Emergency Chest Imaging


This article presents the anatomy of the chest, heart, and upper airway and describes types of traumatic pathology and injuries of the chest. Chest imaging in a variety of settings is described. Radiography, computed tomography, and ultrasonography are discussed, along with the benefits and limitations of each modality. Finally, promising technological developments that could aid chest imaging in emergent situations are reviewed.

After completing this article, the reader should be able to:
- Identify the anatomy of the chest, heart, and upper airway.
- Describe the types of traumatic skeletal and soft tissue injuries of the chest.
- Explain methods and best practices for imaging chest injuries and producing high-quality radiographs in these situations.
- Explain the role of other imaging modalities, including computed tomography and ultrasonography.

In the United States, trauma is the leading cause of death for people younger than 45 and is ranked fourth overall among causes of death.1 Specifically, chest or thoracic trauma ranks third overall as the most common type of trauma and has a high morbidity and mortality rate.2 Nearly 25% of trauma-related deaths are associated with chest trauma; only head trauma is associated with more deaths.2 The most common mechanism of injury for patients with chest trauma is motor vehicle crashes (MVCs), which account for nearly two-thirds of cases.1

Chest trauma is classified into 2 categories: blunt trauma and penetrating trauma. Blunt chest trauma accounts for about 90% of chest trauma injuries; penetrating injuries account for the remaining 10%. The most common mechanism of injury for penetrating chest trauma are gunshot wounds, stab wounds, or injuries associated with violence and war.1 Other than MVCs, the most likely reasons for blunt chest trauma are falls from height and blows from blunt objects.2 In 2013, the Healthcare Cost and Utilization Project published a report based on the causes of injuries treated by U.S. emergency departments in 2010.3 According to the report, the cost of patients who sought care in the emergency department and were admitted was $5.1 billion for injuries sustained as a result of MVCs. Overall, MVC-related injuries accounted for 12.5% of emergency department visits, only behind injuries related to falls (35.7%) and being struck by an object (18.3%).3

Imaging is important in diagnosis, treatment planning, and continuing care for patients with chest trauma. Although radiography, computed tomography (CT), and ultrasonography (US) have become common diagnostic tools for emergency department patients, trauma situations can make imaging difficult.

Chest, Lungs, and Airway Skeletal Anatomy

The main organs located in the chest play an important role in the circulatory and respiratory systems. These
vital organs are protected by the bony thorax, a skeletal structure of bones and cartilage encircling the heart and lungs. The posterior bony thorax is supported by the 12 thoracic vertebrae, which serve as an attachment point for the 12 right and left rib pairs. Anteriorly, the rib pairs attach to the sternum via costal cartilage, providing structure and support for the heart, great vessels, and other mediastinal anatomy. Detailed anatomy of the bony thorax is shown in Figure 1. The skeletal anatomy of the bony thorax and the clavicles help protect the vital anatomy located in the chest and mediastinum.

Ribs

The ribs are divided into 2 groups: true ribs and false ribs. Each true rib attaches directly to the sternum via its own cartilage. The remaining ribs are termed false ribs because they lack direct attachment to the sternum. The costal cartilage of false ribs joins to form the connection to the sternum. The true ribs are right and left rib pairs 1 through 7; the false ribs are right and left rib pairs 8 through 12. False ribs 11 and 12 are known as floating ribs because they have no attachment to the anterior bony thorax and no costal cartilage.

In addition, some people have a cervical rib, a lumbar rib, or both. Cervical ribs articulate with the C7 vertebra and typically do not attach to the sternum. They might be free or either articulated or fused with the first rib. Less common are lumbar ribs, which sometimes are misread as a fractured transverse process of the L1 vertebra.

Sternum

The sternum is one of the most difficult bony structures to image successfully because of the variety of dense skeletal and soft-tissue structures that could project in the way of the sternum. The sternum lies directly anterior to the heart, typically in line with the midsagittal plane. This placement causes the soft-tissue structures of the mediastinum and the thoracic vertebrae to be superimposed over the sternum in the true antero-posterior (AP) or posteroanterior (PA) projection.

The sternum is a flat bone made up of 3 sections and is approximately 6 inches long. The sections of the sternum are the manubrium, body, and xiphoid tip or process. The body of the sternum is typically approximately 4 inches long and projects inferiorly from the manubrium. The distal portion of the sternum’s body attaches to the xiphoid process at the xiphosternal joint. The lateral portions of the sternum include facets that provide an attachment point for the costal cartilage of the ribs.

Clavicles

The clavicles are part of the shoulder girdle and are the only bony attachment between the upper extremity and the trunk at the sternoclavicular joint. The clavicles are long bones that extend laterally from the manubrium. They consist of the central body of the clavicle, the sternal end, and the acromial end. Typically, men’s clavicles are longer and more curved than women’s clavicles.

Thoracic Vertebrae

There are 12 thoracic vertebrae, numbered from superior to inferior. The size of the thoracic vertebrae increases from top to bottom, with the 12th thoracic vertebra...
Anatomy of the Lungs and Respiratory System

The respiratory system delivers oxygen to the bloodstream. Disruption of its ability to function is an acute medical emergency. The system’s main sections are the pharynx, larynx, trachea, bronchi, and lungs. Air enters the nose or mouth and is transferred to the lungs for delivery of oxygen to the blood cells. This is accomplished through downward movement of the diaphragm. The diaphragm is a dome-shaped muscle that is separated into right and left hemi-diaphragms. As the diaphragm moves downward, the volume of the thoracic cavity increases, which causes a decrease in intrathoracic pressure. This change causes a negative pressure effect, which draws air into the lungs via the mouth or nose, through the pharynx, larynx, trachea, and bronchi. The lungs and pleura are shown in Figure 3.

Pharynx

The pharynx is the most superior structure of the respiratory system and functions as a part of the respiratory and digestive systems by acting as a passageway for both food and air. It lies posterior to the mouth and nose, is typically about 5 inches long, and is separated into 3 sections: nasal, oral, and laryngeal. The nasopharynx is the most superior portion and communicates directly with the nasal cavity. The uvula is suspended from the posterior soft palate and lies between the nasopharynx and oropharynx. The oropharynx communicates with the oral cavity and extends approximately to the end of the hyoid bone. Below the oropharynx is the laryngopharynx, which communicates with the larynx and attaches directly to the esophagus.

Larynx

The larynx is commonly known as the “voice box” and is the passageway between the pharynx and trachea. It is suspended from the hyoid bone below the base of the tongue and extends to the trachea. Superiorly, the epiglottis sits between the pharynx and larynx and acts as a cover during swallowing, blocking food or drink from entering the trachea. The main structure of the larynx is made up of groups of cartilage connected by ligaments and muscles that allow movement and assist in the ability to speak and make sounds. The anterior wall of the larynx includes the largest
of these cartilages, the thyroid cartilage. The laryngeal prominence, or “Adam’s apple,” is the most prominent part of the thyroid cartilage and is easily seen and palpated near the level of the fifth cervical vertebra. Below the thyroid cartilage sits the cricoid cartilage, which forms the junction between the larynx and trachea by attaching to the trachea’s first cartilaginous ring.

Trachea, Bronchi, and Lungs

The trachea is a tube of cartilaginous rings extending from the larynx to its division into the right and left primary bronchi at the carina. The superior portion of the trachea corresponds to approximately the level of the C6 vertebra, and the carina sits at approximately the level of the T4 or T5 vertebra. In an average adult, the total length of the trachea is about 4.5 inches, with a diameter of approximately 0.5 inches.

The right and left primary mainstem bronchi branch from the trachea at the carina and form passageways into the right and left lungs. The left primary bronchus has a smaller diameter, is much longer, and sits more horizontally than the right primary bronchus. Because of its increased width and vertical position, the right primary bronchus is more likely to be where food or other foreign bodies become lodged, blocking the passage of air into the right lung.

The lungs are the main organs of respiration and are made up of a spongy material called the parenchyma. The superior portion of the lungs is the apex, which reaches a level just above the clavicles. The wide and concave inferior portion of the lungs is the base, sitting on each hemi-diaphragm. On the right side of the chest, the right lung and hemi-diaphragm sit over the liver, causing the base of the right lung to sit higher than the left lung. In addition, the 3-lobed right lung is about 1 inch shorter than the 2-lobed left lung.

The right lung is divided into 3 lobes by the inferior fissure and the oblique fissure. The left lung has a single fissure separating the 2 lobes; this is termed the deep oblique fissure. The highly elastic parenchyma allows the lungs to expand and contract, making respiration possible. The expansion pulls air into the lungs. Contraction expels waste products of respiration, including carbon dioxide, from the body. The lung tissues are contained within a 2-layer membrane; the inner pulmonary pleura covers the lungs, and the outer parietal pleura lines the walls of the chest and diaphragm. Between the layers is the pleural cavity, which acts as a lubricant for movement of the lungs during respiration.

The area where the bronchi and pulmonary vessels enter and exit the lungs is known as the hilum. The left hilum typically appears higher than the right hilum on a chest radiograph because the left pulmonary artery passes over the left primary bronchus. This fact proves helpful for diagnosis of some acute injuries of the chest.

Heart and Great Vessels

The central portion of the chest between the right and left lungs is called the mediastinum. This area includes the heart and great vessels, trachea, esophagus, and thymus gland. It is bordered anteriorly by the sternum and posteriorly by the vertebrae.

Within the mediastinum the heart sits at approximately the level of the fifth through the eighth thoracic vertebrae. Like the lungs, the heart also sits within a double-walled support structure, named the pericardial sac. The tissue of the heart is a specialized muscle type called myocardium. The heart is made up of 4 chambers lined with endocardium, a specialized skin cell. The chambers on the right side of the heart are the right atrium and right ventricle, which are separated by the tricuspid valve. The left side also has an atrium and a ventricle, which are separated by the bicuspid valve. The atria receive blood from the body; the ventricles pump oxygenated blood out to the body. The right and left sides of the heart are separated by the interatrial septum and the interventricular septum.

The great vessels that sit in the mediastinum are the superior vena cava, the inferior vena cava, pulmonary veins, pulmonary arteries, and the aorta. Blood enters the heart to become oxygenated through the vena cava. The superior vena cava delivers deoxygenated blood from the upper extremities, chest, and head; the inferior vena cava delivers blood from the abdomen and legs. The blood is pumped into the lungs by the right ventricle through the pulmonary arteries to become oxygenated. The pulmonary veins then deliver the oxygenated blood back into the heart through the left atrium. Next, the oxygenated blood is delivered to the
patient has been assigned an AIS rank of 6, the ISS automatically is ranked as 75. However, for less severe injuries, programs that calculate the overall ISS are available. A linear correlation exists between a patient’s ISS and his or her mortality, morbidity, and length of hospital stay. The ISS is the outcome of a complex system, and an incorrect AIS rank affects the accuracy of its results.

**Imaging Chest Trauma**

Multiple injuries can be sustained when a blunt or penetrating force impacts the chest. Traumatic injury to the bony thorax, upper airway, respiratory system, and heart could be life threatening. Therefore, when chest trauma occurs, quick diagnosis and treatment is vital and a delay can increase morbidity and mortality.

A whole-body CT scan consists of multiplanar imaging of the head, neck, chest, abdomen, and pelvis and is an established diagnostic tool in emergency medicine. Increases in availability, improvements in speed, and advancements in dose reduction have made the use of whole-body CT an option in many trauma situations.

An observational study in California examined patients with blunt multisystem trauma who met certain criteria. The criteria included no visible evidence of chest or abdomen trauma, no unstable bleeding, and significant injury resulting from an MVC, fall from more than 15 feet, pedestrian hit by a vehicle, or assault victims with change in mental status. Patients meeting these criteria had whole-body CT scans, and treatment changes as a direct result of the CT scan diagnoses were documented. The study found clinically significant abnormalities in 20% of cases, and 18.9% of patients had their treatment plans changed based solely on the results of the whole-body CT scan. Abnormalities found included undiagnosed rib fractures, hemothorax/pneumothorax, lung contusion, and aortic injuries. The treatment changes for patients with previously undiagnosed abnormalities included admission for serial examination, further evaluation
Box 1

Organ-specific Options for Injury Severity Scoring

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including angiography, and immediate surgical intervention. An additional finding was that patients who did not have an abnormal finding were discharged from the emergency department more quickly, limiting the use of costly hospital resources and unnecessary medical care.18

Although a chest radiograph is part of every trauma protocol and can provide valuable information, when patients have major trauma and are severely injured, whole-body CT scanning can be an efficient and effective way to diagnose injuries. Radiography, CT, and other modalities might be used alone or together, depending on the patient and his or her suspected injuries.

**Traumatic Injury of the Chest**

Given the high rate of emergency department admissions related to MVCs, the trauma sustained from automobile collisions is widely studied.4,8-12,15,19,20 For example, Yoganandan et al reviewed data regarding more than 500,000 individuals involved in MVCs that occurred between 2009 and 2012.15 From the sample, 17,718 people had a maximum AIS ranking of 2 or higher (MAIS2+), and 4,387 had injuries ranked 3 or higher (MAIS3+). Of those who had MAIS2+ level injuries, 51% of the injuries sustained involved the head and 19% involved the thorax. For individuals who had MAIS3+ level injuries, 50% involved the head and 69% involved the thorax. The research demonstrated that injury severity increased with increased factors such as velocity, age, and physique or size. In addition, Yoganandan suggested that thorax injuries are underscored in older versions of the AIS system.15 For example, in the 1990 version, a combined code is provided for individuals who have fractured ribs and pneumothorax, but the 2005 version codes the 2 injuries separately. The latest version of AIS also gives an individual with 3 or more ipsilateral fractured ribs an AIS ranking of 3, but to be ranked a 3 under the 1990 system, more than 3 ribs must be broken or any of the fractures must be open, displaced, splintered, or crushed into numerous pieces.15

**Impalement**

Impalement of the thorax is rare and causes serious injury.21-24 Managing impalement injuries to provide the best chance of survival includes these basic concepts21-24:

- Leave the object in until it can be removed by a medical team, usually in the surgical environment. It might be acceptable to cut the object’s protruding ends, if it can be done safely.
- Transport as quickly as possible to a medical facility capable of handling the injuries; delays in medical treatment can have a detrimental impact on the outcome.
- Follow trauma protocols for hemodynamic and airway maintenance, even if the patient is alert and hemodynamically stable.
- Clean and irrigate the wound thoroughly after the object is removed to avoid infection. Many facilities treat patients prophylactically with broad-spectrum antibiotics because of the high risk of infection.

Impalement by rebar and other construction material is a recurring theme in the literature. Yokosuka et al reported on a 78-year-old man who fell 3 stories and became impaled on 2 reinforcement rods. After being transported to the emergency medical facility, a whole-body CT was performed to assess the extent of the internal damage. One rod had entered the right upper lobe of the lung, and the CT scan revealed an intra-pulmonary hemorrhage and significant subcutaneous emphysema, without evidence of hemopneumothorax. The other rod entered the patient’s left side but did not demonstrate evidence of injury to the subclavian vessels or penetration of the thoracic cavity. A chest radiograph revealed that the internal injuries on the right side were progressing, and the medical team decided to remove the rods. The patient received antibiotics and a tetanus shot as part of the postsurgical treatment and was discharged 10 days after the surgery.

Gyanendra et al reported on a 10-year-old in Nepal who fell and become impaled on a bamboo stake. The stake entered the left lower abdomen and exited the posterior triangle to the neck. The stake was not removed but was uprooted by individuals on the scene and the child was transported to an emergency medical center more than 3 hours away. The patient was stable and alert upon arrival, and chest and abdomen radiographs revealed a nail in the upper left abdomen but no evidence of hem-thorax or pneumothorax (see Figure 5). A CT scan revealed the extent of the child’s injuries (see Figure 6). The stake penetrated the body of the stomach and the diaphragm. The left lower lobe of the lung was transected, and a laceration was present in the left upper lobe. Aside from contamination with gastrointestinal contents, the mediastinum was relatively untouched, and none of the greater vessels were damaged. The stake was removed, and a lobectomy was performed on the left lower lobe. The patient received antibiotics, a tetanus shot, and a psychiatric evaluation that determined the child was not suffering from post-traumatic stress disorder. After 21 days, the child was discharged and follow-up did not reveal any neurological or functional deficits.

Literature about traumatic impalement as a result of an MVC is scarce. Nevertheless, there are reports...
of people becoming impaled during a crash.\textsuperscript{26-30} The potential for impalement from objects that become projectiles during a crash is low.\textsuperscript{26-30} Not all instances mentioned here resulted in injury or death, but the danger of impalement is a possibility during an MVC, and technologists might encounter these patients.\textsuperscript{27,28,30}

According to the National Highway Traffic Safety Administration, road debris has caused more than 50,000 crashes, with much of that debris coming from items not properly secured with straps or a tarp for transportation.\textsuperscript{27} In 2012, a logging truck traveled across a median, and a log penetrated the windshield of a minivan. The occupants’ injuries were not life-threatening.\textsuperscript{27} In another incident, a wooden plank was propelled through the windshield of a car after a truck drove over the plank in the road.\textsuperscript{27}

Incidents like these also can be caused by carelessness with equipment as one couple discovered when an axe penetrated their windshield, nearly impaling the passenger.\textsuperscript{29} After entering the passenger side of the vehicle, the axe became impaled in the dashboard. The driver of a landscaping truck had failed to secure the axe, leaving it on the hood of the truck. No one was injured.\textsuperscript{29}

Impalement injuries caused by MVCs can be life-threatening or fatal.\textsuperscript{26-29} In the spring of 2014, a driver was impaled by what was mostly likely an 11-pound leaf spring that had come off of a semi-truck.\textsuperscript{26} The metal object entered the individual’s cheek and exited the posterior aspect of the skull, severing the ear from the ear canal. The individual survived.\textsuperscript{26}

Lunca et al reported a passenger in the rear seat of a car that collided with a cart carrying logs.\textsuperscript{29} The passenger’s right thorax was impaled by a log. The log was cut to allow for transport, but the medical facility was ill-equipped to treat the serious nature of the injuries. The patient was transferred to another facility and arrived there 2 hours after the injury. At that facility, it was decided the patient should be transferred to a university medical hospital, and the patient arrived there 7 hours after the injury. The patient was hemodynamically stable but cyanotic with edema of the right arm and right hemi-face.\textsuperscript{23}

In this case, diagnostic imaging was not performed before the patient received a large thoracotomy.\textsuperscript{23} The log was removed, although several smaller branches made the removal difficult. Surgeons discovered that the log had caused an incomplete rupture of the right bronchus. The right subclavian artery was partially ruptured, and the patient suffered extensive pulmonary and chest wall damage. The patient developed bronchopneumonia during hospitalization, was treated with a broad-spectrum antibiotic, and was discharged 40 days after surgery.\textsuperscript{23}

In another incident, an individual was pronounced dead at the scene after being impaled in the upper thorax and head areas by a 3-foot long ‘comealong,’ a tool used by truck drivers to tighten straps on the loads they haul. It could not be determined whether the tool came off of a semi-truck directly in front of the vehicle, or if it was road debris.\textsuperscript{29}

**General Blunt Thoracic Trauma**

Blunt trauma to the thorax can cause damage to bony structures, pulmonary injuries, and life-threatening damage to the great vessels.\textsuperscript{31} In the United States, 25% of all deaths associated with falling can be attributed to blunt thoracic trauma.\textsuperscript{11} Rib fractures are indicative of serious thoracic injury,\textsuperscript{31} and blunt trauma to the thorax also can result in partial or complete transection of the great vessels. Eighty-four percent of vascular injuries in blunt thoracic trauma affect the thoracic aorta.\textsuperscript{32}

Liodakis et al reported the case of a patient who was admitted for chest pain following an MVC.\textsuperscript{23} Although the patient was stable and alert for the first 2 hours following the crash, there was gross damage to the mediastinum. A focused assessment with sonography for trauma (FAST) scan was performed on the patient, which did not reveal any intraperitoneal fluid. The radiographic examinations performed demonstrated pectus excavatum combined with multiple rib fractures and a pelvic fracture. The patient became unstable approximately 2 hours after the crash, and pericardiocentesis was performed to stabilize the patient. In surgery, a 1-cm laceration to the left atrium and right ventricle was discovered and repaired.\textsuperscript{33}

**Skeletal Injuries**

Skeletal injuries to the bony thorax can occur after both major and minor trauma and often signal injuries to underlying soft-tissue structures of the mediastinum.
Rib Fractures

When rib fractures occur as a result of blunt force trauma, they can be both a cause and a sign of significant injury. The diagnostic rib series is a common examination performed in most radiography departments. The rib series uses lower kVp than routine chest radiography to reduce the energy of the x-ray beam and, along with closer collimation, produce higher resolution and contrast of the bony structures of the chest. In certain radiology departments, the radiologist might request that the technologist place radiopaque ball-bearing markers over the area of injury. The typical examination requires that the patient be positioned with the injured side nearest to the image receptor (either AP or PA).

Most patients require multiple images to capture all of the ribs. Separate upper and lower rib projections are common. For the lower rib projection, the patient should be recumbent and the exposure should be taken on full expiration to allow the diaphragm to reach its highest position and flatten out the abdomen, causing less soft tissue to be superimposed over the lower ribs. For upper rib projections, the patient should be erect or in a seated position so that gravity helps to lower the diaphragm, increase respiratory inflation (on full inspiration), and project ribs 1 through 10 above the diaphragm. Oblique projections typically are required to view the axillary portion of the ribs. When the injury is anterior, the projection used is an anterior oblique with the injured side facing up. For injuries to the posterior ribs, a posterior oblique projection is taken with the injured side facing down.

For many patients with minor trauma, these routine positions are possible; however, because of pain after trauma, some technologists might prefer not to switch between erect and recumbent positions for the upper and lower rib projections to limit the amount of movement required by the patient. In more serious trauma cases, it might not be possible to take these routine rib projections, and alternate methods can be used to image the ribs successfully.

For severe trauma in which the patient must remain supine, a common method for imaging the ribs in an oblique plane is to angle the x-ray tube instead of the patient. With the patient positioned supine on the examination table, the tube should be angled 45° mediolaterally. In this situation, it is necessary to angle the beam mediolaterally for both anterior and posterior rib injuries to prevent the spine from being superimposed over the ribs.

A rib series is not a common examination for patients with severe chest trauma and typically is performed after other diagnostic tests or stabilization. Most trauma patients have a chest radiograph taken with a portable unit, which might show rib fractures or dislocation. However, the sensitivity of this examination for detecting rib fractures ranges from 15% to 50%. Because of this low sensitivity and the high risk of mortality and morbidity associated with blunt chest trauma, CT imaging of the chest has become the preferred method for diagnosing skeletal injury after chest trauma (see Figure 7).

When a fracture of the first rib is diagnosed in a patient with blunt force chest trauma, the injury often is associated with complications. Because the first rib is well protected by the clavicle and surrounding soft tissues, it is the least-fractured skeletal structure of the chest. Thus, a high amount of force is necessary to cause fracture. When these fractures are diagnosed, the attending physician should suspect injuries to surrounding structures, including the lungs, cervical spine, thoracic spine, heart, and great vessels. Specific life-threatening injuries associated with first-rib fractures...
are deep vessel thrombosis, great vessel aneurysm, fistula between the bronchi and trachea, and thoracic outlet syndrome. Because of these complications and the potential for life-threatening injury, the advanced trauma life support system lists fracture of the first rib as the second most likely radiological sign of severe injury to large blood vessels of the chest.

Despite best efforts, in trauma situations, up to 50% of rib fractures might be missed with a traditional radiographic series. Studies have found that US might be more accurate for diagnosing rib or costal cartilage fractures and might limit the number of missed diagnoses. A 2010 study used US to image 20 patients with negative rib radiographs but continued symptoms. Eighteen of the 20 patients had a positive sonographic examination and diagnosis of rib or costal cartilage fracture. One reason US might have an advantage for diagnosing rib fractures is that costal cartilage injuries cannot be seen accurately on radiographs unless the cartilage is highly calcified. Although studies have reported that this might be a useful method for diagnosing rib fracture, the current American College of Radiology Appropriateness Criteria do not recommend US as the imaging method of choice. However, with increased training and use of bedside ultrasound equipment by emergency department physicians, this modality might be used more in the future for diagnosing these fractures.

Flail Chest

Flail chest is a special situation associated with 3 or more consecutive rib fractures in 2 or more locations. When consecutive ribs lose their structural integrity, the chest wall might become unstable. This can result in the patient’s inability to ventilate fully and increased probability that the lung will collapse (atelectasis). Because of the associated pain and severity of flail chest injury, chest radiography might be difficult for the technologist to perform. A portable examination in a semierect position with an AP projection typically is performed. However, this initial radiograph might not be of sufficient quality to diagnose flail chest and could fail to show some or all of the rib fractures and associated injuries. A CT scan is the best method to get quick and accurate diagnostic images of patients who have suspected flail chest. With multiplanar CT images, radiologists can identify the number and location of rib fractures and locate potential hemothorax, pneumothorax, or other pulmonary injuries. In addition, using CT imaging, radiologists can diagnose fractures of the costal cartilage. This would be impossible with traditional radiography.

In most situations, patients with flail chest can be treated successfully by maintaining respiratory function and oxygen saturation. Severe flail chest might require mechanical ventilation or use of continuous positive airway pressure (CPAP) to maintain adequate respiration.

Sternal Fracture

Another skeletal injury associated with chest trauma is sternal fracture, which occurs in 3% to 8% of blunt chest injuries. In the past, this injury was considered to have a high level of morbidity because of its proximity to the mediastinum. Multiple studies showed mortality rates from 24% to 45% in cases when the sternal fracture was not an isolated injury. A major concern with sternal trauma is cardiac contusion and complications affecting the mediastinal vessels, nerves, trachea, and esophagus. Enactment of seat belt laws increased the incidence of sternal fractures, and subsequently many studies have examined sternal fracture management.

Common causes of direct sternal injury and fracture are deceleration injury or blunt chest trauma. Deceleration injury often is caused by MVCs. Other causes of direct sternal injury include impact sports, assaults, and car/pedestrian accidents. In the clinical setting, the location of the sternal fracture and the presence of associated injury can indicate whether the injury is life threatening or minor. When a sternal fracture is an isolated injury without dislocation, the patient typically can be treated with pain relief. However, when the sternal fracture causes complications or there are associated injuries, it can become life threatening.

The location of the sternal fracture can be used to determine the likelihood of an associated injury and its significance. A 2013 study by Scheyerer et al found correlations between sternal fracture locations and associated injuries. For example, patients with traumatic fracture of the manubrium had a high incidence of traumatic head injury. In addition, patients with fractures of
the manubrium had the highest prevalence of additional fractures of the ribs and vertebral column. Specifically, researchers found thoracic vertebral fractures in 61% of patients with fractures of the manubrium.44 One reason for the prevalence of associated spinal injuries is the amount of structure and stability the sternum and rib cage provide for the vertebral column. A study on cadavers in the 1990s found that the rib cage and sternum are crucial in stabilizing the thoracic vertebrae, providing 40% of the stability in flexion and extension, 22% in lateral bending, and 15% in rotation.45 The incidence of associated thoracic vertebral fractures decreases if the fracture of the sternum is below the manubrium, ranging from 36% for the superior sternal body to 9% for the inferior portion of the body of the sternum.46

Although sternal fractures as a result of seat belt use are rare, especially those of the manubrium, they can indicate underlying serious injuries.47 Schulz-Drost et al found that 79 out of 538 individuals who sustained trauma because of seat belts demonstrated sternal fracture, and only 10 of those were caused by seat belts.48 Careful evaluation for peristernal injuries is needed to exclude serious injury deep to the manubrium.49 Evidence suggests that CT imaging will better visualize fractures of the manubrium, which often are missed on chest radiographs.50

Many radiologic technologists have had difficulty successfully capturing the sternum in an AP or PA radiographic image. Injuries to the sternum are rare, and technologists do not perform these projections often. In fact, a 2006 article ranked sternum right anterior oblique projections as 233 out of 273 examinations likely to be performed by an entry-level technologist.51 In trauma situations in which the patient cannot move into the required position, this projection is even more challenging. Traditionally, a sternum series consists of a right anterior oblique projection and left lateral projection.52 In many trauma situations, patients cannot be turned prone for the right anterior oblique projection. In these cases, the patient remains supine on the table or stretcher, and the x-ray beam is angled 20° from the patient’s right to left.53 This results in an image similar to a left posterior oblique projection, which causes some size distortion because of magnification.

Because of the difficulty of radiographic imaging and the potential seriousness of the injury, CT often is the modality of choice for diagnosis or further characterization of sternal fracture (see Figure 8).3 When CT is used, the coronal and sagittal reformats are key to successful diagnosis of sternal fracture and associated injuries.5 Because of the prevalence of multiple injuries in patients with chest trauma and the potential for injuries associated with suspected sternal fracture, a whole-body CT scan might be performed. This can aid in diagnosing potential vertebral fractures and associated soft-tissue injuries of the thorax, airway, and abdomen. Recommended protocols for patients with chest trauma include the use of high scan speeds to limit respiration artifacts, high z-axis resolution for creating reformat images, and dose-saving software in consideration of the large scan area. The use of intravenous contrast material is important to diagnose injury to the vascular anatomy and active bleeding.5 Oral contrast usually is not necessary in acute trauma situations, but if rupture of the esophagus is suspected, a small amount of water-soluble oral contrast can be used.

Figure 8. CT scan showing a comminuted fracture of the sternum and retrosternal hematoma. Image courtesy of Monkhouse SJ, Kelly MD (modified by user Delldot on October 8, 2008) via Wikimedia Commons. Licensed under the Creative Commons Attribution 2.0 Generic license.
**Diagnosing Respiratory Injuries**

**Inhaled Foreign Bodies**

Another type of acute situation that can affect the chest is the inhalation of foreign bodies. Foreign bodies that become lodged in the airway can block the inhalation of air and endanger life; many of these patients die before reaching a hospital. Inhalation or aspiration of foreign bodies is most common in children and geriatric populations. A major decline in the incidence of foreign body inhalation occurs after age 12, but in patients older than 65 years, the incidence begins to increase and continues increasing with age. However, patients of any age can inhale foreign bodies, including teeth, during trauma or intubation. With any patient demographic, the foreign body typically is directly visualized and removed using rigid bronchoscopy.

In children, the highest risk of foreign body inhalation exists between 1 to 3 years, with a higher occurrence in boys. With pediatric patients, the most common signs of foreign body inhalation are cough, shortness of breath, wheezing, and reduced lung sounds. The most common type of foreign body aspirated is food, especially seeds and beans. The typical practice is for these patients to have a 2-projection chest radiograph with PA and left lateral projections.

In one study of pediatric patients suspected of foreign body aspiration, the most common radiographic findings were collapse of the associated lung (41.65%), negative findings (24.3%), and obstructive emphysema (20.5%). These clinical findings and patient history help in the diagnosis and removal of the foreign body. Definitive visualization of foreign bodies on radiographs is rare because of their resemblance to surrounding tissues and low subject contrast, with absolute visualization occurring in fewer than 3% of patient images.

Patients older than 65 present with different clinical symptoms of aspiration, and according to a study by Lin et al., only 29% of patients were able to supply a history of the aspiration. These patients typically have cough and sputum (88%), but they also have a wide range of other symptoms common to most respiratory pathology, including dyspnea, fever, and chest pain. For this patient group, a chest CT examination often is performed. Common findings on chest CT for inhaled foreign body are pneumonic patch (93%), high-density lesions in the airway (29%), identification of the foreign body (21%), and atelectasis (14%).

**Traumatic Lung Injury**

In trauma situations, the tissues of the lung can be damaged by blunt force, penetration, or injury caused by associated fractures. The most common lung injury caused by blunt trauma to the chest is pulmonary contusion. This bruising of the lung tissue causes damage to the capillaries in the alveoli and lung wall and blood leakage into the surrounding lung tissue. This injury occurs at the time of trauma and can be located at the injury site, or it can be a contrecoup injury caused by tissues bouncing off contralateral skeletal structures or fractures. Although patients typically undergo an initial chest radiograph in the emergency department, this injury might not be diagnosed on the initial radiograph, requiring repeat imaging after 6 to 24 hours to allow blood to pool and the radiographic pathology to become more recognizable. However, CT scanning can show evidence of pulmonary rupture without a delay for pooling of blood. Pulmonary contusion appears as ground-glass or nodular opacities that can cover multiple lung lobes. Pulmonary contusion can be life
Trauma-related Pneumothorax

Pneumothorax is the abnormal buildup of air in the pleural spaces surrounding the lungs. Chest trauma results in pneumothorax in up to 40% of cases and can be caused by rib fractures piercing the lung wall, penetrating injury, tracheobronchial injury, or a sudden increase in lung pressure caused by impact to the chest. An upright chest radiograph can show signs of pneumothorax, including increased lucency at the diaphragm and sharply defined borders of the heart or mediastinum (see Figure 10). In trauma situations, an upright projection might not be possible, and supine chest radiographs can miss subtle pneumothorax. CT is much more sensitive than radiography and is preferred for diagnosing pneumothorax in patients with chest trauma. It is important to diagnose even small pneumothoraces, because patients with chest trauma might require intubation, mechanical ventilation, or anesthesia, all of which can make a small pneumothorax larger and cause complications.

Tension pneumothorax is a serious condition in which the buildup of air outside of the lung causes the mediastinum to shift away from the affected side. This shift can cause the superior vena cava to be compressed, stopping the return of blood from the veins to the heart. A chest radiograph can show the shift of the mediastinum away from the pneumothorax and hyperinflation and increased lucency of the opposite lung (see Figure 11).

Hemothorax is similar to pneumothorax, except blood, not air, builds up in the pleural space. This occurs in up to 50% of chest trauma cases and progresses more quickly when arterial blood is involved. CT most often is used for diagnosing hemothorax. Fluid can be differentiated from tissue or air based on Hounsfield unit measurements. Blood has an attenuation of between 35 HU and 70 HU.

Lung Laceration

When the lung is penetrated, torn, or lacerated, the injury is classified into one of 4 types according to the mechanism of the injury. Type I, compression rupture injury, is the most common type and occurs when the lung is forced against the tracheobronchial tree. Type II, lung laceration, is another type of compression injury and occurs when the lower lobes of the lung are sheared against the spinal column. The injured tissue is...
Findings on chest radiography include rapid opacification of the affected lung, irregular position of the hilar structures, and a reticular pattern due to venous congestion. On CT images, the lobe in question can show poorly enhanced tissues with increased volume, ground-glass attenuation, and poor parenchymal enhancement after injection of radiopaque contrast media.

Lung herniation is another serious injury that can occur after chest trauma. It is a concern when the chest wall is compromised during trauma (e.g., multiple rib fractures) or if a pre-existing condition has weakened the chest wall. In these situations, the lung tissue pushes through the defect in the chest wall as a result of increased intrathoracic pressure caused by the trauma. Herniation of the lung is easily diagnosed with CT scanning, which can show the amount of herniated lung and the size and significance of the chest wall defect. After diagnosis, the patient might require surgery if symptoms persist. Surgery also might be necessary if the patient requires intubation, because mechanical ventilation can push more lung tissue through the chest wall.

Diaphragm Rupture

In approximately 5% of blunt injury chest trauma cases and 8% of abdominal trauma cases the diaphragm is ruptured. Diaphragmatic rupture occurs when the pressure between the abdomen and chest becomes too great on the fixed diaphragm or when the muscle is penetrated by an object such as a knife or bullet. Approximately 90% of cases are the result of MVCs, and the left side is affected about 3 times more than the right. The injury cannot heal on its own because of the continuous motion of the muscle and the pressure differences between the pleura and peritoneum. Because this injury is often the result of major trauma affecting multiple locations, CT is the diagnostic imaging standard. Helical scanning with multiplanar reformats compared with nonhelical scans has increased the sensitivity of CT for this diagnosis from 66% to 100%, with a specificity of nearly 100%. On CT scans, direct signs of diaphragm rupture include segmental diaphragm defect, which is the visualization of torn muscle, possible associated hemorrhage, and increased thickness due located against the spinal column and can be seen as a tubular structure near the spine on CT images. When a rib penetrates the periphery of the lung, it is a type III laceration and is commonly associated with pneumothorax. Type IV lung lacerations are associated with existing lung adhesions and appear as round cavities when the lung tissue next to the adhesion retracts. On a chest radiograph, a lung laceration might not be visible because a surrounding contusion usually is superimposed over it. CT scanning is more diagnostically successful than radiography for locating lung lacerations and determining the extent of the injury.

Lung Torsion and Herniation

Lung torsion is a rare but serious injury that can occur after chest trauma. This injury can affect the whole lung or specific lobes and is caused by lung tissue rotating around hilar structures, causing the airway and blood vessels to malfunction. Findings on chest radiography include rapid opacification of the affected lung, irregular position of the hilar structures, and a reticular pattern due to venous congestion. On CT images, the lobe in question can show poorly enhanced tissues with increased volume, ground-glass attenuation, and poor parenchymal enhancement after injection of radiopaque contrast media.

Figure 11. Tension pneumothorax with mediastinal shift. Image courtesy of Nevit Dilman via Wikimedia Commons. Licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license.
to muscle retraction. Another direct sign is the dangling diaphragm defect, seen when the image shows a curled free edge of the torn muscle. A final direct sign is absent diaphragm, which appears as either the entire hemi-diaphragm or part of it being absent from the image in areas where it should be seen. This is usually accompanied by visualization of herniation of abdominal organs through the diaphragm into the thorax.67

Secondary or indirect signs of diaphragm rupture include the67:

- Presence of peritoneal fat or abdominal structures in the pleura.
- "Collar" sign (constriction around the rupture).
- "Hump and band" sign, which appears as a hump of liver through a collar sign showing right hemi-diaphragm.
- "Dependent viscera" sign, which is seen as direct contact between abdominal organs and posterior lung.

Signs of diaphragmatic rupture also might appear on initial chest radiographs of patients with traumatic injury. For example, the diaphragm contour might be disrupted, which is typically a nonspecific finding. The finding of air from the gastrointestinal tract in the thorax also is likely to indicate rupture of the diaphragm. In addition, when one hemi-diaphragm appears more than 4 cm superior to the other hemi-diaphragm, rupture might be indicated.67

Traumatic Airway Injuries

Injury to the trachea or bronchi is uncommon and is associated with trauma to the chest in 1.5% to 8% of cases.1,2 One study suggested that this diagnosis might be more common, but 50% of patients suffering trachea-bronchial trauma die at the scene of injury because of lack of oxygen.2 Nearly 85% of tracheal lacerations occur within 2 cm of the carina at the cartilage-membranous junction.1 Initial imaging of patients with trauma can indicate signs of airway injury. Chest and cervical spine radiographs can generate diagnostic information for this injury and are a part of routine trauma protocols. On these images, 60% of patients with airway injury have cervical subcutaneous emphysema and free air in the mediastinum.44 Additional radiographic signs of traumatic airway injury include overinflation of the endotracheal tube balloon, or displacement of the endotracheal tube when patients are intubated.44

For definitive diagnosis, CT is the imaging modality of choice. On CT scans, airway laceration and separation of the tracheal and bronchial wall can sometimes be detected.2 Other signs of this injury include pneumothorax on the ipsilateral side of injury, persistent pneumothorax after chest tube placement, and subcutaneous emphysema in the neck.44 Figure 12 shows multiple CT images used to diagnose a bronchial rupture and right-sided lung laceration.

Diagnosing Traumatic Cardiovascular Injury

Cardiac injury is the second most likely reason for death in patients with trauma in the United States.70 The main types of injury causing cardiac trauma are direct impact to the chest, abdominal trauma, penetration, and hydraulic effect. When direct impact occurs with the chest wall, the soft tissues of the heart and mediastinum are compressed between the rigid skeletal structures of the thorax, the sternum, and the thoracic vertebrae. The heart also can be compressed during trauma to the abdomen and lower extremities.

Figure 12. CT images after chest trauma. A. Bilateral pneumothorax, pneumomediastinum, and subcutaneous emphysema. B. Multiple lucencies around the right bronchial tree depicting bronchial rupture (arrow). C. The Macklin effect around the right lower pulmonary vein (arrow). D. Coronal view demonstrating lung lacerations on the right side (arrows). Image courtesy of M Le Guen, C Beigelman, B Bouhemad, Y Wenjie, F Marmion. via Wikimedia Commons. Licensed under the Creative Commons Attribution 2.0 Generic license.
In these cases, the abdominal structures might be forced upward, crushing the mediastinum and potentially damaging the heart. The hydraulic effect occurs when trauma causes blood returning to the heart to travel in high-pressure waves, which can damage the heart muscle and valves.\textsuperscript{70}

CT is the imaging modality of choice for evaluating thoracic trauma and cardiac injury. Hemopericardium, the buildup of blood within the pericardial sac, can be seen on CT images and can indicate cardiac rupture.\textsuperscript{70} The source of the blood can be identified by visualization of extravasated contrast material from one of the heart’s chambers. Cardiac tamponade occurs when blood, pus, or gas builds up in the pericardial sac, compressing the heart. This can be seen as a flattening of the heart segments on CT scans.\textsuperscript{7} Other CT findings suggestive of cardiac tamponade include high attenuation pericardial effusion and distension of the inferior vena cava.\textsuperscript{70} Figure 13 shows pericardial effusion.

Patients with penetrating injuries to the heart seldom arrive at the hospital alive; of those who do not die before arriving at the hospital, only 50% are treated successfully and survive.\textsuperscript{79} Of those who arrive at the hospital alive, US, chest radiography, and CT scanning can be used for diagnosis.

US is an important diagnostic tool for initial assessment in the emergency department. It can identify free pericardial fluid easily and is sensitive and specific for diagnosing traumatic pericardial effusion.\textsuperscript{70} The FAST scan is an important diagnostic tool used in trauma centers. However, user experience greatly affects the ability to detect pericardial fluid and cardiac injury successfully.\textsuperscript{71}

Diagnostic chest radiography also can be useful for diagnosing heart injury due to a gunshot or explosion because remaining fragments might indicate the path in which the injury occurred.\textsuperscript{79} In addition, chest radiographs can show increased size of the heart silhouette, which might be a sign of blood enlarging the pericardial sac.\textsuperscript{70}

Using CT images, physicians can detect the same injuries for penetrating heart trauma as they do for blunt heart trauma with high specificity and sensitivity. In stable patients with penetrating chest trauma, CT is the best modality for identifying details of the injury and developing a plan for surgical intervention.
Seat Belt Injuries

The effect of seat belts on injuries has been studied from different perspectives, including point of impact, individual positions within the vehicle, and size of the individual. Arbogast et al studied the age-based differences in 20 individuals to further define how seat belts transfer the load to the individual in MVCs. They analyzed data regarding individuals who were positioned in the rear seats during a frontal impact MVC while wearing lap and shoulder seat belt restraints and who received thoracic injuries of AIS2+. The seat belts caused an abrasive bruise on most patients (AIS1); however, of the 7 individuals aged between 8 and 15 years, 6 had either a pulmonary contusion or pneumothorax, and 3 had fractures of the ribs or sternum. For the 16 to 24 age group, 4 of 5 people presented with rib fractures, and all 8 individuals older than 25 had rib fractures. Although the specific injuries varied between the age groups, all injuries sustained to the thorax were primarily caused by seat belt compression.

Despite the similarities, Arbogast et al identified notable differences between the age groups. For example, the

### Box 2

**Injuries Found on Computed Tomography Imaging**

- Active extravasation
- Aortic contour changes
- Aortic dissection
- Flap obstruction to the descending aorta
- Focal aneurysm formation
- Internal tears
- Intramural hematoma with or without changes to contours

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**Figure 14.** Ruptured thoracic aorta (blue arrow) seen on chest CT with contrast after trauma. The white arrow indicates blood in the thorax. Image courtesy of James Heilman, MD, via Wikimedia Commons. Licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license.
researchers concluded that bony injuries occurred more frequently in older individuals because the thorax stiffens as people age. In addition, even when vehicle size and velocity were considered, many of the individuals younger than age 15 had abdominal as well as thoracic injuries, which is termed seat belt syndrome.\(^9\) Possible explanations for seat belt syndrome included that more load was transferred to the abdominal area because of the increased flexibility of the thorax or that the geometric design of rear seat belts is not ideal for younger people, which results in the seat belt not being positioned on the lower waist.\(^9\) Although the study was somewhat limited and might not adequately represent the general population, the findings suggest that more research is needed to assess how age correlates to seat belt–related injuries.

Although seat belts can cause significant injuries in MVCs, the repercussions of not wearing a seat belt can be detrimental.\(^72-74\) The Motor Vehicle Safety Act was enacted by Congress in 1966 to mandate motor vehicle safety standards to improve safety features of automobiles from both a production and operation standpoint.\(^72\) The use of seat belts increased 74% from 1981 to 2010; however, 1 in 7 people still do not use seat belts.\(^74\) In 2009, more than 33 000 individuals were killed in MVCs, and more than half of the people who died were not wearing a seat belt. An additional 2.2 million individuals were injured as a result of MVCs in 2009.\(^74\) On July 12, 2015, a serious MVC between a truck and a sports utility vehicle occurred in New Mexico.\(^73\) None of the 9 people in the sport utility vehicle were wearing seat belts, and 2 of them died at the scene after being ejected from the vehicle. The remaining 7 were transported to a level 1 trauma center with life-threatening injuries.\(^73\)

**Future Considerations**

In the past 20 years, CT has become a part of nearly all trauma algorithms. The availability, speed, and accuracy of multiplanar reformats has made CT the preferred method for diagnosing many trauma-related injuries and a vital tool for every emergency department provider. Before the advancement of CT, chest radiographs were the most relevant diagnostic tool for chest trauma. However, chest radiography often was performed supine because of patients’ conditions and likely missed certain diagnoses. With the development of new technology, other tests could become useful in chest trauma situations.

Dual-energy subtraction chest radiography is an advanced imaging technique that digitally subtracts elements of the resultant radiographic images, allowing certain structures to become more visible. The system uses 2 x-ray beams of different energy levels to expose the image receptor. Based on the different attenuation levels of the body tissues, images can be produced weighted toward either soft-tissue or skeletal structures.\(^73\) Current research on this method of chest imaging has focused on chronic illness, including pulmonary nodules, but in certain trauma situations it might be a helpful diagnostic tool. Direct visualization of the mediastinal structures without skeletal superimposition could aid in diagnosing soft-tissue injuries and possibly allow more accurate diagnosis of rib or sternal fractures. This imaging technique could be well suited for localizing and visualizing inhaled foreign bodies. Specifically, dual-energy subtraction chest radiography improves the visualization of foreign matter in bone-selective images.\(^73\) This method could reduce the radiation dose from CT imaging, which becomes especially important considering the higher incidence of this injury type in pediatric patients. However, more research on this imaging technique is necessary before it becomes a commonly used method for trauma situations.

**Conclusion**

In trauma situations, a seemingly basic chest radiograph can turn into a challenge for radiologic technologists. Radiographers who work at locations where they could perform examinations on patients with trauma should stay up to date on chest trauma pathophysiology and develop skills to image these patients accurately. Conditions ranging from rib fractures to cardiac rupture can result from chest trauma. Trauma patients often are imaged in areas outside of the radiology department using portable equipment at the bedside or in trauma rooms located in or near the emergency department. Critical thinking skills and knowledge of anatomy and radiologic physics are vital to successful imaging in these situations.
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Reprint requests may be sent to the American Society of Radiologic Technologists, Communications Department, 15000 Central Ave. SE, Albuquerque, NM 87123-3909, or e-mail communications@asrt.org.

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References


1. Nearly ______ % of trauma-related deaths are associated with chest trauma.
   a. 25
   b. 40
   c. 55
   d. 70

2. What is the most common mechanism of injury for patients with chest trauma?
   a. sports injury
   b. motor vehicle crashes
   c. falls
   d. blast injury

3. What differentiates true ribs from false ribs?
   a. shape
   b. attachment directly to the thoracic vertebrae
   c. attachment directly to the sternum
   d. lack of cartilage

4. Typically, the body of the sternum is approximately how many inches long?
   a. 3
   b. 4
   c. 5
   d. 6

5. Unlike the rest of the vertebral column, the thoracic vertebrae have:
   a. transverse foramen.
   b. foramen ovale.
   c. costal cartilage.
   d. costal facets.

6. Anatomically, what blocks food and drink from entering the trachea?
   a. nasopharynx
   b. epiglottis
   c. mediastinum
   d. hilum

continued on next page
7. At what vertebral level does the heart generally sit?
   a. C7-T3
   b. T1-T4
   c. T5-T8
   d. T7-L1

8. Through which great vessel does blood pass into the heart to become oxygenated?
   a. aorta
   b. pulmonary veins
   c. pulmonary arteries
   d. vena cava

9. Which anatomical regions are included in a whole-body computed tomography (CT) scan used during trauma diagnosis?
   a. head, neck, shoulders, chest, and upper extremities
   b. head, neck, chest, abdomen, and pelvis
   c. neck, chest, abdomen, pelvis, and hips
   d. neck, chest, abdomen, hips, and lower extremities

10. In one study discussed in the article, what percentage of patients had their treatment plans changed based solely on the results of whole-body CT scanning?
    a. 0
    b. 7.2
    c. 12.5
    d. 18.9

11. Which of the following statements is true regarding imaging of the lower ribs?
    a. The patient should be recumbent and the exposure should be taken on full expiration.
    b. The radiographer should obtain a true lateral with the patient erect.
    c. The patient should be erect and exposure should be taken on full inspiration.
    d. The patient should be supine and exposure should be taken on full inspiration.

12. What does the advanced trauma life support system list as the second most likely radiological sign indicating severe injury to large blood vessels of the chest?
    a. fractured clavicle
    b. CT evidence of thoracic vertebral compression
    c. sternal fracture
    d. fracture of the first rib

13. Why might ultrasonography (US) have an advantage over traditional radiography for diagnosing costal cartilage fractures?
    a. The cartilage cannot be seen accurately on radiographs unless it is highly calcified.
    b. US has a higher spatial resolution.
    c. Radiographs take longer to process.
    d. The sound waves have a therapeutic effect.

14. Which term describes 3 or more consecutive rib fractures in 2 or more locations?
    a. pneumothorax
    b. hemotherax
    c. flail chest
    d. bronchial rupture

15. An advantage of CT compared with traditional radiography when imaging patients with suspected flail chest is that it:
    a. results in lower radiation dose to the patient.
    b. offers a visualization of free air.
    c. is quicker and less expensive.
    d. can diagnose fractures of the costal cartilage.

16. Which injury has a high prevalence in patients with traumatic fracture of the manubrium?
    a. traumatic spleen injury
    b. fractured pelvis
    c. pneumothorax
    d. traumatic head injury
Directed Reading Quiz

22. The “hump and band” sign appears as a:
   a. rupture of the left hemi-diaphragm.
   b. hump of peritoneal fat in the pleura.
   c. hump of liver through a constricted right hemi-diaphragm rupture.
   d. direct contact of abdominal structures with the lung.

23. Which term refers to the buildup of blood within the pericardial sac?
   a. hemomediastinum
   b. hemopericardium
   c. hemicardia
   d. hemopleura

24. Which modality is sensitive and specific for diagnosing traumatic pericardial effusion?
   a. multiplanar CT
   b. dual-energy radiography
   c. US
   d. positron emission tomography scanning

25. Which of the following is not a CT-visualized sign of aortic trauma?
   a. extravasation of contrast material from the aorta
   b. the “hump and band” sign
   c. irregular contour
   d. pseudoaneurysm

26. In patients with chest trauma, which usually causes esophageal rupture?
   a. bone fragments from adjacent vertebral fractures
   b. impalement
   c. increased pressure
   d. compression from seat belts

27. Dual-energy subtracted chest radiography might be well suited for localizing and visualizing which of the following traumatic chest injuries?
   a. diaphragm rupture
   b. lung torsion
   c. aorta rupture
   d. inhaled foreign bodies