World J Surg (2009) 33:14–22
DOI 10.1007/s00268-008-9770-y

World Journal of Surgery

Rib Fracture Repair: Indications, Technical Issues, and Future Directions

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Published online: 24 October 2008

Abstract Rib fracture repair has been performed at selected centers around the world for more than 50 years; however, the operative indications have not been established and are considered controversial. The outcome of a strictly nonoperative approach may not be optimal. Potential indications for rib fracture repair include flail chest, painful, movable rib fractures refractory to conventional pain management, chest wall deformity/defect, rib fracture nonunion, and during thoracotomy for other traumatic indication. Rib fracture repair is technically challenging secondary to the human rib's relatively thin cortex and its tendency to fracture obliquely. Nonetheless, several effective repair systems have been developed. Future directions for progress on this important surgical problem include the development of minimally invasive techniques and the conduct of multicenter, randomized trials.

Introduction

Rib fracture repair has been performed at selected centers around the world for more than 50 years; however, the operative indications have not been established and are considered controversial. In this review, the historical perspective, pertinent clinical presentations, potential indications, and the unique technical challenges of rib fracture repair are reviewed with the objective of 1) identifying the patient population most likely to benefit from rib fracture repair, 2) delineating the most efficacious techniques of repair, and 3) quantifying the potential short and long-term individual benefits of repair.

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Historical perspective

Open surgical treatment of rib fractures dates at least as far back as the first century of the Common Era (CE) when the Roman surgeon Soranus (CE 78–117) described the resection of depressed rib fractures for the relief of pleuritic pain [1]; 1500 years later, Ambroise Pare advised an initial attempt at closed reduction of displaced rib fractures by adhering strong cloth to the chest wall with pitch and flour and then "plucking with great violence" to elevate the fracture [2]. If that failed, he recommended open resection of the offending fragment(s). Closed reduction of displaced rib fractures was eventually abandoned as ineffective [3], but resection of rib fragments driven into the pleural space and lung was advocated during the first half of the Twentieth Century [4], was performed by American surgeons during World War II [5], and recently has been achieved thoracoscopically [6, 7].

Flail chest, described historically in the American literature as "stoved-in" or "crushed" chest, was a very ominous finding during the preventilator era. Nonoperative attempts at stabilizing unilateral flail chest with external strapping, the placement of sandbags, or by positioning the patient laterally with the injured side down were potentially successful, and, for bilateral flail or sternal flail, external fixation combined with traction was eventually described [8–11]. The complications of external fixation/traction, the prolonged bedrest necessary for fracture union, and the occasional failure or inapplicability of this technique, however, led surgeons to consider internal fixation. A series of patients receiving wire suture fixation of rib fractures was reported in 1950 [12] and intramedullary "Rush nail" fixation was reported in 1956 [13]. The advent of positive pressure ventilation had a major impact on the management of flail chest, and its gradual widespread adoption and success in preventing respiratory failure in patients with multiple rib fractures and flail chest rendered external fixation/traction obsolete and brought investigation of the efficacy of internal fixation to a halt [14–17]. The era of "internal stabilization" of flail chest with mechanical ventilation began and continues selectively today [18–22].

During the 1960 s and 1970 s, a minority of surgeons recognized that select patients with flail chest might benefit from surgical fixation if a trial of mechanical ventilation failed. Sporadic series of rib fracture repair utilizing a variety of plating, wiring, and intramedullary techniques were reported [23–31]. Patients with severe deformities also were considered candidates for fixation if the displaced rib fractures or chest wall defect was considered too severe to heal on its own [26]. "On the way out" or "thoracotomy for other indication" was reported as a valid indication for rib fracture repair [23, 26, 27]. Applying the technique used to reconstruct pectus excavatum with a substernal stainless steel prosthesis, Brunner successfully repaired sternal flail [32].

Potential indications

Table 1 summarizes the potential indications and inclusion criteria for rib fracture repair.

Flail chest

Flail chest is anatomically defined by the presence of four consecutive, unilateral ribs each fractured in two or more places; however, clinically a flail chest is diagnosed when an incompetent segment of chest wall is large enough that paradoxical motion of the chest wall is visible with respiration. A sternal flail occurs when the sternum becomes dissociated from the hemi-thoraces because of bilateral, multiple, anterior cartilage or rib fractures.

Two recent, randomized trials indicate that select patients with flail chest may benefit from operative repair in both the short- and long-term. Tanaka et al. [33] randomized 37 flail chest patients who required mechanical ventilation to surgical stabilization or nonoperative management. The surgically repaired group demonstrated significantly fewer days on the ventilator and in the ICU, had a lower incidence of pneumonia, had better pulmonary function at 1 month, and had a higher return to work percentage at 6 months than the nonoperative group. Granetzny et al. [34] reported a randomized trial of 40 patients in which the operative group demonstrated significantly less mechanical ventilation, ICU and inpatient days, and pneumonia compared with a group of patients treated with an external adhesive plaster. Visual chest wall deformity or persistent flail chest were less in the operative group, whereas forced vital capacity and total lung capacity were significantly higher at 2 months. Recent, nonrandomized, cohort-comparison trials have generally confirmed these findings with the caveat that in patients with significant pulmonary contusions, flail chest repair is not advised [35–38]. The optimal number of days after injury at which to perform repair is controversial: one trial randomized patients at 5 days [33] and the other at 36 to 48 hours [34].

Despite these trials, fracture fixation is not widely practiced; many trauma centers maintain the belief that most patients with flail chest are satisfactorily managed without operative fixation [39]. Some propose that operative intervention for flail chest has "significant potential to

Table 1 Potential indications and inclusion criteria for rib fracture repair

1. Flail chest
Inclusion criteria
a) Failure to wean from ventilator
b) Paradoxical movement visualized during weaning
c) No significant pulmonary contusion
d) No significant brain injury
2. Reduction of pain and disability
Inclusion criteria
a) Painful, movable rib fractures
b) Failure of narcotics or epidural pain catheter
c) Fracture movement exacerbates pain
d) Minimal associated injuries (AIS $\leq$ 2)
3. Chest wall deformity/defect
Inclusion criteria
a) Chest wall crush injury with collapse of the structure of the chest wall and loss of thoracic volume
b) Severely displaced, multiple rib fractures or tissue defect that may result in permanent deformity or pulmonary hernia
c) Severely displaced fractures are significantly impeding lung expansion or rib fractures are impaling the lung
d) Patient is expected to survive any other injuries
4. Symptomatic rib fracture non-union
Inclusion criteria
a) CT scan evidence of fracture nonunion (>2 months after injury)
b) Patient reports persistent, symptomatic fracture movement
5. Thoracotomy for other indications (i.e., "on the way out")

cause mischief in sick patients," is not applicable to patients with severe concomitant pulmonary contusion, and may not have a favorable risk-to-benefit ratio [39]. Other centers have developed multidisciplinary clinical pathways for select patients with severe rib fractures, including aggressive respiratory therapy, anesthesia pain management, physical therapy, and a nutritional consult [22, 40]. These centers report excellent short-term outcomes without any consideration of surgical intervention. The recent Eastern Association for the Surgery of Trauma Practice Management Guideline for Pulmonary Contusion—Flail Chest recognizes the surgical fixation of severe unilateral flail chest as a Level III recommendation only, citing the low numbers of patients randomized, the strict exclusion criteria in the study by Tanaka et al. [33], and the absence of trials comparing operative repair with "modern" nonoperative treatments, including epidural anesthesia and chest physiotherapy [37].

The long-term outcome of a strictly nonoperative approach to flail chest may not be optimal. Landercasper et al. [41] retrospectively reviewed 62 consecutive patients with flail chest and found that only 43% had returned to their previous full-time employment within 5 years. The most common long-term problems associated with flail chest in up to 50% of patients were chest wall pain exacerbated by physical exertion and permanent chest wall deformity [41, 42]. In contrast, pulmonary function after severe rib fractures or flail chest, with notable exceptions, e.g., patients with severe pulmonary contusions, often recovers with only mild or minimal impairment [41, 43, 44]. The possibility that acute surgical fixation of flail chest could diminish expected long-term pain and disability related to the chest wall has been hypothesized but is unproven [45–48].

Chest wall deformity/defect

Chest wall defects/deformities occur in a variety of traumatic circumstances and are characterized by severely displaced rib fractures that visibly deform the chest wall with or without soft tissue loss. Paradoxical motion may or may not be present and many of these patients, especially those who are young with adequate pulmonary reserve, do not require endotracheal intubation. Minimal to moderate-sized tissue defects ($\leq$10 x 10 cm) can be caused by penetrating missiles or impalement with surrounding objects during motor vehicle crashes (MVCs) or falls [49]. Repair of both rib fractures and soft tissue may be indicated to restore an incompetent or "caved in" segment of the chest wall even if the patient does not require mechanical ventilation. Unrepaired segments may lead to the development of chest wall herniation [50]. Comminuted rib fractures can be repaired with absorbable plates and absorbable suture cerclage [51]. Intercostal muscle defects may be closed by suturing the surrounding ribs together or by placing an intra-thoracic patch of Alloderm® (www.lifecell.com) (Mayberry J, 2005, unpublished data). Larger chest wall defects, such as those resulting from close-range shotgun blasts or explosions, are a formidable therapeutic challenge [52]. A thorough debridement of devitalized muscle, bone, skin, and removal of foreign bodies will result in a large defect over which soft tissue coverage by rotation of myocutaneous flaps is necessary. Diaphragmatic transposition, detachment of the diaphragm peripherally and suturing it above the chest wall defect, has been described for lower chest wall defects [53]. This procedure converts the chest wall injury to an abdominal wall defect.

Acute pain and disability reduction

Although conventional wisdom and practitioner experience indicates that the majority of rib fractures heal without complications or permanent disability, few clinical studies with long-term follow-up of nonoperative management have been published. In a prospective study of 40 patients presenting to an urban level 1 trauma center, patients with rib fractures were found to be significantly more disabled at 30 days after injury than patients with chronic medical illness and lost an average of 70 days of work [54]. Thus, it has been hypothesized that selected patients without flail chest may benefit from open reduction with internal fixation [51, 55–58]; however, this has not been confirmed by cohort comparison or randomized trial. The premise is that select patients with displaced and movable rib fractures who do not require assisted ventilation, but rather are experiencing persistent, unrelenting pain with breathing, coughing, or mobilization from recumbancy, could have their fractures surgically stabilized and thereby have their pain alleviated and return to work/usual activity sooner than if the fractures were not stabilized. In addition, it is possible that these select patients would have their risk of long-term pain and disability lessened by surgical repair [48].

Nonunion

An unknown but small percentage of rib fractures do not heal and manifest as a nonunion months to years after their injury [56, 57, 59, 60]. Although a fibrous capsule may envelope the fracture, bony union has not occurred (Fig. 1). A chronic nonunion may cause intermittent discomfort associated with movement of the fracture and can be quite disabling for the patient. The rationale for nonunion repair is based on the assumption that without intervention complete bony healing will not occur. The fibrous callous enveloping the nonunion is resected and a plate is placed to fixate the rib ends during the rehealing process. Whether fixation of rib fracture nonunions will consistently produce

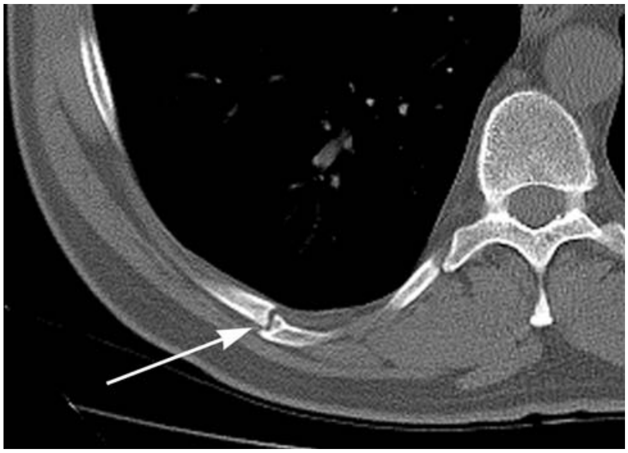

Fig. 1 Rib fracture nonunion 2 years after injury

positive outcomes has not been established, but reported experience has been encouraging [56, 57, 59–62].

Thoracotomy for other indications

A patient with multiple rib fractures or a flail chest who needs a thoracotomy for another indication, e.g., open pneumothorax, pulmonary laceration, retained hemothorax, or diaphragm laceration, also is a candidate for rib fracture repair [37]. Thoracotomy for nontrauma indications, e.g., tumor resection, also may result in rib fractures that could be surgically repaired.

Technical issues of rib fracture repair

The geometry and character of human ribs is unique among the bones of the body. Human rib thickness ranges from 8–12 mm with a relatively thin (1–2 mm) cortex surrounding soft marrow [63]. Individual ribs, therefore, do not have great stress tolerance nor are they expected to hold a cortical screw as well as bone with a thicker cortex. Rib fractures may be oblique or even comminuted further complicating the challenge of a reliable repair (Fig. 2). In addition, the intercostal nerve lies adjacent to the inferior undersurface of the rib and its operative injury or crimping may lead to postthoracotomy pain syndrome [62, 64].

Many techniques of rib fracture repair have been described, including using wire sutures, intramedullary wires, staples, and various plates made of metal or absorbable materials [35, 38, 51, 55, 60, 65–69].

Anterior plates with wire cerclage

Several series report fixating rib fractures with a variety of malleable, flat plates cerclaged to the anterior surface of the rib for a distance of several centimeters [26, 38, 59]. Wire

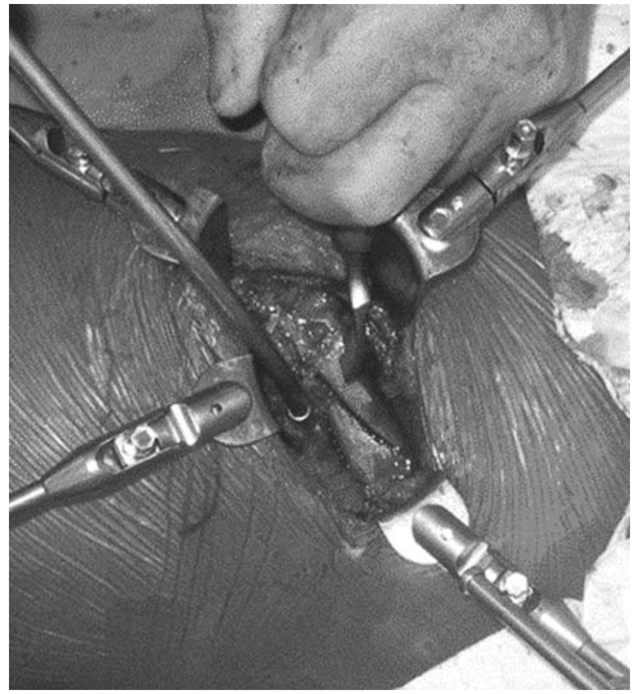

Fig. 2 Oblique acute rib fracture exposed during rib fracture repair

cerclage, however, is an imperfect means of stabilizing the fracture because of the risk of wire breakage and plate dislodgement. In addition, cerclaging the rib with a permanent material will potentially impinge the intercostal nerve and lead to chronic pain. For this reason, in one instance, we have had to remove plates cerclaged with wire [48]. An alternative is to drill holes through the rib and anchor the strut to the rib with interrupted wire suture [38].

Anterior plating with bicortical screws

This is the standard, time-tested technique against which innovations should be compared (Fig. 3) [27, 36, 46, 55, 60, 67, 69, 70]. Dynamic compression osteosynthesis is a variation of anterior plating where eccentric plate holes and conical screw heads combine to impact and immobilize the fracture ends [70]. Locking screw designs are a relatively recent innovation where threads in the screw head "lock" to threads in the plate hole that may improve fixation in softer bone [69].

Intramedullary fixation

Intramedullary wire or plate fixation of rib fractures with or without subsequent wire/plate removal has been used successfully [26, 29, 34, 35]. This technique, however, carries a risk of wire dislodgement and is very technically demanding. Wire migration through the skin has been reported and, in a series of rib fracture repair in newborn

Fig. 3 Postoperative chest radiograph of multiple rib fractures repaired with anterior plates and bicortical screws

foals, migration of an intramedullary pin injured the heart of one pony and resulted in its death [26, 35, 71]. Internal wire fixation also has been criticized because it does not provide rotational stability [69].

Judet strut

The Judet strut is a bendable metal plate that grasps the rib with tongs both superiorly and inferiorly without transfixing screws (Fig. 4) [25, 33, 36, 65]. The fixation of this plate around the inferior margin of the rib, however, like a cerclaging wire, could crimp the intercostal neurovascular bundle and therefore has a potential for intercostal nerve injury and subsequent chronic pain, although this has not been reported. A variation of the strut that has been used successfully is a self-gripping, elastic band that envelopes the rib like a ribbon around a maypole [72].

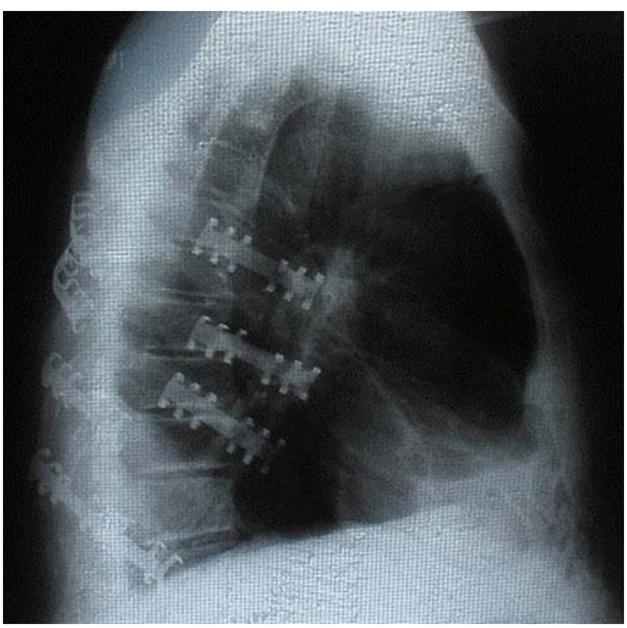

Fig. 4 Lateral chest radiograph of multiple rib fractures repaired with Judet struts

U-plate

The U-plate theoretically overcomes the inherent softness of the human rib by grasping the rib over its superior margin and by securing the plate with anterior to posterior locking screws that do not rely on screw purchase in bone (Fig. 5). In a simulation of an unstable rib fracture with a small bony gap, U-plate rib fracture repair was superior in durability to anterior plate repair, despite reduced fixation length [63]. The U-plate may facilitate the application of a much less invasive rib fracture fixation than the anterior plate technique. In this sense, its application is similar to the Judet strut, but without the potential for crimping of the intercostal nerve. Both the Judet strut and the U-plate can be placed with minimal dissection of the rib in the extra-pleural space and with preservation of the periosteum. The U-plate system includes drill targeting guides, which align the screws with the posterior leaf and prevent the drill from protruding into the pleural space.

Absorbable plates

Absorbable alpha esters, especially the various polylactide polymers, have been successfully used in the fixation of maxillofacial, tibia, and rib fractures [6, 51, 73–77]. Polylactide and polydioxanone prostheses also have been successfully used in the reconstruction of chest wall

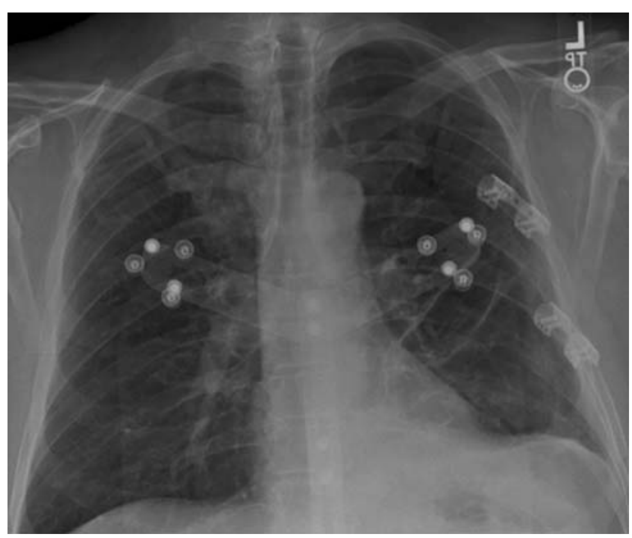

Fig. 5 Chest radiograph of rib fractures repaired with u-shaped plates

deformities and in rib reapproximation after thoracotomy for nontraumatic indications [58, 78–80].

Absorbable plates have practical and theoretical advantages over titanium plates. First, they do not need to be removed, as may be the case in the minority of metal plates. Additionally, because metal plates are much stiffer than bone, "stress-shielding" of the plated bone is possible [81, 82]. "Stress-shielding" occurs because the plated bone is protected from normal stress and therefore does not heal as robustly as nonplated bone. Animal models support the concept that fractures heal faster and stronger with absorbable plates compared with metal [83, 84]. In a rabbit model, rib fracture reduction was maintained to a greater degree with polylactide plate rib fracture fixation compared with nonoperative treatment, resulting in improved bone healing [85].

Contrary to original hopes, polylactide plates are probably not clinically bacteriostatic. Although polylactide plates mildly inhibit *Staphylococcus epidermidis* growth in vitro, this weak effect is not likely to be clinically significant, and polylactide plates do not inhibit *Staphylococcus areus* at all [86, 87]. It is possible, however, that antibiotics or bone-healing promoting agents could be added to absorbable plates [88, 89]. This is an area of future investigation.

Preoperative preparation

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 [47, 51, 60]. If clinically possible, any chest tube is removed from the pleural space the day before the procedure to minimize the potential for bacterial contamination. A preoperative antibiotic targeting gram-positive organisms is given 30 minutes before incision. Thorascopic assistance may be planned to facilitate a less invasive approach and to prevent injury to the lung during screw or wire fixation of the plates.

Complications

Among 650 rib fracture repairs described since 1975, there were 8 superficial wound infections (1.2%), 4 cases of wound drainage without infection (0.6%), 2 pleural empyemas (0.3%), 1 wound hematoma, and 1 persistent pleural effusion reported [26–28, 33–36, 38, 45, 46, 48, 51, 55–57, 59, 60, 65–67, 69, 70, 90–95]. Fixation failure, including plate loosening or wire migration, occurred in eight patients (1.2%) and postoperative chest wall "stiffness," "rigidity," or "pain" necessitating plate removal was reported in nine patients (1.4%). Rib osteomyelitis was reported in one patient and was ascribed to operative contamination from a preoperative chest tube, which was colonized by *Staphylococcus areus* [48].

Future directions

Minimally invasive approach

In the past, patients undergoing rib fracture stabilization have undergone formal thoracotomy for adequate exposure and fixation of selected rib fractures. With three-dimensional CT scan imaging it is possible to hone in on those segments of the thoracic cavity that are most critical in terms of producing dysfunctional thoracic cage mechanics and pain thereby obviating the need for a full thoracotomy and allowing for a less invasive approach. The addition of intraoperative thorascopy may improve the surgeon's ability to keep the external exposure to a minimum. Muscle-sparing techniques, such as division of the latissimus dorsi in the direction of its fibers rather than across the belly of the muscle, can provide adequate exposure of one to three rib fractures through an incision 10–15 cm in length. Instead of making one larger incision, the surgeon can make two or even three smaller, more strategic incisions that avoid muscle division. In addition, the surgeon does not need to fix every rib fracture because the fixation of alternating ribs usually provides stability to the fracture in between, and the periosteum does not need to be stripped, in fact, leaving the periosteum in situ will promote bony healing. These strategies of minimizing operative dissection should minimize postoperative morbidity. Finally, as technology improves, it may become feasible to repair rib fractures completely thoracoscopically [6, 7, 61].

Multicenter trial

The majority of the current literature with respect to surgical stabilization has been comprised of small studies with short-term follow-up. Well-designed clinical trials comparing operative management to modern critical care and pain control that have enrolled large numbers of patients are conspicuously absent. Several barriers currently exist that must be removed before an attempt at such a randomized trial. First, individual centers cannot accumulate enough patients with severe chest wall injuries to be able to conduct meaningful randomized trials on their own. A multicenter trial that includes surgeons with enough experience in rib fracture repair to be beyond the learning curve will be necessary. Second, specific indications for repair must be established as well as sensitive assessments of expected outcomes. Our categorization of these indications will be helpful in this regard. Because preliminary, yet small, randomized trials already exist for flail chest, this indication should be chosen as the initial multicenter investigation, and, if this endeavor proves fruitful, the potential benefits of rib fracture fixation in patients with multiple nonflail rib fractures also should be investigated. Assessment of short-term outcomes, such as pneumonia, ventilator days, inpatient length of stay, and hospital costs, as well as long-term outcomes, including time loss from work or usual activity, pulmonary function, and pain and disability assessments, will be necessary. Ultimately, the trauma surgeon caring for a patient with rib fractures, whether isolated or in association with other significant injuries, is responsible not only for their survival and short-term outcome but also their long-term functional capacity and quality of life. Third, a multicenter, randomized trial will be expensive. Power calculations by the authors indicate that approximately 300 patients with flail chest would have to be randomized into a clinical trial of surgical fixation to observe a potential difference in long-term disability outcomes. As part of a randomized trial of fixation versus nonoperative management, institutional review boards may require that the cost of the "experimental" surgical fixation be borne by the investigator and not by the patient or their insurance. Such a study would be prohibitively expensive in a practice environment such as the United States, unless recognition of the short- and long-term benefits of operative fixation grows. Finally, the preferred technique among the many options will need to be established by the participating surgeons. These barriers are large, but with persistent effort and sufficient time should be surmountable. This review will hopefully serve as a roadmap and a stimulant for progress in this important clinical arena.

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