

Surgical Treatment of Flail Chest and Rib Fractures: A Systematic Review of the Literature

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ABSTRACT

Rib fractures are relatively common injuries which are predominantly managed non-operatively. However, there has been an increasing amount of evidence over the past two decades supporting the role of surgical management in the presence of multiple rib fractures and flail chest. The purpose of this systematic review is to provide a comprehensive overview of the surgical management of flail chest and rib fractures along with outlining the relative indications, trends in surgical technique, and the evidence comparing operative versus non-operative treatment.

Key words: Flail chest; Rib fractures; Surgical fixation; Review

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INTRODUCTION

Rib fractures are a common injury, occurring in 10% of polytrauma patients and 39% of blunt chest trauma^[1,2]. This may result in respiratory compromise from altered mechanics of respiration^[3,4], in addition to pain, deformity and potential mortality following these injuries. Flail chest, defined as at least three consecutive ribs fractured in more than one location per rib, is a severe manifestation^[5]. This causes a paradoxical motion of the chest wall, altering respiration and ventilation^[6]. The incidence of flail chest in the setting of rib fractures is 7%^[7], with a mortality rate as high as 33%^[8].

Moreover, it is important to understand the associated soft tissue implications with high energy blunt chest trauma. In the polytrauma patient with an injury severity score (ISS) > 15, the incidence of pulmonary contusion is 27%^[9]. The physiologic consequences include alveolar hemorrhage and parenchymal destruction which manifest themselves within hours of injury and resolve in approximately 7 days. The clinical symptoms, including dyspnea from hypoxia and hypercapnia, typically peak at 72 hours^[9]. Computed tomography (CT) imaging is recommended to evaluate for pulmonary contusion and is also helpful for predicting the need for mechanical ventilation^[9]. The most feared complication of pulmonary contusion is acute respiratory distress syndrome (ARDS), which is the predominant cause of death following blunt chest trauma^[10]. The likelihood of developing ARDS is predicted by the volume of contused lung parenchyma. When greater than 20% of lung volume is contused, ARDS has an 82% chance of occurrence^[11].

Historically, rib fractures and flail chest were predominantly treated non-operatively with mechanical ventilation, oral analgesics,

lidocaine patches, thoracic epidural catheters, and intercostal nerve blocks^[12-15]. However, non-operative management has been associated with decreased pulmonary function, increased risk of pneumonia, longer stays in the intensive care unit, increased ventilator times, and need for tracheostomy^[1,16,17]. There has been an increasing amount of evidence over the past two decades supporting the role of surgical management in the presence of multiple rib fractures and flail chest. Not only has surgical management for flail chest injuries demonstrated improved clinical outcomes compared to non-operative management, but it has also been reported to be a cost effective intervention^[4]. In a large retrospective analysis of nearly 30,000 patients, Kane et al. demonstrated a 76% increase in surgical rib stabilization^[18]. The purpose of our systematic review is to provide a comprehensive overview of the surgical management of flail chest and rib fractures including along with describing the relative indications, trends in surgical technique, and the evidence comparing operative versus non-operative treatment.

INDICATIONS

Recently in 2017, clinical practice guidelines were published, which is based on a consensus from 14 experienced surgeons and intended to be an evidence-based resource for surgeons performing surgical stabilization of rib fractures (SSRF), proposed several indications for SSRF^[2]. Among these indications are flail chest, multiple severely displaced fractures, and those who fail early non-operative management. Moreover, pulmonary contusion and traumatic brain injury (TBI) do not necessarily contraindicate SSRF. It is recommended to perform SSRF within 72 hours of surgery as delay past this point results in a considerably more difficult procedure and less prompt recovery. Exceptions include hemodynamic instability, higher priority injuries, and trial of non-operative management. Despite recent trends, they found that less than 1% of flail chest patients actually receive operative treatment.

Flail chest remains a strong indication for surgical management^[9,16,19-27]. In a systematic review of 986 patients, Kasotakis et al. found that those patients with flail chest treated with SSRF had lower mortality, shorter duration of mechanical ventilation, shorter length of stay in both the ICU and hospital, lower rates of pneumonia, and lower rates of tracheostomy^[28]. However, of the 22 studies included, only 3 were prospective randomized clinical trials. Additionally, SSRF has been advocated for more than flailed chest alone. Displaced rib fractures may undergo SSRF secondary to the injury leading to chest wall deformities, decreases in thoracic volume, injury to the aorta or other underlying tissue, or even to resolve a pneumothorax or hemothorax^[9,16,29].

Despite the medical advancements in the past several decades, failure of conservative medical management is common. Medical management includes pulmonary toilet, analgesics, nerve blocks, mechanical ventilation, and tracheostomy. Failure of medical management is not easily defined. Pieracci et al. have used the metrics of increasing pain scores, decreased incentive spirometry, poor cough, and respiratory rate greater than 20 breaths per minute to help define failure of medical management^[2,29].

Lastly, symptomatic nonunion and malunion of rib fractures have been noted to be relative indications for SSRF^[16]. Nonunion and malunion may alter the dynamics of respiration and be a source of significant pain. This pain can be debilitating and may decrease respiratory effort resulting in atelectasis and pneumonia. Fabricant et al and Gauger et al have recently shown surgical fixation of symptomatic nonunion is a viable option for management^[30,31].

TIMING

There is no clearly defined timeline of when surgical intervention should take place. Several authors have reported favorable outcomes with earlier fixation^[19-21]. Recently, Pieracci et al. published a retrospective review of prospectively maintained SSRF databases from four American college of surgeon-certified Level 1 trauma centers^[2]. The evaluated patients who underwent surgical stabilization of rib fractures over a ten year period and the effect of timing of surgery on various outcomes were reviewed. Five hundred and fifty-one patients were categorized into one of three time categories (early < 1 day, mid 1-2 days, late 3-10 days) based on time from hospital admission to surgery. Overall, the early surgery group had favorable outcomes, as well as, a shorter length of surgery. After controlling for multiple covariates and comparing the late group to the early group, the late group was 2.37 times as likely to develop pneumonia and 3.24 times as likely to require prolonged mechanical ventilation. Delayed surgery also had a 26% increase in the likelihood of tracheostomy. They recommend surgical fixation of ribs as soon as possible after admission, preferably within 24 hours.

PREOPERATIVE PLANNING

3D CT-imaging is a valuable tool for pre-operative planning in the setting of multiple rib fractures. A retrospective analysis of 35 patients with flail chest found that while 2D CT-imaging has the highest diagnostic accuracy for rib fractures, 3D CT-imaging changed operative management in 66% of cases. The most common alteration in surgical plan was change in length or position of the incision (87%), while fracture fixation alterations accounted for 22%. They concluded that 3D CT is a worthwhile adjunct to 2D CT for pre-operative planning^[32].

APPROACHES

An increasing amount of orthopedic trauma surgeons are becoming familiar with approaches to the chest wall for surgical stabilization of rib fractures. Exposure, fracture reduction and fixation are usually performed solely by the orthopedic surgeon, however, a general surgeon is typically present for chest tube thoracostomy following fracture fixation. Taylor et al. described various surgical approaches to the chest wall to facilitate and allow for fracture fixation^[24].

Standard Posterolateral Thoracotomy

This approach provides access to posterior, posterolateral, lateral rib fractures, as well as anterior rib fractures with extension of the incision. The patient is placed in the lateral decubitus position with the ipsilateral arm prepped or placed on supportive armboard. The skin incision is oriented vertically and equal distance between the spinous process and medial border of the scapula. The incision can be curved laterally in a transverse manner beginning 1.5-2.0 cm caudal to the inferior angle of the scapula. Superficially, in the vertical aspect of the incision, the trapezius is retracted medially and superiorly. Then the rhomboid musculature is elevated off the thorax to expose ribs. The rhomboids must be handled carefully as damage can cause lateral winging of the scapula. Next, the latissimus dorsi is identified more inferiorly and transected in line with the skin incision to gain access to the deeper musculature. The serratus anterior and external oblique muscles are split in line with their fibers to expose underlying ribs. Careful blunt dissection must take place in the midaxillary line as to not damage the long thoracic nerve. For far posterior rib

fractures, the trapezius, rhomboids, or paraspinous muscles need to be elevated off thoracic spinal processes.

Muscle-sparing Thoracotomy

Patient is positioned similarly to that of the posterolateral thoracotomy. A vertical skin incision is made based on the given fracture pattern. Fascia overlying the trapezius and latissimus dorsi is elevated to expose the muscular intervals. The triangle of auscultation is identified and the surrounding musculature is retracted giving access to ribs 4 through 8. To access lateral and anterior rib fractures, a more anterior skin incision is needed followed by identification of the anterior border of the latissimus dorsi and blunt dissection of the subscapular bursa. With retraction of the latissimus and scapula, the serratus anterior muscle is split in line with its fibers to expose the underlying ribs.

Axillary Approach

This approach is useful for anterior and anterolateral rib fractures. The patient is placed in a lateral decubitus or a 45 degree lateral position. A vertical incision is made 1.5-2.0 cm anterior to the lateral border of the scapula. The latissimus can be retracted posteriorly, and the long thoracic nerve should be identified and protected. The serratus anterior is split in line with its fibers to gain access to the ribs. If more anterior exposure is necessary, then the external oblique muscle can be split.

Inframammary and Pectoralis-lifting Approach

More anterior and superior fractures can be reached with this approach. The patient is positioned supine with a skin incision made in the inframammary crease. The pectoralis major muscle can be elevated anteriorly and superiorly to gain access to the pectoralis minor muscle. The pectoralis minor can be split in line with its fibers to expose the underlying ribs.

Implants

There are a multitude of different implants available and to date there have been no studies that demonstrate superiority of one over the other. Several different extramedullary fixation devices are available for rib fixation. First, multiple case series have reported on successful outcomes with minimal complications following use of locking plates for SSRF^[20,33,34]. Precontoured locking plates may offer a theoretical advantage over traditional non-precontoured locking plates as they do not require contouring during surgery which may lead to decreased surgical times. Another available technology is bioabsorbable plates. They are composed polylactide have been used successfully for rib fixation with the theoretical advantage of avoiding long-term stress shielding at the fracture site^[16,35,36]. Next, Judet struts are metal plates that have small projections on the superior and inferior aspect of the plate that are bent over the cephalad and caudal aspect of the rib. A theoretical disadvantage is the potential to injure the neurovascular bundle in the costal groove at the inferior aspect of the rib. Lastly, U-plates are a hybrid technology of locking plates and Judet struts. This plate wraps over the superior aspect of the rib and subsequently is fixed to the rib with a locking screw that engages the plate on the superficial and deep cortices of the rib.

Intramedullary (IM) splints are helpful for posterior rib fractures and fractures under the scapula. This is partly because no prostheses have been specifically designed for posterior rib fractures and partly because the cortical bone of posterior ribs is thicker, has a rounder cross section, and has a tighter radius of curvature. Additionally, forces acting on posterior ribs are greater than the other parts of

the rib with overlap and deformity being more common if not stabilized^[37,38]. An additional advantage of IM splinting is fixation with less hardware; only one bicortical screw needed reducing the incidence of symptomatic hardware. The downside to this technology is that the cyclical motion of respiration can lead to these splints cutting out of the bone, especially in osteoporotic patients.

Utilization of intramedullary fixation has been studied^[35]. In this study, the indication for intramedullary splinting was difficult to access areas such as posterior rib fractures and fractures under the scapula. Fifteen patients were analyzed with 35 intramedullary splints with follow up at 3 and 6 months with 3D CT. At 3 months, there was complete bony healing noted in 3 (9%), partial healing with cartilaginous union in 28 (85%), and nonunion in 2 (6%). Failure in two patients was found to occur at the rib/splint interface following sneezing. The splint remained intact but in both patients the superior cortex was fractured and hardware was removed prior to the 3 month follow up. No hardware failures were reported. By 6 months, all rib fractures were completely healed. This small retrospective review demonstrated that while fracture healing may be delayed on CT-imaging, functional recovery is comparable to cortical plating^[39].

OUTCOMES

There is a growing body of evidence supporting surgical management of flail chest and multiple rib fractures, and many institutions are implementing surgical management of these injuries more commonly. Three prospective randomized controlled trials comparing surgical and non-surgical management of flail chest are available. Tanaka et al. reported on 37 patients with flail chest and ventilator dependent respiratory failure who were randomized to surgery with Judet strut fixation devices or non-operative management with continued mechanical ventilation and respiratory physiotherapy^[21]. The mean time to fixation for the surgical group was 8 days following injury. The surgical group was found to have statistically significant improved results in all categories including length of ventilation (10.8 vs 18.3 days), rate of pneumonia (22% vs 90%), length of ICU stay (16.5 vs 26.8 days), need for tracheostomy (3 vs 15 patients), and lower medical expenses (\$13,500 vs 23,400). Furthermore, the patients in this study were followed for one year and the surgical group demonstrated improved forced vital capacity at 3, 6, and 12 months compared with non-operatively treated patients. The operative group also reported less thoracic pain, chest tightness, and dyspnea.

Moreover, in a prospective review of 40 patients randomized to non-operative treatment with an adhesive bandage or surgical treatment involving an early technique of K-wire or stainless steel wire fixation, Granetzny et al found that the surgical groups demonstrated lower length of ventilation (2 vs 12 days), lower rate of chest infection (10% vs 50%), decreased mean ICU length of stay (9.6 vs 14.6 days), decreased overall hospital stay (12 vs 23 days), and less chest infection (10% vs 50%)^[22]. They also found that forced vital capacity and total lung volume was better in the surgical group as early as 2 months.

Lastly, Marasco et al. prospectively reviewed 46 patients who were randomized to bioabsorbable rib plating or conservative management^[35]. Outcomes were again favored in the surgical group with decreased length of ICU stay (317 vs 456 hours), decreased rate of pneumonia (48% vs 74%), decreased rate of tracheostomy (39% vs 78%), and decreased rate of non-invasive ventilation (22 vs 67 hours). Additionally, an initial cost saving of over \$14,000 for

patients with surgical stabilization was noted.

A meta-analysis of these randomized controlled trials with flail chest favored SSRF as it was associated with a 66% reduction in the incidence of pneumonia, in addition to shorter duration of mechanical ventilation, decreased length of stay in the ICU, and decreased length of stay in the hospital overall. To date, this is the only meta-analysis exclusively reviewing level I evidence, and concluding strong favor of surgical stabilization.

However, meta-analyses that include both retrospective and prospective studies evaluating the utility of SSRF vs conservative management have been performed. In a two-part analysis, Swart et al reported on outcomes of operative fixation of flail chest and provided a decision analysis model comparing costs and outcomes of operative and non-operative management. With SSRF, they found a decrease in mortality, pneumonia, need for tracheostomy, time in ICU, and total length of stay^[41]. Cost analysis revealed higher costs with operative fixation (\$23,682 vs \$8,629) though quality adjusted life year (QALY) analysis was 32.60 in the operative group versus 30.84 in the non-operative group resulting in an incremental cost-effectiveness ratio of \$8,577/QALY. The gains in QALY are attributed to increased survivorship during initial hospitalization. In conclusion, this analysis found that there was decreased mortality and a universal decrease in complications associated with surgical fixation. Furthermore, it was found that SSRF was the more cost effective intervention as the increased cost of surgery was offset by decreased length of stay in both the ICU and total hospital days. These results were validated following a re-analysis using only prospective level I evidence^[41]. Several studies have since validated that ORIF was more cost effective irrespective of quality of life improvement (QOL)^[40]. Despite the increased cost of the surgery, the reduced rate of pneumonia, decreased ventilator time, and decreased length of stay lead to an overall reduction in cost compared with pneumatic stabilization.

Several retrospective studies have supported SSRF. In reviewing over 117,000 patients with rib fractures throughout Canada over a ten-year period, Dehghan et al tried to determine the prevalence, management, and outcomes of patients with flail chest injuries compared to patients without flail chest injuries^[41]. Of all these patients, 1.5% had flail chest, 41% had multiple rib fractures, and 58% had a single rib fracture. Overall, patients with flail chest had significantly worse outcomes; in addition to a higher mortality rate they were much more likely to require a chest tube, mechanical ventilation, tracheostomy, and to develop pneumonia. Only 4.5% of patients with flail chest were treated surgically but those that were had a statistically significant reduced mortality risk both in the short term at 30 days (2.6% vs 9.8%) and in the long term at 2 years (8% vs 17%). In fact, SSRF reduced the mortality rate of flail chest to that of multiple rib fractures without flail chest. Despite the low overall rate of SSRF for flail chest in this study, it is worth noting that this rate increased from 1% prior to 2010 to 10% after 2010 demonstrating the increasing trend towards SSRF. Moreover, they analyzed variables and identified risk factors that most influenced the outcome of 30 day mortality. The most significant were age, pneumonia, admission to ICU, and mechanical ventilation over 48 hours. While retrospective in nature, it includes a large number of patients and validates the utilization of operative management of flail chest^[41]. These findings have been further supported in the literature, with a 99% union rate reported following SSRF for flail chest^[34]. Moreover, even in the setting of pulmonary contusion, favorable outcomes have been reported following SSRF^[34].

In a review following rib plating versus non-operative

management in patients age 65 and older, a patient population that has a well documented increased mortality rate at 20% and increased pneumonia rate at 19%^[42]; Fitzgerald et al found that those 50 patients treated non-operatively there were 4 respiratory related readmissions, 2 deaths, 7 cases of pneumonia, 7 pleural effusions, and 19 pneumothoraces compared with zero in the operatively managed group^[43]. Again, the rib plating group had decreased ICU length of stay and accelerated rehabilitation compared with the injury matched control group despite having higher overall ISS scores. Due to the small sample size, this data did not reach statistical significance. It is worth noting that patient questionnaires in this study implied that rib plating was associated with decreased narcotic use, earlier absence of respiratory fatigue, and earlier lifestyle satisfaction achievement^[43].

To our knowledge, there are currently 3 studies that examine long term outcomes and QOL in patients who have undergone SSRF. Caragounis et al. examined long term outcomes of surgical treatment for flail chest and rib fractures in 54 patients and administered a questionnaire concerning pain, breathing, and QOL at 6 weeks, 3 months, 6 months, and 1 year post-op^[1]. Moreover, they objectively measured lung function, breathing, range of motion, and physical function at those times. They found that pain, shortness of breath, and analgesia use significantly decreased throughout the year. Quality of life, overall perceived health, and lung function testing continued to improve throughout the whole year. At 1 year, 13% of patients had pain at rest, 47% had local discomfort, and 9% still used analgesics. They concluded that you should not assess surgical outcome prior to 1 year as parameters continue to improve^[1]. Similarly, Majercik et al. reported on long term outcomes following SSRF in 101 patients at a minimum of 6 months following surgery and found resolution of pain at an average of 5 weeks from surgery. 8 patients (16%) reported ongoing pain with 6 of these reporting minimal pain with 2 reporting chronic pain which still required opiates. The average patient satisfaction after SSRF was 9.2 on a scale of 10. 90% returned to work at the same job at an average of 8 weeks. They concluded that patients with surgical stabilization are satisfied and able to return to normal activity with few limitations^[15]. These findings corroborated an earlier study done by Bille from the UK who evaluated 10 patients after surgical stabilization of rib fractures and found good results at an average of 14 months postoperatively. Seventy percent of patients reported no pain with only one patient reporting a poor quality of life^[44].

Although the trend in literature is in favor of SSRF, especially in the setting of flail chest, there is some evidence on the contrary. Defreest et al. published a retrospective study including of 86 patients, 41 treated with SSRF and 45 treated conservatively^[45]. Hospital length of stay and intensive care unit length of stay were significantly longer in the SSRF group. The SSRF trended toward longer ventilator time. The authors report there was not a formal protocol for the non-operative group and the SSRF group may have been inherently sicker given that they underwent surgery after failing non-operative management. They have not excluded SSRF for rib fractures, but do believe optimal patient selection has yet to be identified to optimize this treatment modality. Additionally, Farquhar et al. also conducted a small retrospective study and demonstrated superior outcomes in the nonoperative management group versus the surgical fixation group for the treatment of flail chest^[46]. Similar to Defreest et al, there was a selection bias toward the operative group since they were patients who failed nonoperative management. The authors of this study call for the need of large randomized control trials to help define management strategies.

COMPLICATIONS

Nonunion

It is reported that 5-10% of rib fractures treated nonoperatively may develop a nonunion^[44]. Nonunions develop for a variety of reasons, including soft tissue injury with damage to the periosteum and nutrient vessels, soft tissue interposition between bony fragments, comminution, and displacement. Furthermore, a poor host can increase risk of nonunion. Risk factors identified include age, diabetes, anemia, malnutrition, vasculopathy, hypothyroidism, smoking, NSAIDs, steroids, and alcoholism^[44].

Operative management may be considered if symptomatic nonunion persists beyond 3 months. This becomes more important in the setting of severe pain as it results in decreased respiratory effort which increases the risk for atelectasis and pneumonia. Pain also disturbs eating habits, sleeping habits, and can affect activities of daily living and ability to work. There are multiple reported methods of management of rib nonunions in literature^[30,31].

In a prospective review of 24 patients with rib nonunions, Fabricant et al performed resection of callous with or without rib plating, depending on the size of the gap^[30]. < 1 cm led to plating or absorbable suture fixation while > 2 cm did not receive SSRF. For gaps in between 1 -2 cm the decision was based on surgeon preference. At 6 months patients reported improved activity level, SF 36 scores, and pain. However, there was no change in functional or work status overall. They did find that patients treated with resection and plating had superior results to resection alone with statistically significant subjective improvement in chronic pain and activity tolerance^[30]. Additionally, Gauger et al performed a retrospective study that evaluated the outcomes of 10 patients with 16 symptomatic rib nonunions treated with reconstruction using iliac crest autograft and tension band plate with a locked precontoured plating system^[31]. All patients went on to union at an average of 14 weeks with a low complication rate, one wound infection that resolved with irrigation and debridement and antibiotics and one symptomatic implant removal^[31]. Due to the success of multiple methods of nonunion management, prospective studies are needed to determine which patients benefit from reconstruction versus resection.

CONCLUSION

Rib fractures are a common injury in the setting of blunt chest trauma and flail chest is a manifestation with a high mortality rate. CT-imaging has become nearly universal for the evaluation of major blunt chest trauma and multiple rib fractures because it allows an accurate diagnosis of rib fractures and evaluates for other pulmonary and mediastinal injuries. Several randomized controlled trials have demonstrated that surgical management of rib fractures with internal fixation has several advantages to conservative management including decreasing ventilation times, earlier discharge from the ICU, cost savings, and earlier return to work. Large randomized controlled trials are still needed to further establish absolute indications for surgical stabilization of rib fractures, as well as to determine long term outcomes.

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