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Surgical Fixation of Rib Fractures

Evidence Based Medicine Guideline

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SUMMARY
Rib fractures are common following blunt trauma to the chest. While most rib fractures heal uneventfully with pain control and aggressive pulmonary support, some patients require more invasive treatment to prevent future pulmonary complications. Surgical fixation of rib fractures has been increasingly performed in recent years to stabilize the chest wall, especially in patients with flail chest.

RECOMMENDATIONS

- **Level 1**
  - **None**
- **Level 2**
  - **Surgical fixation of rib fractures should be considered as the primary treatment in the following patients without severe head or other major organ system injury**
    - **Flail chest**
    - **Symptomatic fractures of 3 or more consecutive ribs and/or failure to wean from mechanical ventilation**
    - **Severe chest wall deformity with or without pulmonary herniation**
- **Level 3**
  - **Surgical fixation of rib fractures should be considered for patients with symptomatic malunion or nonunion of rib segments (chronic rib fractures)**
  - **Early fixation should be performed where possible**
  - **Absorbable plates are not recommended for fixation of posterior rib fractures**

INTRODUCTION
Among patients suffering traumatic thoracic injuries, 10% have associated rib fractures with considerable risk of pulmonary-related morbidity and mortality (1). Patients with rib fractures are at particular risk for developing pulmonary complications such as atelectasis, pneumonia and respiratory failure due to poor chest wall mechanics, decreased ventilatory capacity, and diminished ability to cough and clear secretions. Most simple rib fractures are treated non-operatively using pain control and pulmonary hygiene (2). The vast majority of these injuries heal spontaneously without major complications. Severe rib fractures may require the use of mechanical ventilation if conservative management fails. Recently, surgical management of rib fractures has gained popularity. Indications for surgical fixation of rib fractures include flail chest, severe chest wall deformity, failure to wean from mechanical ventilation, chronic pain or disability, pulmonary herniation, non-union, and during thoracotomy closure (3,4). Increasing research points toward the benefit of operative management of these chest wall injuries in select patients (4).

LEVEL OF RECOMMENDATION DEFINITIONS
- **Level 1:** Convincingly justifiable based on available scientific information alone. Usually based on Class I data or strong Class II evidence if randomized testing is inappropriate. Conversely, low quality or contradictory Class I data may be insufficient to support a Level I recommendation.
- **Level 2:** Reasonably justifiable based on available scientific evidence and strongly supported by expert opinion. Usually supported by Class II data or a preponderance of Class III evidence.
- **Level 3:** Supported by available data, but scientific evidence is lacking. Generally supported by Class III data. Useful for educational purposes and in guiding future clinical research.

LITERATURE REVIEW

Flail Chest

Flail chest is typically defined as fracture of two or more consecutive ribs in two or more places resulting in paradoxical movement of the chest wall during respiration. Multiple studies describe the benefit of early operative flail chest wall stabilization to facilitate weaning from mechanical ventilator support and reduce overall pulmonary complications (1,5,6).

Slobogean et al. performed a meta-analysis of comparative studies of operative vs. nonoperative management of flail chest (6). 753 patients across 11 manuscripts met study inclusion criteria. They found that surgical fixation resulted in better outcomes for all analyses in ventilator days (mean of 8 days) and incidence of pneumonia [odds ratio (OR) 0.2]. They also found a decrease in number of ICU days (mean of 5 days), mortality (OR 0.31), septicemia (OR 0.36), and tracheostomy (OR 0.06).

Leinicke et al. evaluate operative fixation vs. nonoperative management of flail chest in a systematic review and meta-analysis (7). Nine randomized controlled trials and observational studies were evaluated with a total of 538 patients. Compared with conservative treatment, operative fixation of flail chest was associated with a decreased length of mechanical ventilation, length of hospital stay, and mortality.

Pieracci et al. performed a prospective, controlled evaluation of patients with severe rib fractures undergoing surgical stabilization (8). They evaluated 70 patients over a 2-year span with flail chest, three or more fractures with bicortical displacement, 30% or greater hemithorax volume loss, and severe pain or respiratory failure despite optimal medical management. The study measurements were respiratory failure, tracheostomy, pneumonia, ventilator days, tracheostomy, length of stay, daily incentive spirometer volumes, narcotic requirements, and mortality. 35 patients were included in each arm, operative and nonoperative. After controlling for group differences, the operative group had a lower likelihood of respiratory failure and tracheostomy. Additionally, duration of ventilation was lower in the operative group as well. They advocated for the superiority of operative management in these patients.

Simon et al. described the management of flail chest and pulmonary contusion in a 2012 guideline from the Eastern Association for the Surgery of Trauma (EAST) (9). They conducted a review of 129 articles from multiple databases from January 1966 to June 2011. They concluded that surgical fixation of flail chest was indicated in patients with severe flail chest failing to wean from the ventilator or when the patient was to undergo thoracotomy for other reasons.

Pulmonary contusion provides an exception to the benefits of surgical rib fixation in the polytrauma patient with flail chest. Liu et al. evaluated severe polytrauma patients with flail chest from January 2015 to July 2017 (10). 50 patients with flail chest were identified and randomly assigned to an operative vs. nonoperative group. Operative fixation gave benefits in mechanical ventilation days, ICU stay, risk of acute respiratory distress syndrome (ARDS), pneumonia, and thoracic deformity. Exceptions to these benefits were patients with associated pulmonary contusion, showing non-superiority of surgical rib fixation in this group.

Severe Rib Fractures

Favorable long-term outcomes of patients undergoing chest wall stabilization for rib fractureS without flail segment have also been documented in the literature. Pieracci et al. evaluated the efficacy of surgical stabilization of rib fracture in patients without flail chest (11). 110 subjects were enrolled in a combined randomized and observational arm at patient discretion. 23 patients selected randomization and 87 selected the observation arm. 51 underwent surgical fixation of rib fractures. There were no statistically significant differences in the two groups. At 2 weeks, the numeric pain score was significantly lower in the operative group. Narcotic consumption was lower in the operative arm. The operative group also saw fewer pulmonary space complications (0% vs. 10.2%, p=0.02).

Majercik et al. studied operative vs. nonoperative rib fracture management in 411 patients admitted to a single Level 1 trauma center (12). They measured ventilator days, ICU length of stay (LOS), hospital costs, and need for tracheostomy. They found that patients managed operatively had shorter ICU LOS and fewer ventilator days, but higher hospital cost than non-operative patients.

A prospective study by Lardinois et al. determined the outcomes of 66 patients who received surgical fixation of chest wall injuries from 1990-1999 (13). The indications for surgical fixation included respiratory failure (28 patients), flail chest (15 patients), failure to wean from mechanical ventilation (21 patients), and following thoracotomy (2 patients). Repair was completed using a lateral approach with 3.5mm reconstruction plates at a mean of 2.8 days after admission. Patients remained on mechanical ventilation for an average of 2.1 days with a mean total ICU stay of 6.8 days and mean hospital stay of 17.4 days. With regard to morbidity and mortality, five patients developed pneumonia and two patients developed superficial wound infections requiring debridement, but not removal of hardware. Four patients died from pneumonia and multi-organ failure. These patients received delayed operative fixation after an extended trial of mechanical ventilation. At 6 months post-operatively, 57 patients were assessed for follow-up. Six patients complained of chest wall pain which was relieved in three patients following removal of the hardware. Patients returned to work an average of 8 weeks post-operatively. Pulmonary function testing of 50 patients at 6 months demonstrated normal findings in 52%, an obstructive pattern in 22% and a mixed obstructive and restrictive pattern in 16%. A restrictive pattern, defined as a total lung capacity (TLC) <85% of the expected value, was found in 10% of patients. Based on these findings, the authors concluded that surgical fixation of the chest wall injuries does not significantly affect post-operative pulmonary function tests and that surgical fixation can reduce costs and complications associated with severe chest wall injuries among select patients.

Chronic Pain / Disability and Nonunion

Chronic pain from rib fractures is often associated with malunion or nonunion of rib segments. The intercostal nerve runs within the intercostal groove immediately inferior to the ribs and is susceptible to irritation by non-united rib fractures. A rib segment may also cause a jabbing sensation of the lung with deep inspiration. The pain can be severe and disabling, preventing an individual from participating in exertional activities or physical labor (14). A thorough review of the nonoperative options for acute pain management in patients with multiple rib fractures has been described by Karmarkar and Ho (2). However, only a handful of case reports can be found in the literature addressing patients with chronic pain from malunited or nonunited rib fractures who are treated with surgical fixation.

> Fabricant et al. performed a prospective clinical trial of resection with or without plate fixation of nonunion rib fractures in symptomatic patients (15). 24 patients at least 4 months postinjury underwent surgical intervention for rib fracture nonunions and found improved activity levels ($p<0.0001$), but functional and work status were not improved.
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> Ng et al. described a 57-year-old male with 11-months of pain from spontaneous fractures of his right 5th, 6th, and 7th ribs due to forceful coughing (16). The fibrous pseudoarthrosis was removed and the ribs were united with 3.5mm reconstruction plates. The postoperative course was complicated by a hematoma and subsequent wound infection treated successfully with intravenous antibiotics. The patient later returned to his daily activities without any further complications or complaints.
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> Cacchione et al. reported on a 47-year-old male with a symptomatic chest wall deformity due to a motor vehicle collision two years prior that had been unsuccessfully treated with various pain remedies (17). The patient experienced chronic pain and dyspnea on exertion. Fixation of the 4th, 5th, and 6th ribs was accomplished with titanium reconstruction ribbon plates and 4.0mm screws. The patient was discharged on the fifth post-operative day and subsequently demonstrated complete relief of symptoms with complete union of the ribs 6 months later.
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> Slater et al. reported a 57-year-old man who had sustained a flail chest injury 6 years prior due to an all-terrain vehicle crash (18). The patient complained of dyspnea on exertion and pain when lifting or rotating his body. Operative fixation was accomplished with resection of the pseudoarthroses and segments of the deformed ribs followed by reduction and stabilization using 3.5mm and 4.5mm reconstruction plates and steel wire. The patient was discharged on post-operative day 5. At 18 months, the patient reported working full-time with significant improvement of his dyspnea and pain.
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> Anavian et al. described a 50-year-old man who had suffered multiple rib fractures after falling from a ladder (19). He complained of pain with movement and tenderness of his right ribs. Surgical fixation of the 7th and 8th right ribs was accomplished with 2.7mm locking reconstruction plates. The patient returned to full-time work as a painter and his typical physical hobbies with no complaints of pain or limitations.

Severe Chest Wall Deformity

Severe chest wall deformity is a rare injury that may occur from blunt trauma to the thoracic cage. A retrospective study by Solberg et al. describes 16 patients who experienced an implosion deformity of the chest wall from a high-energy side impact mechanism (20). Patients with anterior flail chest injuries and severe head trauma were excluded from this study. Nine patients were treated with surgical fixation while 7 patients were managed non-operatively.

Surgical stabilization occurred within 48 hours after injury (mean of 18 hours) and was accomplished with 2.4mm titanium plates via a para-midline posterior approach. Patients undergoing surgical stabilization demonstrated significant benefits in terms of less total intubation time (2 vs. 13 days), less ICU length of stay (5 vs. 21 days), less chest tube duration (6 vs. 17 days). Of note, five patients (71%) in the non-operative group and three patients in the operative group (33%) had pulmonary contusions.

Following Thoracotomy

Rib plating has been identified as potentially beneficial in patients who are undergoing thoracotomy for retained hemothorax, intercostal artery hemorrhage, pulmonary laceration with persistent air leak and hemorrhage, pulmonary hematocele with hemoptysis, open pneumothorax, or diaphragm laceration (14,21). The Practice Management Guidelines established by the Eastern Association for the Surgery of Trauma supports surgical fixation “in severe unilateral flail chest or in patients requiring mechanical ventilation when thoracotomy is otherwise required” as a Level III recommendation (1). In a survey of trauma, orthopedic and thoracic surgeons, 18% of the participants agreed that “after thoracotomy for other trauma indications” would be an acceptable indication for rib fracture repair in selected patients (22).

Pulmonary Herniation

Pulmonary herniation is an uncommon occurrence in which the lung parenchyma and pleura membranes protrude through a weakness of the thoracic cage. It has been reported to occur secondary to a variety of causes such as blunt chest wall trauma, seatbelt use, chest compressions, chronic coughing, or post-operatively. However, due to its infrequency, treatment with surgical fixation has yet to be assessed in a prospective randomized controlled trial. Nonetheless, it was selected by 58% of trauma, orthopedic and thoracic surgeons as an acceptable indication for rib fracture repair, thereby making it the most popular indication among the cohort of practitioners (22). Numerous techniques have been reported to surgically treat pulmonary herniation and include use of wire or absorbable suture to provide pericostal fixation of adjacent ribs and synthetic mesh or biologic tissue patches (23-25).

TECHNIQUES AND TECHNICAL CHALLENGES

Surgical fixation of rib fractures poses unique challenges that require special consideration during operative treatment. Timing of rib fracture stabilization is also debated. A prospective study by Pieracci et al. collected data from four trauma centers from 2006-2016 (26). They identified three groups based on timing of fixation from admission: early (<1 day), mid (1-2 days), and late (3-10 days). The outcomes measured length of operation, number of ribs repaired, prolonged (>24 hours) mechanical ventilation, pneumonia rates, tracheostomy, hospital LOS, and mortality. A total of 551 patients were identified and median time to operative fixation was 1 day. Over the 10-year study period, there was a shift toward earlier operative intervention. Operative intervention within 1 day of admission was associated with less operative time, lower likelihood of tracheostomy, and increased likelihood of pneumonia.

In terms of unique physical characteristics, the rib has a thin cortex spanning 1-2 mm surrounding a core of soft marrow. As a result, it has limited potential to provide adequate purchase for cortical screws. As mentioned earlier, the intercostal neurovascular bundle runs along the inferior border of the rib posing a threat for impingement and chronic pain with the application of certain hardware. Nirula and Mayberry reviewed the complications of 704 surgically repaired rib fractures that have been reported in the literature since 1975 (21). They reported 14 superficial wound infections, four draining wounds, two pleural empyemas, one persistent pleural effusion, one wound hematoma, and one case of osteomyelitis secondary to a contaminated chest tube. Fixation failure due to hardware was noted in nine patients (1.3%) and removal of hardware due to patient discomfort was found in nine patients.

In a survey of 238 trauma surgeons, 97 orthopedic trauma surgeons, and 70 thoracic surgeons, 26% reported that they had either assisted or were the primary surgeon on a rib fracture repair (22). Because there is a paucity of surgeons who are experienced with surgical rib fracture repair, researchers have recommended a team approach consisting of trauma surgeons, orthopedic surgeons and thoracic surgeons when approaching this procedure (21,27). The use of three-dimensional computed tomography has also been suggested to further aid the pre-operative and intra-operative experience (19,21,27).

Metal Plates

Various types of hardware exist for the fixation of rib fractures. One technique is to secure metal plates to the anterior surface of the rib with wire cerclage (14). This method has been reported to be unsatisfactory due to wire breakage and the potential for nerve impingement (33). One described technique to avoid nerve impingement is to run the wire through holes drilled in the middle of the rib (14).

The Judet strut is a metal plate with crimps along its edges designed to fasten to the superior and inferior borders of the rib. While it has reported success in the literature, it does not avoid the complication of impinging the intercostal nerve along the inferior border. The U-plate is designed to avoid damage to the neurovascular bundle by clamping onto the superior aspect of the rib only, secured with locking screws. Sales et al. compared the stability of U-plates to anterior locking plates through a model using cadaveric ribs (28). They attempted to simulate the long-term mechanics of breathing in which surgically reconstructed ribs underwent two Newtons of force 50,000 times. The anterior locking plate lost a significant amount of stiffness (9.9%) whereas the U-plate did not demonstrate a loss of significant stiffness (1.9%) suggesting that U-plate fixation is more durable than anterior plate fixation.

The 3.5 mm reconstruction plates have been commonly employed due to their frequent use in other orthopedic procedures. However, these plates require intra-operative contouring resulting in increased time and technical skill. Additionally, there are several reports in the literature of their mechanical failure resulting in screw pullout and loosening (29,30). Anatomic rib plates were introduced by Bottlang et al. based on the research of Mohr et. al who described the geometry of human ribs (31,32). By using pre-contoured rib plates, a surgeon can avoid the time and skill required to reshape standard plates which can be particularly valuable when reconstructing multiple ribs.

Absorbable Plates

The use of biodegradable polymer materials for the fixation of rib fractures has been shown to be safe and effective in preliminary trials (33-35). They are an attractive option for fracture fixation because they preclude the need for future removal and are compatible with magnetic resonance imaging. Furthermore, they may result in faster and stronger bone healing by avoiding the stress-shielding occurring from metallic plates (36). Mayberry et al. reported ten cases of rib fixation for flail chest using absorbable plates (33). All flail chest patients were weaned at an average of nine days postoperatively. All patients with acute pain reported decreased pain and increased stability postoperatively. The one patient with a chest wall defect healed without complications and returned to his preoperative level of physical activity. Two of the cases in which the absorbable plates were fixated using only absorbable screws resulted in partial loss of rib alignment that was noticeable only on chest radiograph. The researchers used screw fixation combined with absorbable suture cerclage thereafter without any future complications. In a retrospective chart review, Mayberry et al. reported 3 out of 46 patients with fixation failure following rib fracture repair, all of whom had absorbable plates used as primary fixation posteriorly (14). Thereafter, the authors recommended using metal plates in conjunction with absorbable plates for posterior chest wall stabilization. High rates of fixation failure have been reported in preliminary studies when stabilizing posterior rib fractures with absorbable plates (33,34). Furthermore, adverse tissue reactions and sinus formations are reported complications with the use of bio-absorbable materials for fracture fixation (37).

Intramedullary Fixation

Rib fixation with intra-medullary hardware generally requires less dissection compared to reconstruction with extra-medullary plates. Furthermore, the intra-medullary nature of the appliance limits the potential for chronic iatrogenic injury or irritation of surrounding structures. Intra-medullary hardware is particularly useful for posterior rib fractures where adequate exposure for plate-fixation requires extensive dissection. The Kirschner wire is a type of intra-medullary implant that has fallen out of favor due to reports of its poor rotational stability and potential to migrate. The Rehbein plate was developed in 1972 and attempted to improve the rotational stability of the Kirschner wire design. This plate is rectangular rather than cylindrical and exposes one end extra-medullary to be sutured to the surface of the rib thereby preventing migration. Similar to the Rehbein plate, an intra-medullary pre-contoured rib splint has been recently introduced that uses a locking screw for fixation to the rib (38). Bottlang et al. evaluated the biomechanics of the pre-contoured intra medullary rib splint and determined that after 360,000 cycles of simulated heavy breathing, cadaveric ribs repaired with the Rehbein plate was 48% stronger (p=0.001) than K-wires (31).

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