Fixing the Cage: What The Surgeon Wants to Know About Traumatic Rib Fractures

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Authors: A. Atinga, M. De La Hoz Polo, D. Dalili, R. A. Young, I. Sinha, E. A. Dick, D. Amiras; London/UK
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Learning objectives

1. To review the anatomy and anatomical variants of the ribs and chest wall using multi-detector computed tomography (MDCT), especially 3D volumetric reconstructions, highlighting the structural factors that predispose to injury.
2. To describe the common patterns of traumatic rib fractures (TRFs) and the spectrum of TRF-related injuries, using examples taken from our institution, a level 1 major trauma centre.
3. To discuss the different non-surgical and surgical management of TRFs, the post-surgical complications and the peri-operative imaging considerations including the use of skin-rendered reconstructions to aid surgical planning.
Background

The incidence of TRFs is reported as between 7-40%. TRFs are associated with serious complications, conferring a mortality rate of between 8 and 12%. The morbidity and mortality increase as the number of fractured ribs increase and can be as high as 30% and 70% respectively.

Flail chest is a serious subtype of TRF, resulting in paradoxical chest wall movement. This impairs ventilation and has an associated mortality ranging between 11 and 40%.

Increasing evidence shows more aggressive management of TRFs, such as intercostal nerve blocks, regional serratus anterior blocks, neuraxial blocks (eg thoracic epidural), mechanical ventilation and surgery are associated with reduced morbidity, mortality and shorter hospital stay. In our own institution the uptake of a rib trauma pathway has lead to a reduction of mortality from 12% to 8% (TARN database to be published) between 2014 and 2016.

More recently, minimally invasive strategies such as minimally invasive plate osteosynthesis (MIPO), have developed for the operative fixation of TRFs. This is technically demanding and pre-operative imaging is crucial in selecting appropriate patients. Volumetric MDCT reconstructions have shown benefit in accurate fracture description and selection of the correct prostheses based on rib length and thickness. Additionally, skin-rendered reconstructions have helped determine the best site of incision in MIPO.
Imaging findings OR Procedure Details

Rib Anatomy

The thorax contains 12 pairs of ribs which are classified on the basis of their attachments: true ribs if the costal cartilage attaches directly to the sternum (one to seven), false ribs if the costal cartilage attaches to the cartilage of the next most superior rib (eight to ten), and floating ribs (if there is no costal cartilage connection (eleven to twelve). They are also classified based on their morphology as either typical or atypical. Ribs 3-10 are typical as they have a facet at each end and a long thin body connected to the head by the neck and a tubercle. The first and second ribs are atypical because of their special morphology to accommodate the thoracic outlet and attachment sites for upper limb musculature. Ribs eleven and twelve are also atypical because they lack an anterior facet, neck and tubercle (Fig 1, 2).

Each rib consists of a head that articulates with the corresponding vertebrae. In ribs 2-9, the head also contains a second facet that articulates with the superior vertebrae. Each rib contains a costal groove on the inferior surface of the body that contains the intercostal artery, vein and nerve (Fig 3).

Rib Variants

Radiologists should be familiar with congenital variants of the ribs to avoid unnecessary concern and further evaluation. Some congenital syndromes also include characteristic rib anomalies. Among the most common rib variants are: cervical ribs, forked ribs (bifid), duplication of the anterior portion of the rib, fusion or bone bridging, rudimentary or hypoplastic ribs, pseudoarthrosis of the first rib and intrathoracic and pelvic ribs (Fig 4).

Traumatic Rib Fractures

The middle ribs, arches four to eight, are the most commonly fractured and associated with thoracic injury, most commonly pneumothorax, haemothorax and pulmonary contusion. Fractures of the first three ribs serve as an indicator of high energy trauma and are associated with thoracic aorta, brachial plexus and subclavian injury in 3-15% of patients. The bottom ribs are associated with traumatic injury to the upper abdomen, most commonly the liver, spleen and kidneys.
The spectrum of traumatic rib fractures (TRF) includes buckle fracture, non-displaced and displaced fractures and segmental fractures (flail chest).

1. Buckle rib fracture: There is disruption of either the inner or outer cortex, with no observable fracture of the other cortex (Fig 5).

2. Non-displaced rib fracture: Rib fracture with complete cortical disruption but with maintained alignment and minimal or no displacement (Fig 6).

3. Displaced fracture: There is cortical disruption and significant displacement. Injury to the surrounding tissues and structures can occur and there is a higher incidence of associated severe complications (Fig 7, 8).

4. Segmental rib fracture: This implies at least two separate complete fractures located in the same rib and in more than 2 consecutive ribs. Flail chest is a clinical diagnosis identified by the paradoxical movement of the chest during breathing due to segmental rib fractures (Fig 9).

Other types of rib fractures include:

5. Costal cartilage fracture: This type of fracture probably occurs more frequently than is currently recognized. Flail chest fractures may involve the chondrocostal or chondrosternal junctions, but these are not identified radiographically unless the fracture involves a strongly calcified cartilage. These fractures are better demonstrated on CT or sonography. In one study involving 8 patients with chest injury, the fractures were recognized by visualizing focal interruption in the relatively high costal cartilage density on CT images, or in the linear echogenic anterior margin of the hypoechogenic cartilage on ultrasound. Additionally, a thin area of gaseous density in the cartilage cleft was visualised in lesions involving the chondrocostal or chondrosternal junctions. This accumulation of gas is probably the result of a vacuum phenomenon in the fracture cleft (Fig 10).

6. Costovertebral fracture: these have been typically described in child abuse. Each rib articulates with the vertebra at two points: between the head of the rib and the lateral portion of the vertebral centrum (the costocentral joint) and between the tubercle of the rib and the tip of the transverse process (the costotransverse joint). Most descriptions of costovertebral fractures include both joints (Fig 10).

Management of TRF
The management of TRF can be divided into non-surgical management and surgical management.

- **Non-surgical management:** This is mostly supportive and targets pain due to the fracture. There are a variety of techniques that can be used including epidural analgesia, intercostal rib blocks, intrapleural instillation of local anaesthetic, intravenous opiate treatment, and oral non-steroidal anti-inflammatory treatment. The complications associated with TRF may require additional interventions such as intubation and chest drains. If there is active bleeding, transcatheter embolization offers a reliable treatment option to control the haemorrhage.

- **Surgical management:** Surgical stabilization of rib fractures (SSRF) is aimed at restoring chest wall stability and reducing deformity, while allowing normal breathing mechanism. Early surgical repair of flail chest with rib plating is associated with decreased pain, shortened duration of mechanical ventilation, decreased incidence of pneumonia, decreased likelihood of tracheostomy and decreased length of both intensive care unit (ICU) and overall hospital stay. Thus, SSRF should be considered in all patients with flail chest and multiple, severe bicortical displaced fractures.

Traditional contraindications for SSRF include pulmonary contusion and severe traumatic brain injury; nevertheless, the current consensus advises that the evaluation for SSRF should be on an individual case basis. Additionally, repair of ribs 1, 2, 11 and 12 does not confer additional benefit in terms of either chest wall stability or pain control, except in certain circumstances such as marked displacement, vascular compromise or localized refractory pain.

In general, rib fixation is technically easier within one week of injury. Once inflammation and callus formation has started, it may be more difficult to reduce the fragments to normal alignment. There are some exceptions to this premise, which include hemodynamic instability or other higher priority injuries, such spinal injury fixation, which should be addressed first.

In our institution combined procedures of both pelvic and rib fixation have been performed to reduce anaesthetic time.
Preoperative evaluation requires specific surgical planning. Patients require a CT scan, usually part of the initial trauma assessment, to evaluate the number of fractured ribs, the location of the fracture on the rib in relation to surrounding structures (costal cartilage, transverse process) and characterization of the fracture itself, such as the degree of displacement, angulation and bone loss. Some authors recommend the use of CT with 3 dimensional (3-D) reconstructions as a very helpful tool in planning the surgical approach including the optimal site for incision, anatomical characteristics of the ribs and rib measures. When using 3-D reconstructions, several ribs are simultaneously viewed along their entire course in a single image (Fig, 11,12,13).

Although several approaches are described, surgical fixation is mainly achieved using a posterior or lateral approach or a combination of the two. The incision is based on the position of the rib fracture and its relationship to the scapula. For those fractures that lie directly under the scapula an extended posterolateral approach or two separate posterior or lateral windows can be used.

At our institution, a level 1 major trauma centre, standard MDCT images are acquired as part of our major trauma imaging protocol, and volumetric and skin-rendered reconstructions are generated in post-processing. The skin rendered reconstructions help surgical planning and identification of the the 'ausculatory window', a posterior paramedian approach preferred for posterior fractures using the interval between the latissimus dorsi muscle, trapezius muscle and the inferior scapular border. Once exposed, the triangle can be extended using retractors or by splitting the bordering muscles (Fig 14).

Currently, the most common modes of fixation include outer cortical plates with bicortical screw fixation and intramedullary struts. Both are accepted methods of fixation, though plate fixation is more popular. At least 2.5 cm of healthy rib is required to achieve adequate fixation and fractures should be repaired sequentially.

Among the complications of the procedure, hardware infection has been described in 1-3% patients. One of our patients presented with impingement between the hardware and the tip of the scapula causing significant pain with shoulder movements (Fig 15).
Fig. 1: Fig 1. First (A) and second (B) ribs which are considered to be atypical because of their specialized shapes and attachments.

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Fig. 2: Fig 2A,B. A) Drawing shows the eighth rib, which is a typical rib with a head, tubercle, and body and a facet at each end. B) Example of an atypical rib, considered so as it lacks the anatomic distinctions of the typical ribs.

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Fig. 3: Fig 3. Graphic demonstrates details of costal groove along the inferomedial aspect of each rib to accommodate the intercostal neurovascular bundle (vein, artery, and nerve).

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Fig. 4: Fig 4. CT coronal MPR reconstruction showing congenital bony bridging between the posterior aspect of the right fourth and fifth rib

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**Fig. 5:** Fig 5A,B. Examples of buckle type fractures (arrows) in two different patients.

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**Fig. 6:** Fig 6A,B,C. Axial (A) and coronal CT reformats (B,C) showing examples of nondisplaced or minimally displaced rib fractures in three different patients.

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**Fig. 7:** Fig 7A,B. Axial CT reformats illustrating different degrees of displaced rib fractures (arrows in A and B). Note the extensive surgical emphysema in B.

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**Fig. 8:** Fig 8A,B. CT 3-D reconstructions in two different patients. Note the right sided displaced rib fractures in A and B

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**Fig. 9:** Fig 9A,B. CT 3D reconstructions. Examples of multiple segmental rib fractures in two different patients

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**Fig. 10**: Fig 10A,B. A) Axial CT MPR shows a right costovertebral junction fracture (arrow) and a fracture through the right first costal cartilage with gas within the fracture cleft (arrow). Note the extensive surgical emphysema and pneumomediastinum. B) Coronal CT reformat showing a fracture through the costal cartilage (arrow).

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**Fig. 11**: Fig 11A,B,C. CT 3-D reconstructions. A) Note the multiple posterior displaced rib fractures involving more than one adjacent segment (Circle). B,C) Post-surgical fixation with outer plates in three consecutive levels.

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**Fig. 12:** Fig 12A,B,C,D.

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**Fig. 13:** Fig 13A,B. AP chest radiographs of the same patient. A) Note the multiple left rib fractures (circle). B) Same patient with improved chest wall stabilization using plates

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**Fig. 15:** Fig 15. Axial CT bone dose post-fixation. The patient complained from pain over the scapular region. CT revealed impigement of the plate with the tip of the scapula causing patient symptoms.

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**Fig. 14:** Fig 14. Skin and muscle rendered CT reconstruction demonstrates the latissimus dorsi (a) and inferior border of the scapula (b) and lateral border of inferior trapezius (c) forming the sides of the auscultatory triangle. Using this CT reconstruction the surgeon can understand the surgical access of the posterior rib fractures.

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Conclusion

TRFs are common and are associated with significant mortality and morbidity. Recent evidence shows improvement in mortality and morbidity rates following surgical fixation.

Our single centre experience highlights the important contribution of volumetric and skin-rendered MDCT reconstructions in determining patients with fractures that will benefit from rib fixation and in guiding the surgery.
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Personal Information

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