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Traumatic Chest Wall Injuries

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11.1 Introduction

A chest wall injury can occur as the result of an accidental or a deliberate penetration of foreign objects into the chest. This type of injury can also result from blunt trauma causing rib bruises, fractures, lung or heart contusions.

Blunt chest wall injuries account for over 15% of all trauma admissions to emergency departments (ED) worldwide [1], with a mortality that ranges between 4 and 60%, depending on the grade of the trauma suffered [2].

The patients may present minor chest wall injuries, with rib fractures being the most common findings, (about 50% of cases); the overall incidence is probably higher because not all rib fractures are detected, in the acute phase, on chest X-ray (CXR). Other minor chest wall injuries include soft-tissue contusions and hematoma that might result from arterial or venous bleeding. A hematoma from a high-pressure arterial injury may enlarge rapidly requiring an intra-arterial embolization, whereas a bleeding from a low-pressure venous injury is usually self-limiting. Patients treated with anticoagulants are at higher risk for developing hemorrhagic complications even from minor trauma.

The pain is normally the only symptom referred to the clinician in the ED, and few risk factors have to be taken into account in the management of chest wall trauma patients: age, preexisting disease, number of fractured ribs, and the onset of respiratory and vascular complications, 24–72 h after the trauma [2].

Major chest wall traumatic injuries include deep organs laceration and flail chest syndrome (seen in 6% of patients with rib fractures), an immediate life-threatening injury that require evaluation and treatment during the primary survey.

The AAST (American Association of the Surgery of Trauma) developed a scale, where site, extent of fractures, and concomitant soft-tissue injuries define the grade [3].

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Trauma scoring might be considered evaluating the following:

Grade I	Contusion	Any size
	Laceration	Skin and subcutaneous tissue
	Fracture	<3 adjacent ribs
		Nondisplaced clavicle
Grade II	Laceration	Skin, subcutaneous, and muscle
	Fracture	>3 adjacent ribs
		Open or displaced clavicle
		Nondisplaced sternum
		Scapular body
Grade III	Laceration	Full thickness including pleura
	Fracture	Displaced or flail sternum
		Unilateral flail segment <3 ribs
Grade IV	Laceration	Avulsion of chest wall tissues with underlying rib fractures
	Fracture	Unilateral flail chest >3 ribs
Grade V	Fracture	Bilateral flail chest

More than two-thirds of cases of chest wall trauma are the result of a motor vehicle collision (MVC). Other causes include falls from height, sport injuries, motorcycle/bike accident, or of blows from blunt objects.

Imaging plays an important role in the diagnosis. CXR is typically used as the first and, in most cases, as the only diagnostic technique. Multidetector computed tomography (MDCT) must be performed in stable polytrauma patients or in doubtful cases at initial plain film study and has a very high sensibility and specificity; it can demonstrate significant disease in patients with negative initial CXR images, thus changing their clinical management [4].

11.2 Anatomy of the Chest Wall

11.2.1 Bones

The rib cage surrounds the thoracic cavity and supports the pectoral girdle (shoulder girdle, scapulae, and clavicles), enclosing the thoracic organs and with its muscle being a component of the human respiratory system.

In its normal shape, the human thoracic cage consists of 12 pair of ribs, the sternum, and the 12 thoracic vertebrae.

11.2.1.1 Ribs

About 1 in 200–500 people have an additional cervical rib, with female predominance. Bifid ribs (with the sternal end cleaved in two) occur in about 1.2% of the population. An extra cervical rib, from the seventh vertebra is also a common variant, which may mechanically interfere with the nerves (brachial plexus) going to the arm.

Ribs that articulate directly with the sternum are called true ribs (the first seven), whereas those that connect indirectly via cartilage are termed false ribs.

The last two pair of ribs are called floating rib, attached only to the vertebrae, not to the sternum.

Between the ribs there are the intercostal spaces, containing the intercostal muscles, nerves, arteries, and veins.

Each rib consists of a posterior head and neck, attached posteriorly to the thoracic vertebrae (the insertion point of the longissimus dorsi muscle), a body and a cartilaginous anterior part articulating with the sternum.

Ribs body has a flattened shape with a lateral convex face and a concave medial face, two margins: a smooth superior one and an inferior one, where there is a rut due to the passage of the intercostal nerves and vessels.

11.2.1.2 Thoracic Spine

Dorsal vertebrae, in number of 12, compose the middle segment of the vertebral column, between cervical and lumbar spine.

They are distinguished from the other ones by the presence on either side of the bodies of two semi-facets articulating with the ribs heads and the presence of complete facets on the transverse processes, except for the 11th and 12th one, joining them with the ribs tubercula.

Pedicles and laminae are broad, thick, and directed backward and slightly upward.

Spinous processes are long and triangular shaped, directed obliquely downward, arising from the lamina with a pointed end.

Superior and inferior articular processes arise at the junction between pedicles and laminae, articulating the vertebrae with the one below and above.

Posterior to the latter ones the transverse processes arise, directed obliquely backward and laterally.

11.2.1.3 Sternum

The sternum is a flat bone, forming the middle portion of the front of the thorax. It consists of three parts, from the top: manubrium, body, and xiphoid process.

The manubrium is the upper part of the sternum. It has a quadrangular shape, with a superior jugular notch, located in the middle part of the manubrium; its lateral surface presents two clavicle notches, articulating with the medial parts of the clavicles and the costal notches, articulating with the first pair of ribs.

The manubrium, in his lower part, articulates with the body of the sternum, with a synarthrosis, (the angle between the manubrium and the body is named angle of Louis) laterally at this point there is the attachment of the second pairs.

The sterno-pericardial ligament attaches the pericardium to the posterior side of the manubrium.

The body of the sternum, the longest part, is flat with a front and back surface. Laterally, there are the costal notches, articulating with the ribs.

The xiphoid process is located at the inferior end of the body of the sternum and might remain cartilaginous also in the elderly people.

11.2.1.4 Clavicle

Clavicle or collarbone is a long bone between the scapula and the sternum, with a body, a medial and a lateral end. Clavicle body is flat, forming a superior and posterior face with two margins; the superior and posterior face gives attachment to many muscles: deltoid, trapezius, subclavius, pectoralis major, sternocleidomastoid, and sterno-hyoid muscles.

11.2.1.5 Scapula

The scapula is a flat bone with a lower apex and a triangular shape, attached to the rear face of the rib cage, forming the shoulder skeleton, articulating with humerus at its lateral margin with the glenoid cavity.

It has an anterior and a posterior face, with three margins: a medial, a lateral, and an upper one. The anterior face is concave, with the attachment of the subscapular muscles.

The posterior one is divided into two parts due to a bone process, named spine, dividing it into a small supraspinous fossa and in the larger infraspinous fossa.

The spine becomes more prominent assuming a triangular shape, constituting the so-called acromion, articulated with the clavicle.

The superior margin has a bone process called coracoid process, giving attachment to ligaments and muscles (biceps and pectoralis minor muscle) [5].

11.2.2 Muscles

Chest muscles may be divided into intrinsic and extrinsic according to their origin and insertion entirely in the thorax. Intercostal, levatores costarum and transversus thoracis muscles are the only intrinsic chest muscles.

11.2.2.1 Intrinsic Muscles

Intercostal muscles are a group of three muscles, located between the ribs in order to reduce or increase the size of the rib cage during respiration. They are the external intercostal, internal intercostal, and the innermost intercostal muscles.

External intercostal muscles are obliquely oriented, from the lower edge of a rib to the upper part of the lower one and functioning to elevate the ribs as an inspiratory muscle. The internal intercostal muscles are oriented postero-inferiorly and functions to depress the ribs, as an expiratory muscle. The innermost intercostal muscles are a thin layer of fibers oriented similarly to those of the internal intercostal, separated from them by the intercostal neurovascular bundles.

The intercostal blood supply is derived from the posterior intercostal branches of the aorta and the anterior intercostal branches of the internal thoracic artery.

Other intrinsic muscles are the levatores costarum muscles: they are 12 in number on either side, with a triangular shape, lateral to the spine, originating from the transverse processes of the vertebrae ending on the upper edge of the rib below, with the role of helping in inspiration.

Another intrinsic muscle is the transversus thoracic muscle that is a flat muscle, originating from the body and the xiphoid process of the sternum, ending on the cartilaginous part of the ribs from the second to the sixth, helping in expiration.

11.2.2.2 Extrinsic Muscles

Extrinsic muscles include thoracoappendicular, spinoappendicular, spinocostal muscles, and the diaphragm.

The pectoralis major is a fan-shaped muscle, originating from the medial clavicle, the anterolateral surface of the sternum, the costal cartilages (from second to sixth ribs) and inferiorly from rectus muscle fibers and the aponeurosis of the external oblique muscle; inserting on the lateral lip of the bicipital groove of the humerus. Its actions are to flex, adduct, and rotate the arm medially.

The pectoralis minor muscle is located deep to the pectoralis major and mainly acts as an inspiratory muscle, also stabilizing the scapula. It originates from the outer face and the posterior margin of the third, fourth, and fifth ribs, near the costal cartilages. Its fibers are obliquely oriented superiorly and converge at the apex of the coracoid process of the scapula.

The serratus anterior is located on the side of the chest wall; this muscle is embedded in the vertebral border of the scapula and originates from the first ten ribs. It is usually divided, given its size, in three parts depending on where the fibers originates from the ribs and where they fit exactly in the shoulder bone. This muscle mainly acts abducting and externally rotating the scapula as well as make it adhere to the chest (the latter action coupled to the rhomboids and trapezius muscles). It lowers the shoulder blades with his lower beams, raises them with the upper beams. If taken as a fixed point elevates the coasts participating in the forced inspiration (inspiratory accessory muscle) [6].

11.3 Mechanisms of Injury

Four main mechanisms of injury are responsible for chest wall injury: direct chest impact, thoracic compression, rapid acceleration/deceleration, and blast injury.

Direct impact injuries are normally less risky, affecting mainly only the soft tissues and muscles of the chest wall (hematomas, bruises, cuts, and scratches). On occasion, a localized injury to the osseous part may occur, mainly rib fractures, but also sternal fracture and sternoclavicular dislocation. Rarely direct impact forces may be transmitted through the chest wall to the deeper organs, causing serious injury to the heart, lung, or large mediastinal vessels.

In the thoracic compression injuries, the chest wall is put against a fixed anatomical bone structure, anteriorly the ribs or sternum and posteriorly the vertebrae causing deep organs laceration, contusion, or rupture. Thoracic compression may cause contusion or laceration of lung parenchyma, pneumothorax or hemothorax, tracheobronchial fractures as well as rupture of the diaphragm.

In acceleration/deceleration injuries, the production of shearing forces causes direct compression against fixed points. This type is the most common and potentially lethal injury, may causing major tracheobronchial disruption, cardiac contusions, aortic, and diaphragmatic rupture [7].

Blast injuries are increasing recently, resulting from the sudden conversion of a solid or liquid material into gas after activation of explosive material. A primary blast injury results from the creation of a blast pressure wave, applying pressure differentials, mostly at air-tissue interfaces within the chest wall, affecting mainly the pulmonary and gastrointestinal systems.

Secondary blast injuries result from objects driven by the explosion impacting the individual and creating a chest wall injury. Tertiary blast injuries might also be indirect, due to the blown out of the individual subject to the explosion [8, 9].

11.4 Anterior Rib Fractures, First Rib and Lateral Rib Fractures

11.4.1 Pattern of Injury

Rib fractures are the most common injury after blunt chest trauma which occurs in approximately 50% of patients. It is important to consider the specific location of rib fractures because this is an important indicator of related injury. Rib fractures can be studied as three distinct patterns according to their location: (1) fractures of the first rib and those of the second to fourth ribs, (2) fractures of the fifth to ninth ribs, and (3) fractures of the 10th to 12th ribs. These three distinct patterns of rib fractures represent different pathophysiology and associated morbidity. A rib score has been proposed to predict adverse pulmonary outcomes [10].

A high-energy trauma is necessary to result in fracture of the first, second, or third ribs because these ribs are well protected by the scapulae, clavicles, and musculature. The presence of this fracture should prompt the evaluation of vascular thoracic injuries, brachial plexus injury, or subclavian vascular injuries [11].

Isolated first rib fractures are seen in association with cranial and maxillofacial injuries and are probably secondary to avulsion of the first rib by its muscular attachment rather than direct trauma to the rib, which is relatively protected.

Fractures of the fourth up to the eighth ribs are the most common [12].

The compression of the rib cage with associated fracture of the 10th, 11th, or 12th rib might cause internal abdominal organs injuries, of course fractures of the right lower ribs are more often associated with hepatic injury, fractures of the left lower ribs with splenic injury, and fractures of the posterior portion of the lower ribs with renal injury.

Injury to the liver might result in tearing, intraparenchymal or subcapsular hematoma, active bleeding, or there might be injury of major liver vessels. Injury of the spleen or kidney might result in subcapsular hematoma or abdominal rupture in greater force impact. Even hemorrhage around and within the adrenal glands represents a risk that is associated with fractures of the lower ribs.

Fracture of any rib can be associated with pneumothorax, hemothorax, or extrapleural hematomas. Although lung trauma is generally seen immediately, the occurrence of a pneumothorax and hemothorax may be delayed for hours after the injury. Hemothorax of a significant degree secondary to rib fractures is usually the result of laceration of an intercostal artery rather than bleeding from the lung. It is important in the evaluation of rib fractures to check in particular the lower sulcus of the ribs where the intercostal arteries are located; fractures that involve the sulcus are more prone to hematomas and the hemothorax resulting from a laceration of an intercostal artery can be life threatening.

The risk of intra-abdominal or intrathoracic injury increases if two or more rib fractures are present at the same level [13–15]. These injuries should always be ruled out by MDCT [16].

Elderly individuals are prone to rib fractures because of decreased rib cage compliance; limited respiratory movement may cause an increased prevalence of atelectasis and subsequent pneumonia which lead to pulmonary insufficiency, even from single rib fractures, that may increase morbidity and mortality [11, 17].

A study showed that in elderly people more than three rib fractures may indicate the need to transfer to a trauma center, and the more ribs broken, the greater the death rate [18].

In contrast, children's bones are immature and more compliant, due to the greater pliability of children's ribs, greater force is required to produce a fracture and rib fractures in this group of patients are indicative of high-energy transfer trauma [4, 9].

Anyway in elderly and not elderly people, knowing the number of ribs fractured might influence treatment decisions and might change morbidity and mortality.

A single blow may cause rib fractures in multiple places. At the level of the rib cage, the typical pattern of fractures varies depending on the site of compression: if the compression comes

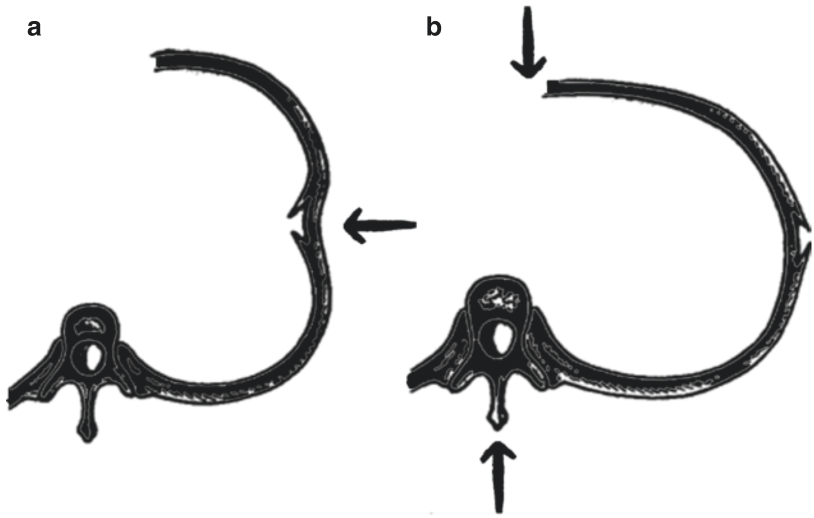

Fig. 11.1 Chest trauma: different mechanisms of injury secondary to different axial load force (*arrows*). (**a**) Lateral impact. (**b**) Anterior-posterior impact

from the front we usually observe sternal compression fractures and antero-lateral rib fractures; if the compression comes from the back we usually observe posterior rib fractures; if a lateral force occurs, we usually observe posterior fractures and detachment from the costochondral cartilage or anterior fractures.

If the compression is anterior and posterior, lateral rib fractures occur on the lateral cortical margins; if the force is laterally direct to the ribs, internal cortical rib fracture might occur (Fig. 11.1).

Traumatic fractures most often occur at the site of impact or the posterolateral bend, where the rib is the weakest. Both displaced and nondisplaced fractures can be seen in adults and children.

Fractures might be anterior; there might be lateral fracture with rib cage deformation and posterior fractures occasionally involving the costovertebral joint; it is important to note that buckle fractures are easy to overlook even at CT and additional coronal image scan be helpful in the diagnosis of rib fractures that are not seen on axial images [19, 20].

11.4.2 Imaging Evaluation and Findings

11.4.2.1 Plain Radiography

A standard CXR is almost always the initial study for the evaluation of non-traumatic chest pain and for traumatic injuries. If rib fractures are suspected clinically, a rib plain film series might be performed; this radiograph consists of oblique views and optimization of the X-ray parameters by the technologist to highlight bony detail. The decision to image a rib fracture in the absence of other underlying abnormalities or associated injuries depends on the clinical scenario.

Even in the absence of associated injuries, radiographic confirmation of a rib fracture can help prevent complications such as atelectasis and is particularly important in patients with comorbidities such as chronic obstructive pulmonary disease, cardiac disease, hepatic disease, renal disease, dementia, and coagulopathy.

Despite its routinary use, CXR, even with dedicated oblique rib series, has limited sensitivity, showing only 40–50% of rib fractures [21, 22].

11.4.2.2 MDCT

MDCT is the study of choice to fully evaluate trauma-associated injuries and bony details; it is the most sensitive technique for imaging rib fractures since it can help determine the site and number of fractures. It is however relatively costly, time-consuming, not always 24 h available, and exposes the patient to a significant amount of radiation [21].

With the help of reconstructed maximum intensity projections (MIP) and volume-rendered (VR) images, MDCT depicts with great detail the number and sites of rib fractures [12].

MDCT angiography plays a crucial role in the evaluation of the vascular injuries associated with chest trauma and should be considered in stable patients with first rib fractures if there are absent or decreased upper extremity pulses, if regional hemorrhage, and/or brachial plexus injury are present. Additional criteria for angiographic MDCT include displacement of bone fragments and multiple thoracic injuries.

11.4.2.3 US

Ultrasonography (US) can be used to look for broken ribs and costal cartilage fractures, in cases in which they occur in an accessible thoracic point, especially in pediatric population and in young women. Unfortunately, US is unable to adequately assess certain portions of the thorax such as the first rib under the clavicle, and the upper ribs under the scapula.

Other limitations include subcutaneous emphysema and the pain at the site of the transducer compression, making it difficult in traumatized patients; and its results depend greatly on the skill of the performer [23]. Even if with these limitations, US might demonstrate cortical discontinuity, linear edge shadow (Fig. 11.2), and acoustic reverberation artifacts in accessible points and associated injuries such as pneumothorax and hemothorax; abdominal organ injuries might be evaluated too.

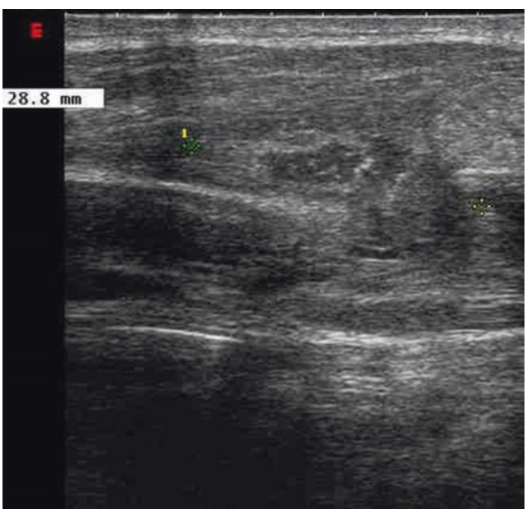

Fig. 11.2 US imaging showing interruption of cortical margins and a 2.9 cm hematoma after chest wall trauma (calipers)

Studies have found it to be much more sensitive than plain radiography in detecting rib fractures, whereas other studies have suggested that it is only equally sensitive or slightly better, but it should be underlined that US is not as panoramic as plain radiography and MDCT.

11.4.2.4 MRI

Magnetic resonance imaging (MRI) has not yet a role in rib fracture evaluation and is not considered appropriate for evaluating rib fractures, due to the fact that it is time-consuming and not easily available in trauma centers. However, it may be useful if there is concern about soft-tissue or vascular abnormalities [21].

11.4.3 Natural History and Mortality

Pain from rib fractures can be severe for several days following the injury and even if most of them heal within 6 weeks, many patients are able to resume daily activities much sooner. Follow-up CXR after the injury are not routinely recommended and should be performed only if indicated by clinical findings or if in complicated cases [24]. Clinical signs of worrisome might be unilateral decreased breath sounds suggesting pneumothorax or persistent pain suggesting difficult consolidation or non-union. A follow-up examination 6–8 weeks after the injury is reasonable to assess the patients, if they are unable to return to sports or work by that time.

The number of displaced rib fractures and fracture location could be a significant predictor for developing pulmonary and other organs complications. For patients with fewer than three rib fractures without rib displacement and initial lung or other organ injuries, conservative management could be safe and efficient [25].

As the number of rib fractures increases, morbidity and mortality grows substantially in all age groups owing to major risk of complications such as pneumothorax, pneumonia, and acute respiratory distress syndrome (ARDS).

Other associated injuries such as concomitant great vessel injury might happen in 3% of traumatic injuries to the first rib that affect prognostic outcome. Pneumothorax occurs in about 14–35% of rib fractures, hemopneumothorax in 20–25%, pulmonary contusions in 17%, and a flail chest in 5.8%.

Chest wall injuries in older people should not be dismissed. Older patients have twice the morbidity and mortality compared with younger people; for every increase in the number of ribs fractured, mortality increases by 19% while the risk of pneumonia increases by 27%.

11.4.4 Treatment

Simple rib fractures themselves are usually not significant in isolation and are treated symptomatically. They have a good prognostic outcome and are rarely life threatening [12].

Virtually, all non-pathologic rib fractures heal well with conservative management. Some patients are able to return to work within a few days, depending on their occupation. One small case series suggests that some patients experience prolonged pain and disability [26]. It found that patients with an isolated rib fracture regain pain-free function at a mean of 51 days.

11.5 Costochondral Injuries

Costochondral injuries refer to the fracture at the joints between each rib and its costal cartilage. They are primary cartilaginous joints and represent the demarcation of the unossified and ossified part of the rib. There is no movement at these joints. Costal cartilages form part of the thoracic cage and anterior chest wall. There are ten costal cartilages, one for rib 1–10, each of which forms a costochondral joint. Costal cartilages 1–7 articulate with the sternum at sternocostal joints, and costal cartilages 8–10 are attached to each other via small interchondral synovial joints forming the costal margin.

11.5.1 Patterns of Injury

Costal cartilage fractures are rare lesions, which may be located at the chondrocostal or chondrosternal junction.

While in adult patient pain is the primary complaint, in young children, a costal cartilage fracture may present as a thoracic wall mass associated with pain.

Costochondral injuries might occur in three locations: costochondral, midchondral, and sternochondral. Disruptions or fractures of costal cartilage might result in an unstable rib cage and may expose thoracic contents, such as the heart, to injury.

While the more fixed first and second rib seems to be easily subjected to costochondral separation, the lower ribs can suffer costal cartilage fracturing more frequently.

11.5.2 Imaging Evaluation and Findings

11.5.2.1 Plain Radiography

Fractures of the costal cartilages are challenging to establish on physical examination and on plain radiographs, where they are easily overlooked. However, when there is severe calcification of the cartilage, a traumatic interruption might be displayed at this level [27, 28].

CXR is indicated to show associated findings such as pneumothorax, hemothorax, pulmonary contusion, and subcutaneous emphysema.

11.5.2.2 MDCT

MDCT is the gold standard technique to represent costal cartilage fractures and eventually associated injuries such as thoracic wall hematoma, pneumothorax, subcutaneous emphysema, hemothorax, and pulmonary contusions [21, 29].

11.5.2.3 US

US is a reliable method to diagnose costal cartilage fractures and can increase the sensitivity of their detection when used together with MDCT scanning. US is preferable in a pediatric population, in young or pregnant women and for follow-up examinations [30].

In pediatric population, US examination might be useful when costal cartilage fracture presents as a chest wall mass associated with pain to exclude neoplasm or post-traumatic hematoma.

Furthermore, it is suggested an US examination when there is a high clinical suspicion and other modalities have not demonstrated an injury.

Sonographic signs of a cartilage damage include a fracture line, disruption of the anterior echogenic margin, a step-off deformity or gas located at the costochondral junction [27, 31].

Pitfalls in US examination include false fractures that might be produced when the probe overlies the rib and partly the intercostal space. Also costal cartilage calcifications, running parallel to the rib margin, at the costochondral junction, may give rise to the false identification of a fracture due to normal sharp indentation (less likely in pediatric population) [32].

11.5.2.4 MRI

MRI can easily demonstrate costal cartilage fractures and, like US, doesn't result in radiation exposure.

Costal cartilage injuries are detected on MRI due to the high T2 signal from the surrounding edema, and they are often more easily detectable than on MDCT. Even in cases of remote injury, persistent high T2 signal at the site of fracture might be seen, presumably due to nonunion in persistent clinical symptoms.

When costochondral injury is suspected, a fat-saturated T2-weighted or STIR sequence in the coronal view are recommended [33].

11.5.3 Natural History and Mortality

Costochondral fractures slightly increases mortality rate as they may determine rib cage instability and flail chest, impairing respiratory function [34].

11.5.4 Treatment

These injuries are usually treated like the osseous rib fractures, typically with nonsurgical management involving ice, nonsteroidal anti-inflammatory medications and taping of the ipsilateral chest wall or use of a rib belt; in addition, athletes are restricted from sport for 3 weeks or longer [33, 35, 36].

However when returning to sports, especially contact sports at risk for direct trauma (e.g., hockey, rugby), a protective padding may be used to allow for further healing while reducing the risk of any repeated injury.

11.6 Flail Chest

A flail chest deformity may be a severe consequence of multiple rib fractures. It occurs when three or more contiguous ribs are fractured in two site, or five or more contiguous ribs are fractured in one site with or without associated sternal fractures [37].

With regard to injury mechanism, such trauma may be caused by MVC, falls, and assaults in younger, healthy patients.

The initial diagnosis of flail chest is performed with physical examination, when paradoxical or reverse motion of a chest wall segment is detected while spontaneously breathing. This pattern of injury gives the rib cage an unstable dynamic of motion because a segment can act as a flail segment. The movements of this segment are opposite to the expected in the dynamic of the rib cage motion: in inspiration the unstable segment of the rib cage is attracted towards the pleura and in expiration it goes away from it. In this pattern of fracture in a non-ventilated patient, this segment of the rib cage movement is contrary to the expected and is called paradoxical. The segment of the chest wall that is flail is unable to contribute to lung expansion. This abnormal movement hinders the creation of negative intrathoracic pressure during inspiration and positive airway pressure during expiration.

The force that is needed to produce a flail chest varies on the structure on which it impacts, if the structural components (i.e., the ribs) are weakened for any reason (i.e., osteoporosis, total sternotomy, and multiple myeloma, as well as individuals with congenital absence of the sternum), then much lower force may be required. Mechanically, however flail chest generally requires a significant traumatic energy diffused over a large area (i.e., the thorax) to create multiple anterior and posterior rib fractures.

The motion of the flail segment is usually limited by the surrounding structural components, the intercostalis, and the surrounding musculature. This mechanical limitation of motion affects the actual size of the changes in thoracic volume and patient-generated tidal volume. Underlying pulmonary or cardiac disease determines the physiologic perturbations to respiration caused by the flail segment.

Although the diagnosis of flail chest is initially clinical, it always requires radiological studies including CXR and MDCT.

11.6.1 Patterns of Injury

The chest wall is inherently stable, with 12 ribs attaching posteriorly to the spinal column and anteriorly to the sternum. Intercostal muscles with fascial attachments, coupled with other muscle groups, including the trapezius and the serratus groups, add further strength to the bony cage around the thoracic organs.

Borrelly and Aazami [38] reported that contraction of the serratus anterior muscle digitations pulls the flail segment posteriorly and superiorly. Canine flail chest experiments have also shown that the degree of inward inspiratory displacement is related to force differences between intrapleural pressure and parasternal muscle activity [39].

Frontal and lateral impact may result in multiple anterior and posterior rib fracture points. Severe anterior compressive forces may cause sternochondral disruption and a subsequent sternal flail.

Flail chest can be subdivided into anterior and posterior flail chest depending on the presence of fractures along the anterior or posterior rib angles, respectively [40]. Flail segment might include the sternum with ribs on both sides of the thoracic cage fractured.

The rib cage is a flexible ring-like structure; the arch design of the ribs allows some flexing in trauma. The rib cage is less compliant in adults rather than in children and in the latter can absorb small amounts of blunt kinetic energy. Consequently, flail chest in children is observed with lower frequency, rather than injury to the underlying structures. Contrary in an adult, a transfer of significant kinetic energy in blunt trauma to the rib cage or a crushing rollover injury is the most frequent cause of flail chest.

11.6.2 Imaging Evaluation and Findings

Patients with flail chest, resulting from a high-energy trauma, need to be considered at risk for severe associated injuries such as massive pulmonary contusion or laceration, pneumothorax with subcutaneous emphysema, hemothorax (which are the major contributors to respiratory insufficiency) and vertebral fractures.

11.6.2.1 Plain Radiography

CXR is the first examination performed in case of acute chest trauma and the strict definition of three ribs broken in two or more places, or more than five contiguous ribs injured can be confirmed eventually by means of specific ribs plain films too. The inherent structural stability of the chest wall due to the ribs and intercostal muscles usually does not show abnormal or paradoxical motion without three or more ribs involved.

11.6.2.2 MDCT

CXR is less sensitive than MDCT for the diagnosis of flail segments, and thoracic MDCT is routinary performed in case of severe trauma with paradoxical chest movements to exclude associated complications, such as pulmonary contusions, usually subjacent to the point of impact or on the counterpoint; lung laceration frequently masked by the surrounding pulmonary contusion; pneumothorax that is very common, but might be not clearly evident on supine CXR; hemothorax; pneumomediastinum; subcutaneous emphysema; mediastinal hemorrhage; and major vascular injuries (Figs. 11.3, 11.4, 11.5, 11.6, 11.7, and 11.8).

11.6.3 Natural History and Mortality

The incidence of flail segments is 10–15% in major thoracic trauma and might be associated with cranial, thoracic, and abdominal injuries.

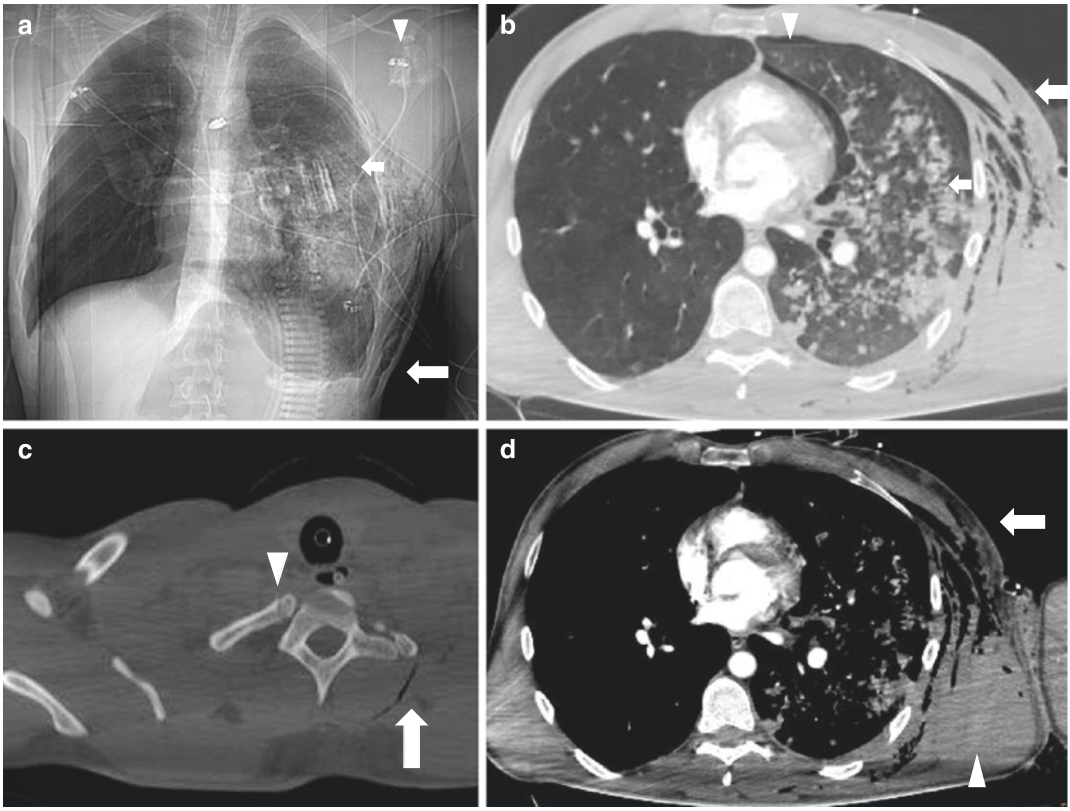

Fig. 11.3 CT scout of a patient underwent to a severe chest trauma after MVA, showing subcutaneous emphysema (*long arrow* in **a**, arrow in **b**) of the left thoracic wall, lung contusions (*short arrow* in **a** and in **b**). Left scapular fracture (*arrowhead* in **a**). Not dislocated fracture of the proximal part of the first right rib of the same patient (*arrowhead* in **c**). Subcutaneous emphysema in the left neck (*arrow* in **c**). Chest wall hematoma without active bleeding (*arrowhead* in **d**)

Early mechanical ventilatory assistance is provided to patients with severe concomitant injuries. The paradoxical movements of the flail segment disappears after intubation with positive pressure ventilation.

Patients may demonstrate only the paradoxical chest wall motion, with minimal respiratory insufficiency, although they usually show some tachypnea with a notable decrease in resting tidal volume due to painful fractures. The impairment of respiratory function is typically related to the underlying lung injury and loss of negative intrathoracic pressure, rather than the chest wall abnormality. It can cause the development of atelectasis and adult respiratory distress syndrome secondary to impaired pulmonary drainage, with progressive hypoxemia, elevated airway pressures, and a progressive infiltrate in the affected lung [41].

Flail chest can lead to severe respiratory failure and requires prompt intensive respiratory ventilation, sometimes also for prolonged periods in more than 50% of cases [12, 37].

Flail chest has a reported mortality rate between 10 and 15% that is primarily caused by associated injuries.

The mortality rate of patients with severe associated injuries may be decreased from 50% to 6% if mechanical ventilation is instituted within 24 h of injury; on the opposite, the mortality rate can exceed 90%, however, when there is hypotension and hypoxia for a period of more than 24 h [40].

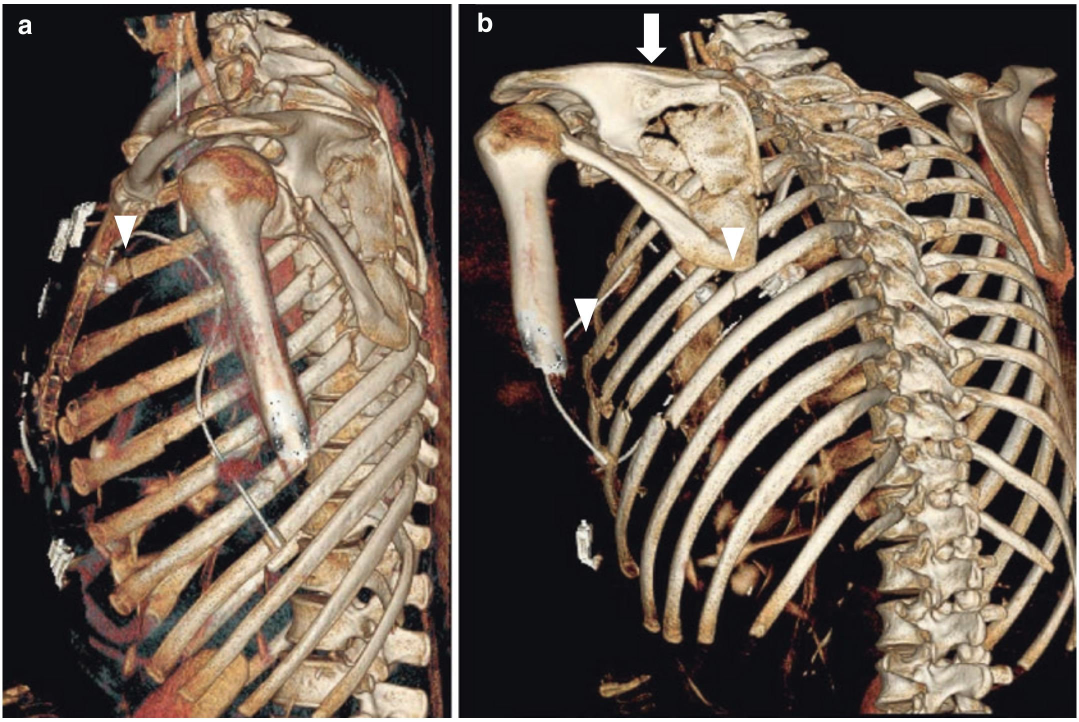

Fig. 11.4 3D reconstruction (**a**. Left lateral view; **b**. Left posterolateral view) of a patient underwent to a severe chest trauma, after a MVA, showing flail chest with fractures, in two points, from the second to seventh rib (*arrowheads*). Left scapular fracture (*arrow*). Chest, endotracheal, and nasogastric tube placement

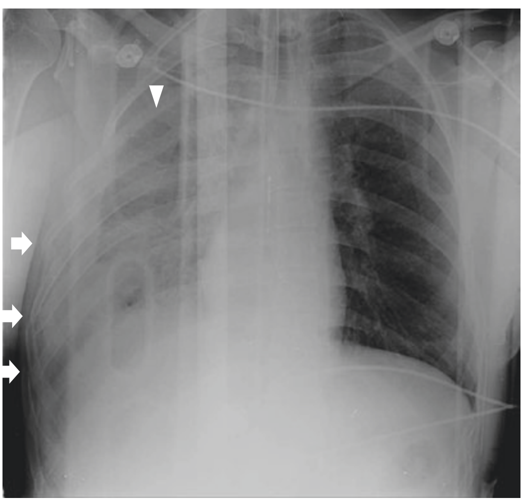

Fig. 11.5 Chest X-ray performed in shock room in supine position on the spinal board, in a patient who underwent a severe chest trauma after a MVA, showing subcutaneous emphysema of the right chest wall, multiple rib fractures (*arrows*), lung contusions (*arrowhead*). Endotracheal tube placement

Fig. 11.6 CT axial imaging of the same patient showing subcutaneous emphysema (*arrow*) of the right chest wall, lung contusions (*curved arrow*). Right pneumothorax (*black arrowhead*). Chest tube placement (*star*)

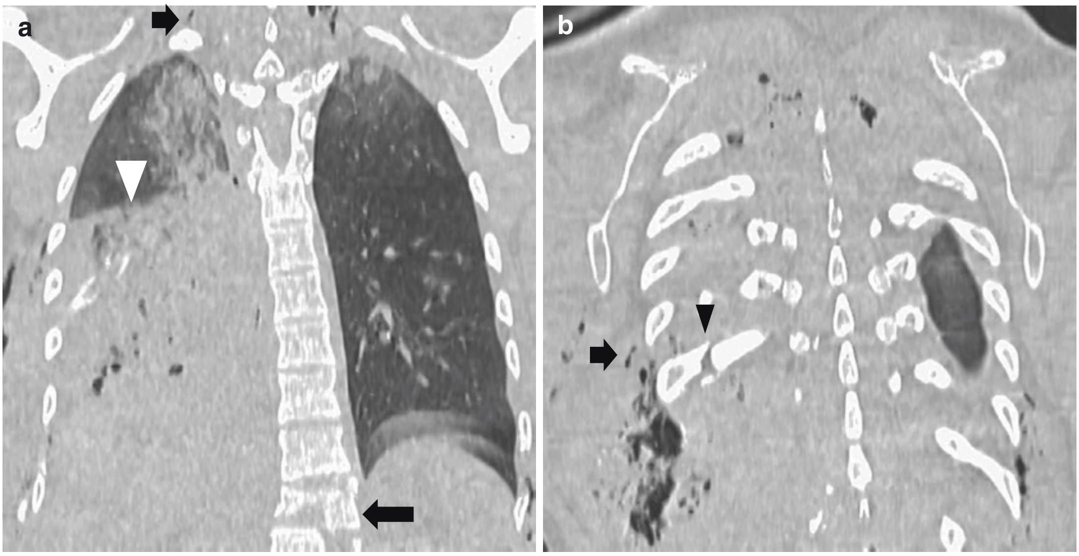

Fig. 11.7 MPR images (**a**, **b**) of the same patient showing lung contusions and subcutaneous emphysema (*black arrow* in **b**) of the right chest wall and lower portion of the neck (*short black arrow* in **a**). Multiple rib fractures (*arrowhead* in **b**) and T12 vertebral fracture (*long black arrow* in **a**)

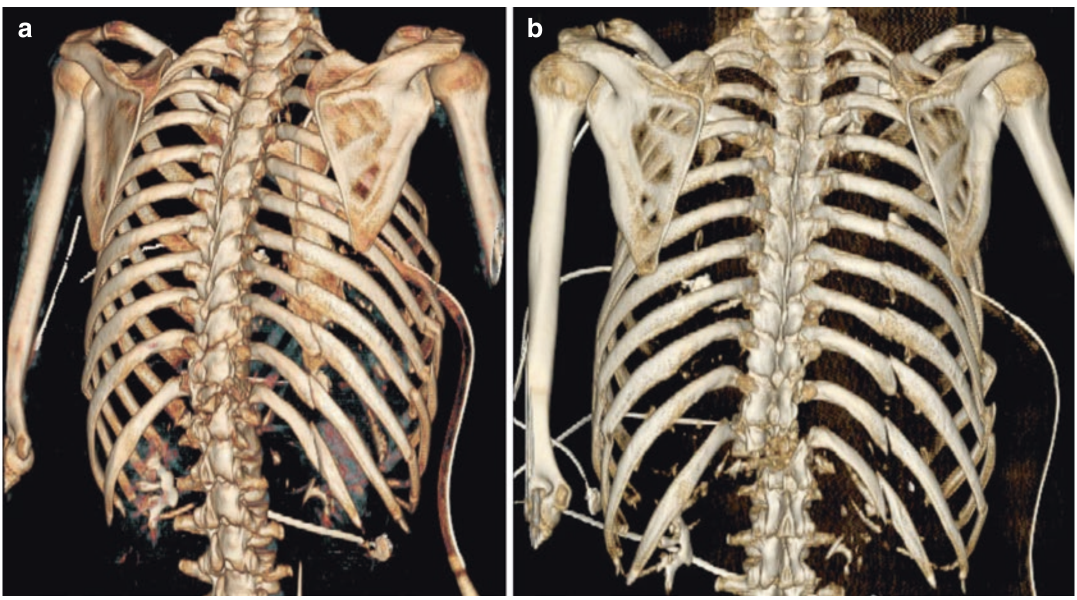

Fig. 11.8 3D reconstruction (**a**. Right posterolateral view; **b**. Posterior view) of the same patient showing flail chest with fractures from the seventh to twelfth rib. Chest drainage, endotracheal tube, venous catheter placement

Prolonged mechanical ventilation and pulmonary contusion are associated with the development of pneumonia and a poor outcome.

11.6.4 Treatment

Flail chest is usually managed supportively, with adequate analgesia and chest physiotherapy to assist volume expansion and secretion management, and to prevent secondary complications of atelectasis and pneumonia. Adequate analgesia is of paramount importance and may contribute to the return of normal respiratory mechanics.

Chest tube insertion might be necessary in case of complications such as hemo- or pneumothorax.

Posterior flail segments are easier to manage clinically because of the presence of strong muscular and scapular support and because of a patient's natural tendency to lie with his or her back against the mattress.

The surgical management has traditionally been reserved for the following indications: flail chest who require thoracotomy for other intrathoracic injuries, severe chest wall instability, persistent pain secondary to fracture malunion, and persistent or progressive loss of pulmonary function [40]. Surgical stabilization can effectively reduce the duration of mechanical ventilatory support and facilitating a shorter intensive care unit (ICU) stay and quicker recovery. The long-term benefits include restoration of normal chest wall geometry and improved pulmonary function testing.

Open fixation is also indicated for flail chest when thoracotomy is performed for other concomitant injuries. Rarely, severe rib injuries (e.g., flail chest) may be treated with open reduction internal fixation (ORIF), often in the setting of other severe traumatic injuries and in the hope that respiratory function will improve [12].

11.7 Sternal Fractures, Sternochondral Injuries, and Sternoclavicular Dislocation

11.7.1 Sternal Fractures

Sternal fractures usually occur in patients who involved in high-speed motor vehicle collision, with an incidence of 8–10%. Their importance lies in the high frequency of associated injuries such as fractured ribs, pulmonary and cardiac trauma, cranio-cerebral injuries, thoracic and lumbar spinal fractures, whiplash, and lower-extremity injuries [42].

Sternal fractures have associated mediastinal injuries in more than 50% of cases and a mortality of 22% due to cardiac and great vessel lesions.

11.7.1.1 Patterns of Injury

Fractures may occur in any segment of the sternum but most commonly affect the upper third of the sternal body and the manubrium. In 18% of cases, fractures occur at the manubriosternal joint. The fractures of the manubrium, rather than the ones at the sternal body, require higher force [43, 44].

The degree of displacement is proportional to the energy of the impact and, thus, to the likelihood of concomitant injuries.

The most common mechanism of sternal injuries is a direct impact between the sternum and the steering wheel or seat belt or air bag as a result of sudden deceleration. These injuries are more common in front-seat and/or restrained passengers and in frontal collisions.

Fractures may be displaced or undisplaced: an isolated undisplaced sternal fracture is considered a benign entity not associated with appreciable morbidity [45].

On the contrary, a sternal fracture with displacement or multisystemic trauma may alert the clinician to search for possible associated serious injury. In these cases, displaced fragments are often associated with soft-tissue and cardiothoracic damage due to the posterior shift of the lower fragment. The manubrial fractures may be associated with aortic and brachiocephalic vessel injuries, while the depressed sternal body fractures may determine myocardial injuries in 1.5–6% of patients. A general rule is: the more displaced the fracture, the higher the association with additional chest injuries.

Clinically, sternal fractures can be detected by inspection and palpation of the chest wall, but usually the diagnosis relies on imaging.

11.7.1.2 Imaging Evaluation and Findings

Plain Radiography

Frontal CXR detects only sternal fractures with lateral displacement and may be useful in detecting concomitant injuries (rib fractures, pulmonary contusions, hemothorax/pneumothorax). The presence of widened mediastinum, usually reflects a mediastinal hematoma; however, a hematoma due to a sternal fracture may be indistinguishable from one that is secondary to an acute aortic injury [46].

The essential radiographic projection required to establish the diagnosis of sternal injury is the lateral projection. Although lateral CXR is the best view to depict sternal fractures with sensitivity of 70%, it is hard to be obtained in the acute trauma setting and furthermore, it cannot show the associated thoracic injuries [22, 47].

US

Chest US may demonstrate sternal fractures as a focal discontinuity, or stepping of the anterior cortex, sometimes associated with a localized presternal hematoma, pericardial effusion, cardiac wall motion abnormalities, or hemopneumothorax [48]. US pitfalls are determined by its inaccuracy for the evaluation of the degree of fracture displacement and misdiagnosis in case of incomplete sternal fusion in children and in case of subcutaneous emphysema [49].

MDCT

In multitrauma patients, chest US and X-rays are replaced by MDCT examination because it identifies not only all sternal fractures and dislocations but also internal thoracic injuries and retrosternal hematomas. Moreover, multiplanar reconstructions (MPR) allow to visualize horizontal fracture lines [37], which may be missed on the axial scans (Fig. 11.9).

Electrocardiography (ECG), echocardiography, serial enzyme analysis, and telemetry monitoring are useful to show pericardial effusion or other signs of myocardial injury in case of depressed, displaced sternal fractures. In 40% of

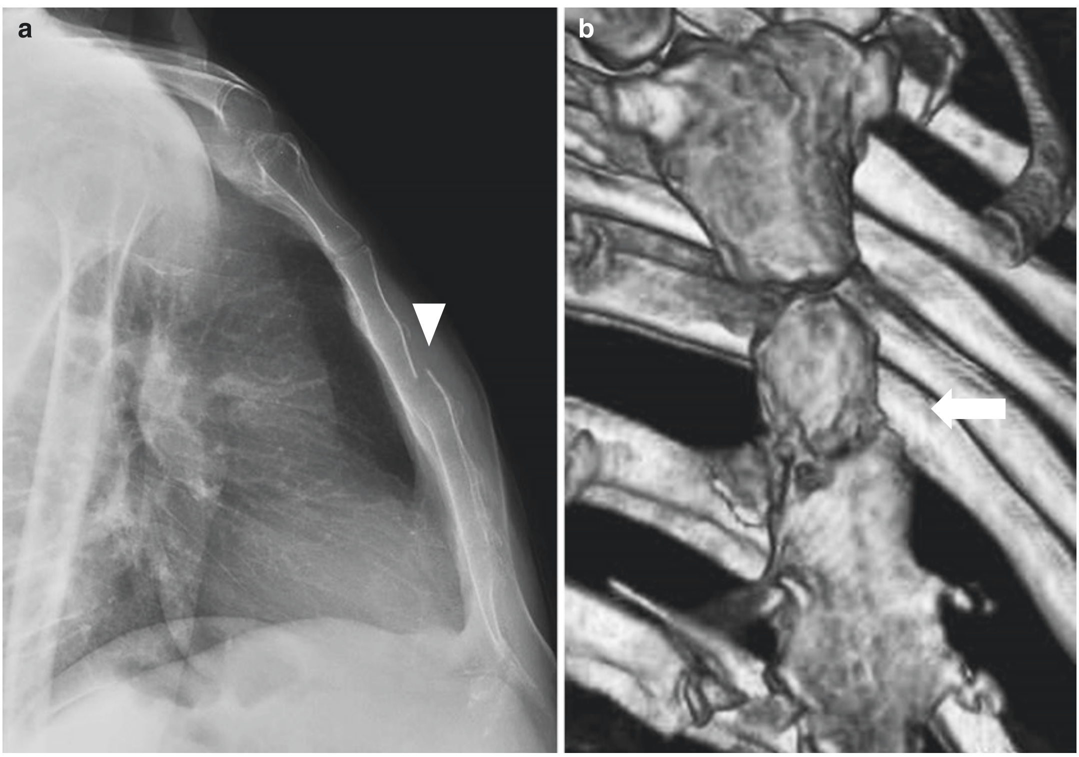

Fig. 11.9 Lateral X-ray projection of the sternum (**a**) showing a fracture in the upper third of its body (*arrowhead*) confirmed in 3D reconstruction of MDCT (**b**) (*arrow*)

cases, there are also compression fractures of the upper thoracic spine and more rarely of the cervical and lumbar spine. Clinically, there is violent chest pain, tenderness, bruising, and a stair-step sometimes palpable at the fracture line [44].

11.7.1.3 Natural History and Mortality

The isolated sternal fractures have a very good outcome in patients without abnormality in the ECG and no underlying chest pathology, with conservative management; most healing in a few months with a very low mortality rate (<1%).

The sternal fractures associated with other injuries have a higher mortality rate, ranging from 25–45%. Two-thirds of displaced or unstable sternal fractures have concomitant injuries which can be subdivided into three categories:

- soft-tissue injuries
- injuries to the chest wall
- injuries to the spine, extremities, and skull

Chest wall injuries include rib fractures, flail chest, and sternoclavicular dislocation. Pneumothorax, hemothorax, cardiac tamponade, and pulmonary contusions, as well as injuries to the abdomen and diaphragm are common soft-tissue injuries. Thoracic spine compression fractures, as well as trauma to the head, neck, and extremities are also common [50, 51].

The complications following sternal fractures may include short-term sequelae, such as chest pain post-injury and long-term problems such as nonunion and painful pseudarthrosis that may require surgical correction.

11.7.1.4 Treatment

Satisfactory pain control is usually achieved with oral analgesics as well as codeine and non-steroidal anti-inflammatory drugs (NSAIDs), in case of noncomplicated sternal fractures. Otherwise, the treatment of the underlying complication is necessary.

11.7.2 Sternochondral Injuries

There are few published papers on sternochondral injuries as they are often misdiagnosed.

11.7.2.1 Patterns of Injury

Most reported cases are in young males as the result of blunt trauma or a fall in sports, and they are represented by fractures and dislocations. The sternochondral dislocations are encountered especially in children and, when multiple, they produce an anterior flail chest. The most frequently reported site of injury is the sternochondral junction of first or second rib; in particular, Subhas et al. reported a characteristic pattern of injury at the sternochondral junction of the first rib, in which a small triangular chondral fragment remains attached to the sternum [29, 33].

11.7.2.2 Imaging Evaluation and Findings

Plain Radiography

The clinical presentation of sternochondral injuries may be identical to that of rib fractures, but cartilage injuries are not detectable with CXR, unless considerable costal calcification is present, so these injuries are usually overlooked on plain films.

US

US have been reported as effective in revealing sternochondral fractures [29].

On sonographic examination, the cartilages appear hypoechoic than the adjacent muscle and are delineated by a thin echogenic anterior margin. US has the advantage of an easy multiplanar scanning, the lack of ionizing radiations, and the opportunity of a bedside examination.

MDCT

Axial and MPR images from thin MDCT slices demonstrate focal interruption in the relatively high sternochondral density. Moreover, MDCT shows displacement of the adjacent segments and adjacent soft-tissue swelling [44], allowing to detect a hematoma with or without an active bleeding (Fig. 11.10).

MRI

MRI, with its intrinsic soft-tissue contrast and the ability to evaluate cartilage elsewhere in the musculoskeletal system, is very suitable for the evaluation of sternochondral junction; however, this approach has received low attention in literature, with only a single published series by Subhas et al. [33].

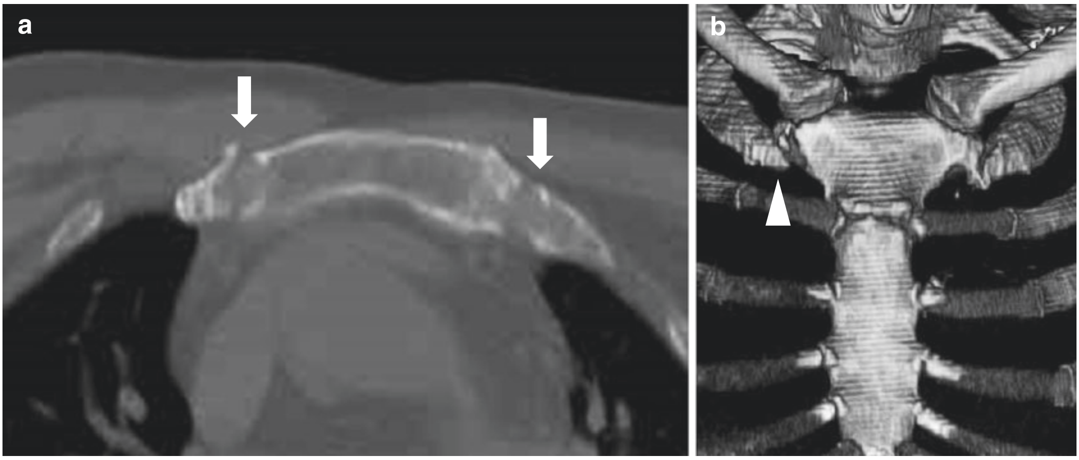

Fig. 11.10 Axial CT image (**a**) and 3D reconstruction (**b**) of a fracture of the first sternochondral joint (*arrows* in **a**) with right dislocation (*white arrowheads* in **b**)

11.7.2.3 Natural History and Mortality

Fracture or subluxation of the sternochondral joints is very common in wrestlers and mixed martial arts artists as a result of leverage and twisting again resistance. Symptoms are dyspnea, chest pain, worsening with deep breaths or arm movements, and tenderness (touching the joint area makes the pain worse). The outcome of these injuries is very good if they are isolated, while the presence of associated lesions (such as myocardial contusion, aortic rupture, pneumothorax, and hemothorax) worsens prognosis.

11.7.2.4 Treatment

Pain relief is the most common treatment. Oxygen terapy is used in response to possible hypoxemia and to decrease workload on the myocardium; cardiac monitoring is employed to treat eventual cardiac arrhythmias due to trauma. Pain management is used during the initial setting; the later rehabilitation allows healing and deep breathing, in order to prevent atelectasis, pneumonia, and other lung expansion complications.

In conclusion, these injuries are managed nonsurgically like osseous rib fractures.

11.7.3 Sternoclavicular Dislocation

The sternoclavicular dislocation are rare; they represent only 2–3% of shoulder dislocations, usually result from blunt or sport trauma and are distinguished in anterior or posterior.

11.7.3.1 Patterns of Injury

The anterior dislocations usually result from an anterior blow to the shoulder. They are more common than posterior ones and typically less dangerous because there is no significant risk of great vessel injury.

The posterior (or retrosternal) displacement results from a posterior blow to the shoulder or a blow to the medial clavicle; in particular, the most common mechanism is a massive direct trauma to the anterior chest wall, driving the medial end of the clavicle posteriorly or posterolaterally. It is frequently associated with life-threatening complications caused by the compression of vital structures such as the trachea, great vessels, and nerves [52].

Posterior dislocations at the left sternoclavicular joint are particularly dangerous considering the contiguity with the left subclavian vessels [53].

11.7.3.2 Imaging Evaluation and Findings

Even if all these fractures/dislocation can be detected by inspection and palpation of the chest wall, usually the diagnosis relies on imaging studies.

Plain Radiography

Standard view of a CXR may not provide a definitive diagnosis, but an abnormal position of the clavicle may arouse suspicion about the presence of sternoclavicular joint dislocation. Alternative views such as "*serendipity view*" (40° cephalic tilt) may provide more information.

MDCT

MDCT gives a detailed depiction of the sternoclavicular joint [46] and helps distinguish dislocation as either anterior or posterior and to assess an eventual vascular compromise (Figs. 11.11 and 11.12).

11.7.3.3 Natural History and Mortality

Clinically, they may present with pain, tenderness, a large hematoma and ecchymosis of the upper anterior chest wall, and a palpable or visible abnormality of the injured joint.

The main symptom of anterior dislocation is the deformity with palpable bump while in posterior dislocations there are dyspnea, dysphagia, tachypnea, and stridor, worsening in supine position. At physical examination, there is a prominence that increases with arm abduction and paresthesias increasing in elevation of the affected upper extremity; also venous congestion or diminished pulse when compared with contralateral side might be present [54, 55].

Many complications have been reported in the literature related to retrosternal dislocation of the medial end of the clavicle including subclavian compression and laceration, mediastinal com-

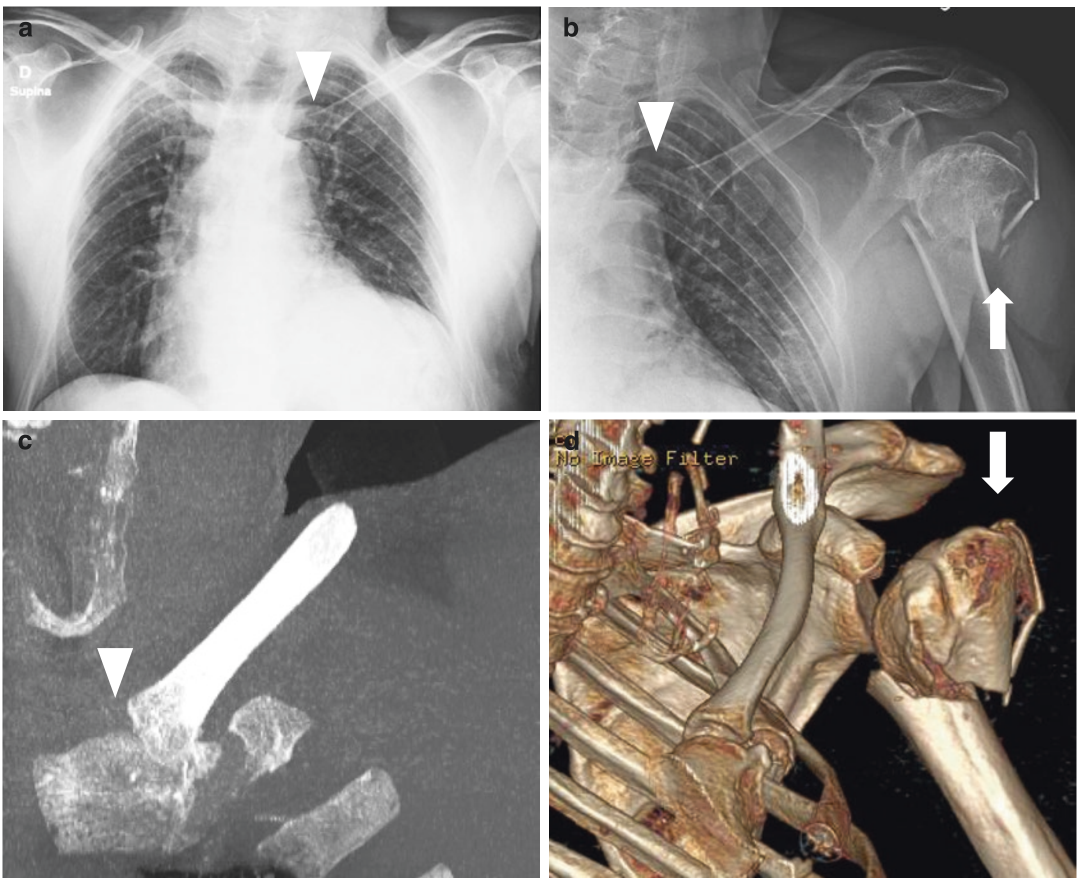

Fig. 11.11 Chest X-rays showing posterior dislocation of the left clavicle (*arrowhead* in **a**). Shoulder X-plain film of the same patient demonstrating subluxation of the left sternoclavicular joint (*arrowhead* in **b**) and left humeral head comminuted fracture (*arrow* in **b**). MIP (**c**) and 3D reconstruction of left shoulder at MDCT (**d**) confirms the left sternoclavicular subluxation (*arrowhead* in **c**) and the comminuted fracture of the left humeral head (*arrow* in **d**)

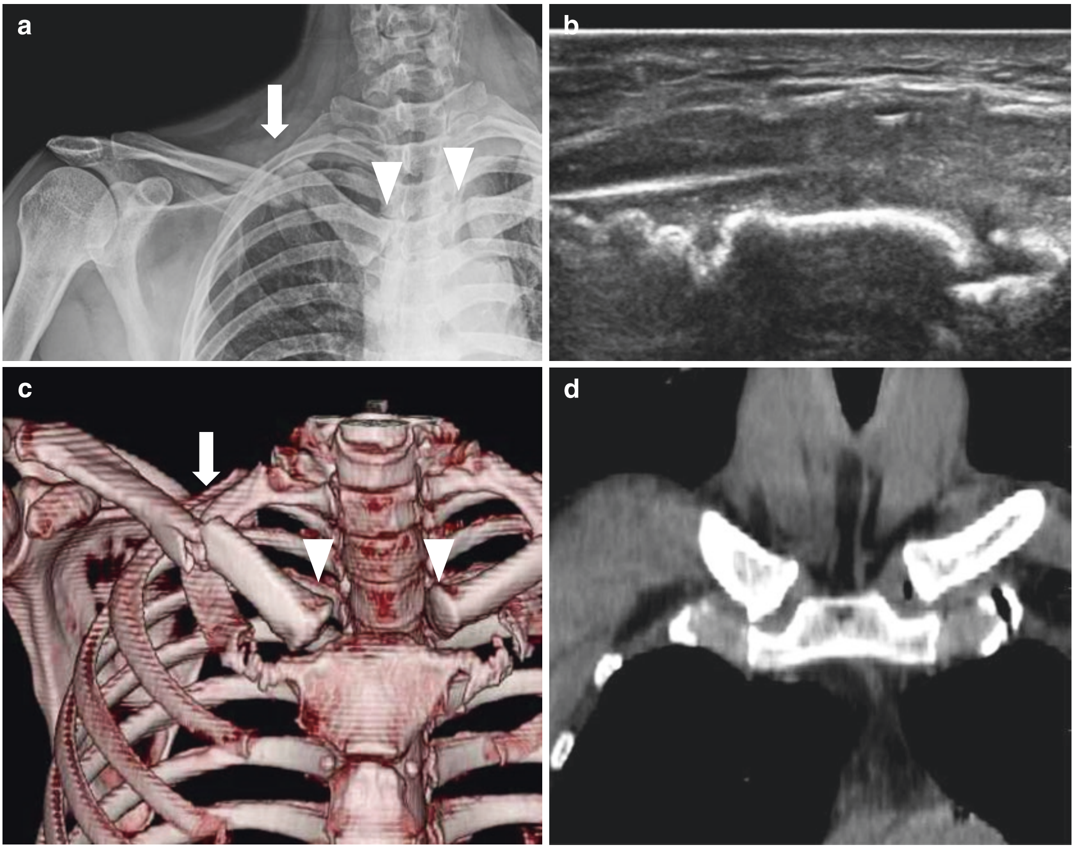

Fig. 11.12 (**a**) Chest X-rays showing a fracture of the medial third of the right clavicle (*arrow*) with a sternoclavicular subluxation (*arrowheads*) in a polytrauma patient; (**b**) US of the same patient demonstrates subluxation of the sternoclavicular joint; (**c**) 3D reconstruction confirming the right sternoclavicular subluxation (*arrowhead*) and clavicular fracture (*arrow*); (**d**) coronal MPR image of the bilateral sternoclavicular dislocations

pression, pneumothorax, esophageal rupture, and tracheal tear [56].

Anterior dislocations typically have a more benign course and conservative treatments are usually justified. However, they may result in chronic pain, ankylosis, and deformity.

11.7.3.4 Treatment

It consists of conservative therapy with ice, analgesia, and shoulder sling for immobility leading usually to complete recovery in about 1 week. Subluxation of the sternoclavicular joint will require the application of a clavicular splint or sling for 3–6 weeks.

Different therapies will be requested if the dislocation is associated to other chest wall or internal thoracic structures injuries.

11.8 Costovertebral Dislocation

The costovertebral articulations permit the respiratory movements of the ribs and consist of two gliding type of synovial joints, the costocentral joint (between the head of the rib and the lateral portion of the vertebral body) and the costotransverse articulation (between the tubercle of the rib and the tip of the transverse process).

In costovertebral joints, the head of a rib has two facets separated by a ridge which articulate with two vertebra, in particular the lower rib facet articulates with the upper costal facet of its own vertebra and the upper facet articulates with the lower facet of the vertebral body above.

The first rib articulates with the T1 vertebra only and the lowest three ribs articulate only with their own vertebral body [57].

The costovertebral joints are stabilized by articular capsules, the radiate ligaments, and the intra-articular ligaments (where they exist), the latest binding the medial ends of the ribs to the intervertebral disks.

The first, tenth, eleventh, and twelfth costocentral joints have no intra-articular ligament, so they have only one synovial compartment.

The costotransverse joints consist the tubercle of a rib articulating with the transverse process. The tubercle has two facets, the medial and the lateral articulating, respectively, with the tip of the transverse process (forming a plane synovial joint, reinforced by a capsule) and with the transverse process through three ligaments—lateral costotransverse, costotranverse, and superior costotransverse. Superior costotransverse ligament attaches the superior border of the neck of the rib to the transverse process, immediately above. The first rib has no superior costotransverse ligament [58]. All ribs have a feeble posterior costotransverse ligament which attaches the neck of the rib to the base of the transverse process and lateral border of the inferior articular process of the vertebra immediately above [59].

The lower two floating ribs are only attached by ligaments and do not form costotransverse joints.

11.8.1 Pattern of Injury

When subjected to severe trauma, these joints may be subluxated or dislocated. The costotransverse joint is the more likely of the two to be injured. The first costotransverse joint is especially vulnerable because of its unique position at the top of the rib cage [59].

The predominant mechanism of injury is a blunt trauma such as motor vehicle collision, sports, fall, and gunshot. Significant associated injuries include fracture dislocation of the spine and of the sternum. Symptoms include pain, swelling, deformity, altered motility, anesthesia, or paresthesia up to paraplegia (especially with a fracture of the spine associated).

11.8.2 Imaging Evaluation and Findings

11.8.2.1 Plain Radiography

CXR is the first radiological examination performed in case of suspected costovertebral dislocation but it is not the best because these displacements can be subtle, especially when CXR is performed with portable devices on the spinal board, as in multitrauma patients. On AP view, the more significant finding is an asymmetric rib interspace narrowing above and widening below the level of injury.

11.8.2.2 MDCT

The effect on ligamentous disruption and/or fracture may be assessed with axial MDCT images.

An important anatomic reference on MDCT axial images is the position of the head of the rib that is located at the level of the intervertebral disk enabling to evaluate this structure and the number the vertebral level as well. MDCT findings include the displacement of the costal head from the pedicle and the transverse process with its associated rib displaced out of view usually anteriorly (naked transverse process) [57].

11.8.3 Natural History and Mortality

Because these costovertebral articulations provide the contact points of the rib cage, disruption could impede the thoracic spine's ability to resist normal physiologic loads; particularly when it is involved the first costovertebral joint, associated with massive trauma to other part of the body, including the thorax, head, and abdomen [59]. The most common associated injuries are pneumothorax, hemothorax, pulmonary contusion, and flail chest. Local injuries more directly related to the first costovertebral fracture/dislocation include trauma of the brachial plexus, Horner's syndrome, and tear of the subclavian artery.

The outcome of these injuries depends on associated fractures and on the presence of neurologic impairment.

11.8.4 Treatment

Treatment ranges from strapping or bandaging of the chest and immobilization in uncomplicated cases up to surgical reduction in severe cases [60].

11.9 Scapulo-Thoracic Dissociation

The scapulo-thoracic dissociation (STD) is defined as the lateral displacement of the scapula from the thoracic cage after severe scapular girdle trauma [61], which leads to the disruption of the attachments of the shoulder girdle to the trunk, either by acromioclavicular or sternoclavicular dislocation or a fracture of the clavicle [62].

Closed rupture of the subclavian or axillary vessels, paralysis of the brachial plexus, and complete or partial avulsion of the shoulder muscles might be associated [63]. First described by Oreck et al. in 1984, STD is a rare situation and only a few other similar cases have been reported. It has different variants, from the absence of neurovascular injury [64] to bilateral involvement [65].

11.9.1 Patterns of Injury

STD is related to high-energy trauma, and it is usually caused by a lateral traction injury to the shoulder girdle. Approximately half of the cases is related to motorcycle accidents. Less frequently, other injury mechanisms are reported: motor vehicle crashes, rollover accidents, pedestrian accidents, and falls from heights [66]. The traction force disrupts the muscular tissues and the acromioclavicular ligaments/sternoclavicular ligaments making the neurovascular tissues vulnerable to injury [67].

Significant cardiac, chest wall and pulmonary injuries might be associated, while the skin is usually intact.

The concomitant lesions might be:

- arterial (88% [68]), such as subclavian or, less frequently, axillary artery ruptures
- osteo-articular, such as scapula or clavicle fractures, acromioclavicular dislocation/separation, sternoclavicular dislocation, or flail extremity (complete loss of motor and sensory function)
- neurologic, such as complete or, less frequently, partial brachial plexus paralysis with root avulsion or trunk rupture, or phrenic nerve injury with diaphragmatic paralysis

11.9.2 Imaging Evaluation and Findings

In STD, the first imaging procedure required is CXR in anterior-posterior projection; lateral view of the chest and shoulder plain film is recommended. STD diagnosis should be considered in patients with major trauma, with neurovascular upper limb deficit and if on CXR the ratio of distances between affected and the non-affected sides is 1.5 centimeters or greater (measured between the spine and the medial border of scapula) [66]. Widely displaced clavicle fracture, acromioclavicular separation, and sternoclavicular dislocation are usually related findings. If the diagnosis is uncertain, additional trans-scapular or oblique views of the affected scapula as well as MDCT scan are recommended [67].

MDCT angiography is indicated to detect injury of subclavian and axillary artery and is recommended in hemodynamically stable patient before surgery.

Bone and joints injuries must be reported on X-ray examinations, but the diagnosis is frequently missed [69], because of the presence of other severe associated injuries and the limited quality of radiographs performed in shock room (Figs. 11.12, 11.13, 11.14, and 11.15).

In the case of brachial paralysis, an MRI must be used to assess the nervous damage. This is essentially a preoperative assessment for the possibility of repair by nerve graft from an intact root [70].

11.9.3 Natural History and Mortality

The typical clinical presentation of STD is a swollen shoulder containing a large hematoma and extending to the thoracic wall; absent distal

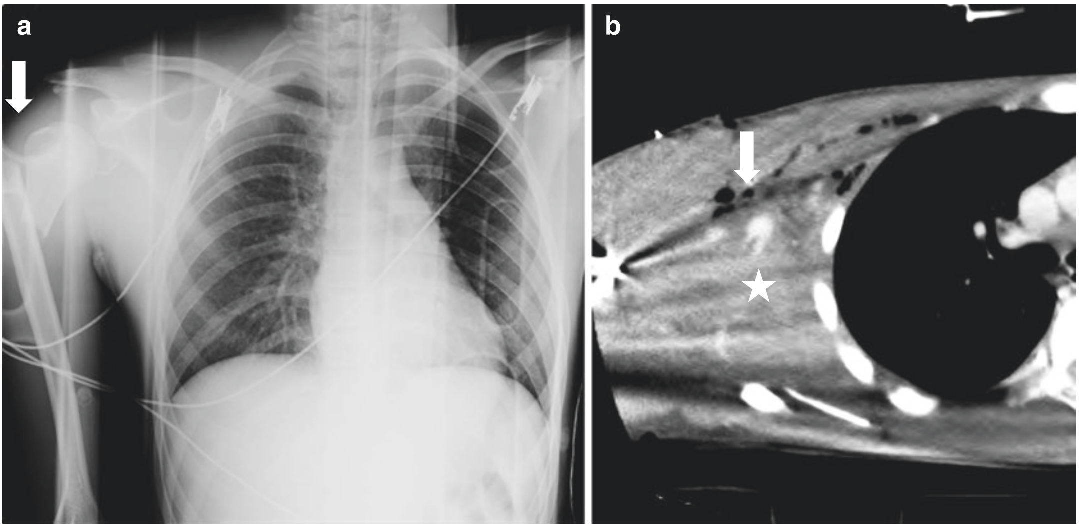

Fig. 11.13 Chest X-rays after MVA in a 14-year-old patient showing humeral shaft fracture with medial dislocation of the humeral head (*arrow* in **a**). Intraluminal axillary artery thrombosis (*star* in **b**) and subcutaneous emphysema (*arrow* in **b**)

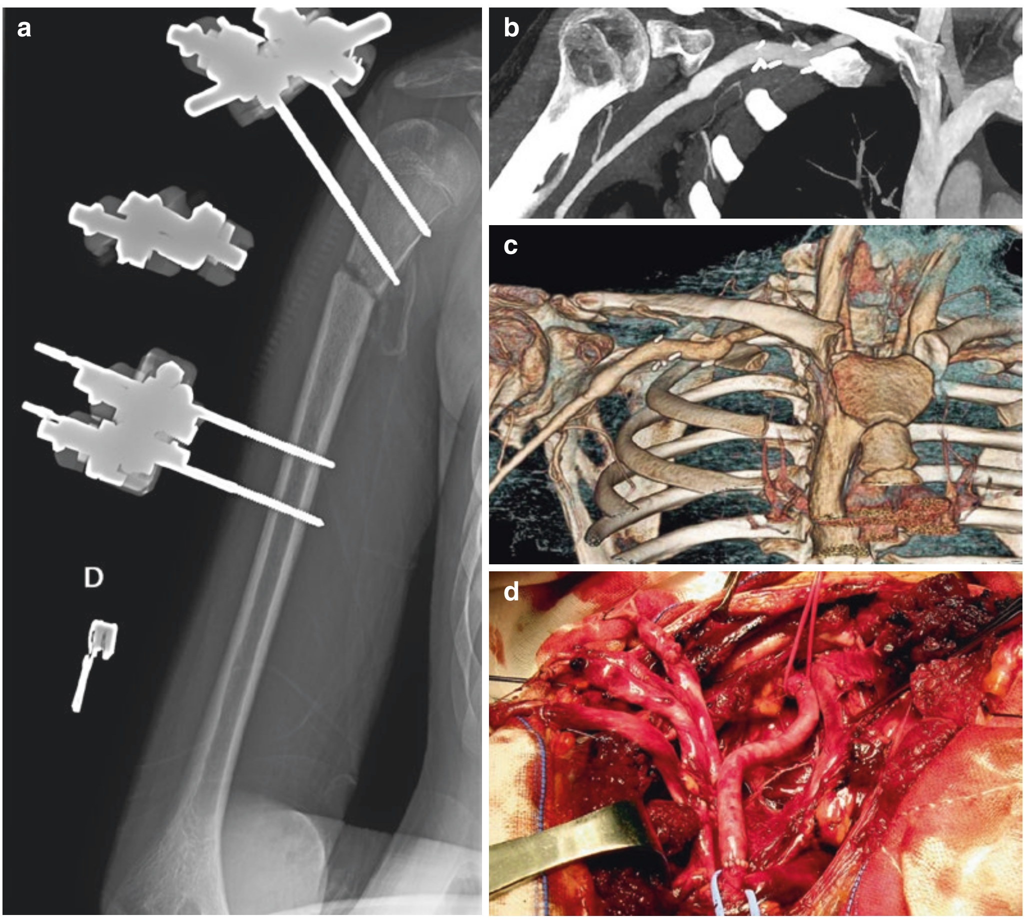

Fig. 11.14 Humeral X-ray after external fixation in the same patient (**a**). MIP (**b**) and VR reconstruction (**c**) of the subclavian and axillary artery after surgical repair. Surgical imaging of vascular reconstruction with saphenous vein stent graft of the axillary artery (**d**). Courtesy of Professor Seccia

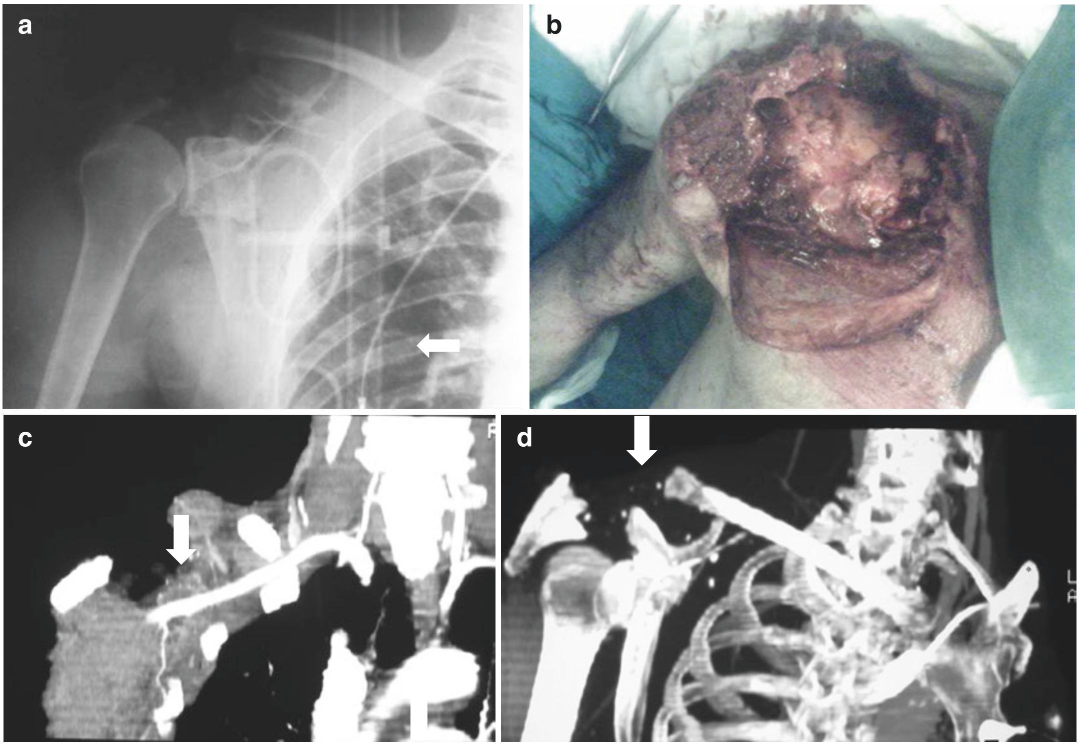

Fig. 11.15 (**a**) Shoulder X-ray of a 51-year-old patient after a MVA with clavicular fracture and scapulo-thoracic dissociation; (**b**) macroscopic appearance of the right shoulder's injury at the arrival in the emergency room. (**c**) MIP imaging with intravenous contrast medium of the shoulder showing clavicular fracture (*arrow*) with integrity of the subclavian and axillary artery; (**d**) 3D volume rendering reconstruction of the shoulder showing scapulo-thoracic dissociation

pulses with pallor of the distal end of the upper limb; a brachial plexus palsy and a sternoclavicular dislocation; a displaced fracture of the clavicle or a dislocation of the acromioclavicular articulation [62, 63, 71]. Common symptoms are pain and numbness or tingling in involved upper extremity. STD is often a missed or delayed diagnosis because in polytrauma patients the presence of concomitant severe injuries represents a sort of "distraction" for the emergency physician.

The arterial injury may be lethal in case of ongoing bleeding, and there is a 10% death rate in those who reach hospital, due to failure to treat hypovolemic shock or associated injuries [62]. Despite of arterial injuries are frequent, upper limb ischemia is a quite rare situation (12.5%), probably due to the good collateral arterial network around the shoulder [62]. It is important to notice that diagnosis of upper limb ischemia in this clinical situation is not so obvious because radial pulse might be absent due to the hypovolemic shock.

Nerve injuries occur in 94% of the patients [66]. Brachial plexus paralysis is usually complete, and it is associated with supraclavicular root avulsions or even rupture of the trunks in the interscalene space [61]. Partial damage is more frequently observed in retro- and infraclavicular injuries, and spontaneous recovery occurs in some cases but this is never complete [72].

It is important to emphasize that double lesions might occur in this type of traumatic injury: root lesions upper in the neck region and trunk ruptures lower down the arm [63]. Damage of the plexus determines the functional prognosis of STD.

There is a classification system for the injury severity of the STD [73]:

Type 1: Musculoskeletal injury alone
Type 2A: Musculoskeletal injury with vascular disruption
Type 2B: Musculoskeletal injury with incomplete neurological impairment of the upper extremity
Type 3: Musculoskeletal injury with incomplete neurological impairment of the upper extremity and vascular injury
Type 4: Musculoskeletal injury with complete brachial plexus avulsion

11.9.4 Treatment

The STD is usually associated with other life-threatening injuries, which lead the further management. In hemodynamically stable patients, MDCT angiography is widely recommended prior to surgery or interventional radiology. In hemodynamically unstable cases, however, urgent surgical intervention is required to control the arterial bleeding [66]. In arterial injuries, emergency revascularization is recommended only in patients with signs of severe ischemia, such as cold, temperature, and blue mottled color of the limb (compared with the opposite side) [62].

When the patient is stable, the shoulder is investigated in depth and then a decision regarding the final treatment could be taken. Shoulder stability in such cases can be obtained later by an arthrodesis. In many cases, scapulohumeral arthrodesis as a primary or secondary procedure has proven to be satisfactory [66, 71, 74]. In summary, the nerve reconstructions must try to restore elbow flexion. If it is weak and/or the shoulder is unstable and painful, a shoulder arthrodesis may be indicated [62].

Management of the nerve lesions is not in itself an emergency, but their severity means that there should be early assessment to plan the most appropriate time for surgical intervention. Nerve reconstruction by neurotization and/or nerve graft, preferably within a period of 2–6 months of the accident, is performed with the sole objective of recovering elbow flexion [62]. In case of complete brachial plexus avulsion, the functional recovery is usually poor and results mostly in a flail, anesthetic upper extremity [66].

Upper arm amputation remains a radical procedure which is only indicated when upper extremity function is not restorable. In these cases, the recommended treatment is an early above-elbow amputation with immediate prosthetic fitting in order to obtain a better functional outcome [66, 75].

The analysis of the previous literature about STD shows that approximately 11% of the reported patients died. However, probably the mortality of STD is overestimated because many of these patients die from the concomitant injuries during the preclinical course [66].

11.10 Scapular Fractures

Scapular fractures are about the 3–5% of all fracture of the shoulder girdle, where the most frequent fractures occur in the clavicle and proximal humerus [76].

This low fracture rate might be explained by its high mobility, helping in dissipating energy during trauma, together with the anatomical protection of the rib cage and the surrounding muscles [77].

The new evidences recently acquired show that the scapula plays an important role as dynamic stabilizer of the shoulder joint complex [78].

This is supported by several studies in the last two decades which have reported poor results following nonoperative management of both intra- and extra-articular fractures [79–81].

11.10.1 Pattern of Injury

Usually, scapular fractures are caused by high-energy injury (motor vehicle accidents account for 50%) through direct trauma to the shoulder region or indirect trauma by falling on outstretched hand. Non-accidental causes might be found in children injuries [82, 83].

Scapular fractures might be initially underestimated because attention is centered on the other frequent associated chest lesions such as a pneumothorax, hemothorax, pulmonary contusion, and spinal injuries [77]. In a retrospective review of data in the national trauma database, Baldwin et al. assessed that in association with scapular fractures rib fractures were present in 52.9% spine fractures, in 29.1%, lung injury in 47.1%, head injury in 39.1%, and clavicle fractures in 25.2% [84].

Also neurovascular lesions might be associated, especially regarding the brachial plexus, which is present in 13% of scapular fractures [85].

They are divided into three main groups:

- fractures of the body (50%); due to direct impact to the scapula or sudden muscular contraction (seizures or electric shocks) and respond well to conservative management.
- fractures of the scapular neck and glenoid fossa; among which, the fractures of the anatomic neck are rare, unstable, and necessitate surgical treatment. The variant, called "floating shoulder," is a scapular-neck fracture associated with an ipsilateral clavicular fracture.
- fractures of the acromion and the coracoid process [77].

11.10.2 Imaging Evaluation and Findings

A standard CXR should be initially performed in order to evaluate associated injuries, such as pneumothorax. Eventually, MDCT scan should be indicated to evaluate associated parenchymal lesions and exclude spinal fractures [76]. A correct radiographic study for scapular fractures should include an upright anterior-posterior scapula (called Grashey view), axillary, and scapula Y views.

In the Grashey view, we evaluate the glenopolar angle (GPA) and the lateral border offset (LBO). First measure is created by the intersection of a line drawn from the inferior glenoid fossa to the superior apex of the glenoid fossa and a line drawn from the superior apex of the glenoid fossa to the inferior angle of the scapula. The second measure concerns the medial displacement of the proximal fragment, relative to the distal fragment at the lateral border. In the Y view, we should draw a line parallel to the proximal fragment and a line parallel to the distal fragment and then measured the resulting angle in order to evaluate the angulation of the scapular fracture. The indications for surgery are based on these X-ray parameters. The axillary view is helpful to show fracture of the acromion and coracoid [76], subluxation or dislocation and intra-articular step-off (Figs. 11.16, 11.17, 11.18, and 11.19).

As scapular fractures are often encountered in polytrauma patients, MDCT scan is almost always performed with higher accuracy in defining the scapular deformity, especially thanks to the presence of MPR and three-dimensional imaging [86].

11.10.3 Natural History and Mortality

The physical examination, as well as prognosis, may depend on the commonly associated injuries, especially those that are life threatening, usually located to the spine, skull, and thorax. When possible, the suspected shoulder should be assessed preferably while patient is sitting or standing and the clinical findings are medial and caudal displacement of the shoulder with marked asymmetry [85].

11.10.4 Treatment

Treatment approaches are decided on the basis of imaging evaluation and measurements, in particular on angular deformity and displacement. However, it is recommended to take into account other ipsilateral injuries, patient activity level, hand dominance, and any comorbidities. In the review article of P. A. Cole et al. about scapular fractures nonoperative management of extra-articular scapula fractures is recommended for displacement smaller than 15–20 mm and angle lower than 30°–45° (minimal displacement) in order to obtain a better clinical outcome. When a clear deformity of scapula is depicted on X-ray, a MDCT scan with

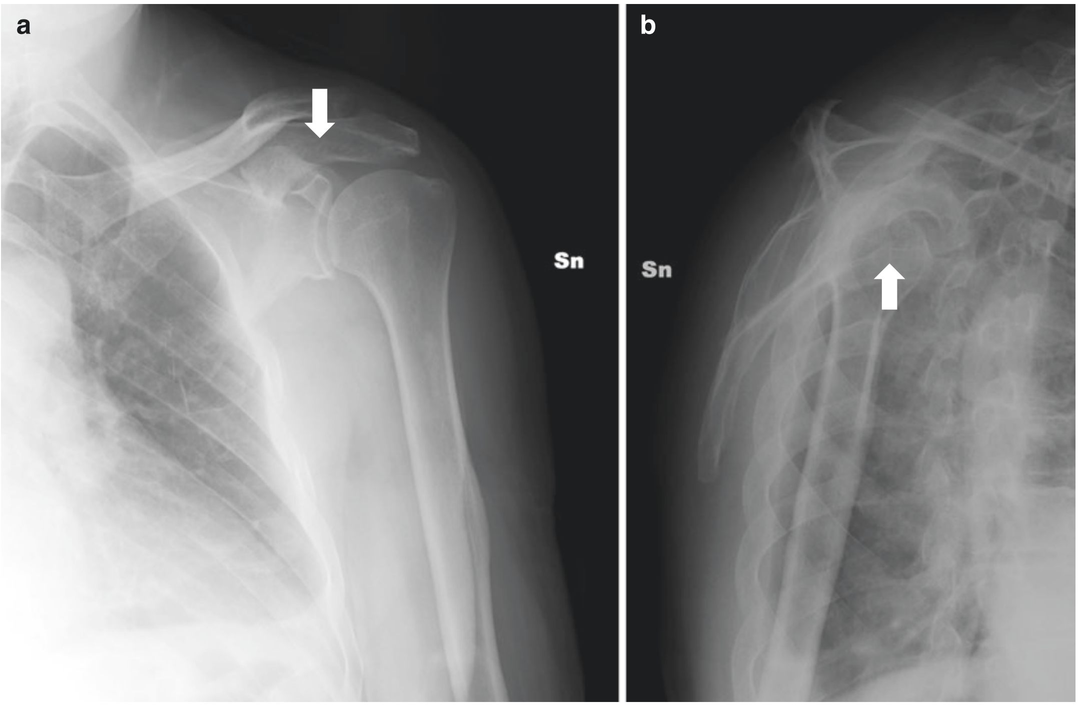

Fig. 11.16 Anterior-posterior (**a**) and Y (**b**) X-ray shoulder projections of a 64-year-old man after thoracic blunt trauma showing multiple fractures of the left scapula with fragments displacement (*arrows*)

Fig. 11.17 Axial CT images showing multiple scapular fractures. The fractures involve the scapular apex (*arrow* in **a**) and cross the whole body (*arrow* in **b**). Axial 4 mm-thick MIP images showing the involvement of the spine of the scapula (*arrows* in **c**, **d**)

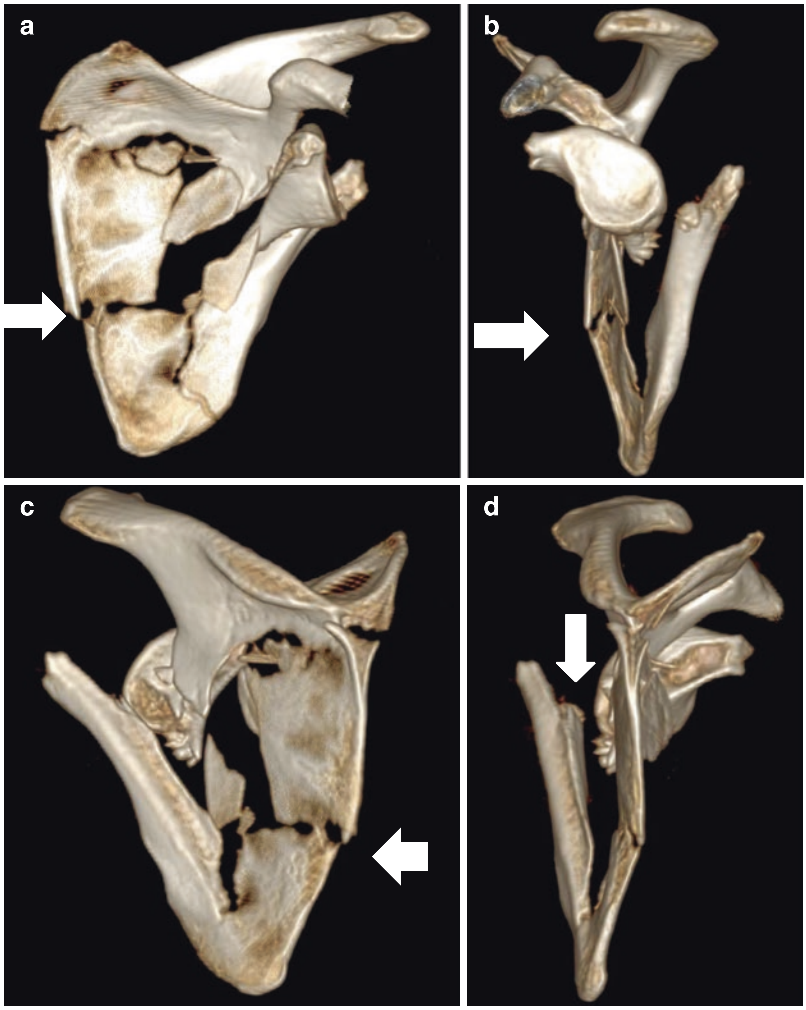

Fig. 11.18 Selective 3D reconstruction images of a 26-year-old man showing multiple fractures of the scapular bone involving the whole body. Anterior (**a**), lateral (**b**), posterior-medial (**c**), and medial view (**d**). Displacement and angulation of the multiple fragments of the body are here depicted (*arrows*). These images demonstrate that the acromial process and the glenoid cavity are not involved

3D reconstruction should be performed prior to surgical intervention to confirm the entity of displacement. Surgical intervention is indicated if GPA ≤ 22°, LBO ≥ 2 cm, angulation ≥ 45°, and articular gap/step-off ≥ 4 mm. In case of multiple shoulder elements, fractures involving the superior shoulder suspensory complex (SSSC, which consists in the shoulder's osseo-ligamentous connection of the acromion, coracoid, and glenoid processes of the scapula and their respective capsule–ligamentous connections) causing instability of the displaced floating shoulder the threshold for open reduction internal fixation is lower: LBO ≥ 15 mm and angulation ≥ 30° [87].

It is important to note that skin integrity should be assessed for appropriate timing of surgery. It is preferable to wait on surgery until the skin has re-epithelialized [76].

11.11 Chest Wall Hematoma

Chest wall hematoma often is caused by traumatic event or iatrogenic procedures and it is usually treated conservatively due to his self-limiting course [88].

Post-traumatic expanding chest wall hematomas, with underlying active arterial bleeding, are a rare eventuality and they require urgent surgical

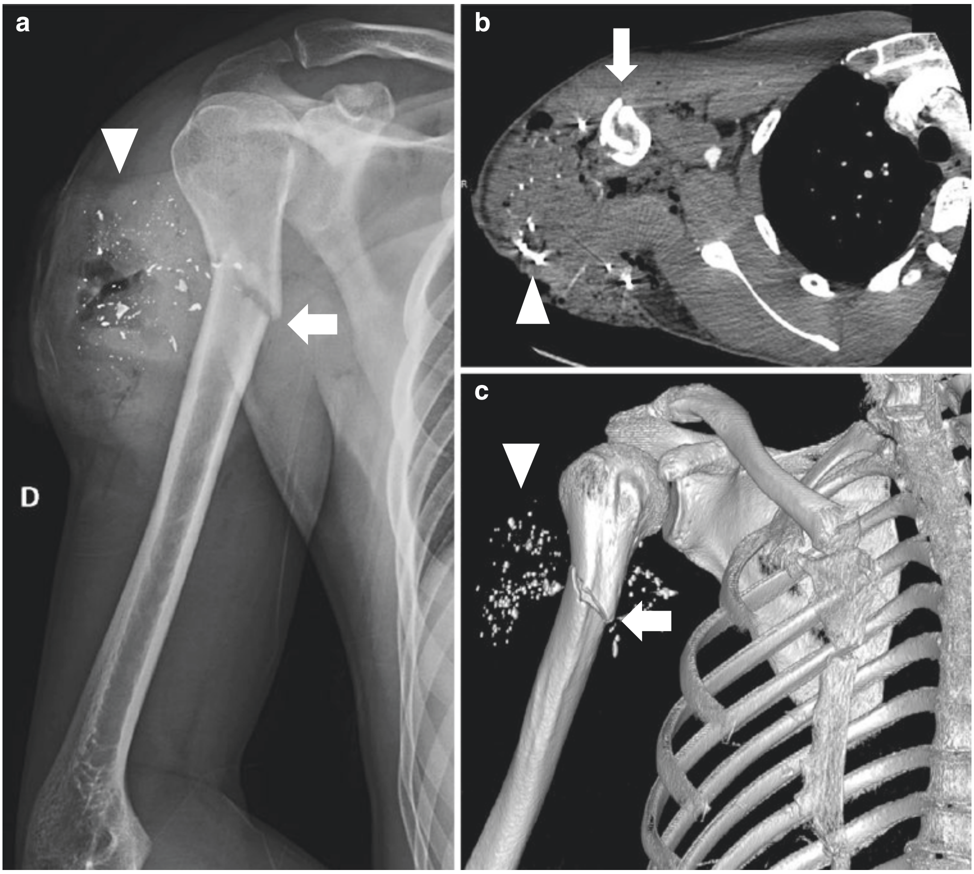

Fig. 11.19 Shoulder X-rays (**a**) in a 39-year-old patient after a gunshot. Axial CT imaging (**a**) and VR reconstruction (**b**) showing humeral shaft fracture (*arrows* in **a**–**c**) and multiple metallic fragments (*arrowheads* in **a**–**c**)

exploration with hemostasis and/or angiographic embolization [89].

11.11.1 Pattern of Injury

Chest wall hematoma are usually associated with blunt and penetrating trauma, in particular when rib fractures occur. Frequently in traumatic rib fractures, the intercostal, internal mammary, or subclavian arteries might be injured, creating a blood collection between parietal pleura and endothoracic fascia, defined as extrapleural hematomas [37].

The mandatory use of seat belts resulted in the last decades in a significant decrease of injuries and deaths from car accidents [90].

At the same time, hollow viscus and soft-tissue injuries number increased because of the seatbelt itself, especially in women [91].

In female population, the seat belt during motor vehicle accident might represent a potential cause of injuries of the breast due to the shear and compressive forces from the chest strap over the breast and bony thorax [92, 93].

Soft-tissue injuries are most of the time represented by nonexpanding hematomas or ecchymosis or avulsion.

11.11.2 Imaging Evaluation and Findings

Radiographically, extrapleural hematoma might be depicted as bulging convex chest wall mass that may project into the thoracic cavity.

11.11.2.1 MDCT-US

Usually, a MDCT scan is performed in polytrauma patients. Imaging studies like US or MDCT might help to confirm the diagnosis by differentiating the belonging chest wall compartment. The typical imaging features are the same as bleeding in the other areas. US scan shows inhomogeneous hypoecoic fluid collection in the chest wall thickness. Non-contrast-enhanced MDCT scan might confirm the hyperdense fluid collection within the wall. Contrast-enhanced MDCT is able to differentiate arterial or venous origin of the hematoma. In arterial bleeding, we can find hyperdense spot in the arterial phase within the collection and we might identify the source of bleeding. In subsequent phases, the density of the fluid should increase due to the contrast medium accumulating within the collection. The typical clinical low-pressure and self-limiting features together with the absence of hyperdense spot in arterial phase of enhanced MDCT allows to diagnose the venous origin of hematoma (Figs. 11.20 and 11.21).

Angiography is usually performed in order to treat active arterial bleeding, when indicated (Fig. 11.22).

11.11.3 Natural History and Mortality

Chest wall hematoma could be induced by arterial or venous injuries. Arterial bleeding usually leads to rapidly enlarging hematomas with mass effect and displacement of adjacent structures. Venous blood collection are commonly low-pressure and self-limited. Diagnosis might be made clinically by swelling/bruising or might be nonspecific findings like chronic anemia, fever, and plural effusion. Usually, the clinical presentation is characterized by a painful, pulsating mass was on the chest wall. Physical examination might show distended discoloration of the involved chest wall area. The active

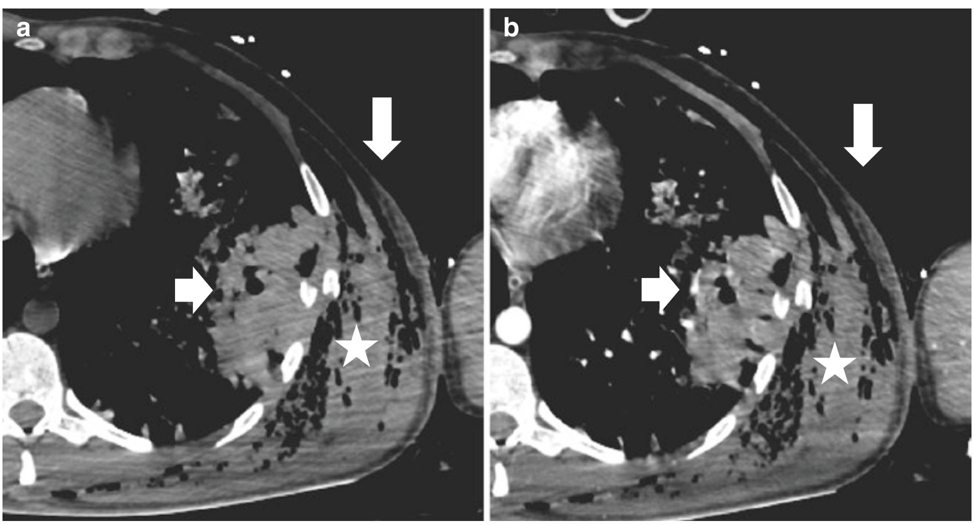

Fig. 11.20 Axial CT images of a 26-year-old man after thoracic blunt trauma showing a hematoma of the posterior-lateral thoracic wall (*stars* in **a**–**d**) associated with subcutaneous emphysema (*long arrows* in **a**–**d**) and with left lateral rib fracture and lung contusions (*short arrows* in **a**–**d**). Different phases acquired: unenhanced CT scan (**a**), arterial (**b**), venous (**c**), and delayed (**d**) scan show there is no active bleeding

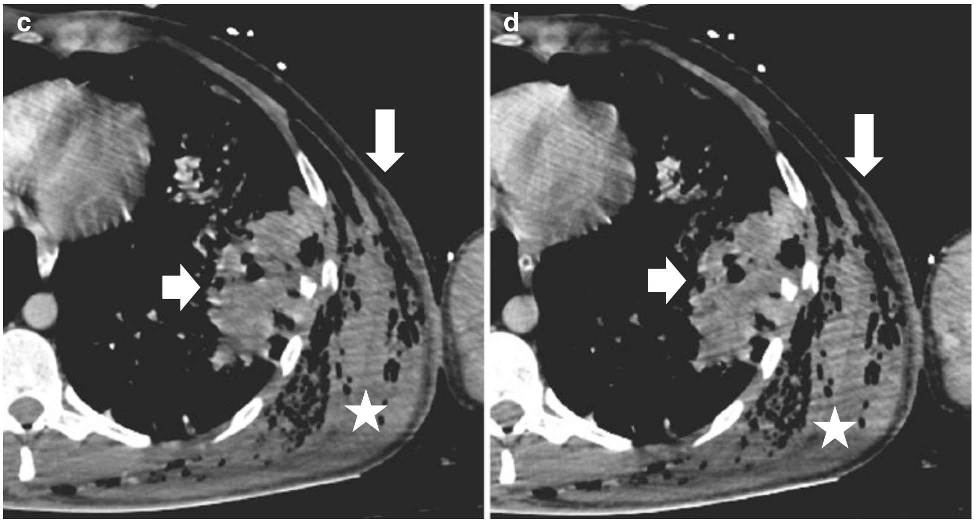

Fig. 11.20 (continued)

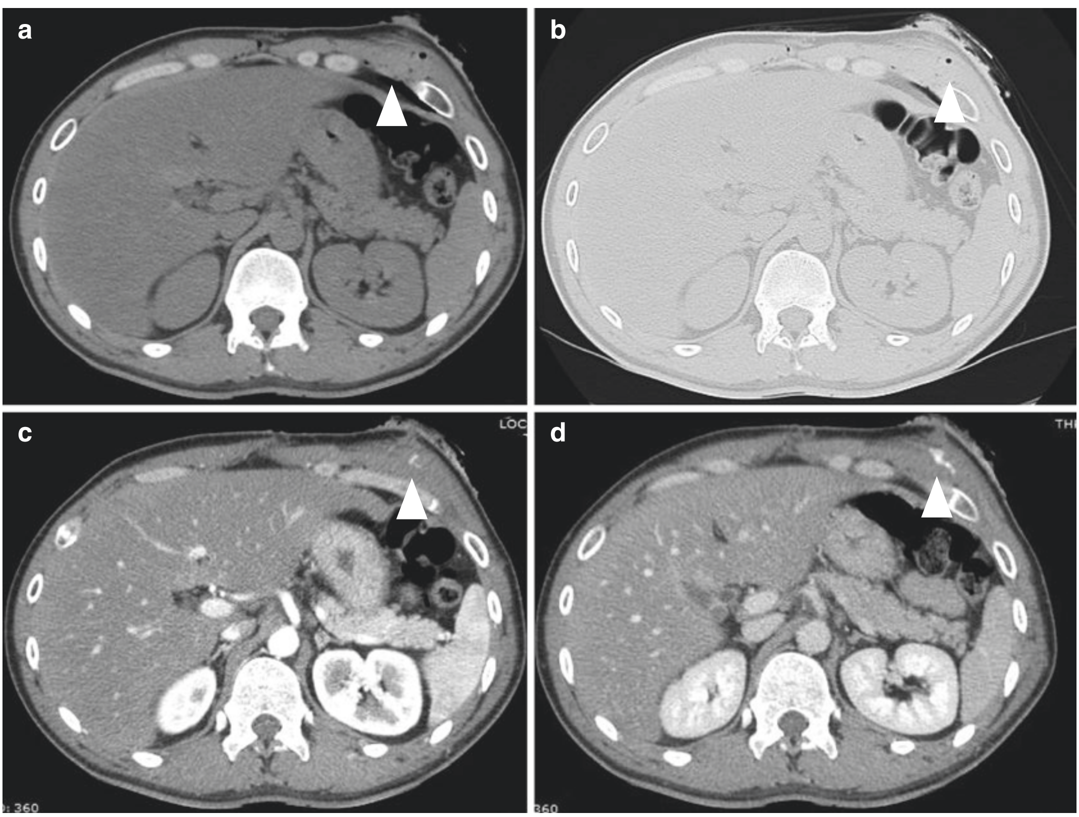

Fig. 11.21 Anterior left chest wall trauma after stab wound injury, in a 26-year-old patient, showing chest wall hematoma with subcutaneous emphysema (*arrowheads* in **a**, **b**) and signs of active bleeding in arterial (**c**) and venous (**d**) phase (*arrowheads*)

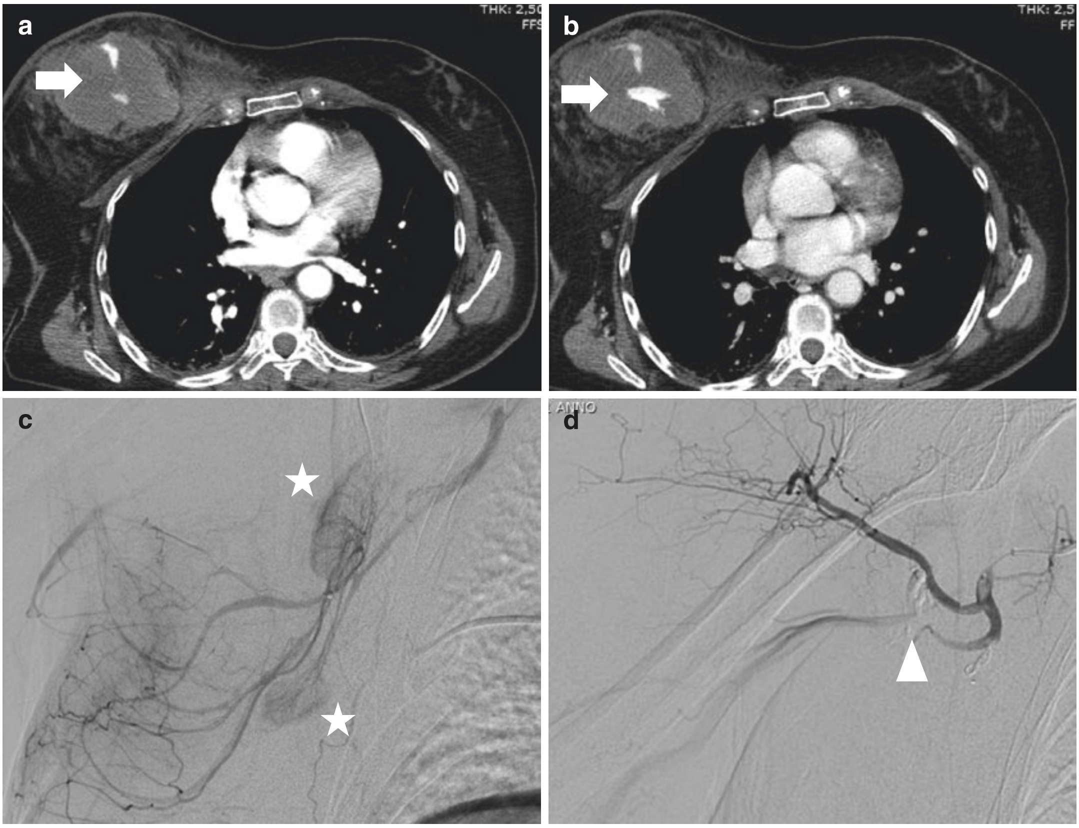

Fig. 11.22 Blunt traumatic hematoma of right breast showing signs of active bleeding in arterial (**a**) and venous (**b**) phase (*arrows*); Diagnostic angiographic procedure (**c**) showing arterial blush (*stars* in **c**). Angiographic endovascular embolization imaging post coils placement showing resolution of bleeding (*arrowheads* in **d**)

range of motion over the ipsilateral shoulder might also be limited because of this expanding anterior chest wall hematoma. Large chest wall hematomas with important active arterial bleeding might be life-threatening due to their systemic and hemodynamic consequences [88].

11.11.4 Treatment

Venous hematomas are usually self-limiting and treated conservatively. In case of arterial bleeding, there are several ways to manage the hemorrhage: selective angiographic embolization, US-guided hemostatic injection, and conservative management, such as compression [94].

When there's no injury of the great vessels, MDCT angiography often allows to detect bleeding from branches of the internal mammary artery, which can be embolized successfully with low complication rates [95].

If blunt injury to the subclavian artery is described, surgical intervention is needed in order to guarantee the blood supply to the upper limb [96].

References

1. Demirhan R, Onan B, Oz K, Halezeroglu S. Comprehensive analysis of 4205 patients with chest trauma: a 10-year experience. Interact Cardiovasc Thorac Surg. 2009;9:450–3.
2. Battle CE, Hutchings H, Evans PA. Risk factors that predict mortality in patients with blunt chest wall trauma: a systematic review and meta-analysis. Injury. 2012;43:8–17.
3. Moore E, et al. Organ injury scaling III: chest wall, abdominal vascular, ureter, bladder and urethra. J Trauma. 1992;33(3):337–9.
4. Mayberry JC. Imaging in thoracic trauma: the trauma surgeon's perspective. J Thorac Imaging. 2000;15: 76–86.

5. Cattaneo L. Compendio di anatomia umana. 1986.
6. Anastasi G. Trattato di anatomia umana, vol. 1; 2010.
7. Scaglione M, et al. Multi-detector row computed tomography and blunt chest trauma. Eur J Radiol. 2008;65:377–88.
8. Wolf SJ, et al. Blast injuries. Lancet. 2009;374:405–15.
9. Wanek S, Mayberry JC. Blunt thoracic trauma: flail chest, pulmonary contusion, and blast injury. Crit Care Clin. 2004;20:71–81.
10. Chapman BC, et al. A novel radiographic score based on fracture pattern that predicts pneumonia, respiratory failure and tracheostomy. J Trauma Acute Care Surg. 2016;80(1):95–101.
11. Rathachai Kaewlai MD, et al. Multidetector CT of blunt thoracic trauma. Radiographics. 2008;28:1555–70. doi:10.1148/rg.286085510.
12. Oikonomou A, Prassopoulos P. CT imaging of blunt chest trauma. Insights Imaging. 2011;2:281–95. doi:10.1007/s13244-011-0072-9.
13. Easter A. Management of patients with multiple rib fractures. Am J Crit Care. 2001;10(5):320.
14. Sirmali M, et al. A comprehensive analysis of traumatic rib fractures: morbidity, mortality and management. Eur J Cardiothorac Surg. 2003;24(1):133.
15. Al-Koudmani I, et al. Chest trauma experience over eleven-year period at al-mouassat university teaching hospital-Damascus: a retrospective review of 888 cases. J Cardiothorac Surg. 2012;7:35; Epub 2012 Apr 19.
16. Collins J. Chest wall trauma. J Thorac Imaging. 2000;15:112–9.
17. Barnea Y, Kashtan H, Skornick Y, Werbin N. Isolated rib fractures in elderly patients: mortality and morbidity. Can J Surg. 2002;45:43–6.
18. Stawicki SP, Grossman MD, Hoey BA, Miller DL, Reed JF. Rib fractures in the elderly: a marker of injury severity. J Am Geriatr Soc. 2004;52:805–8.
19. Cho SH, Sung YM, Kim MS. Missed rib fractures on evaluation of initial chest CT for trauma patients: pattern analysis and diagnostic value of coronal multiplanar reconstruction images with multidetector row CT. Br J Radiol. 2012;85(1018):e845–50.
20. Love JC, Symes SA. Understanding rib fracture patterns: incomplete and buckle fractures. J Forensic Sci. 2004;49(6):1153–8.
21. Bhavnagri SJ, Mohammed TL. When and how to image a suspected broken rib. Cleve Clin J Med. 2009;76(5):309–14. doi:10.3949/ccjm.76a.08026.
22. Primack SL, Collins J. Blunt nonaortic chest trauma: radiographic and CT findings. Emerg Radiol. 2002;9:5–12.
23. Hurley ME, Keye GD, Hamilton S. Is ultrasound really helpful in the detection of rib fractures? Injury. 2004;35(6):562–6. doi:10.1016/S0020-1383(03)00263-8.
24. Bansidhar BJ, et al. Clinical rib fractures: are follow-up chest X-rays a waste of resources? Am Surg. 2002;68(5):449–53.
25. Chien CY, et al. The number of displaced rib fractures is more predictive for complications in chest trauma patients. Scand J Trauma Resusc Emerg Med. 2017;25:19. doi:10.1186/s13049-017-0368-y.
26. Kerr-Valentic MA, et al. Rib fracture pain and disability: can we do better? J Trauma. 2003;54(6):1058.
27. Orth RC, Laor T. Isolated costal cartilage fracture: an unusual cause of an anterior chest mass in a toddler. Pediatr Radiol. 2009;39(9):985–7. doi:10.1007/s00247-009-1276-8.
28. Ontell FK, Moore EH, Shepard JA, et al. The costal cartilages in health and disease. Radiographics. 1997;17(3):571–7. doi:10.1148/radiographics.17.3.9153697.
29. Malghem J, Vande Berg B, et al. Costal cartilage fractures as revealed on CT and sonography. Am J Roentgenol. 2001;176:429–32.
30. Lopez V, et al. Costal cartilage fractures and disruptions in a rugby football player. Clin J Sport Med. 2013;23(3):232–4. doi:10.1097/JSM.0b013e31825b55ed.
31. Turk F, Kurt AB, Saglam S. Evaluation by ultrasound of traumatic rib fractures missed by radiography. Emerg Radiol. 2010;17(6):473–7. doi:10.1007/s10140-010-0892-9.
32. Griffith JF, Rainer TH, Ching AS, et al. Sonography compared with radiography in revealing acute rib fracture. AJR Am J Roentgenol. 1999;173(6):1603–9. doi:10.2214/ajr.173.6.10584808.
33. Subhas N, Kline MJ, et al. MRI evaluation of costal cartilage injuries. Am J Roentgenol. 2008;191:129–32.
34. Nummela M. et al. The incidence and effect on mortality of costochondral fractures in blunt polytrauma patients—a review of 1461 consecutive whole body CT studies for trauma. Radiological Society of North America 2016.
35. Piao Z, et al. The response of costal cartilage to mechanical injury in mice. Plast Reconstr Surg. 2007;119(3):830–6. doi:10.1097/01.prs.0000240817.11002.3e.
36. Gregory PL, Biswas AC, Batt ME. Musculoskeletal problems of the chest wall in athletes. Sports Med. 2002;32(4):235–50.
37. Sangster GP, González-Beicos A, et al. Blunt traumatic injuries of the lung parenchyma, pleura, thoracic wall, and intrathoracic airways: multidetector computer tomography imaging findings. Emerg Radiol. 2007;14:297–310. doi:10.1007/s10140-007-0651-8.
38. Borrelly J, Aazami M. New insights into the pathophysiology of flail segment: the implication of anterior serratus muscle in parietal failure. Eur J Cardiothorac Surg. 2005;28:742–9.
39. Cappello M, Legrand A, De Troyer A. Determinants of rib motion in flail chest. Am J Respir Crit Care Med. 1999;159:886–91.
40. Pettiford BL, et al. The management of flail chest. Thorac Surg Clin. 2007;17:25–33.
41. Athanassiadi K, et al. Management of 150 flail chest injuries: analysis of risk factors affecting outcome. Eur J Cardiothorac Surg. 2004;26:373–6.
42. Oyetunji TA, Jackson HT, et al. Associated injuries in traumatic sternal fractures: a review of the National Trauma Data Bank. Am Surg. 2013;79(7):702–5.

43. Crestanello JA, Samuels LE, et al. Sternal fracture with mediastinal hematoma: delayed cardiopulmonary sequelae. J Trauma. 1999;47:161–4.
44. Jurik AG, editor. Imaging of the sternocostoclavicular region. Heidelberg: Springer. isbn:103-540-33147-6.
45. Khoriati A-A, Rajakulasingam R, et al. Sternal fractures and their management. J Emerg Trauma Shock. 2013;6(2):113–6.
46. Restrepo CS, Santiago Martinez MD, et al. Imaging appearances of the sternum and sternoclavicular joints. Radiographics. 2009;29:839–59.
47. Soto J, Lucey B. Emergency radiology: the requisites. 2nd ed. Philadelphia, PA: Elsevier. isbn:978-0-323-37640-2.
48. Fisher DA. Imaging in sternal fractures. Medscape, Jan 11, 2016.
49. Wongwaisayawan S, Suwannanon R, et al. Emergency thoracic US: the essentials. Radiographics. 2016;36(3):640–59. doi:10.1148/rg.2016150064.
50. Grosse A, Grosse C, et al. MRI findings of prolonged post-traumatic sternal pain. Skelet Radiol. 2007;36(5):423–9.
51. Roy Shapira A, Levi I, et al. Sternal fractures: a red flag or a red herring? J Trauma. 1994;37(1):59–61.
52. Laffosse JM, Reina N, et al. Variations du syndrome d'impaction de l'épaule: la luxation sternoclaviculaire postérieure. Revue de Chirurgie Orthopédique et Traumatologique. 2010;96(7):869–73.
53. Peters S, Nicolas V, et al. Multidetector computed tomography-spectrum of blunt chest wall and lung injuries in polytraumatized patients. Clin Radiol. 2010;65(4):333–8.
54. Morell DJ. Thyagarajan. Sternoclavicular joint dislocation and its management: a review of the literature. World J Orthop. 2016;7(4):244–50.
55. Kirby JC, Edwards E, et al. Management and functional outcomes following sternoclavicular joint dislocation. Injury. 2015;46(10):1906–13.
56. Cruz MF, Erdeljac J, et al. Posterior sternoclavicular joint dislocation in a division football player: a case report. Int J Sports Phys Ther. 2015;10(5):700–11.
57. O'Brien SD, Bui-Mansfield LT. Costovertebral fracture dislocations: important radiographically difficult diagnosis. J Comput Assist Tomogr. 2009;33:748Y751.
58. Saker E, Graham RA. Ligaments of the costovertebral joints including biomechanics, innervations, and clinical applications: a comprehensive review with application to approaches to the thoracic spine. Cureus. 2016;8(11):e874.
59. Christensen EE, Dietz GW. Injuries of the first costovertebral articulation. Radiology. 1980;134:41–3.
60. Brooksher WR, Smith F. Costovertebral dislocation of the twelfth rib. JAMA. 1933;100(11):816.
61. Leffert RD. Brachial plexus. In: Green DP, Hotchkiss RN, Pederson WC, editors. Green's operative hand surgery. 4th ed. New York: Churchill Livingstone; 1999. p. 1557–87.
62. Masmejean EH, et al. Brachial plexus injuries in scapulothoracic dissociation. J Hand Surg Br. 2000;25(4):336–40.
63. Oreck SL, Burgess A, Levine AM. Traumatic lateral displacement of the scapula: a radiographic sign of neurovascular disruption. J Bone Joint Surg. 1984;66-A:758–63.
64. An HS, Vonderbrink JP, et al. Open scapulothoracic dissociation with intact neuro-vascular status in a child. J Orthop Trauma. 1988;2:36–8.
65. Lange RH, Noel SH. Traumatic lateral scapular displacement: an expanded spectrum of associated neurovascular injury. J Orthop Trauma. 1993; 7:361–6.
66. Brucker PU. Scapulothoracic dissociation: evaluation and management. Injury. 2005;36:1147–55.
67. Jangir R, et al. Scapulothoracic dissociation: a rare variant: a case report. Malays Orthop J. 2014;8(2):46–8.
68. Damschen DD, et al. Scapulothoracic dissociation caused by blunt trauma. J Truama. 1997;42:537–40.
69. Tüzüner S, et al. Scapulothoracic dissociation: a case report. Isr J Med Sci. 1996;32:70–4.
70. Alnot JY, Narakas A. Traumatic brachial plexus injuries, Monographie de la SocieÂ teÂ FrancË aise de Chirurgie de la Main. Vol. 22. Paris: Expansion Scientifique Francaise; 1996. p. 275.
71. Sampson LN, et al. The neurovascular outcome of scapulothoracic dissociation. J Vasc Surg. 1993;17:1083–9.
72. Ebraheim NA, et al. Scapulothoracic dissociation (closed avulsion of the scapula, subclavian artery, and brachial plexus). A new recognized variant, a new classification, and a review of the literature and treatment options. J Orthop Trauma. 1987;1:18–23.
73. Zelle BA, et al. Functional outcome following scapulothoracic dissociation. J Bone Joint Surg Am. 2004;86:2–7.
74. Rubenstein JD, et al. Traumatic scapulothoracic dissociation. Radiology. 1985;157:297–8.
75. Clements RH, Reisser JR. Scapulothoracic dissociation: a devastating injury. J Trauma. 1996;40:146–9.
76. Cole PA, et al. Scapula fractures. Curr Rev Musculoskelet Med. 2013;6:79–87.
77. Mazaheri P, et al. Advanced imaging of the scapula: what every radiologist needs to know. J Comput Assist Tomogr. 2016;40(4):567–75.
78. McClure PW, et al. Shoulder function and 3-dimensional scapular kinematics in people with and without shoulder impingement syndrome. Phys Ther. 2006;86:1075–90.
79. Van Noort A, et al. The floating shoulder. A multicentre study. J Bone Joint Surg Br. 2001;83:795–8.
80. Cole PA, et al. Extra-articular malunions of the scapula: a comparison of functional outcome before and after reconstruction. J Orthop Trauma. 2011;25:649–56.
81. Bozkurt M, et al. Conservative treatment of scapular neck fracture: the effect of stability and glenopolar angle on clinical outcome. Injury. 2005;36:1176–81.
82. Egol K, et al. Handbook of fractures. Philadelphia, PA: Lippincott Williams & Wilkins; 2010.

83. Rockwood CA, et al. Rockwood and green's fractures in adults. Philadelphia, PA: Lippincott Williams & Wilkins; 2010.
84. Baldwin KD, et al. Scapula fractures: a marker for concomitant injury? A retrospective review of data in the national trauma database. J Trauma. 2008;65: 430–5.
85. Mayo KA, et al. Displaced fractures of the glenoid fossa. Results of open reduction and internal fixation. Clin Orthop Relat Res. 1998;347:122–30.
86. Armitage BM, et al. Mapping of scapular fractures with three-dimensional computed tomography. J Bone Joint Surg Am. 2009;91:2222–8.
87. Goss TP. Double disruptions of the superior shoulder suspensory complex. J Orthop Trauma. 1993;7:99–106.
88. Antevil JL, Holmes JF, Lewis D, Battistella F. Successful angiographic embolization of bleeding into the chest wall after blunt thoracic trauma. J Trauma. 2006;60(5):1117–8.
89. Yu P-C, et al. Angiographic embolization in chest wall hematoma due to handlebar injury—a rare case report. Am J Emerg Med. 2015;33:1328.e3–5.
90. McDermott FT, Hough DE. Reduction in road fatalities and injuries after legislation for compulsory wearing of seatbelts: experience in Victoria and the rest of Australia. Br J Surg. 1979;66:518–21.
91. Newman RJ. Chest wall injuries and seatbelt syndrome. Injury. 1984;16:110–3.
92. Murday AJ. Seatbelt injury of the breast—a case report. Injury. 1982;14:276–7.
93. Dawes RFH, et al. Seatbelt injury to the female breast. Br J Surg. 1986;73:106–7.
94. Yoo DH. Transcatheter arterial embolization of intramuscular active hemorrhage with N-butyl cyanoacrylate. Cardiovasc Intervent Radiol. 2012;35:292–8.
95. Jonsson K, Karlsson S. Angiography of the internal mammary artery. Acta Radiol. 1985;26:113–20.
96. Costa M, Robbs J. Non-penetrating subclavian artery trauma. J Vasc Surg. 1988;8:71–5.