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Operative Treatment of Chest Wall Injuries: Indications, Technique, and Outcomes

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- Most injuries to the chest wall with residual deformity do not result in long-term respiratory dysfunction unless they are associated with pulmonary contusion.
- Indications for operative fixation include flail chest, reduction of pain and disability, a chest wall deformity or defect, symptomatic nonunion, thoracotomy for other indications, and open fractures.
- Operative indications for chest wall injuries are rare.

Operative management of chest wall injuries is a controversial topic. This was highlighted by a recent survey of 238 members of the Eastern Association for the Surgery of Trauma, ninety-seven members of the Orthopaedic Trauma Association, and seventy thoracic surgeons. The majority of the respondents (82% of the general surgeons, 66% of the orthopaedic surgeons, and 71% of the thoracic surgeons) responded that operative repair of rib fractures was indicated in selected patients. Fewer (17% of the general surgeons, 32% of the orthopaedic surgeons, and 23% of the thoracic surgeons) responded that operative repair of rib fractures was rarely or never indicated. Only 21% of the trauma surgeons, 16% of the orthopaedic surgeons, and 52% of the thoracic surgeons indicated they had ever performed or assisted in open reduction and internal fixation (ORIF) of rib fractures. Twenty-two percent (eighty-nine) of all 405 respondents indicated that they were familiar with a randomized trial of surgical repair of flail chest.

In 2004, over 300,000 people were treated for rib fractures in the U.S. with 102,000 patients being admitted to U.S. hospitals. Because the majority of patients with rib fractures are not admitted to the hospital, the true incidence may be higher than estimated. Fractures of consecutive ribs have been found to be independent markers of injury severity, resulting in increased morbidity and mortality. An estimated 25% of annual traumatic deaths result from chest trauma. Rib fractures have been detected in up to 39% of patients (548 of 1417) who have sustained blunt chest trauma and up to 10% of trauma admissions overall (711 of 7147). Flail chest is present in up to 6% of patients (eighty-two of 1417) who have sustained blunt chest trauma. These injuries are potentially fatal, with in-hospital mortality rates of up to 12% (eighty-four of 711) for patients with multiple rib fractures and up to 33% (thirty of ninety-two) for patients with a flail chest. Nonoperative management, consisting of pulmonary toilet, pain control, and selective ventilatory support, is the standard treatment for these injuries at most institutions. Operative intervention is controversial, although several reports indicate that patients who underwent ORIF of flail chest injuries or multiple rib fractures required a shorter duration of ventilator support, were less likely to develop infections and septicemia, and were less likely to require tracheostomy than patients managed nonoperatively.

The orthopaedic surgeon is often consulted about concomitant fractures and is often the specialist who follows the patient for the longest period of time. Thus, it is paramount that orthopaedic surgeons be aware of the short and long-term sequelae of these chest wall injuries as well as the potential benefit of ORIF of fractured ribs in the setting of massive chest wall trauma.

**Diagnosis**

Up to 54% of rib fractures (208 of 388) are missed on routine chest radiographs. Oblique radiographs or special rib views increase sensitivity but are not routinely ordered. Nuclear scans can also detect occult rib fractures. Computed tomography

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(CT) scans, which are now commonly performed during the routine workup for trauma patients, have been shown to be the most sensitive imaging study for detecting rib fractures24.

Epidemiology, Morbidity, and Mortality
A recent biomechanical study demonstrated that the main loading modes during impacts causing rib fractures are local bending and shearing27, resulting in the typical short oblique fracture pattern seen. Mortality rates of up to 33% (thirty of ninety-two) have been reported for patients with flail chest injuries18,28-33. In a retrospective study of 388 patients with at least one rib fracture identified on CT scans, Livingston et al.24 found that the mortality rate associated with rib fractures was lower than previously reported. The authors theorized that this was due to previous investigators relying on chest radiographs to detect rib fractures7,13,34, which led them to miss the rib injury in 54% (208) of 388 cases4,43,36. The study by Livingston et al. revealed a fourfold increase in the mortality of patients with even a single rib fracture on chest radiographs. Using chest radiograph data, they found that mortality increased incrementally with five or more fractures and that there were large increases in mortality when there were seven or more fractures. However, with use of the more sensitive CT data, this curve shifted. Mortality incrementally increased with two or three fractures, and large increases in mortality were not observed until nine or more fractures were present. In that study, the mean number of rib fractures per patient was 4.2, with 21% (eighty-one) of the 388 patients having a single rib fracture and 17% (sixty-six) having six or more rib fractures. Ribs 4 through 9 were the most often injured. The vast majority of fractures were posterolateral, and there was a slight left-sided propensity.

Nearly half (187) of the patients in the study had pulmonary contusions associated with the fractures.

Several studies have demonstrated a direct correlation between the number of rib fractures and intrathoracic injury, morbidity, and mortality5,14,15,34. A study of 105,683 trauma patients revealed that the presence of three or more rib fractures increased the relative risk of splenic injury to 6.2 and the relative risk of liver injury to 3.6 but did not predict the presence of aortic injury12. Up to 55% of patients (391 of 711) with rib fractures have been found to require immediate surgery or admission to the intensive-care unit, primarily because of associated injuries4.

Studies have shown that many patients treated non-operatively for chest wall injuries have several long-term morbidities (Fig. 1). When patients with rib fractures were compared with chronically ill patients, the former group was found to be significantly (p < 0.001) more disabled at thirty days in all categories of the Short Form-36 Health Status Survey except emotional stability (they showed equivalent disability in that category) and their perception of general health (they showed significantly less disability in that category). Patients who have had a flail chest often report long-term dyspnea and chest pain and have abnormal test results on spirometry32.

The morbidity and mortality rates for patients with chest wall injuries are higher at the extremes of age5,7,10,11,13,14,18,37,38. Ribs may become brittle with advancing age. With a less compliant chest wall, less energy is required to cause fractures. A recent study of 181,331 adults in the National Trauma Data Bank showed that “the odds ratio for death for younger patients (aged 18-45) was 1.4 (95% CI 1.3-1.6) if rib fractures of at least AIS 3 or greater were present. For older patients (over 64 years) the odds ratio was 2.5 (95% CI 2.3-2.8). In other

Fig. 1
A young female patient with a deformity of the posterior aspect of the thorax secondary to multiple malunited rib fractures.
words, regardless of the presence or absence of concomitant trauma, crash-injured patients with rib fractures of at least AIS 3 have a significantly increased risk of in-hospital mortality, and of two patients having similar non-rib trauma, one with AIS 3 + rib fractures has a substantially higher expected risk of death than one without. This effect is more dramatic for older patients1,15 Bulger et al.1 found that elderly patients who had sustained blunt chest trauma with rib fractures had twice the mortality and thoracic morbidity compared with younger patients with similar injuries. In their study, for each additional rib fracture in an elderly patient, mortality increased by 19% and the risk of pneumonia increased by 27%. Rib fractures in children are of particular concern. The chest wall of a child is more pliable because of a lack of calcification, which allows plastic deformation. Hence, children can have substantial intrathoracic trauma in the absence of rib fractures39, and pediatritic rib fractures themselves indicate very high-energy injury mechanisms. Therefore, rib fractures are considered to be more of a marker of severe trauma in children than in adults31,12,49. The likelihood of rib fractures noted in a child being the result of a nonaccidental injury decreases with increasing age. Rib fractures in children less than three years of age have been found to be highly predictive of child abuse3,5,38,40,51, with 82% (fifty-one) of sixty-two children who were seen with rib fractures when they were less than three years of age being victims of abuse38. It is rare for children to have more than three rib fractures51.

**Pulmonary Contusion**

Rib fractures are often associated with pulmonary contusions8. Multiple rib fractures have been found to predispose patients to pulmonary insufficiency and compromised ventilation. Furthermore, in patients with a flail chest injury, paradoxical chest wall motion and pain can result in low tidal volumes, substantial alveolar collapse, arteriovenous shunting, and hypoxemia, necessitating prolonged mechanical ventilation20, all of which can result in severe complications such as pneumonia and sepsis28,29,42-44. The presence or absence of pulmonary contusion has been found to be an important factor guiding the decision regarding whether to proceed with ORIF. Patients with pulmonary contusion do not seem to benefit as much as do those without it10,22,45,64. Perhaps this is because most injuries to the chest wall do not result in long-term respiratory dysfunction unless pulmonary contusion is associated. Fibrosis and scarring of the contused lung have been proposed as reasons for respiratory derangements detectable by spirometric testing46.

**Nonoperative Management**

Nonoperative treatment is appropriate for the vast majority of rib fractures, and operative management should be considered for very few cases. Healing usually occurs spontaneously without placement of orthopaedic implants. Advantages of nonoperative treatment include avoidance of potential surgical complications such as infection, injury to intercostal neurovascular structures, lung injury, and the need for subsequent operations to remove implants. However, nonoperative management of rib fractures has been associated with substantial pain and discomfort46. The mainstays of nonoperative management include conventional pain control methods (oral analgesia, intercostal blocks, patient-controlled analgesia systems, pleural infusion catheters, and epidural analgesia), aggressive pulmonary toilet, and mechanical ventilation3. Fractured ribs managed nonoperatively are subjected to continued displacement during breathing in the healing phase. This may lead to symptomatic malunion or nonunion, requiring later operative intervention50,47,48. Long-term problems continue to be rare, with the vast majority of rib fractures healing uneventfully.

**Operative Management**

**Proposed Benefits of Operative Fixation**

Reported short-term benefits of ORIF of rib fractures and flail chest include accelerated restoration of pulmonary function20,28,42,44,45,49,50, reduced morbidity associated with prolonged mechanical ventilation6,21,28,29,42,44,49,51, and shortened stays in the intensive-care unit and the hospital30,42,52. These advantages typically lead to a shorter recovery time and a faster return to work. Early restoration of chest wall integrity and respiratory pump function after ORIF may prove to be cost effective through the prevention of prolonged mechanical ventilation and restriction-related work capacity. Reported long-term benefits of ORIF include a decreased likelihood of clinically relevant long-term pain, respiratory dysfunction, and skeletal deformity28,36,55. There is also a theoretical advantage of improved lung functional reserve following ORIF secondary to restoration of greater lung volumes.

Although surgery is rarely utilized, a review of the literature indicates that there are occasional situations where operative management of rib fractures should be considered. All indications are currently considered relative; there are no absolute indications based on available studies. Treatment must be individualized on the basis of the patient’s fracture pattern, overall medical condition, and functional status (Table I)19.

**Flail Chest**

Flail chest is variably defined in the literature. The most commonly cited definition is unilateral fractures of four consecutive ribs, with each rib fractured in two or more places. Clinically, flail chest is diagnosed when an incompetent segment of chest wall is large enough to allow paradoxical motion of the chest wall with respiration3,29,48 (Figs. 2-A, 2-B, and 2-C). A sternal flail chest occurs when the sternum becomes dissociated from the hemithoraces as a result of bilateral, multiple, anterior cartilage or rib fractures. Two recent randomized trials indicated that selected patients with flail chest may benefit from ORIF in both the short and the long term30,44. Several nonrandomized, cohort-comparison trials have also generally confirmed these findings, with the caveat that flail chest repair is not advisable for patients with substantial pulmonary contusions3,5,29,45. In the Eastern Association for the Surgery of Trauma (EAST) Practice Management Guideline for “Pulmonary Contusion—Flail Chest,” ORIF for severe unilateral flail chest or for patients requiring mechanical ventilation when thoracot-
omy is otherwise indicated was considered to be a Level-III recommendation. Level-III recommendations are defined by EAST as being supported by Class-III studies (retrospectively collected data). EAST states that this type of recommendation is useful for educational purposes and in guiding future clinical research only. They cited the low numbers of patients randomized, the strict exclusion criteria in the study by Tanaka et al., and the absence of trials comparing operative repair with “modern” nonoperative treatments as reasons for the Level-III designation.

**Chest Wall Deformity or Defect**

Chest wall defects or deformities can result from severely displaced rib fractures with or without soft-tissue loss. Paradoxical
motion may be noted if a flail segment is present. Many patients, especially those who are young and have adequate pulmonary reserve, do not require endotracheal intubation. Minimal to moderate-size tissue defects can be caused by penetrating missiles, shotgun injury, or impalement by surrounding objects. In these cases, repair of both rib fractures and soft tissues may be indicated to restore chest wall competency (Fig. 3).

**Acute Pain and Disability**

It has been hypothesized that certain patients experiencing persistent, unrelenting pain with breathing, coughing, or mo-

| TABLE 1 Potential Indications and Considerations for Operative Fixation of Rib Fractures* |
|---------------------------------|---------------------------------|
| **Operative Indications** | **Other Considerations** |
| Flail chest | Failure to wean from ventilator  
Paradoxical movement visualized during weaning  
No substantial pulmonary contusion  
No substantial brain injury |
| Reduction of pain and disability | Painful, movable consecutive rib fractures  
Failure of narcotics or epidural pain catheter  
Fracture movement exacerbating pain, inhibiting respiratory effort  
Minimal associated injuries |
| Chest wall deformity/defect | Chest wall crush injury with collapse of the structure of the chest wall and marked loss of thoracic volume  
Severely displaced, multiple rib fractures or tissue defect that may result in permanent deformity or pulmonary hernia  
Severely displaced fractures substantially impeding lung expansion or fractured ribs impaling the lung  
Patient expected to survive other injuries |
| Symptomatic rib fracture nonunion | Radiographic evidence of fracture nonunion  
Patient reports persistent, symptomatic fracture movement |
| Thoracotomy for other indications in the setting of rib fractures | Open rib fracture |

bilitation may benefit from ORIF. This suggestion has not been confirmed by cohort-comparison or randomized trials. It has been suggested that, if their pain were alleviated by acute ORIF, patients could possibly return to work and their usual activities sooner.

Nonunion
A small percentage of rib fractures do not heal and may develop into a symptomatic nonunion. Fibrous tissue and pseudarthrosis are characteristic histological findings. Patients with nonunion have reported pain, tenderness, a sensation of “jabbing” into the lung with deep respiration, clicking with motion of the ipsilateral shoulder girdle, or pain with sneezing and other bodily motions involving a Valsalva maneuver. In the past, rib nonunions have been treated with rib resection or cancellous bone-grafting, although resection does not always guarantee lasting relief of pain. More recently, ORIF has been employed to treat rib nonunion.

Thoracotomy for Other Indications
A patient who undergoes a thoracotomy for another indication such as an open pneumothorax, pulmonary laceration, retained hemothorax, or diaphragmatic laceration may be a candidate for ORIF of rib fractures. Thoracotomy for non-traumatic indications such as tumor resection also may result in rib fractures that can be surgically repaired. Stabilizing the fractured ribs prior to closure after completion of the primary procedure may increase patient comfort and improve pulmonary care.

Open Fractures
Although, to our knowledge, no published study has addressed the treatment of open rib fractures, it is reasonable to apply standard principles of open fracture management to these injuries. The goals of treatment of open rib fractures are to prevent infection, allow the fracture to heal, and restore function. We believe that the standard principles of imparting stability to open extremity fractures after irrigation and debridement may be equally relevant to the treatment of chest wall injuries in order to decrease pain and the risk of infection and nonunion.

Preoperative Planning
The geometry and character of human ribs are unique among the bones of the body and contribute to the challenge of rib fracture fixation. Human rib thickness ranges from 8 to 12 mm with a relatively thin (1 to 2-mm) cortex surrounding soft marrow. Individual ribs do not have good tolerance to stress...
and do not provide good cortical screw purchase. Rib fractures may be oblique or even comminuted, further complicating the challenge of obtaining reliable fixation. In addition, the intercostal nerve lies in a groove under the inferior surface of the rib, and iatrogenic injury from manipulation of the fractured ribs or placement of orthopaedic implants may lead to post-thoracotomy pain syndrome. Three-dimensional CT reconstructions may be useful to completely define all rib fractures and the extent of their displacement and to help plan the surgical approach. If possible, chest tubes are removed from the pleural space at least a day before ORIF to minimize the potential for bacterial contamination. Antibiotics are routinely given perioperatively.

**Operative Technique: Our Preference**

Mayberry et al. found that 33% (seventy-nine) of 238 trauma surgeons, 48% (forty-seven) of ninety-seven orthopaedic trauma surgeons, and 91% (sixty-four) of seventy thoracic surgeons considered themselves competent to perform the surgery. We recommend that a thoracic surgeon be present to assist with the operative approach if the orthopaedic surgeon is unfamiliar or inexperienced with thoracic approaches.

The patient is placed in the lateral decubitus position. A standard thoracotomy incision is made overlying the fractured ribs. Dissection is carried sharply through skin, subcutaneous tissues, and fascia. The serratus anterior muscle is retracted anteriorly and the latissimus dorsi muscle is retracted posteriorly, to the extent necessary as determined by how anterior or posterior the incision is placed. Muscle-sparing techniques, such as division of the latissimus dorsi muscle in line with its fibers, can provide adequate exposure of up to three rib fractures through an incision 10 to 15 cm in length. Alternatively, instead of making one larger incision, the surgeon can make multiple smaller incisions that avoid muscle division. The intercostal muscles are incised over the superior border of the rib at the desired level. By entering the pleural cavity, this approach provides excellent visualization during ORIF. The ability to reduce the rib from inside the thoracic cavity via manipulation is important, given that the fractured ribs displace toward the midline. Throughout the procedure, the lung is observed and protected.

Single-lung ventilation is useful to improve exposure and avoid injury to the lung parenchyma on the intrathoracic side of the dissection. However, the presence of a pulmonary contusion may limit tolerance of single-lung ventilation. In addition to the lung affected by contusion, there can be impairment of the noncontused lung due to the systemic inflammatory response syndrome initiated by the trauma in some patients. If there is no evidence of contralateral lung injury, single-lung ventilation is likely to be successful.

Early ORIF reduces the extent of thoracic wall dissection necessary for mobilization and excision of callus. The ends of the fractured ribs are cleared of their soft-tissue attachments for a distance of 1 to 2 mm with use of an elevator. Curets and pituitary rongeurs are used to carefully clean any debris from the fracture site. Care must be taken to avoid violating the intercostal neurovascular bundles located on the inferior aspect of the ribs. When there is a nonunion, the medullary canal is reestablished with an appropriately sized drill bit in oscillate mode to avoid cortical penetration. The fracture ends are mobilized and reduced with use of a combination of bone reduction clamps and dental picks. unicortical drill holes are useful to create purchase points for reduction tools during mobilization, reduction, and fixation. Displaced rib fractures tend to shorten and overlap; thus, gaining compression is not generally an issue once reduction is obtained.

Plates may be applied directly over the peristomeum of the rib. The fractured ribs adjacent to the thoracotomy site are typically plated first. The senior author (P.A.C.) chooses a plate of sufficient length to allow at least six cortices of fixation on both sides of the fracture. As is the case for long-bone fractures, osteoporotic bone may require longer plates or locking constructs to help prevent fixation failure. Given that the fracture site will experience immediate continuous motion with respiration, we recommend the use of locking plates. This fixation option allows use of shorter plates and less surgical exposure. The choice of implants as well as relative screw configurations depend on many factors such as the bone quality and whether the surgeon desires secondary or primary healing. If precontoured plates are not available, the senior author recommends using a template to contour a 2.7-mm locking reconstruction plate or 3.0-mm mandibular locking plate of appropriate length. The fractured ends of the ribs should be placed under compression before screws are placed, with bone graft possibly added in cases of nonunion. The ribs on both sides of the thoracotomy are sequentially approximated. It is unnecessary to plate all of the fractured ribs in a large thoracic segment, but enough of them must be plated to provide internal splinting to the remaining ribs and to help restore thoracic contour (Figs. 2-A, 2-B, and 2-C). Ribs anterior to the scapula are difficult to access safely and generally should be left unfixed given the added muscular protection and stabilization from the peri- scapular musculature. Additionally, deformity of the upper ribs results in less lung-volume loss. At the conclusion of fixation, the pleural cavity can be filled with saline solution and the lung can be reinflated to check for air leaks. If a leak exists, a chest tube should be placed. Wound drains are used at the discretion of the operating surgeon, on the basis of an assessment of the wound. A layered muscular closure with absorbable suture is typically given perioperatively.

**Fixation Options**

Fixation must be able to tolerate up to 25,000 breathing cycles per day as well as coughing. Both rigid and nonrigid systems have been developed. Potential disadvantages of both rigid and nonrigid internal fixation systems include interference with CT and MRI (magnetic resonance imaging) studies, stress-shielding, palpable implants, and the potential need for another.
operation for implant removal due to pain or loosening of implants. Metal Plates

The use of metal plates is the standard choice for operative fixation of rib fractures. Generic 3.5-mm and 2.7-mm reconstruction plates, one-third tubular plates, dynamic compression plates, and low-contact dynamic compression plates contained in standard small and mini-fragment implant sets have been utilized, as have plates designed for maxillofacial surgery. These maxillofacial plates may be 2.4, 2.7, or 3.0 mm and are made of titanium or stainless steel. Recently, there has been a move toward using locking plates with either bicortical or unicortical screws, especially in patients with osteopenic bone or in whom there is poor screw purchase. Generic small and mini-fragment plates have the disadvantage of requiring extensive contouring. Because of the complex geometry of ribs, intraoperative contouring of plates can be difficult. Furthermore, the use of generic plates has been accompanied by screw loosening and pullout in several reports. Recently, investigators have attempted to address these deficiencies. Mohr et al. performed a study to establish a biometric foundation to generate specialized, anatomically contoured implants for rib fixation. These implants theoretically should improve maintenance of reduction and stability, decrease the incidence of implant loosening, shorten the operative time, and consequently decrease the risk of infection and nonunion or failure of the implant. Precontoured plates are relatively thin, which minimizes stress-shielding while allowing physiologic motion during respiration. The clinical superiority of precontoured plates has not been proven, making the added cost of these specialized implants difficult to justify at the present time.

Absorbable Plates

Absorbable polymers have been successfully used in the fixation of maxillofacial, tibial, and rib fractures; in the reconstruction of chest wall deformities; and in rib reapproximation after thoracotomy for nontraumatic indications. Plates made of absorbable polymer are typically applied with use of absorbable suture material. The plates may be applied on either the inferior or the exterior surface of the rib and may be secured by placing the suture either around the rib or through drill holes. These implants retain sufficient rigidity until adequate healing has taken place, resorbing at a rate that slowly transfers mechanical load to bone. This may minimize the problem of stress-shielding, which has been reported with metal implants, and eliminate the potential need for a second operation for implant removal. Findings in animal models have supported the concept that fractures heal faster, with stronger bone after healing, with use of absorbable plates. In a rabbit model, rib fracture reduction was maintained to a greater degree with polylactide plate fixation of ribs than with nonoperative treatment, resulting in improved bone healing. Antibiotics could be added to absorbable plates.

Although they have not been reported with the treatment of rib fractures, there are concerns about complications, such as foreign-body reactions, swelling, fluid accumulation, and cyst formation, related to bioabsorbable materials utilized in fracture fixation elsewhere in the body. For these reasons, the use of bioabsorbable materials for fracture fixation in other locations has been largely abandoned. Absorbable implants are also more costly than standard metal implants.

Intramedullary Fixation

Intramedullary fixation of rib fractures has been used successfully but is technically demanding and carries the risk of implant dislodgment and migration as well as poor rotational stability. Recently, anatomically contoured titanium intramedullary struts designed for rib fracture fixation have been introduced and have improved rotational stability. A broad flat design and the addition of a single unicortical locking screw to hold the strut suggest that this implant design may lessen the risk of dislodgment and migration. 

Judget Struts

The Judet strut is a bendable metal plate that grasps the rib with tongs both superiorly and inferiorly without transfixing screws. Fixation of this plate around the inferior margin of the rib can potentially crimp the intercostal neurovascular bundle, causing intercostal nerve injury and subsequent chronic pain. One variation of the strut that has been reported is a self-gripping, elastic band that envelops the rib.

U-Plates

U-plates are applied in a manner similar to that used to apply the Judet strut, but they do not have the potential for crimping of the intercostal nerve because the plate is placed along the superior border. U-plates can be placed with minimal dissection of the rib in the extrapleural space, with preservation of the periosteum. They are secured by locking screws placed through the midsubstance of the rib with use of a targeting guide. Locking screws engage the exterior and interior aspects of the plate and do not rely on screw purchase in bone; thus, they may prove useful in patients with osteoporosis. 

Outcomes

Nonoperative Treatment

Few clinical studies with long-term follow-up of the results of nonoperative management of rib fractures have been published. Kerr-Valentic et al. compared forty patients treated nonoperatively for rib fractures with the chronically ill reference population in the RAND Medical Outcomes Study and found that the nonoperatively treated patients were significantly more disabled at thirty days in all categories.
of the Short Form-36 Health Status Survey except emotional stability (they showed equivalent disability in that category) and their perception of general health (they showed significantly less disability in that category; \( p < 0.001 \)). The total mean number of days lost from work/usual activities of daily living was \( 71 \pm 41 \). Patients with isolated rib fractures went back to work/activities of daily living at a mean of \( 51 \pm 39 \) days compared with \( 91 \pm 33 \) days for patients with associated extrathoracic injuries (\( p < 0.01 \)). Landercasper et al.\(^{32} \) interviewed thirty-two patients at a mean of five years after they had sustained a flail chest injury and found that 63% reported dyspnea, 49% experienced chest pain, and 25% experienced chest tightness. Spirometry results were abnormal in 57%. Beal and Oreskovich\(^{101} \) evaluated twenty-two patients who had sustained a flail chest as their only major injury and found that 64% had long-term disability. Chest wall pain, deformity, and dyspnea on exertion were the most frequently reported symptoms. Bulger et al.\(^{7} \) studied 216 elderly patients (over the age of sixty-five years) and 168 younger patients and found that many were unable to return directly home from the hospital, with the discharge destination significantly affected by age. Only 56% of the elderly patients and 73% of the younger patients with rib fractures were discharged to home (\( p < 0.01 \)). Other destinations included subacute nursing facilities (16% of the elderly patients and 8% of the younger patients), short-term rehabilitation facilities (10% and 8%), and other acute-care hospitals (18% and 7%). Similarly, Sharma et al.\(^{5} \) found that 41% (ninety-eight) of 240 elderly patients, 74% (386) of 522 adult patients, and 87% (forty) of forty-six surviving children were discharged to home. These studies indicate that many patients with rib fractures and flail chest require prolonged care.

**Operative Treatment**

Several studies have demonstrated benefits of ORIF for rib fractures; however, only two randomized studies have been published to our knowledge. Tanaka et al.\(^{42} \) randomized thirty-seven patients at five days after injury to be treated with Judet struts or internal pneumatic stabilization. Respiratory management was identical for the two groups. At one month following injury, patients who underwent ORIF required significantly less ventilator support (\( p < 0.05 \)) and had a lower prevalence of pneumonia (\( p < 0.05 \)), shorter stays in the trauma intensive-care unit (\( p < 0.05 \)), and lower medical costs (\( p < 0.05 \)) than patients treated with intubation and mechanical ventilation. Moreover, ORIF improved the percentage of predicted forced vital capacity during the early phase after ORIF. Also, the percentage of patients in the ORIF group who were able to return to their previous employment six months after injury was significantly higher than the percentage of those treated with internal pneumatic stabilization (\( p < 0.05 \)).

More recently, Granetzny et al.\(^{54} \) reported on a randomized trial of forty patients with flail chest in which an operatively treated group was compared with patients treated with external adhesive plaster. Stability of the chest wall occurred in 85% of the patients in the surgical group compared
with 50% of the conservatively treated group. Forty-five percent of the patients in the operatively treated group required ventilatory support after fixation, for an average of two days, while 35% of the patients in the conservatively treated group required ventilatory support, for an average of twelve days. Chest wall deformity was noted in nine patients in the conservatively treated group compared with only one patient in the operatively treated group. Pulmonary function tests at two months indicated that the operatively treated group had a significantly less restrictive pattern (p < 0.001), as indicated by measurement of forced vital capacity and total lung capacity. The operatively treated group also had significantly fewer days of ventilator support, treatment in the intensive-care unit, and in-patient treatment (p < 0.001) and a lower rate of pneumonia (p = 0.014).

Mayberry et al.102 recently performed a retrospective review of long-term outcomes of forty-six patients who had undergone surgical repair of severe acute chest wall injuries. Indications for the surgery included flail chest with an inability to be weaned from the ventilator, acute intractable pain, acute chest wall defects/deformity, acute pulmonary herniation, and thoracotomy for other traumatic indications. Three patients had a concomitant sternal fracture repair. Fifteen patients with a mean age of 60.6 years (range, thirty to ninety-one years) were surveyed at a mean of 48.5 ± 22.3 months (range, nineteen to ninety-six months) postinjury. RAND-36 indices103 indicated equivalent or better health status compared with reference populations, with the exception of role limitations due to physical problems when compared with the general population.

Campbell et al.78 retrospectively reviewed the cases of thirty-two consecutive patients who had undergone ORIF of traumatic rib fractures with the Inion biodegradable orthopedic trauma plating system (OTPS) during their index admission. All patients were followed with a questionnaire assessing chest symptoms, disability, and quality of life. Wound infection occurred in 19% of the patients and nonunion of a rib fracture, in one patient. Patients reported low levels of pain at rest and with coughing. Chest wall stiffness was experienced by 60% of the patients, while dyspnea at rest was reported by 20%. Fifty-five percent of the patients returned to work, at a mean of 3.9 ± 3.3 months. All patients reported satisfaction with the results of the operation.

Nirula et al.22 compared thirty patients who had undergone ORIF with thirty controls and found a trend toward fewer total days of ventilator support in the ORIF group (2.9 days compared with 9.4 days in the control group). The investigators concluded that ORIF may reduce ventilator requirements in trauma patients with severe thoracic injuries.

Karev31 treated 133 consecutive patients with flail chest injuries with either ORIF (forty patients) or nonoperative treatment (ninety-three patients); the two groups were similar in all respects. Various types of extramedullary ORIF were performed within twenty-four hours after admission. Non-
operative treatment included mechanical ventilation, placement of an epidural catheter, and regional analgesia. The investigators concluded that ORIF should be considered when extensive flail chest is present, particularly for patients with severe pulmonary and heart contusion.

Voggenreiter et al. specifically examined the effect of pulmonary contusion on the success of ORIF. Forty-two patients with flail chest injuries were divided into four groups for analysis. In group 1, ORIF was performed for flail chest without pulmonary contusion. In group 2, ORIF was performed for flail chest with pulmonary contusion. In group 3, flail chest without pulmonary contusion was not treated with ORIF. In group 4, flail chest with pulmonary contusion was not treated with ORIF. In patients with flail chest and respiratory insufficiency without pulmonary contusion, ORIF permitted early extubation. Patients with pulmonary contusion did not benefit from ORIF despite being matched with the other groups for age and injury severity. These findings indicate that pulmonary contusion can be considered a relative contraindication to operative fixation of rib fractures. The results of this study suggest that pulmonary contusion is an independent risk factor for failure, as there were no significant differences in age, severity of injury, or extent of injury among the groups.

Ahmed and Mohyuddin retrospectively reviewed sixty-four cases of flail chest over a ten-year period. Twenty-six patients were treated with ORIF with Kirschner wire fixation, and thirty-eight were treated with intubation and mechanical ventilation. The average duration of ventilator use in the ORIF group was 3.9 days, and 80% of the patients were weaned from the ventilator in an average of 1.3 days. The remaining 20% of the patients needed ventilator support for a longer duration. For the patients treated with intubation and ventilation alone, the average duration of assisted ventilation was fifteen days. The mortality rate was 8% in the ORIF group and 29% in the intubation group. In the group treated with ORIF, 11% of the patients ultimately required a tracheostomy compared with 37% of the patients treated with intubation and ventilation alone. In the ORIF group, 15% of the patients had a documented chest infection; 4%, septicemia; and 0%, barotrauma. These complications occurred in 50%, 24%, and 8% of the cases in the nonoperatively treated group, respectively. The average stay in the intensive-care unit and the hospital, but this possibility requires additional study."

Overview
The vast majority of rib fractures are appropriately managed nonoperatively. However, operative stabilization should be considered for certain patients. Patients with multiple rib fractures treated nonoperatively have been shown to require longer periods of ventilator support; have longer stays in the intensive-care unit; and have an increased risk of pulmonary infection, septicemia, mortality, and requiring a tracheostomy. Additionally, several reports have demonstrated that nonunions of rib fractures do occur and that it is likely that the incidence of nonunion and malunion is underreported.

Operative stabilization of a flail chest is increasingly recognized as a valid approach to improve pulmonary mechanics in selected trauma patients. Debate centers on patient selection and the timing of operative intervention. The best indication at this time for early operative chest wall stabilization appears to be the presence of flail chest and respiratory failure without severe pulmonary contusion. Non-intubated patients with deteriorating pulmonary function in the setting of a flail chest benefit from stabilization in terms of respiratory dynamics, better pulmonary toilet, and improved pain control. Finally, patients with symptomatic malunion or nonunion of rib fractures and flail chest injuries appear to benefit from delayed ORIF, although clinical series have been small and retrospective. Pain and prolonged hospitalization are associated with both increased hospital costs and lost revenue for the patient because of a delay in return to work.

Larger randomized controlled trials across multiple centers will be necessary to more definitively determine the efficacy of these procedures. In the study by Mayberry et al., among the subset of surgeons who were opposed to surgical repair, 95% of general surgeons, 90% of orthopaedic surgeons, and 82% of thoracic surgeons indicated that a randomized trial confirming efficacy would be necessary to change their opinion. We agree with Mayberry et al. that a lack of familiarity with the published literature and a lack of experience with chest wall repair are common, and likely contribute to the limited use of these techniques. Most importantly, in order for optimal procedures to be performed with acceptable complication rates, surgeons advocating chest wall repairs will need to further refine operative techniques and operative indications and adequately train colleagues. On the basis of the available literature, no formal recommendation can be made regarding which fixation technique is best. The technique chosen should be based on the individual surgeon’s critical analysis of his or her own competency in this evolving area. Lastly, the cost associated with ORIF may be offset, in appropriately selected patients, by the decreased number of days in the intensive-care unit and the hospital, but this possibility requires additional study.
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