open pneumothorax, or sucking chest wound, is an uncommon injury that produces a large chest wall defect and is usually caused by impalement, high-speed motor vehicle accident, or shotgun blast. These injuries can also occur from large lacerations in the chest wall after an assault. The defect in the chest wall allows equilibration of intrathoracic and ambient pressures, leading to collapse of the lung. If the defect is large enough, air flows through the chest wall defect rather than through the trachea and into the lungs with each inspiratory effort. This can result in rapid and profound ventilatory compromise, an immediately life-threatening situation. The diagnosis of a sucking chest wound can be made on simple inspection of the chest wall and hearing the flow of air through the wound. The defect should be occluded with an impermeable dressing, such as petrolatum gauze, essentially converting the situation to a closed pneumothorax. Tube thoracostomy is then performed to reexpand the lung. The chest wall defect usually requires operative débridement and formal chest wall closure. In most cases, closure can be accomplished primarily, although large soft-tissue defects may require tissue transfer techniques.

## *Pleural Space Injuries*

### Simple Pneumothorax.

Pneumothorax, defined as air in the potential space between the visceral and parietal pleurae, is a common occurrence. The loss of negative intrapleural pressure allows the lung to collapse from elastic

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recoil. Pneumothorax ordinarily results from ruptured alveoli or from small lacerations in the pulmonary parenchyma and is frequently associated with rib fractures. Pneumothorax also can result from lacerations through the chest wall (e.g., stab or gunshot wounds) and from iatrogenic injuries (e.g., as a complication of placement of a central venous catheter). The diagnosis of pneumothorax is suggested on physical examination by decreased ipsilateral breath sounds; decreased expansion of the affected hemithorax; hyperresonance to percussion; crepitus; or subcutaneous emphysema. The chest radiograph is usually diagnostic (Fig. 11-33). In patients on positive-pressure ventilation, the radiologic diagnosis can be somewhat more difficult because the lung does not always collapse away from the chest wall. The diaphragmatic contour should be carefully evaluated for evidence of subpulmonic air, the deep sulcus sign.

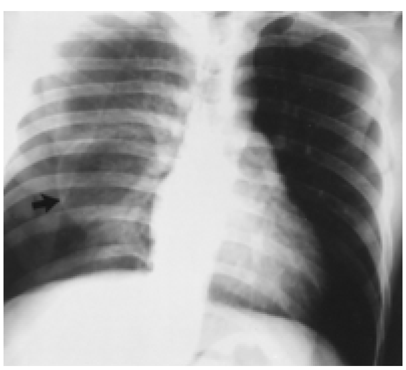

***Figure 11.33.*** Right-sided simple pneumothorax with no significant mediastinal shift (*arrow* indicates lung margin).

In patients with penetrating trauma to the chest but no pneumothorax apparent on supine chest film, upright posteroanterior and inhalation-exhalation views may improve the diagnostic yield. Patients who manifest no evidence of pneumothorax on upright chest radiography after 6 hours of observation may be discharged safely (221).

Traumatic pneumothorax is treated by placement of a tube thoracostomy, as previously described. A large (36F) chest tube should be inserted to evacuate the air and any blood and blood clots that may be present. Patients with only subcutaneous emphysema who are to undergo general anesthesia with positive-pressure ventilation should be considered for prophylactic tube thoracostomy to prevent the potentially lethal complication of tension pneumothorax. A chest radiograph should be obtained after insertion of the chest tube to confirm that proper tube positioning and reexpansion of the lung have occurred.

Patients with small, asymptomatic pneumothoraces who do not require general endotracheal anesthesia or positive-pressure ventilation may be observed carefully without placement of a tube thoracostomy. If the air leak from the lung has sealed, the air in the pleural cavity will be reabsorbed, with subsequent complete reexpansion of the lung. Serial chest films should be obtained to ensure that the pneumothorax is progressively decreasing and that the lung is not collapsed. Small pneumothoraces, particularly those from spontaneous bleb rupture or iatrogenic injury, can be drained effectively with smaller thoracostomy tubes, causing less patient discomfort and shortening hospital stay (222,223).

## Tension Pneumothorax.

A tension pneumothorax occurs if the pressure of accumulated air in the pleural space exceeds the ambient pressure, resulting in a net positive intrathoracic pressure. Although tension pneumothorax can occur in patients who are breathing spontaneously, it is most commonly associated with positive-pressure ventilation. Positive-pressure ventilation increases the air leak into the ipsilateral pleural space and can convert a simple pneumothorax to a tension pneumothorax. Mediastinal shift leads to decreased venous return to the heart and compression of the opposite functional lung. Tension pneumothorax often causes severe respiratory distress and hemodynamic compromise.

Patients with tension pneumothorax can have tachypnea, dyspnea, absent breath sounds on the affected side, and hyperresonance to percussion. As the situation progresses, central cyanosis, tracheal deviation, jugular venous distention, and arterial hypotension occur. The chest radiograph may reveal a collapsed lung, a depressed ipsilateral hemidiaphragm, widened intercostal spaces, and a mediastinal shift away from the hemithorax with positive intrathoracic pressure (Fig. 11-34).

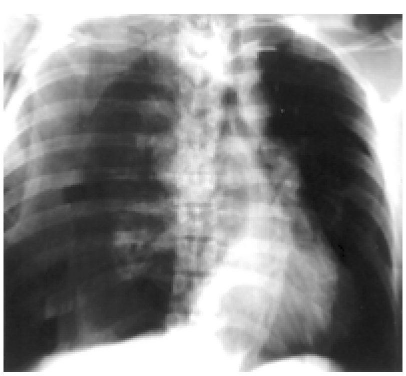

***Figure 11.34.*** Right-sided tension pneumothorax with tracheobronchial and mediastinal shifts.

Immediate decompression of the affected hemithorax is required in patients with respiratory and hemodynamic compromise from tension pneumothorax. Decompression is most rapidly accomplished by needle thoracostomy, which involves placing a large-bore (14- or 16-gauge) needle through the chest wall to relieve the positive intrathoracic pressure. Historically, the second intercostal space in the mid-clavicular line was suggested as the site for this procedure, but the anatomic landmarks are rather difficult, and the potential for mediastinal vascular injuries is significant. The author recommends that the needle thoracostomy be done in the fifth or sixth intercostal space at the mid-axillary line, in the same position as the tube thoracostomy. The body wall is thinnest at this site, and the anatomy is much less complex. Placement of a tube thoracostomy after needle decompression constitutes definitive therapy.

### Hemothorax.

A hemothorax is the accumulation of blood in the pleural space, and it occurs in 50% to 75% of patients with severe blunt or penetrating chest trauma. Though the amount of bleeding is often minimal with small lung lacerations or puncture wounds, there is potential for massive bleeding from injuries to larger branches of pulmonary arteries and veins, major rents in the pulmonary parenchyma, or lacerations of systemic arteries. Patients may be relatively asymptomatic or in frank hypovolemic shock at the time of presentation, and may complain of dyspnea or shortness of breath. Physical examination usually reveals decreased breath sounds and dullness to percussion on the injured side. Supine chest films usually show haziness of the affected lung field or, with massive hemothorax, complete opacification (Fig. 11-35).

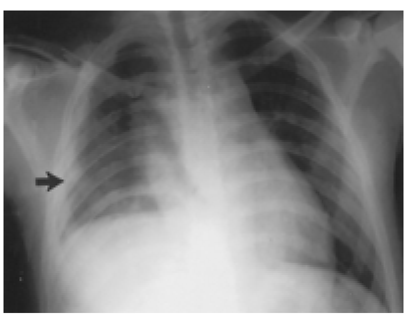

***Figure 11.35.*** Right-sided hemothorax with diffuse unilateral haziness and pleural-based density *(arrow),* indicating intrapleural blood.

The treatment of hemothorax begins with tube thoracostomy to evacuate the blood and reexpand the lung. The pressure of the pulmonary parenchymal circulation is relatively low, and reexpansion of the lung compresses the areas of injury against the interior of the relatively rigid chest wall. This acts to tamponade low-pressure bleeding. In addition, the pulmonary parenchyma has a high concentration of tissue thromboplastin, which probably contributes to hemostasis and sealing of air leaks. Simple tube thoracostomy is adequate treatment for up to 85% of patients with hemothorax.

Massive hemothorax (i.e., more than 1,000 to 1,500 mL) may require thoracotomy for evacuation of clot and control of bleeding. Efforts should be made to evacuate all of the blood from the chest and to reexpand the lung, which leads to tamponade of the injured lung parenchyma. If reexpansion fails or if the patient continues to bleed rapidly, thoracotomy is required for control of bleeding. Persistent bleeding, at a rate greater than 200 mL/h for 4 hours, or greater than 100 mL/h for 8 hours, is also an indication for thoracotomy in adults. If the patient manifests any hemodynamic instability during this period of observation, urgent thoracotomy is mandatory.

### Caked or Clotted Hemothorax.

In some cases, a clot remains around the lung despite the presence of a well placed large-bore tube thoracostomy. This clot keeps the lung from completely reexpanding and can cause pulmonary entrapment or an eventual fibrothorax (Fig. 11-36). The incidence of infected, clotted, or caked hemothorax after tube thoracostomy is 5% to 15% in major trauma patients. Although a small hemothorax is spontaneously absorbed over time, a large hemothorax does not resolve without mechanical drainage. The magnitude of the residual hemothorax that necessitates thoracotomy has not been clearly defined.

***Figure 11.36.*** Large accumulation of intrapleural blood or clotted hemothorax with compression of right lung *(arrows).*

Surgical therapy for a clotted hemothorax consists of evacuation of retained clot and decortication of the lung if a thick fibrinous peel is present. If done relatively early, before the clot has become organized, evacuation often can be accomplished using thoracoscopy, with or without the addition of a limited thoracotomy (224,225,226). This procedure is usually well tolerated, with full reexpansion of the

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lung and discharge from the hospital within a week. After the first 7 to 10 days, removal of the clot is more likely to require full thoracotomy and decortication, which has a significantly greater physiologic impact.

## *Parenchymal Injuries*

### Pulmonary Contusion.

Pulmonary contusion occurs in up to 70% of patients with severe blunt chest trauma. It is associated with rib fractures, flail chest, and sternal fractures. Pulmonary contusion involves extensive interstitial hemorrhage within the parenchyma, with alveolar collapse and extravasation of blood and plasma into the alveoli. As a result, a ventilation-perfusion mismatch develops, which leads to arterial hypoxemia. Under these circumstances, the hypoxemia is usually refractory to increases in inspired oxygen concentration. In addition, pulmonary compliance decreases, and work of breathing increases. These effects tend to worsen over the first several hours after injury and can combine to produce severe respiratory failure. The diagnosis of pulmonary contusion must be considered in patients with rib fractures and flail chest or with any other severe blunt chest trauma. Such patients must be observed carefully for evidence of progressive ventilatory failure.

Physical examination may reveal contusions over the involved chest as well as the rib injuries previously described. The patient who is unable to meet the demands of increased work of breathing may present with significant ventilatory distress. The classic radiographic appearance is that of a poorly defined infiltrate consistent with both alveolar and interstitial edema (Fig. 11-37). These findings on the chest radiograph are present within 1 hour of injury in 70% of patients. The remainder, however, have a delay of 4 to 6 hours before the contusion becomes visible on the chest film. Hypoxemia and significant alveolar-arterial gradient may be evident on arterial blood gas examination.

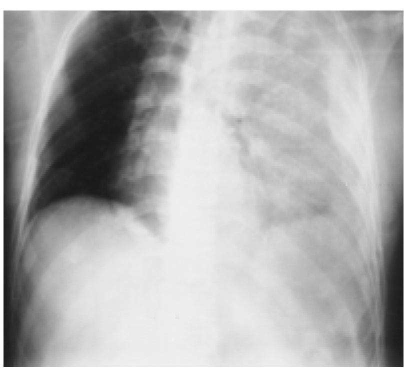


***Figure 11.37.*** Hemothorax and associated massive left pulmonary contusion after blunt chest trauma.

Treatment of patients with pulmonary contusion is primarily supportive. Patients who can maintain satisfactory arterial blood gases (i.e., partial pressure of oxygen >60 mm Hg with inspired oxygen concentration of 50%) and adequate ventilatory mechanics (i.e., a respiratory rate <24 breaths/min, a tidal volume >5 to 7 mL/kg, and a forced vital capacity >10 mL/kg) may not require intubation. These patients should be carefully monitored, and care should be taken to provide adequate analgesia for rib fractures.

Patients who cannot sustain adequate pulmonary function require mechanical ventilation. Gas exchange can be improved in most cases by use of a moderate level of continuous positive airway pressure. Careful optimization of intravascular volume status and cardiac performance is often required in more severely injured patients, and placement of a pulmonary artery catheter should be considered. The therapeutic goals are to maintain adequate peripheral oxygen delivery with airway pressure and inspired oxygen concentration at the lowest possible levels.

Depending on their size and severity, pulmonary contusions may start to resolve within 48 to 72 hours of injury, but 2 to 3 weeks may be required for complete resolution.

### Pulmonary Laceration.

Pulmonary lacerations can be the result of blunt chest trauma, but they are more common with penetrating injuries to the chest. A pulmonary laceration may exist within a surrounding area of contusion. Patients with pulmonary lacerations may have complaints similar to those of patients with pulmonary contusion, but they also frequently have hemoptysis. Chest radiography often reveals an area of pulmonary contusion and hemothorax.

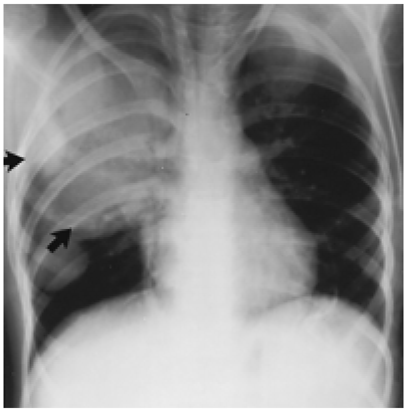
The hemorrhage from pulmonary lacerations is usually from the low-pressure pulmonary system and can be treated with tube thoracostomy and reexpansion of the lung. If the air leak from the tube thoracostomy is large and the lung is not completely reexpanded, the placement of a second tube may be necessary. Bronchoscopy should be performed in patients with large air leaks or hemoptysis to rule out a bronchial injury.

Patients who have a pulmonary laceration and require positive-pressure ventilation are at risk for development of significant bronchopleural fistulae. If the air leak is very large, conventional modes of volume ventilation may not provide adequate alveolar ventilation. Strategies to improve alveolar ventilation include pressure-limited ventilatory modes, higher-frequency low-volume ventilation, and, in rare circumstances, independent lung ventilation. Bronchoscopic procedures to occlude the distal airway leading to the fistula also have been reported (227,228). In most circumstances, the air leak eventually closes, especially if the patient can be weaned from positive-pressure ventilation. If a significant leak persists, if the lung fails to expand, or if hemorrhage from the pulmonary laceration continues at a significant rate, thoracotomy may be necessary.

### Pulmonary Hematoma.

Pulmonary hematoma occurs when bleeding from a laceration is contained within the surrounding parenchyma. The mechanisms of injury and presenting complaints are similar to those for contusion, but hemoptysis is more likely with intraparenchymal hematoma. On the chest radiograph, the margins of a pulmonary hematoma are more clearly defined and spherical, in contrast to the diffuse, ill-defined borders of a contusion (Fig. 11-38). The degree of ventilatory compromise is usually less severe than in patients with pulmonary contusion because the hematoma displaces rather than infiltrates the lung tissue.

***Figure 11.38.*** Right-sided pulmonary hematoma with well-defined spherical margins *(arrows),* in contrast to the ill-defined borders of a contusion.



Conservative treatment with good pulmonary care and chest physiotherapy is the rule, and these lesions usually resolve without specific therapy in 2 to 3 weeks. During this time, the patient may have intermittent low-grade fever; however, if the fever remains high or increases, the

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possibility of an infected pulmonary hematoma should be entertained. Bronchoscopy should be performed to rule out a retained foreign body or clot in the airway. Antibiotics should be started, and vigorous chest physiotherapy should be initiated. A CT scan of the chest may reveal an air-fluid level in the hematoma. Percutaneous placement of a drainage catheter can be effective in resolving infected pulmonary hematomas. If this is unsuccessful, surgical resection may be needed.

### Pneumatocele.

A traumatic pulmonary pneumatocele occurs if there has been sufficient force to rupture a small airway without causing major hemorrhage, forming an air-filled pulmonary cavity. Pneumatocele is usually well tolerated, but the patient may complain of mild chest pain, dyspnea, or hemoptysis. A chest radiograph reveals a spherical, air-filled cavity that may show a fluid level on upright chest film. Preexisting disease, such as pulmonary abscess, tuberculosis, or other cavitary lesion in the lung, should be ruled out. A CT scan of the chest is helpful in establishing the diagnosis. Because infections occur in fewer than 10% of patients with these injuries, prophylactic antibiotics are not indicated. Conservative management with good pulmonary care and observation is the treatment of choice. Resolution of these lesions is slow, taking up to 4 months.

## *Mediastinal Injuries*

### Tracheobronchial Injuries.

Tracheobronchial injuries from blunt trauma are relatively uncommon, occurring in fewer than 1% of patients with severe trauma. These injuries can result from blunt trauma (e.g., high-speed motor vehicle accidents) or from crushing injuries. If significant anteroposterior compressive force is applied to the chest, it causes rapid lateral deformation of the thoracic cavity and results in traction injury of the trachea or main-stem bronchi, usually within 2 cm of the carina. Penetrating injuries to the tracheobronchial tree are most common in the cervical area but can occur anywhere. Clothesline-type injuries can occur in bicyclists, motorcyclists, or drivers of other recreational vehicles. These blunt injuries can cause transection of the cervical trachea, resulting in airway obstruction.

Most patients with severe airway injuries die at the scene of the accident as a result of airway obstruction. Patients who survive to reach the hospital may complain of dyspnea, cough, or hemoptysis. Physical examination may reveal stridor, and subcutaneous emphysema is almost always found. Chest radiographs may reveal pneumothorax, extensive pneumomediastinum, and air in the soft tissues of the neck and chest wall. Placement of a tube thoracostomy may result in a continued massive air leak from the chest tube with no expansion of the lung (Fig. 11-39). If so, a second chest tube should be placed, and bronchoscopy should be undertaken to confirm the diagnosis.

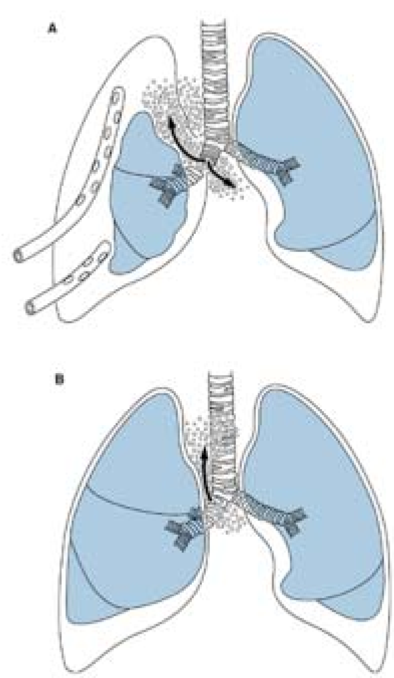


***Figure 11.39.*** *(A)* Ruptured bronchus demonstrating pneumothorax with intrapleural rupture. *(B)* Pneumomediastinum with extrapleural rupture.

Most bronchial injuries, including complete disruptions, heal spontaneously; however, stricture formation is common with more extensive injuries. If the injury involves less than one third of the circumference of the bronchus and the lung can be reexpanded with chest tube placement, nonoperative management probably will be successful. If the injury involves more than one third to one half of the circumference of the airway, early surgical repair is indicated to prevent late stricture (229). Persistent large air leak and inability to reexpand the lung also may necessitate surgical repair of bronchial injuries.

A right posterolateral thoracotomy gives excellent exposure to the thoracic trachea and right main-stem bronchus. Proximal left main-stem bronchial injuries also can be reached through this incision. Complete transection of the left main-stem bronchus requires left posterolateral thoracotomy, especially if the transection is more than 1 cm distal to the carina. Primary repair is the goal in most cases, although severe injuries may require sleeve resection of the bronchus or even lung resection. The repair should establish a mucosal closure with an absorbable suture material to decrease the incidence of suture-line granuloma formation or anastomotic stenosis. Bronchoscopic stent placement also has been used successfully in the repair of isolated bronchial injuries (230).

Transection of the trachea in the low cervical area may be associated with retraction of the tracheal stump into the mediastinum. Preparations should therefore be made for extension of the cervical incision into a median sternotomy if necessary. The repair of cervical tracheal injuries is discussed in greater detail in the section on neck trauma.

### Aortic Injuries.

Blunt aortic disruption is associated with the mechanism of abrupt deceleration. Shear forces act on the vessel at points of anatomic fixation, resulting in transection of the vessel. In patients who survive the initial injury, the hemorrhage is contained by the adventitia and tissues of the mediastinum, forming a pseudoaneurysm.



The most common sites are the proximal aortic arch near the aortic valve; just distal to the origin of the left subclavian artery origin at the ligamentum arteriosum; and at the diaphragmatic hiatus. Patients with ascending aortic tears have a high mortality rate and rarely reach the hospital alive. Most patients who present alive have injuries at the level of the ligamentum arteriosum. Injuries at the diaphragm occur infrequently.

Patients with blunt aortic injuries frequently have associated injuries, with head trauma, fractures, and major visceral injuries being most common. Specific symptoms include severe chest or back pain. The physical examination may reveal fractures of the clavicles, sternum, or ribs. Upper extremity hypertension and asymmetry of pulses in the upper and lower extremities (pseudocoarctation) may be diagnostic. This presentation occurs if the ends of the transected aorta are not in perfect alignment. A careful neurologic evaluation is important because patients may have paraplegia or paraparesis from loss of blood flow through the intercostal arteries that supply the spinal cord.

The timely diagnosis of blunt injury of the thoracic aorta depends on a thorough search for it, which should be triggered initially by an appropriate mechanism of injury (i.e., deceleration). A chest radiograph is a useful screening procedure. Numerous findings on chest film have been associated with thoracic aortic injury. These include the presence of a widened mediastinum (>8 cm at the aortic knob in adults); obliteration of the aortopulmonary window and an indistinct aortic knob; deviation of the trachea, nasogastric tube, or endotracheal tube to the right; depression of the left main-stem bronchus more than 140 degrees with concomitant elevation of the right main-stem bronchus; and the presence of an apical cap (Fig. 11-40). Aortic injury is also associated with fractures of the first or second rib and with scapular fractures. The finding of abnormal contour of the mediastinum or aortic knob is probably the most reliable early finding on chest film and demands further work-up. An anteroposterior chest film taken with the patient in the supine position tends to magnify the size of the mediastinum to some extent. It is often helpful to obtain an upright chest film, if it is not contraindicated.

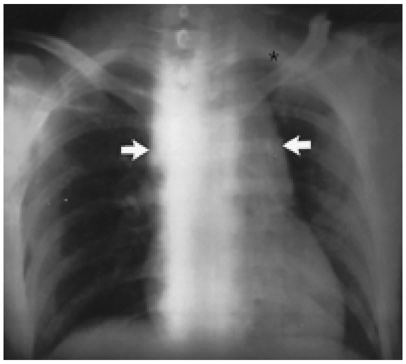

***Figure 11.40.*** Chest radiograph demonstrating wide mediastinum *(arrows)*, a left pleural cap *(asterisk)*, and obliteration of the aortic notch, all consistent with an aortic transection.

Abnormal findings on the chest film—or any suspicion of the injury—must be aggressively investigated. Because of the high morbidity associated with missed injuries, angiography has been the diagnostic study of choice in patients at significant risk. It is important to obtain full arch aortography, four-vessel run-off, and a full aortogram to avoid missing injuries at the aortic root, the diaphragmatic hiatus, or the origins of the great vessels. As discussed earlier in this section, dynamic helical CT scan of the chest may be equivalent to angiography in experienced hands. Chest CT scan is certainly a useful screening procedure in patients who have a negative chest film but significant mechanism of injury (231). Transesophageal echocardiography, also described earlier in the section, has been used with success. Transesophageal echocardiography is especially promising for use in unstable patients who cannot be transported to the angiography suite or the CT scanner.

Most blunt injuries of the aorta require immediate surgical repair. The literature suggests that a subset of patients have stable pseudoaneurysms that may be safely managed with delayed operation if necessary in the presence of other life-threatening injuries (204). In most cases, rapid surgical repair is vital to the survival of patients with blunt aortic injury (232,233). If the pseudoaneurysm ruptures before definitive repair, the mortality rate is extremely high. The preoperative treatment of patients with aortic disruption involves careful control of blood pressure and avoidance of hypertension. A short-acting β-antagonist such as esmolol or labetalol is probably the best choice if blood pressure control is needed. These agents are easy to titrate and they decrease both blood pressure and myocardial contractility, which results in lower shear stress in the arterial wall. Pure arteriolar vasodilation, such as that achieved using sodium nitroprusside, may actually lead to increased wall shear stress because pulse pressure often increases as systolic blood pressure decreases. The use of sodium nitroprusside also should be avoided in patients with head injuries.

An intraarterial catheter should be placed for direct arterial pressure monitoring, and a central venous or pulmonary artery catheter should be placed by an internal jugular or femoral route. The subclavian approach should be avoided because of the danger of entering the mediastinal hematoma.

Injuries of the ascending aorta often require full cardiopulmonary bypass for repair, and median sternotomy provides the best exposure (234). The repair of aortic injuries at or below the level of the ligamentum arteriosum is accomplished through a left posterolateral thoracotomy. Relatively simple injures can be repaired primarily. In young patients, it is often prudent to use pledgetted sutures for the repair. The thoracic aorta has relatively limited mobility, and intercostal vessels should not be sacrificed to facilitate primary repair owing to concerns about spinal cord perfusion. More extensive injuries require placement of a prosthetic graft.

The technique of aortic repair has been the subject of some controversy, primarily because of the risk of spinal cord ischemia with cross-clamping of the thoracic aorta. One review (235) showed no difference in the rate of paraplegia (8%) with or without placement of a heparin-bonded shunt to maintain distal flow during repair. The use of complete cardiopulmonary bypass with full heparinization has been shown to increase the mortality rate in patients who have other cerebral and vascular injuries, and it is probably contraindicated in blunt trauma. However, more recent advances in pump technology allow left

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heart bypass with much lower levels of systemic anticoagulation, and this technique can be safely used in multiply injured patients (233). Although definitive data are lacking, left heart bypass techniques probably decrease the rate of paraplegia, and should be used whenever possible.

Penetrating injuries to the aorta can occur anywhere along its length. Some penetrating injuries, especially from low-velocity projectiles, may result in the formation of a contained pseudoaneurysm, and have limited hemorrhage in the early postinjury phase. It is essential to investigate fully all injuries with a trajectory in proximity to the aorta, especially those traversing the posterior mediastinum. Aortography is essential in stable patients with evidence of mediastinal hematoma, but other modalities, including helical CT, are useful in low-risk patients (236).

Penetrating injuries are often amenable to primary repair, although prosthetic graft placement may be required in larger wounds. As in the case of blunt injuries, left heart bypass techniques are probably beneficial, and should be used in complex cases when circumstances allow.

### Myocardial Contusion.

The incidence of myocardial contusion is difficult to determine because there is no consensus with regard to its definition and diagnostic criteria. It has been suggested that as many as 75% of patients with major blunt chest injury sustain myocardial contusion, although the incidence of clinically significant findings or complications is clearly much lower. Clinically significant dysrhythmia or pump failure probably occurs in fewer than 5% of patients admitted to a trauma center. The mechanisms of injury associated with myocardial contusion include deceleration or crush injuries to the anterior thorax. There are no classic signs or symptoms, although the patient may complain of chest pain and sometimes of palpitations. Physical examination may reveal bruising and tenderness over the anterior chest. Findings of pericardial rubs or murmurs are rare.

The sensitivity and specificity of diagnostic tests for myocardial contusion cannot be determined because there are no universally accepted diagnostic criteria. Findings on electrocardiogram (ECG) that have been associated with myocardial contusion include ST-T-wave alterations, supraventricular and ventricular dysrhythmia, and sinus and atrioventricular nodal dysfunction. Right and left bundle-branch blocks also have been observed. None of these, however, is specific. For example, the ST-T-wave alterations also may be associated with pain, anxiety, hypoxia, and hypovolemia, all of which are common after severe trauma. Determination of creatine kinase (CK) isoenzymes, specifically the myocardial band (MB) fraction, also has been used to aid in the diagnosis of myocardial contusion. Elevation of the CK-MB fraction to greater than 5% of the total, or a total plasma CK concentration greater than 50 to 100 IU/mL, is considered diagnostic of myocardial contusion at some trauma centers, but the clinical significance of this finding is unclear. Elevation of the CK-MB fraction is neither sensitive nor specific for clinically significant injury leading to complications.

Two-dimensional echocardiography also has been used in an effort to diagnose myocardial contusion. This is a sensitive and specific method to assess global cardiac performance, wall motion defects, intramural hematomas, valvular dysfunction, and pericardial effusion. Positive findings are uncommon in patients presenting with trauma, and none of these tests is specific for myocardial contusion (237).

The need for treatment is based on clinical presentation. Dysrhythmias should be treated aggressively, but there are no data to support the use of prophylactic antidysrhythmics. Patients in whom dysrhythmias are likely to develop usually present with dysrhythmia or other ECG abnormalities. It is uncommon for significant dysrhythmia to develop in patients with a normal admitting ECG. Patients with suspected myocardial contusion and clinical evidence of poor myocardial performance should undergo echocardiography. Patients at risk for myocardial contusion who require surgery for other problems should be carefully monitored, but emergency surgery can be accomplished without significant additional morbidity or mortality. Myocardial pump failure is rare, and its treatment is not specifically altered in the posttraumatic patient should it occur.

Some controversy has surrounded the asymptomatic patient. A typical scenario involves the patient with some chest wall pain after a motor vehicle accident but without dysrhythmia. Stable patients with no evidence of dysrhythmia or other injury that would mandate hospitalization can be monitored for as little as 8 hours and discharged safely (238).

### Cardiac Tamponade.

Injuries to the heart resulting in cardiac tamponade can occur from either blunt or penetrating trauma, although penetrating injuries are much more common. The incidence of pericardial tamponade from blunt mechanisms is difficult to assess. Blunt cardiac injuries with tamponade can result from motor vehicle accidents, crush injuries, falls, construction injuries, and explosions. According to autopsy series, approximately 10% of motor vehicle accident fatalities show evidence of some cardiac damage, and 5% of deaths are from cardiac injuries, but patients presenting alive with tamponade from blunt injury are rare.

Pericardial tamponade occurs after blunt trauma from rupture of a chamber of the heart.

This occurs with a severe blow to the chest at the moment when the heart is at end-diastole and maximally distended with blood. The part of the heart most likely to rupture in this scenario is the portion with the thinnest, least muscular wall, usually the right atrial appendage. Rupture of other chambers and disruption of the inferior vena cava from the right atrium also can occur, but these lesions are usually associated with death at the scene. A small atrial injury may allow the patient to survive to be transported to the hospital.

Penetrating trauma is the usual cause of pericardial tamponade, and the outcome is directly related to the character of the weapon. High-velocity, large-caliber weapons or shotguns are predictably lethal. Large stab wounds with free chamber perforation larger than 2 cm are also frequently fatal. Smaller stab wounds and iatrogenic cardiac injuries from central venous catheterization or percutaneous transcoronary angioplasty are more likely to have a good outcome (239).

The diagnosis of pericardial tamponade should be considered in any patient with penetrating chest trauma, particularly to the central portion of the chest. Tamponade also should be considered in patients with severe blunt chest trauma who remain hypotensive and have no evidence of external blood loss or hemorrhage into the thorax, abdomen, or pelvis. The classic Beck's triad, consisting of muffled heart sounds, decreased pulse pressure, and jugular venous distention, occurs in a minority of patients. If the patient is hypovolemic, jugular venous distention may not develop until late in the presentation. Chest radiography may reveal a pneumothorax or hemothorax, or be entirely negative. The pericardium is not acutely distensible, and an enlarged cardiac silhouette is not reliably seen in acute tamponade.

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Two-dimensional echocardiography is highly sensitive for the presence of pericardial fluid and wall motion abnormalities. If available in a timely fashion, echocardiography is the best diagnostic study to rule out tamponade in the stable patient. Placement of a central venous catheter to measure central venous pressure has been advocated as a diagnostic test in the hemodynamically stable patient. A very high central venous pressure (>20 to 25 cm $H_2O$) is probably diagnostic, although elevations of this magnitude are usually associated with visible venous distention. Moderately elevated pressures, in the range of 14 to 16 cm $H_2O$, require further evaluation. Measurements of central venous pressure are neither sensitive nor specific for the diagnosis of pericardial tamponade, and they depend on the patient's volume status and level of agitation. Such tests may be of value, but they must be interpreted with extreme care. Under most circumstances, there is little role for diagnostic pericardiocentesis.

In hemodynamically stable patients with high likelihood of cardiac tamponade, the preferred approach is to perform a subxiphoid pericardial window incision with the patient under general anesthesia, unless echocardiography is immediately available in the resuscitation area or operating room. An extraperitoneal approach is made through a midline incision, or a transperitoneal approach is used at the time of concurrent laparotomy. The xiphoid is retracted superiorly or resected, and an incision is made through the diaphragm into the pericardium. This test is highly accurate for the presence of blood in the pericardial sac, and it allows for decompression of the tamponade. Decompression of tamponade through a subxiphoid window may result in significant hemorrhage that cannot be well controlled. Necessary preparations for immediate median sternotomy must be made before a window incision is performed.

Patients with hemodynamic instability and a penetrating wound in the left chest or parasternal region should undergo immediate left anterolateral thoracotomy with a wide, longitudinal opening of the pericardium. Cardiac lacerations should be digitally controlled until adequate blood volume is restored and the patient is relatively stable. The use of staples also has been advocated to close cardiac lacerations rapidly but temporarily for immediate hemostasis. Small lacerations in the beating heart can be then repaired using nonabsorbable sutures placed through Teflon pledgets. Larger lacerations may require cardiopulmonary bypass for adequate decompression and repair. The left thoracotomy incision can be carried transversely across the sternum into the right chest to facilitate exposure of the entire heart and great vessels if necessary.

Reported survival rates for small injuries to a single chamber are between 60% and 87%, although patients who arrive moribund do poorly regardless of care. The postpericardiotomy syndrome occurs commonly after repair of traumatic cardiac injury. It can occur in mild form in up to half of patients. The more severe form includes pericarditis with fever, malaise, and a friction rub. Pericarditis is usually treated with nonsteroidal antiinflammatory drugs. Symptomatic pericardial effusions should be treated with percutaneous drainage. Recurrent symptomatic pericardial effusions may require complete anterior pericardiectomy.

### Esophageal Injury.

Injury to the thoracic esophagus from external force or compression is a rare event and occurs in fewer than 0.01% of patients who sustain multiple blunt injuries (240). If it does occur, the site of blunt rupture is most often in the distal third of the esophagus, just above the gastroesophageal junction. This injury probably results from an abrupt increase in intraabdominal pressure while the glottis is closed during impact. The resultant rapid rise in pressure causes rupture at the weakest point of the esophagus, similar to that seen in Boerhaave's syndrome. Penetrating trauma to the thoracic esophagus is also uncommon and is usually associated with injuries to the adjacent structures. Symptoms include chest pain and dysphagia, and a Hamman crunch may be noted on auscultation of the mediastinum. A nasogastric tube should be carefully passed for gastric decompression and may return blood. Late findings with missed Esophageal rupture include subcutaneous emphysema, fever, and shock. The chest film may reveal air in the retroesophageal space, pneumomediastinum, pneumothorax, or left pleural effusion, but it also may be negative.

Esophagography should be performed in every patient with suspected esophageal injury. This is best begun with water-soluble contrast rather than barium because of the problems associated with barium contamination of the mediastinum (Fig. 11-41). Patients who are conscious and alert can swallow the contrast material under fluoroscopy. In unconscious and intubated patients, a nasogastric tube is carefully placed into the proximal esophagus, and 30 to 50 mL of water-soluble contrast medium is injected with sufficient pressure to distend the esophagus. If the initial study is negative, a barium study is then performed.

***Figure 11.41.*** Water-soluble contrast esophagogram demonstrating leak from the esophagus into the pericardial sac consistent with a distal esophageal injury.

Esophagoscopy is also of value in the diagnostic work-up. Both flexible and rigid techniques have been advocated, and the choice is probably best made based on operator experience. Visualization of an esophageal laceration is diagnostic, but a negative esophagoscopy must be accompanied by a contrast study of the esophagus to achieve sufficient diagnostic certainty. Esophagoscopy should be used to follow up suspect or technically imperfect contrast studies

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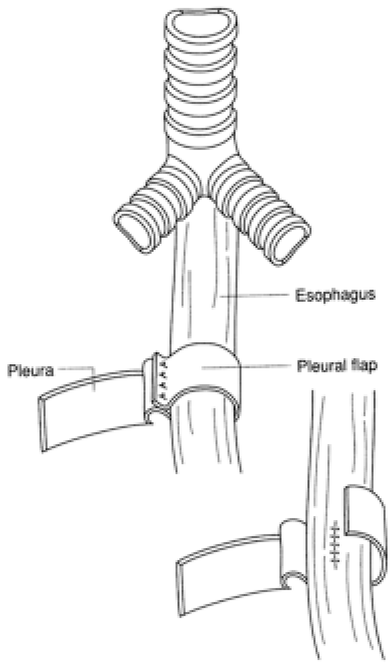
and as a security measure in patients with a high likelihood of esophageal injury. If an esophageal injury is identified, immediate exploration is undertaken.

The surgical approach is dictated by the location of the injury. Cervical esophageal lesions can usually be approached through a collar incision, repaired primarily, and drained widely. This topic is covered more fully in the section on neck injuries. Most injuries of the proximal thoracic esophagus can be approached through a right posterolateral thoracotomy. Injuries near the diaphragmatic hiatus may be more accessible through a left posterolateral thoracotomy. If the diagnosis is made rapidly, most lacerations of the esophagus can be repaired primarily and the mediastinum drained widely. Reinforcement of the repair with a pleural flap or other tissue is recommended for complex injuries (Fig. 11-42). If an adequate pleural flap cannot be obtained, an intercostal muscle pedicle flap can be used to buttress the esophageal repair in a similar fashion. Esophageal injuries at the diaphragmatic hiatus may be repaired primarily and reinforced with a circumferential (Nissen) or partial (Thal) fundoplication.

***Figure 11.42.*** Pleural patch reinforcement of primary closure of the esophagus after penetrating injury.




If the diagnosis of esophageal injury has been delayed, simple repair usually is not feasible because of established mediastinitis. In cases of severe mediastinal contamination, repair of the injury, wide mediastinal drainage, and esophageal exclusion with cervical esophagostomy and temporary closure of the gastroesophageal junction is recommended. A proximal gastrostomy is performed for decompression, and a feeding jejunostomy is performed for nutritional support (Fig. 11-43). Such an approach often allows primary healing of the esophageal injury, avoiding later reconstruction (241). In cases of extensive injury, late reconstruction is required and may be complex (see Chapter 20) (242).

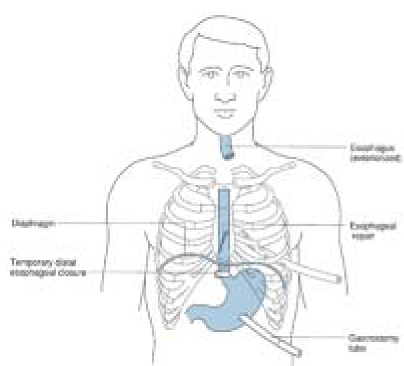


***Figure 11.43.*** Esophageal exclusion including transection and proximal esophagostomy with temporary closure of the distal esophagus to prevent reflux and ongoing leak.