Review Article

# Treatment of traumatic rib fractures: an overview of current evidence and future perspectives

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**Abstract:** Operative management of rib fractures has gained significant popularity over the last years, however, it remains a controversial topic, due to the substantial heterogeneity among rib fracture patients with considerable differences in epidemiology. Hence, the present narrative review aims to provide an overview of the treatment and (long-term) outcomes of rib fractures, with an emphasis on the surgical treatment. Nowadays, computed tomography (CT) has been shown to be most practical and sensitive for detecting rib fractures, of which up to 50% is missed on other imaging modalities. Non-operative treatment by patient-tailored multimodal pain management remains the cornerstone. Still, in the presence of—amidst others—chest wall instability or displaced fractures with physiologic derangements, operative treatment is indicated and should be performed within 72 hours after injury. Here, traumatic brain injury (TBI) and pulmonary contusion are no strict contra-indications, while plate osteosynthesis is considered the standard mode for surgical stabilization. To date, surgical stabilization of rib fractures (SSRF) only benefits selected groups of patients, awaiting results of ongoing studies. Future directions may include the sole use of percutaneous cryoablation of the intercostal nerves as part of conservative management, as well as the application of three-dimensional (3D) printing and use of bio-absorbable materials in the surgical treatment of rib fractures.

**Keywords:** Rib fractures; thoracic injuries; non-operative management; surgical stabilization of rib fractures (SSRF)

Submitted Dec 02, 2023. Accepted for publication Jun 26, 2024. Published online Jul 26, 2024.
doi: 10.21037/jtd-23-1832
**View this article at:** https://dx.doi.org/10.21037/jtd-23-1832

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## Introduction

Thoracic injury is a common and potentially devastating component of acute trauma. The majority—90%—of thoracic injuries result from blunt trauma, accounting for 14% of all blunt traumas. Furthermore, thoracic trauma is associated with significant morbidity and mortality, estimated to be accounting for up to a quarter of early trauma-related mortality (1). Regarding thoracic trauma-related specific injuries, rib fractures are considered the most prevalent, with a large variety in severity, ranging from simple isolated fractures to multiple and multifragmentary fractures resulting in flail chest, for example in polytrauma patients. Despite the generally urgent nature of thoracic trauma, after quick diagnosis most injuries can be mitigated by non-operative management or later definitive surgical treatment. Operative management of rib fractures has gained significant popularity over the last years, however, it remains a controversial topic. The substantial heterogeneity among rib fracture patients with considerable differences in epidemiology (2) perhaps prevents a one-size-fits-all solution to rib fracture management. Hence, the present narrative review aims to provide an overview of the different treatment strategies and (long-term) outcomes of rib fractures, with an emphasis on the surgical treatment.

## Initial management and diagnosis of thoracic injuries

Initial resuscitation and management of acute chest trauma patients is based upon the principles of Advanced Trauma Life Support (3). To evaluate the presence of acute life-threatening thoracic injury at an early stage, an important adjunct in primary survey is plain chest radiography. Although acquired in all trauma patients, chest radiographs are associated with poor diagnostic accuracy (4,5). Approximately 50% of rib fractures are missed on routine chest radiographs (5,6). Oblique and special rib views can increase sensitivity but are not routinely obtained. Chest ultrasound can serve as an alternative to detect thoracic injuries such as traumatic hemopneumothorax and rib fractures. Although ultrasonography is associated with even poorer diagnostic accuracy (7) to detect a traumatic pneumothorax, it has shown superior results in the detection of rib fractures compared to chest radiographs (8). Still, current guidelines do state chest radiographs as the most appropriate primary imaging modality in adults with suspected rib injuries (9). This may be due to the variability in patient habitus and fracture sites (more difficult to visualize in the subscapular and infraclavicular portion) (10), as well as the increased imaging time associated with ultrasound (11). Nuclear imaging could in extremely rare circumstances be used to detect occult rib fractures but should definitely have no place in acute trauma care (12). Computed tomography (CT) has been shown to be most practical and sensitive for detecting rib fractures (6), hence often obtained subsequent to simple radiographs and considered gold standard. The importance to detect rib fractures is underlined by the fact that the pulmonary morbidity and mortality directly increases with each additional rib fracture, approaching a mortality of 40% if more than six ribs are fractured (13), prompting more aggressive management. CT moreover allows for a comprehensive evaluation of the chest, identifying injuries such as pulmonary contusion, a diaphragmatic rupture and entrapped lung parenchyma. In addition, three-dimensional (3D) reconstructions are useful for pre-operative surgical planning.

## Non-operative management

In the absence of a flail chest or chest wall deformity (including e.g., severely displaced ribs), non-operative management remains the standard treatment of thoracic injuries at most institutions.

Healing thus usually occurs spontaneously and is beneficial if it avoids potential surgery-related complications. On the other hand, insufficient bone healing may result from rib fractures that are not surgically repositioned and stabilized, resulting in the development of pseudarthrosis and chronic pain syndromes.

Notwithstanding, spontaneous bone healing is associated with substantial pain and discomfort. Hence, the mainstay of conservative management is adequate pain control to prevent secondary pulmonary complications resulting from inadequate ventilation due to painful respiratory movements. This is best achieved by a staged protocol. It is advised to directly start analgesia at the emergency department by a combination of acetaminophen, non-steroid anti-inflammatory drugs (NSAIDs) or metamizole in the presence of contra-indications, and opioids. Repeated evaluation of pain scores must be performed, both in rest and during exercise or coughing. Inadequate pain control with numeric rating scores of >4 should initiate the placement of a thoracic epidural catheter. A systematic review by Peek and colleagues found that epidural analgesia provides better pain relief than other modalities [including intravenous analgesia and (loco-)regional blocks], though no differences were observed for the length of intensive care unit (ICU) stay and mechanical ventilation and pulmonary complications (14). Another study by Jensen and colleagues predicted a 97% reduction in mortality with thoracic epidural analgesia among patients with one or multiple rib fractures (15), while others particularly advocated for epidural use with more than four rib fractures due to the associated mortality risk reduction (13). In the presence of contra-indications, such as the use of specific anticoagulants, one can refer to a thoracic erector spinae plane block or paravertebral block, which may be of equivalent effect (16,17). Though, it must also be mentioned that different studies question the efficacy and safety of epidural catheters (18,19).

Persistent high pain scores despite adequate non-operative measures should reroute patients towards operative treatment.

Without going into the multitude of individual methods of pain relief, choosing the optimal technique may not always be straightforward, and thus treatment should always take place in cooperation with a pain specialist, respiratory physiotherapist, be multimodal, patient-specific and tailored to local expertise and experiences (20). In addition, one should keep in mind that despite trying to avoid surgery and the associated risks, conservative treatment can also have extremely rare devastating consequences, such as epidural hematoma or abscess formation following epidural catheterization (21).

Over the years, different scoring systems have been developed to identify patients at risk for adverse outcomes. These include the SCARF (22) and BATTLE score (23) and may guide treatment decisions. Predictors of adverse outcomes encompassed in these scores are age, number of rib fractures, presence of chronic lung disease, anticoagulant use, oxygen saturation levels, increased respiratory rate, high pain scores and inadequate coughing, prompting more aggressive management. The thoracic trauma severity score (TTSS) has been shown to be superior specifically in predicting respiratory complications in isolated rib fractures with pulmonary contusion and the rib fracture score (RFS) was proven most useful in patients without pulmonary contusion compared to the abbreviated injury scale (AIS), chest trauma score (CTS) and RibScore (24).

## Operative management

Over the last two to three decades, surgical stabilization of rib fractures (SSRF) has gained popularity compared to conservative treatment options, especially for flail chest (25,26). In general, the assumption that SSRF could alleviate respiratory problems remains the main driver for operative management, as was affirmed by Dutch health care providers using the measurement instrument for determinants of innovations (MIDI) questionnaire, which was used to identify barriers and facilitators of the implementation of SSRF (27). Although the skepticism towards SSRF is largest for non-flail chest patients, different studies suggest suboptimal quality of life and increased morbidity even after isolated rib fractures (28,29), creating opportunities for surgical fixation in selected patients.

The Chest Wall Injury Society (CWIS), represented by a variety of surgical and non-surgical specialists, seeks optimal outcomes for patients with both non-operative and operative management of rib fracture. Being leaders in rib fracture research, CWIS members have reported an evidence-based consensus guideline for indications, timing, surgical approach, and fixation mode of SSRF (30).

### *Indications*

CWIS set distinct recommendations on the indications to perform SSRF for both ventilated and non-ventilated patients. Although the indications slightly differ between both groups, SSRF is generally indicated in the presence of chest wall instability (e.g., flail chest, clinical instability, and paradoxal chest motion), three or more displaced rib fractures (equal to or more than 50% of the rib width in costae 3 to 10) with multiple pulmonary physiologic derangements (e.g., high respiratory rate and pain scores despite adequate multimodal pain management), or failure to wean from ventilation (31). The society also outlined contraindications for SSRF, both absolute and relative. Absolute contraindications include severe traumatic brain injury (TBI) and acute myocardial infarction, while less than severe TBI and spinal injuries are more relative. It has to be mentioned though that since the publication of CWIS guidelines, new evidence has come to light about the benefits of SSRF for patients with multiple rib fractures and simultaneous moderate to severe TBI, despite TBI being a driver for acute respiratory outcomes (32,33). As such, it has been shown that there is no SSRF-related complication risk, and SSRF treatment resulted in a lower 30-day mortality in patients with severe TBI compared to conventional non-operative treatment (34).

### *Optimal timing*

Timing of surgical rib fracture repair is essential and should consider inflammation and callus formation. Furthermore, fractures are known to increasingly displace with time, setting hurdles for anatomic reconstruction. According to CWIS guidelines and a recent study by Prins and colleagues, SSRF should be performed as early as possible (i.e., within 24 hours) and ideally within 72 hours for non-ventilated patients regardless of the indication (31,35). When respiratory failure/ventilator dependence has complicated rib fractures in ventilated patients, SSRF should be performed within 72 hours for both flail as non-flail indications. It is recommended though that SSRF should be delayed in case of other higher priority injuries (e.g., spinal or vascular injuries, pulmonary contusion, or open abdomens), and hemodynamic instability which often necessitates emergency surgery. Especially pulmonary contusion has been considered a relative contra-indication as the risk of pulmonary morbidity is believed to be associated with the contusion itself instead of the rib fractures (36). Recently, a study by Lagazzi and colleagues did show that regardless the severity of the pulmonary contusion, early implementation of SSRF (i.e., <72 hours) is advised, as it was associated with a decrease in hospital and ICU stay, and more importantly lower rates of unplanned intubation or tracheostomy compared to late SSRF (i.e., >72 hours) (37). Following up on this study, Van Wijck and colleagues showed that there is no association between pulmonary contusion and worse SSRF outcomes in patients with three or more displaced rib fractures or flail segment (33). They even showed that SSRF is associated with superior outcomes in patients with mild to moderate pulmonary contusion. Nevertheless, patients experiencing severe pulmonary contusion should be considered for SSRF on an individual basis as outcomes did not differ between surgical and non-operative management. Regardless of the indications and timing for SSRF, it is recognized that the choice of treatment and timing remains partially up for debate because each patient and associated trauma is unique, as are the subjective skills of the surgeon and resource options.

### *Surgical approach*

Conventionally, the SSRF era started with the use of large incisions obtaining full exposure, however the corresponding need to muscle and nerve stripping and potential damage to blood vessels brought along several complications (e.g., post-operative scarring, functional limitations, numbness, wound infection). Currently, SSRF may be assisted by video-assisted thoracoscopic surgery (VATS), offering a wide visualization of the entire chest wall, although not considered mandatory. Addition of VATS has shown to be effective and safe and allows for the identification and repair of additional pulmonary or mediastinal (pathologic) conditions as well as the simultaneous evacuation of for example a hemothorax (25,38,39). However, it has been shown that addition of uniportal VATS to SSRF on a routine basis for severely displaced rib fractures or flail chest does not identify a significantly greater amount of occult intrathoracic injuries compared to using uniportal VATS only on selected cases (40). Notwithstanding, VATS has the function of identifying clinically relevant rib fractures, as not every single fracture requires stabilization through osteosynthesis; combined with intraoperative palpation of the thorax, clinically relevant fractures can be specifically identified and the most atraumatic approach to the corresponding ribs can subsequently be determined.

In theory, VATS-assisted SSRF has also the advantage of video-guided placement of loco-regional anesthesia, which is imperative to successful and proper treatment of rib fractures, as well as chest tube placement. In addition, it can improve the visualization of rib fractures, allowing more accurate fracture identification. Moreover, it allows intrathoracic plate placement to the inner cortex of the rib potentially leading to better healing of the fracture and improved pain control compared to extrathoracic plate placement (41,42). One may even take intrathoracic placement one step further using uniportal instead of multiportal VATS. Although the data on this uniportal VATS SSRF approach is currently limited (43,44), its position is expected to be elucidated in the coming years.

While the use of VATS, either being used in addition to or as a complete procedure, is being gradually accepted and applied for surgical rib fixation, no comparing studies between VATS and thoracotomy for SSRF have been reported yet. On this account, no evidence-based conclusions can be drawn yet whether which approach is superior to the other.

### *Fixation mode*

The ideal SSRF fixation product has a unique geometrical shape that respects the anatomical curvature of the rib in question (i.e., plasticity and biomechanical elasticity).

 

To restore lung volumes and respiratory function, it also requires sufficient strength and stiffness to reestablish chest wall stability. Furthermore, it has good histocompatibility, causes no adverse reaction, and does not affect surrounding tissues. While there is currently no product that perfectly covers all these aspects, CWIS does lay out specific recommendations for the mode of fixation (31). When multiple fractures are identified, all fracture lines should be stabilized wherever possible (45). Since there is no clinical evidence available that suggests superiority of outer cortical plate fixation over intramedullary struts, both may be used to surgically fixate rib fractures. However, intramedullary struts are quite tricky to implant though and only have one anchor point, without distal fixation (46) and are generally considered inferior to cortical plate fixation. Nevertheless, cortical plate fixation is considered time consuming. Another option is to use nitinol plates/clips which apply the properties of shape memory alloys such as NiTi Rib plates and prevent the need for manual bending of the plate (47). When cooled down before application, the material is malleable, and only after heating up to body temperatures by placement onto the fracture site, the plates and clips undergo a phase transformation and return to their original shape.

While bicortical fixation is designed for ribs to be immobilized at a stiffness level optimal for bone healing, a unicortical approach can be used to prevent bicortical-induced theoretical risks of injuring intrathoracic organs, specifically pleural irritation or risk of pneumothorax by the prominence of the screw tip (48). Systems designed for a unicortical approach (such as the L1® Rib system from KLS Martin Group) place converging screws, aiming to match the biomechanical properties of a bicortical approach, including pull-out forces.

Other fixation options include Judet struts and Kirshner wires. The latter are used for transfixation where non-fractured ribs provide stabilization. Although the use of Kirshner wires is characterized for a reduction of operative time, it is associated with increased postoperative morbidity compared to Judet struts and cortical plate fixation (49). For these as well as other reasons (e.g., suboptimal fracture reduction and stability, as well as the risk for injury to surrounding structures), wires are hardly used at present.

Bioabsorbable prostheses for fracture fixation are not a new development, but are mostly utilized in other fields of surgery. These bioabsorbable and bioactive plates consists of poly-L-lactide and hydroxyapatite, the combination of which has osteoconductive properties that bond bones and thereby promotes bone healing. They especially provide strength and stiffness until the fractures are fully healed, and with their slow absorption rate mechanical stresses are slowly transferred to the bone, minimizing stress shielding and the need for surgical removal of foreign body materials. Such bioabsorbable mini plates and screws have been reported in the successful treatment of non-trauma patients who received chest wall reconstructions (50) as well as pectus excavatum patients (51). However, it was not until Mayberry and colleagues first showed good clinical use in surgical rib fracture stabilization in 2003 (52), that is has been recognized as a new revolutionary technique in the field of SSRF. Since then, only few studies have implemented bioabsorbable plates to further enhance bone healing of rib fractures (53-55). While stability issues remain with bioabsorbable plates, these internal fixation materials could be the main direction for future development.

Besides the different types of hardware that can be applied to surgically fixate rib fractures, one must always keep the basic principles of fracture management in mind and consider whether the additional use of bone grafts is necessary.

### *Outcomes*

The question remains whether the enthusiasm for SSRF developed over the years is worth the cost. The overall risk of surgery- and implant-related complications has been reported in 10.3% of the cases, with wound infection in 2.2% and fracture-related infection in 1.3% (56). Risk factors for morbidity and mortality after SSRF, including age and number of fractured ribs, have however been reported inconsistently in the literature (57). Hence, identifying reliable predictors can have significant implications for the clinical outcomes of rib fracture patients, independent of treatment option. In 2012, a simple scoring system has been developed that may assist in the earlier implementation of treatment strategies (58).

While the short-term clinical patient outcomes after SSRF are clearly described in the literature (59-62), with less pain and respiratory-related complications/readmissions, higher rates of home discharge, a decrease in ventilator time and tracheostomy and in-hospital costs, more studies are now investigating long-term benefits of SSRF. Patients receiving SSRF for their rib fractures can return to their usual life or same work as in their pre-injury state with no or few limitations besides from implant-related irritation (63-65). Nevertheless, most studies exclude the patient subgroup of 80 years and older, while it has been shown that specifically in this subgroup SSRF is independently associated with a decreased mortality (66). Thus, specific patient selection is required with more randomized controlled trials. So far, only a few RCTs on surgical versus non-operative treatment for severe chest wall injury have been reported in the literature. While these studies have shown less restrictive impairment of pulmonary function (67), a lower risk of complications as well as less ventilation requirement, intensive care stay, and thus medical resource use after surgical treatment (68,69), most patients with severe chest wall injury still experience moderate to extreme pain as well as impaired physical activity at 1 month after surgery (70). Perhaps, studies should focus first on providing definitive proof for surgical treatment of multiple simple rib fractures. The upcoming FixCon trial could possibly provide more exclusive evidence on the clinical, functional, and economic outcomes of operative fixation versus non-operative treatment of patients with multiple simple rib fractures (71).

## Future perspectives on management

The current potential of peripheral nerve blocks is believed to surpass neuraxial techniques in the future (20). Although the concept of cryoanalgesia dates back to 1962 (72), this peripheral nerve block technique has gained wide popularity for pain control in thoracic surgery over the past years. In SSRF, cryoablation of the intercostal nerves has proven an outstanding pain management modality, premised on the cost-effectiveness by reducing length of hospital and ICU stay, and decreased narcotic consumption compared to SSRF with conventional pain management protocols (73,74). Still, the addition of cryoanalgesia to SSRF may feel as an overshoot since one of the main indications for SSRF is pain control through fracture stabilization. With the option of percutaneous cryoablation it would be interesting to compare cryoanalgesia as stand-alone nonoperative treatment versus SSRF among patients with stable unilateral rib fractures and high pain scores indicating surgical treatment. Thus, future research should focus on elucidating the efficacy of stand-alone cryoanalgesia for rib fracture pain management.

Numerous factors attribute to the success of SSRF, with an adequate reconstruction of the chest wall being key, allowing for proper expansion and retraction of the rib cage during breathing. Due to the complex shape of the ribs in the chest wall, it remains challenging for fixation devices to fully conform to the anatomical structure of the fractured rib. Currently, several studies have been reported using pre-operative 3D printing derived from CT scan data, offering more insight from all angles into the fracture itself as well as the specific anatomical structure of the rib (55,75,76). Hence, these 3D printing molds can be used for pre-bending of the plates and tailoring of the fixation device, saving operative time, and reducing fixation failure in the future. However, to date it remains unknown whether the addition of 3D printing translates into improved patient outcome, and whether it is cost-effective.

## Conclusions

Rib fractures after traumatic thoracic injury can effectively be managed by a patient-tailored non-operative multimodal pain strategy as well as surgical stabilization for selected patients. In both treatment options, it is important to consider a multidisciplinary solution in which pain relief is the key priority. Focusing less on a one-size-fits-all solution and more on future developments, such as percutaneous cryoablation of the intercostal nerves as part of conservative management, as well as the application of 3D printing and use of bio-absorbable materials in the surgical treatment of rib fractures, could possibly benefit patients with rib fractures the most.

## Acknowledgments

*Funding:* None.

## Footnote

*Provenance and Peer Review:* This article was commissioned by the editorial office, *Journal of Thoracic Disease*, for the series “Chest Wall Resections and Reconstructions”. The article has undergone external peer review.

*Peer Review File:* Available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-1832/prf

*Conflicts of Interest:* All authors have completed the ICMJE uniform disclosure form (available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-1832/coif). The special series “Chest Wall Resections and Reconstructions” was commissioned by the editorial office without any funding or sponsorship. J.H.T.D. and E.R.d.L. served as the unpaid

 

Guest Editors of the series. The authors have no other conflicts of interest to declare.

*Ethical Statement:* The authors are accountable for all aspects of the work, ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.



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**Cite this article as:** Franssen AJPM, Daemen JHT, Luyten JA, Meesters B, Pijnenburg AM, Reisinger KW, van Vugt R, Hulsewé KWE, Vissers YLJ, de Loos ER. Treatment of traumatic rib fractures: an overview of current evidence and future perspectives. J Thorac Dis 2024;16(8):5399-5408. doi: 10.21037/jtd-23-1832

 