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Surgical Stabilization of Rib Fractures

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Abstract

Purpose of Review Surgical stabilization of rib fractures (aka rib plating) is underutilized, partly due to a perceived lack of evidence of benefit and unfamiliarity with the operation. The goal of this review is to identify and summarize the evidence surrounding surgical stabilization of chest wall injury in flail and non-flail injury patterns and highlight the limitations of our current knowledge.

Recent Findings Recent meta-analyses and prior trials have provided evidence that rib fixation in flail chest injuries decreases the need for mechanical ventilation, decreases risk of pneumonia, and decreases mortality. Additionally, the Eastern Association for the Surgery of Trauma and the Rib Fracture Colloquium have provided statements supporting rib fixation in flail injuries. The role of rib plating for patients with non-flail rib fractures remains controversial and requires further study.

Summary Surgical stabilization of rib fractures in flail injuries is supported by the evidence and should be utilized in these select patients. More evidence is needed in non-flail injuries before recommendations can be made for rib fixation.

Keywords Surgical stabilization of rib fractures · Rib plating · Chest wall trauma · Flail chest · Open reduction and internal fixation

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Introduction

Rib fractures are common injuries associated with high energy chest wall trauma and carry with them significant morbidity and mortality [1, 2]. Flail chest injury, defined as three or more consecutive fractured ribs at two distinct anatomic points leading to segmental chest wall instability, is strongly associated with respiratory failure and subsequent need for prolonged hospitalization, mechanical ventilation, and, therefore, death [2–7]. This is particularly relevant in the elderly who have less physiologic reserve and more comorbidities than younger patients [7]. Patients who recover from these injuries often report severe chest wall pain, experience long-term disability, and have difficulty returning to work or activity as usual [1, 8, 9].

Surgical stabilization of rib fractures (SSRF or "rib plating") has gained increasing popularity in recent years with the development of new and improved rib fixation systems, growing interest in post-SSRF outcomes, and formation of chest wall injury consortiums including the Chest Wall Injury Society. Concomitantly, short-term data have consistently demonstrated improved outcomes in patients with flail chest injuries including earlier liberation from mechanical ventilation, decreased rates of pneumonia, decreased duration of hospitalization, decreased need for tracheostomy, and improved mortality [3–6, 10]. Moreover, both a Rib Fracture Colloquium and the Eastern Association for the Surgery of Trauma have recently published evidence-based practice management guidelines supporting SSRF for patients with flail chest [11, 12].

While multiple studies including several randomized clinical trials and meta-analyses have demonstrated that patients with flail injuries suffering from respiratory failure likely stand to benefit from SSRF, there is little consensus on SSRF use in non-flail injury patterns [3–6]. Yet, despite the proven benefit of SSRF for patients with flail chest, a recent National Trauma Database analysis demonstrated less than 1% utilization of SSRF for flail injuries. [13].

The controversial nature of SSRF implementation in non-flail injuries and its poor utilization for flail chest trauma is likely reflective of unfamiliarity with the procedure and the perception of poor evidence as most studies are retrospective in nature or have small sample size [14••]. Fundamentally, the ability to conduct randomized clinical trials (RCTs) that randomize patients with either flail injury or severe rib fractures to a non-operative treatment arm is inherently difficult, especially in the setting of respiratory insufficiency or debilitating pain. In that light, this review will summarize the evidence supporting SSRF in flail and non-flail injuries with the goal of providing a succinct resource for reference that highlights both the benefits and pitfalls of SSRF as well as the limitations of the current body of knowledge.

Indications for Surgery

Flail Chest Injuries

Indications for SSRF remain a source of contention and are dependent on the patient's injury pattern, physiology at presentation or time of consultation, and the potential for decompensation. Broadly speaking, SSRF in patients with flail chest leads to decreased pain, decreased duration of mechanical ventilation, decreased need for tracheostomy, shorter hospitalizations, and fewer days in the intensive care unit [3–6, 10, 11, 15, 16]. To that end, generally accepted indications for SSRF in the acute setting include refractory pain that impairs sufficient respiratory effort to clear secretions, significant chest wall deformity, failure to wean from mechanical ventilation that is not attributable to other processes, and ongoing chest wall instability or chronic pain from non-union or malunion (see Table 1; Fig. 1) [14••, 17••, 18••]. To date, there have been three randomized clinical trials that have evaluated the usefulness of SSRF in flail injuries. Granetzny et al. demonstrated that while there were no differences in the overall rate of complications in SSRF patients versus those undergoing non-operative management, SSRF patients had 5 times fewer incidence of pneumonia, a 50% reduction in hospital length of stay, decreased need for tracheostomy, and better pulmonary function tests at a 2-month time mark [15]. Similarly, Tanaka and colleagues demonstrated significant reductions in the rate of pneumonia for patients with flail chest following SSRF and also reported reductions in total medical expenses and improved pain, dyspnea, and return to work following rib fixation at 6 and 12 months [6]. A more recent RCT published by Marasco et al. in 2013 reported similar clinical benefits and cost savings, though they did not demonstrate improvements in Short Form-36 quality of life scores at 6 months [5]. Bhatnagar and colleagues further delved into the economic side of SSRF for flail injuries by evaluating the cost-effectiveness of SSRF versus standard of care (SOC) using a Markov transition state model and the 2010 National Medicare reimbursement rates for diagnoses and procedures [16]. Their findings not only demonstrated cost savings for SSRF compared to SOC regardless of patient quality of life, but SSRF consistently remained more cost-effective when accounting for varying rates of complications including ventilator-associated pneumonia and need for tracheostomy. To date, three meta-analyses have supported these findings while also showing reductions in mortality in flail chest injury patients who undergo SSRF [3, 4, 19].

Table 1 Indications for surgical stabilization of rib fractures

Indications for surgery
Pain refractory to maximal medical and non-operative interventions resulting in or potentiating respiratory failure
Significant chest wall deformity
Failure to wean from mechanical ventilation not secondary to other causes (e.g., severe TBI, pulmonary contusions, etc.)
Significant rib displacement found at thoracotomy being performed for other reasons (e.g., intrathoracic injury)
Malunion or non-union of rib fractures resulting in restrictive pulmonary patterns or ongoing chest wall instability

Non-Flail Injuries

Despite clear advantages with SSRF in flail chest injuries, data on the effectiveness of SSRF in non-flail injuries are more preliminary and suffer the issue of cohort heterogeneity as there have been no published studies specifically looking at this cohort. Nevertheless, there are recent data supporting the efficacy of SSRF in non-flail injury patterns. Pieracci et al. performed a prospective clinical evaluation with a crossover study design that evaluated patients with flail chest, three or more severely displaced rib fractures defined as bicortical displacement, significant hemithorax volume loss on chest computed tomography, or any fracture pattern that failed optimal medical management [10]. The majority of patients meeting inclusion criteria in both operative and non-operative groups had three or more severely displaced rib fractures (but not flail chest), and their findings demonstrated that SSRF led to significant reductions in the duration of mechanical ventilation, progression to respiratory failure, need for tracheostomy, and improvements in incentive spirometry recordings. In addition to the work of Pieracci et al., other case reports, case control series, and retrospective analyses have reported on the potential for amelioration of pain and decreases

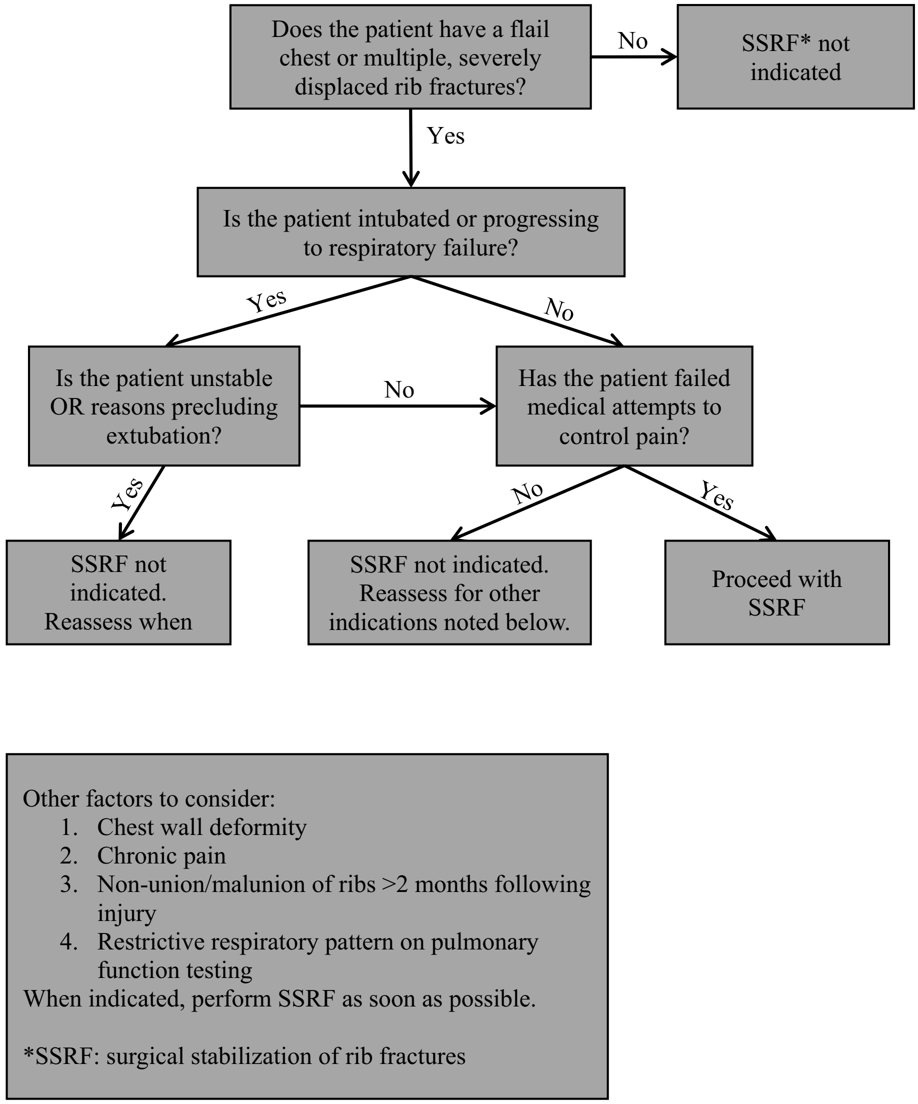

Fig. 1 Practice guideline for surgical stabilization of rib fractures

in the duration of ventilator days and hospitalization, but nearly all of these studies are either underpowered or lack comparison groups to draw meaningful conclusions resulting in changes in practice patterns [17••, 20••–24].

Effects of SSRF on Long-Term Quality of Life

Regarding the effects of SSRF on long-term quality of life, there are some limited data which suggest improved outcomes in patients who underwent operative fixation. In a survey study, Majercik et al. similarly reported favorable long-term quality of life in patients who underwent SSRF for multiple reasons including flail chest, severe fracture displacement, and intractable pain [25]. Perhaps most notably, their study found that in those who were gainfully employed prior to injury, 92% returned to work at previous place of employment. Mayberry et al. reported similar long-term outcomes including low long-term McGill Pain Questionnaire scores and similar RAND-36 scores as adults with one or more comorbidities [1, 26]. However, the limitations of these studies should be taken into consideration as they generally have small sample sizes and lack comparison groups. Moreover, chest trauma specific, long-term quality of life metrics have not been developed or validated, which makes interpretation of these studies difficult.

Management of Chronic Malunion/Non-union

Malunion results from improper fracture callous formation between two separate ribs as a consequence of non-operative management of displaced rib fractures. Non-union occurs in situations where there has been a lack of callous formation at the injury site over a period of time, typically quoted between three to nine months [11, 27]. Common risk factors for non-union include smoking, steroids, NSAID use, alcohol abuse, diabetes, malnutrition, and vitamin D deficiency [27].

Malunion can result from fracture callous formation between 2 separate ribs with resultant chronic pain or dyspnea. Surgery is usually indicated in such cases when this results in a restrictive defect that limits normal respiration or chronic and life-limiting pain. There are limited data on the effectiveness of SSRF in malunion/non-union and available studies have primarily evaluated indications relating to pain. However, in patients with malunion/non-union who are in pain, limited results suggest improvement in long-term pain scores and radiographic evidence of healing following SSRF [11, 28, 29]. Further evidence is needed to characterize which patients with malunion/non-union would most benefit from SSRF.

Contraindications to Surgery

Contraindications for operative rib fixation largely follow the rule that if the primary driver of a patient's clinical course is not related to the degree or extent of chest wall trauma, then they are likely to not benefit from SSRF. Common examples include those with underlying pulmonary contusion or severe traumatic brain injury (TBI). Pulmonary contusions can lead to hypoxic pulmonary vasoconstriction, subsequent ventilation–perfusion mismatching, and potentiate acute respiratory failure. In these cases, the underlying parenchymal pathology may drive clinical outcomes to a greater degree than chest wall instability, and therefore SSRF may not significantly impact a patient's short-term recovery [20••, 30••, 31••]. In a key early study in this field, Voggenreiter et al. compared flail chest patients with and without pulmonary contusion who underwent SSRF and demonstrated that SSRF did not decrease ventilator time in patients with pulmonary contusion [30••]. That being said, there is debate as to what degree of pulmonary contusion may mitigate the efficacy of SSRF and how the interplay between operative timing and pulmonary contusion should effect the decision to pursue operative or non-operative management [14••]. The efficacy of SSRF in severe TBI patients is not known as most studies exclude severe TBI patients from analysis on the basis that their underlying injury is a greater driver of respiratory failure and prolonged intubation.

Patient Selection and Non-operative Treatment Strategies

Not all patients are appropriate for surgical management and some patients and surgeons may opt for non-operative management. This is especially true for patients that have multiple severely displaced rib fractures but do not have a traditional flail injury where the data are still preliminary and unable to fully support strong recommendations for SSRF [12]. Ideally, a scoring system predictive of who would most benefit from SSRF would be used to identify potential surgical candidates. There are currently 4 scoring systems to assess the probability of respiratory failure following rib fracture. These include the RibScore, Rib Fracture Score (RFS), Organ Injury Scale (OIS) Chest Wall Grade, and Chest Trauma Score (CTS), all of which are predictive of pneumonia, respiratory failure, and need for tracheostomy [32–35]. However, these scores have not been validated prospectively and are not designed to specifically identify who would benefit from SSRF.

For patients undergoing non-operative treatment strategies, pain control is paramount to avoid respiratory insufficiency secondary to pain [11]. The most common cause of death following isolated rib fractures is pneumonia due to the inability to expectorate, take deep breaths, and mobilize due to pain. The Eastern Association for the Surgery of Trauma has given a Grade I recommendation to the use of epidural analgesia for patients with severely fractured ribs. Though there is debate on which regional analgesic techniques, epidural versus paravertebral, are most effective in controlling rib fracture pain, there is a consensus that a multimodal pain regimen is crucial to optimal pain control. [14••, 36–38]. Our institution employs a multimodal pain regimen including locoregional analgesia through paravertebral catheter use, round-the-clock acetaminophen and non-steroidal anti-inflammatory drugs, and ketamine infusions. Part and parcel with aggressive pain management, use of pulmonary toilet and protective ventilator strategies is crucial to recovery [39.]

Imaging Options

Because plain X-ray lacks the sensitivity to identify all fractured ribs, lacks the resolution to exactly define the nature of the fracture, routine imaging through the use computed tomography (CT) of the chest has become the workhorse in defining the type and extent of injury for chest wall trauma and aid in operative planning [5, 11, 40•–42]. Whether the need for three-dimensional (3D) reconstruction of CT images is superior to two-dimensional imaging along remains unknown and is largely surgeon-specific; however, a study comparing the two modalities found that 2D imaging is superior for the identification of fractures and 3D imaging may be better for actual operative planning [40•]. There are no data currently on the use of ultrasound, though some have expressed interest in this modality as a means to localize the fracture after the patient has been positioned in the operating room for planning of the incision itself.

Modalities of Fixation and Surgical Approach

Timing of Surgery

Currently there are no studies that have evaluated optimal timing of operation or compared outcomes between early and late fixation. However, the basic tenets of orthopedic injury and repair are early reduction and fixation of fracture lines to avoid mal- or non-union, mitigate pain, and avoid the consequences of immobilization. Given that the intent of SSRF is to avoid or moderate the need for mechanical ventilation and the potential for prolonged pain and infectious complications, it is likely that the expeditious surgery is beneficial. To that end, expert consensus agrees that proceeding with SSRF in the first 24–72 h with an emphasis on fixation in the first 24–48 h is ideal if possible [11].

Positioning, Incision Placement, Number of Fractures to Repair

Patient positioning is dependent on fracture location, but as most rib fractures are in the mid to posterior axillary lines, the lateral decubitus position typically provides the best exposure for incision placement. If fractures are present more anteriorly or posteriorly, the patient can be positioned in the prone or supine position as needed.

Incision orientation does not always necessitate the classic posterolateral thoracotomy incision. Instead, many authors have described placing vertical incisions centered directly on the fracture line and utilizing a muscle sparing approach to provide exposure without the need to raise skin flaps to expose multiple ribs [11]. In flail segments where the fracture lines are relatively close to each other; however, horizontal incision may be more advantageous. If needed, two vertical incisions can also be made to address individual fracture lines that are far apart. This is may be especially helpful in flail segments where anterior and posterior fractures are present and not amenable to exposure through a single, continuous incision.

The majority of movement through the chest wall occurs through ribs 4–9, and therefore many authors believe fixation of ribs 1–3 as well as the floating ribs does not necessarily improve the structural integrity of the chest wall [11, 14••]. Data regarding partial surgical stabilization of flail chest injuries versus repair of every fracture line are sparse and conflicting. For instance, one study suggested partial stabilization was acceptable; however, a separate review demonstrated that partial stabilization did not prevent further deformity and displacement in the unrepaired segments [43, 44].

Types of Plating Systems

Generally speaking, there are two styles of plating systems: anterior plates and U-plates (see Table 2). Other fixation systems have been described, including the use of absorbable plates, steel wires, intramedullary struts, and mesh systems, but these systems have been shown to have inferior outcomes or worse safety profile and therefore have not gained popularity [6, 23, 44–46]. To date, there have been no head-to-head comparative studies of different rib fixation systems to evaluate superiority of one system over another or to define instances when one system may be better than another based on fracture pattern or patient demographic [11]. Anterior plates are technically easier to position and secure requiring dissection and exposure of the anterior surface of the fractured rib only. Some anterior plates are designed to be fixed to both the anterior and posterior cortex of the rib (bicortical fixation) whereas one system is designed for fixation to the anterior cortex only (unicortical fixation). The U-plate design is unique in that it provides both an anterior and a posterior face on either side of the rib to provide fixation to the plate itself both anteriorly and posteriorly, but this requires dissection of the anterior and superior surface to allow the U-shaped end of the plate to wrap around the rib. Depending on which system is used, it may be necessary to measure the thickness of the rib to identity the length of screw needed to obtain bicortical fixation without injury to the lung. Anterior plating systems typically require at least three points of fixation on each side of the fracture for maximal stabilization while the U-plating system requires fixation at two points. Lastly, there is an anterior plating system available which is unique in that it does not use screws to fix the plate to the rib. Instead, it wraps around both sides of the rib. However, there is a report of this plate being dislodged, presumably due to less secure fixation [47].

Despite the differences between these systems, there are several commonalities. First, manipulation of the rib should be from an anterior and superior approach to avoid injury to the underlying neurovascular bundle located on the inferior portion of the rib. Although there is no need to compress the fracture, the maximal gap that can be present across the fracture is 1–1.5 cm. Spanning fractures with greater loss of bone can result in progressive fatigue of the plate and ultimately plate fracture [48].

Necessity of Tube Thoracostomy

Tube thoracostomy is required when the pleural space is violated, either by the index trauma or during the course of

Table 2 Differences and commonalities between plating systems

Anterior plating systems	U-plating systems
Dissection required anteriorly	Requires anterior and superior rib exposure
Requires 3 points of fixation on each side of the fracture line	End plates wrap around rib anteriorly and posteriorly to ensure bicortical stabilization
Must measure rib width prior to drilling or insertion of screws	
Commonalities between systems	
Ribs should be manipulated anteriorly and superiorly to avoid injury to the inferior neurovascular bundle	
Rib width must be measured prior to drilling or insertion of screws	
At least 2 points of fixation must be placed on either side of the fracture	
Approximately 3 cm of clearance on either side of the fracture is required for plate placement	

the operation. This is more common when using the U-plate system than when placing anterior plates only, but may also occur due to manipulation of the rib in cases where the fracture is severely displaced. No comparative study has determined the optimal size or type of tube. When placed intraoperatively, most thoracostomy tubes can be removed within 24 h or so.

Post-Operative Surgical Complications

Post-operative surgical complications are generally uncommon but can be problematic when present [49]. The most significant complications are hardware infection and plating system failure, both of which often require reoperation and hardware removal. The rates of infection are low with reported ranges from 0 to 10%, but it should be noted that the majority of reports detailing infection come from single center, small sample size studies and there does not appear to be a trend of negative long-term sequelae of infection within the limitations of available data [17••, 45]. Hardware failure is even less common with isolated reports of screw displacement in anterior plating systems and plate fracturing overtime [24, 47, 50]. To date, there are no systematic reviews or larger powered studies describing risk factors for hardware failure.

Conclusion

Surgical stabilization of rib fractures may decrease the duration of mechanical ventilation, incidences of pneumonia, and mortality in patients with flail chest injuries and is indicated in instances of respiratory insufficiency secondary to chest wall instability or pain, inability to be liberated from mechanical ventilation, displaced ribs found at the time of thoracotomy performed for other reasons, and significant chest wall deformity. Non-operative treatment strategies including comprehensive and multimodal pain control as well as early mobilization with rigorous pulmonary toilet can be effective in the avoidance of pulmonary complications in select patients. Patients with non-flail injuries may also benefit from rib fixation, but further research is needed to determine which injury patterns will most benefit from operative intervention.

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Compliance with Ethics Standards

Conflict of interest The authors declare no conflicts of interest relevant to this manuscript.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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