Review Article

Surgical Treatment of Flail Chest and Rib Fractures

T. Ty Fowler, MD
Benjamin C. Taylor, MD
Michael J. Bellino, MD
Peter L. Althausen, MD

From Orthopedic One, Mount Carmel Medical Center (Dr. Fowler) and the Department of Orthopedic Surgery, Grant Medical Center (Dr. Taylor), Columbus, OH, the Orthopaedic Trauma Service, Stanford University Medical Center, Stanford, CA (Dr. Bellino), and the Reno Orthopaedic Clinic, Reno, NV (Dr. Althausen).

The supplemental videos that accompany this article are available on www.jaaos.org.

Dr. Fowler or an immediate family member is a member of a speakers' bureau or has made paid presentations on behalf of Synthes and has received research or institutional support from Synthes. Dr. Taylor or an immediate family member is a member of a speakers' bureau or has made paid presentations on behalf of Synthes. Dr. Althausen or an immediate family member has stock or stock options held in the Orthopaedic Implant Company and serves as a board member, owner, officer, or committee member of the Orthopaedic Trauma Association. Neither Dr. Bellino nor any immediate family member has received anything of value from or has stock or stock options held in a commercial company or institution related directly or indirectly to the subject of this article.

J Am Acad Orthop Surg 2014;22: 751-760

http://dx.doi.org/10.5435/JAAOS-22-12-751

Abstract

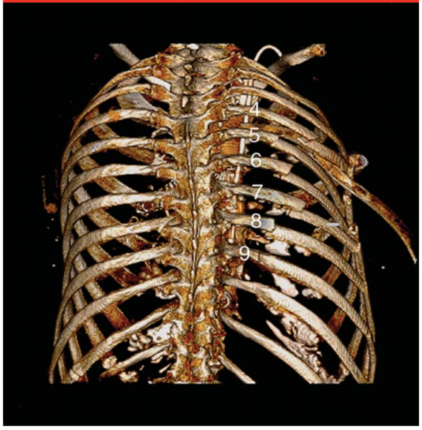
Despite significant advances in critical care management, flail chest remains a clinically significant finding, with a mortality rate of up to 33%. Nonsurgical management is associated with prolonged ventilator support, pneumonia, respiratory difficulties, and lengthy stays in the intensive care unit, as well as chronic pain from nonunion and malunion of the bony thorax. Treatment with aggressive pulmonary toilet, ventilator support, and different modalities of pain control remains the benchmark of care. However, several recent randomized controlled studies of surgical intervention of flail chest have demonstrated an improvement in the number of ventilator days, intensive care unit and hospital stays, incidence of pneumonia, and respiratory function and hospital costs, as well as faster return to work. The success of these surgical constructs compared with those of historical attempts at open fixation is largely the result of modern plating technology and improvement in surgical approaches. Clinical evidence continues to grow regarding proper indications and techniques for surgical stabilization of flail chest.

Rib fractures are common among patients with blunt chest wall trauma and are often a life-altering injury. Mortality rates have been shown to be directly correlated to the number of rib fractures.[1] A flail chest is defined as at least three consecutive ribs fractured at more than one location per rib[2-7] (Figure 1). This injury pattern creates a free segment of the chest wall that moves independently of the remainder of the bony thorax. Flail chest injuries occur in approximately 10% of patients with blunt thoracic trauma; mortality rates for these patients are reported to be as high as 33%.[8]

The mechanical alterations of the chest wall in a flail chest with paradoxical motion are often responsible for debilitating pain during the normal breathing cycle (Figure 2). This alteration results in decreased respiratory effort and function, ultimately leading to increased rates of pneumonia, acute respiratory distress syndrome, and the need for intubation.[9] Rib fractures have traditionally been managed conservatively by aggressive pulmonary toilet, mechanical ventilator support, tracheostomy, and conventional pain control methods, including oral analgesics, intercostal nerve blocks, and epidural analgesia.[6,10,11] Compared with surgical stabilization, nonsurgical management has been associated with increased risks of pneumonia, empyema, prolonged mechanical ventilation, decreased respiratory function, and chronic pain and deformity from nonunion or malunion.[4-7,12-16]

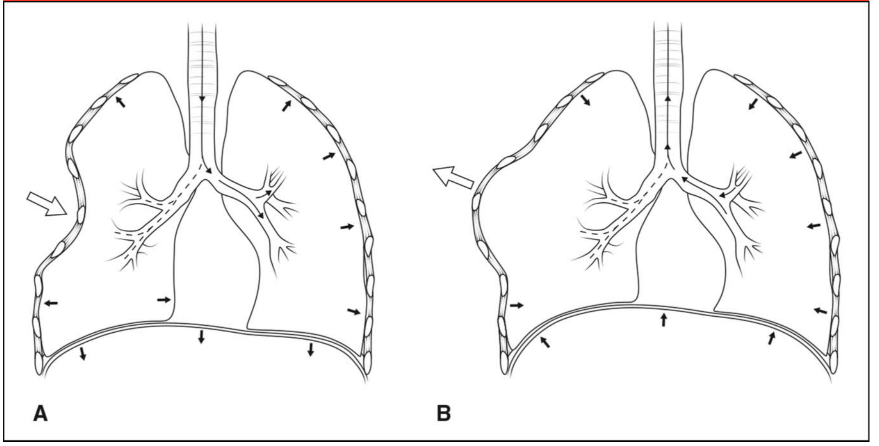
Surgical fixation of chest wall injuries has been an underutilized procedure despite a growing amount of evidence showing surgical management.[6-8,17,18] A recent survey of members of the Eastern Association

Figure 1



PA three-dimensional reformatted CT scan of the rib cage with the scapulae digitally subtracted. Right-side flail segment ribs, labeled 4 through 8, demonstrate instability with inward displacement.

Figure 2



A, Illustration demonstrating the inspiratory phase of the breathing cycle. The flail segment is unable to resist the intrathoracic drop below atmospheric pressure because of the lack of continuity with the remainder of the rib cage; the flail segment will be drawn inward (white arrow) while the remainder of the chest wall expands (black arrows). **B,** Illustration demonstrating the expiratory phase of the breathing cycle. The flail segment will be pushed outward (white arrow) as opposed to the contraction seen by the intact rib cage (black arrows).

for the Surgery of Trauma, Orthopaedic Trauma Association, and various cardiothoracic surgeons highlighted the fact that many have never performed or assisted in surgical fixation of rib fractures, and that only 22% were familiar with a randomized controlled trial on the subject.[19]

Surgical Techniques

Indications

Currently, all possible indications for surgical rib fracture fixation are considered to be relative. As evidence grows, indications become stronger but at present there are no absolute indications for surgical treatment with internal fixation (Table 1).

Flail Chest

Most commonly, the presence of a flail chest is considered to be a strong relative indication for surgery.[4-7,9,10,12-14,17,18,20,21] Other considerations in the presence of a flail chest also make surgical treatment more attractive. Often, these patients require mechanical ventilator support for respiratory compromise; therefore, patients who fail to wean from the ventilator are considered candidates for surgery. Patients with paradoxical movement and gross chest wall instability are often considered to be at greater risk for known complications of nonsurgical treatment, such as prolonged ventilator times, longer stays in the intensive care unit (ICU), and higher rates of pneumonia; they therefore would also benefit from surgical stabilization.

Chest Wall Deformity

Direct crush injuries to the thorax can produce notable deformity to the rib cage with loss of thoracic volume, which can further impede lung expansion (Figure 3). Deformity may be present with a flail chest or with isolated single fractures of sequential ribs with severe displacement. Displaced ribs can impale and lacerate the lung, causing pneumothorax, hemothorax, pulmonary hernias,[2] and recalcitrant pleural effusions.[20] The authors have also experienced other vital structures being injured by severely displaced posterior rib fractures, including aortic lacerations.[22]

Symptomatic Nonunion and Malunion

Rib fractures with significant displacement can lead to symptomatic malunions, which can be treated surgically with osteotomy and deformity correction to restore the normal contour and volume of the thoracic cavity.[2,23] In addition, symptomatic nonunion of rib fractures is another relative indication for surgical intervention and fixation. In the face of multiple rib fracture nonunions, upper extremity motion or chest wall motion during respiration can lead to debilitating pain and dyspnea on exertion, with symptom resolution following surgical stabilization and successful healing.[2,23]

Surgical Treatment of Other Indications

Surgical treatment of thoracic injuries in the setting of rib fractures can be an indication for surgical stabilization. Pulmonary lacerations, hemothorax, or open thoracic injuries may require surgical treatment; these patients may be considered as surgical candidates for rib fixation at the conclusion of the pulmonary procedure.[2]

Pain and Disability

Acute pain from rib fractures that prevents mobilization and inhibits respiratory effort may be considered a relative surgical indication, as well; this concept has been proposed by several authors.[2,4,11,12,17,24-27] Interestingly, Fabricant et al[25] found that one of the most predictive factors for chronic pain after rib fractures is the intensity of pain during the acute postinjury period. However, pain as an isolated indication for surgery has yet to be definitively demonstrated in the literature.

Revision Surgery

As the popularity of rib fracture fixation grows, orthopaedic surgeons at referral centers are encountering unusual fixation methods, often placed by surgeons unfamiliar with orthopaedic instrumentation and standard AO techniques for fracture reduction and construct stability (Figure 4). As with misplaced instrumentation in other sites of the body, which violate anatomic and physiologic principles, these must be revised for acceptable outcome.

Contraindications

A pulmonary contusion injury in association with flail chest has been proposed by Voggenreiter et al[28] to be a contraindication to rib fracture fixation. Although this study was well intentioned, important data were eliminated from statistical analysis because of lack of power, and a true evaluation of the contribution of contusion to rib fracture fixation remains in question. Althausen et al[5] demonstrated a trend that surgical stabilization in patients with pulmonary contusions improved outcomes compared with nonsurgically managed patients with pulmonary contusions. Tanaka et al[6] demonstrated no difference in pulmonary contusions between their randomized, controlled groups of patients who had undergone surgical versus nonsurgical management. For the surgically treated group, these authors demonstrated favorable outcomes in ventilator days, length of stay in the ICU, pneumonia rates, and final-outcome percent forced vital capacity, suggesting that pulmonary contusions do not play a role when surgical and nonsurgical management are directly compared.

Timing of Surgery

One unknown factor under current study is the appropriate timing of fixation. Results from several case series have indicated that earlier fixation leads to shorter ICU and hospital lengths of stay.[4-6] In the authors' opinion, waiting to see whether a patient fails to wean from the ventilator before making a decision for surgical intervention may be doing the patient a disservice. We attempt to surgically treat appropriately selected patients no later than 3 to 5 days after injury. As understanding of flail chest grows, we expect that more aggressive surgical stabilization of certain fracture patterns will be observed.

Approaches

Surgical approaches to the chest wall are well known to general trauma and cardiothoracic surgeons, although they are typically less familiar to orthopaedic surgeons. Some trauma centers employ a collaborative approach to surgically treating rib fractures, with general trauma surgeons or cardiothoracic surgeons performing the approach, while fracture reduction and fixation is undertaken by the orthopaedic trauma surgeon.[5] This collaborative effort, suggested by Althausen et al,[5] is recommended in the early stages of the orthopaedic surgeon's learning curve. In most instances, chest tube thoracostomy is required after fixation, and general trauma surgeons are typically adept at the placement and postoperative management of these devices. Recently, Taylor et al[10] published descriptions of the varied approaches to surgical fixation of rib fractures.

Careful preoperative planning for fracture fixation and approach is vital. Axial CT and three-dimensional CT scans are very helpful in identifying the locations of fractures (ie, anterior, lateral, posterior) and the associated surrounding structures (eg, the scapula) to help guide the surgical approach.

Table 1

Surgical Indications and Authors' Grades of Strength[a]

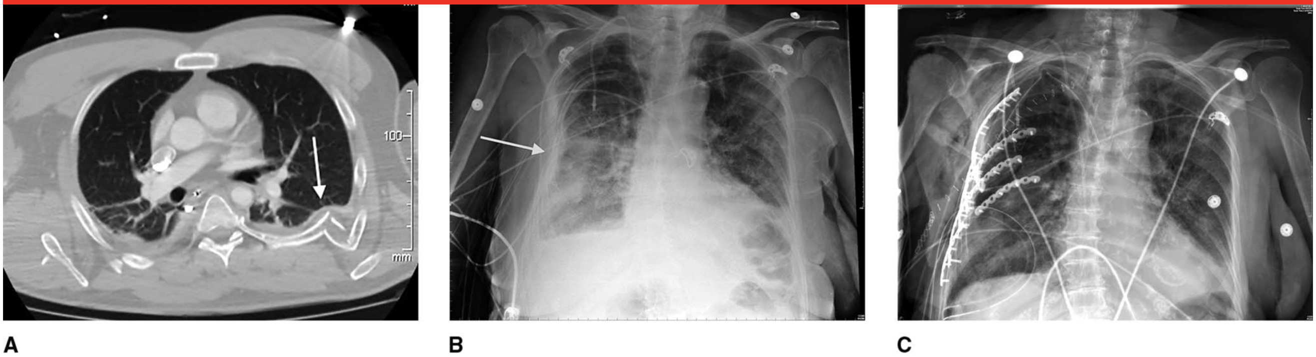
Indication	Grade A	Grade B
Flail chest Respiratory compromise	X	—
Chest wall deformity Fracture displacement	X	—
Nonunion	—	X
Intractable pain	—	X
Surgical intervention for other reasons (eg, pulmonary laceration, hemothorax)	X	—

[a] Authors' strength of recommendation based on available literature. Grade A = levels I–III studies that use the surgical indication with favorable outcomes. Grade B = levels IV and V studies that use the surgical indication with favorable outcomes.

Posterolateral Thoracotomy

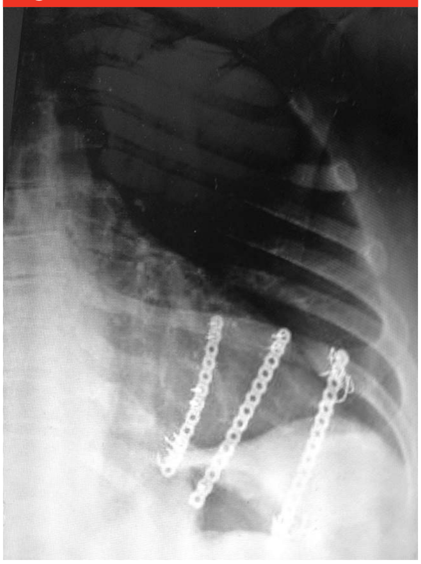
This approach is most commonly used by general and cardiothoracic

Figure 3



A, Axial CT scan demonstrating significant comminution and deformity to the left chest (arrow) with loss of thoracic volume, which can impede lung expansion. **B,** AP chest radiograph demonstrating an indentation deformity to the right chest wall (arrow). **C,** AP chest radiograph of the same patient as in panel B, after rib fixation and reconstitution of the normal thoracic cage anatomy.

Figure 4



AP chest radiograph demonstrating inadequate rib fracture fixation: single screws on either side of the fracture, plates placed perpendicular to ribs, and cerclage wiring for plate fixation.

surgeons, typically for posterior, posterolateral, and laterally based fractures. Anterior fractures can be accessed if the anterior limb of the incision is extended toward the costosternal junction. The approach begins with the patient in the lateral decubitus position with a bean bag. The ipsilateral arm may be draped free or placed on a supportive armboard, at the surgeon's discretion. The skin incision begins with the posterior limb oriented vertically and centered between the spinous process and the medial border of the scapula. The incision is usually carried 2 cm distal to the tip of the scapula before changing direction transversely across the thorax in an anterior direction.

In the superficial layer of the vertical limb of the incision, the trapezius is encountered and can be fairly easily retracted medially and superiorly to gain access to the deeper rhomboid musculature. The rhomboid major can also be elevated fairly easily from the thorax to gain access to the targeted rib fractures. Damage to the rhomboids can cause lateral winging, and respectful dissection should be performed to avoid this complication. Far posterior rib fractures require elevation of the trapezius, rhomboids, or paraspinal musculature off the thoracic spinous processes of the vertebrae to gain access to the fractures or costovertebral junction.

More caudally and anteriorly, the anterior border of the latissimus dorsi is identified. Traditionally, this muscle is transected in line with the skin incision, which allows wide access to the thoracic rib cage and the deeper muscular layers. The serratus anterior and external oblique muscles are usually split in line with their fibers to minimize damage and to gain access to the ribs. This should be done bluntly, and the long thoracic nerve, which lies on the superficial layer of the serratus anterior and is located in the midaxillary line, should be identified and protected.

Muscle-sparing Thoracotomy

This approach is most commonly used by the authors. Preoperative planning and a clear understanding of the spatial relationship of the targeted fracture locations for fixation are imperative. Positioning is identical to that described for the formal thoracotomy approach. The skin incisions can be planned according to fracture pattern and can consist of a spectrum from the full skin incision to carefully identified portals, often posteriorly and laterally, to gain access to the rib fractures.

The vertical-based skin incision is performed, and the trapezius and latissimus dorsi fascia is incised to accurately identify the borders between the two muscles. These muscles are retracted through an area called the triangle of auscultation, bordered by the trapezius superiorly, the latissimus distally, and the scapula medially. This provides a wide portal of visualization to ribs 4 to 8. A more anterior incision is performed to gain access to the lateral- and anterior-based fractures. The anterior border of the latissimus is identified, and the subscapular bursa is accessed with blunt finger dissection. Retractors can assist in elevating the latissimus and the scapula to gain access to the serratus anterior muscles for splitting in line with the fibers to complete fixation. For more anterior and cranial fractures, the latissimus dorsi is often subjected to muscle-splitting techniques. The important distinctive concepts of this approach are that no transection of muscle be performed and that muscle-splitting techniques in line with the fibers are used whenever possible.

Table 2

Rib Fracture Surgical Approaches.

Approach	Fracture Location	Patient Positioning
Posterolateral thoracotomy	Posterior, lateral, anterior	Lateral decubitus
Muscle-sparing thoracotomy	Posterior, lateral, anterior	Lateral decubitus
Axillary	Anterior, anterolateral	Lateral decubitus/45° lateral
Inframammary/ subpectoral	Far anterior, superior	Supine

Axillary Approach

This approach is used for anterolateral fractures and provides a wide exposure of this isolated area of the rib cage. There is limited access to the far anterior structures and posterior and posterolateral portions of the ribs. This approach can be used in combination with other portions of the muscle-sparing thoracotomy to gain access to the posterior rib fractures that cannot be accomplished with the axillary approach. Therefore, its indication is usually isolated to multiple anterolateral rib fractures that would require fairly broad exposure to accomplish the goals of reduction and fixation.

The patient is placed in a lateral decubitus position. A vertical incision 2 cm anterior to the lateral border of the scapula is used. The latissimus is encountered in the posterior aspect of the incision and can be retracted, as described earlier in the muscle-sparing approach, to gain access to fractures in the posterior aspect of the incision. The long thoracic nerve should be identified and protected. The serratus anterior is encountered, and muscle splitting is performed to gain access to the ribs. On the anterior aspect of the incision, the external oblique muscles are encountered and again are subject to muscle-splitting techniques.

Inframammary and Pectoralis-lifting Approach

This approach is useful for far anterior rib fractures or superiorly located rib fractures. The patient is placed in a supine position. The skin incision is placed in the inframammary crease for cosmesis. The inferior border of the pectoralis major muscle is identified and elevated anteriorly and superiorly, along with the overlying breast tissue. This maneuver gains access to the pectoralis minor muscle attached to ribs 3 through 5, and the fibers are split in line to gain access to the associated rib fractures for fixation.

A summary table (Table 2) and supplemental videos (video 1, Axillary Approach; video 2, Posterolateral Thoracotomy Approach; and video 3, Submammary Approach) are included for each exposure technique.

Implants

Although initial fixation of rib fractures made use of Kirschner wires (K-wires) and heavy-gauge suture, these constructs left much to be desired. Nonlocking plate-and-screw technology has inherent limitations, as well, because of the high risk of screw loosening and backout with the cyclical motion of respiration; supplemental fixation with K-wires and/or external fixation was periodically still required with nonlocking constructs.[29] Because of these issues, specific rib fracture fixation systems have since been developed.

Locking Plates

Several case series have reported the successful use of locking plates of different sizes, including 2.4 and 2.7 mm,[5,30] 3.5-mm locking reconstruction plates, and even 1.0-mm–thickness plates accepting 3.0-mm screws.[18,30] These series note very favorable results, with no implant-related complications reported, such as cutout or failure of the screws.

The advantages of anatomically precontoured plating systems results from their theoretical decreased surgical time, ascribed to the lack of a need to contour intraoperatively and the ability to use the devices as reduction tools. Precontoured 2.9-mm titanium alloy locking plates (MatrixRIB, DePuy Synthes) have been developed in efforts to overcome the limitations inherent to non-precontoured systems. Locking plates and screws for rib fracture fixation, regardless of size, have demonstrated excellent clinical results with very low rates of nonunion and minimal complications related to symptomatic instrumentation failure or screw cutout.[5,18,26,30]

Bioabsorbable Plates

Absorbable plates have the theoretical advantage of avoiding long-term stress shielding at the fracture site. These techniques consist of the use of 2.4-mm absorbable polylactide plates and screws supplemented by judicious cerclage sutures. Two small series are currently reported in the literature with these devices; both note a high union rate, with minimal plate failure rates that were insignificant to clinical outcomes.[21,27] Currently, the expense of these implants may be cost prohibitive at many centers.

Judet Struts

Judet struts are simple metal plates with superior and inferior finger-like projections that are crimped over the cephalad and caudad aspects of the rib while spanning the fracture for stabilization. Disadvantages of this style of implant are the possibility for intercostal neurovascular injury on the caudal undersurface of the rib, periosteal injury, and decreased vascularity required for fracture healing.

U-plates

RibLoc U-plates (Acute Innovations) are a hybrid of the concepts of the Judet struts and locking plate technology; they consist of a titanium U-shaped plate that wraps over the superior aspect of the rib. The plate is then fixed to the rib through a locking screw that engages the anterior and posterior aspect of the plate. These plates are relatively short and can be used with minimally invasive techniques. Clinical studies are currently lacking, although a biomechanical study by Sales et al[31] noted that these U-plates were more durable than a 2.4-mm locking plate.

Intramedullary Devices

Several different forms of intramedullary (IM) devices, such as K-wires, Adkins struts, and steel wires, have been used for rib fracture fixation.[7,17,32] Treatment with intramedullary devices has some inherent drawbacks, including lack of rotational control, wire migration, loosening, and loss of fixation.[7,17,32] The MatrixRIB fixation system, mentioned earlier, contains a newly designed, flat titanium intramedullary strut to resist some of the inherent problems of other forms of IM devices in that they provide rotational control with a locked screw at the end to prevent migration. These particular struts have been shown to be 48% stronger than K-wire fixation after dynamic loading, and catastrophic failure is not typically seen with this device.[33] However, as with any IM device, to prevent perforation during insertion of these splints, caution must be exercised through audible and tactile feedback.

Authors' Preference for Surgical Treatment

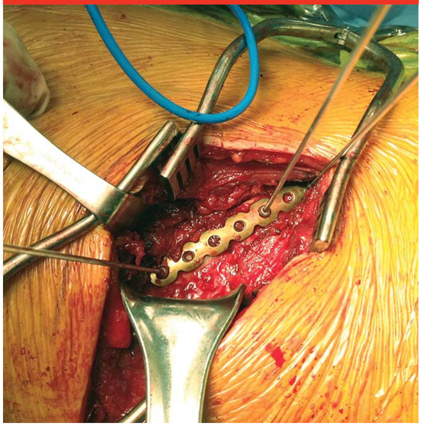
The authors prefer to operate through less invasive, muscle-sparing approaches when feasible. No studies to date compare outcomes between different approaches. However, certain situations or fracture patterns may require a more formal muscle-transecting procedure. In our experience, initial collaboration with a general trauma or cardiothoracic surgeon can help minimize the learning curve of these approaches. The authors perform the approaches without assistance; as familiarity and experience have been gained, the trend has been to make use of more varied fracture patterns and locations through less morbid approaches. Despite this increase in self-reliance, we still often rely on our general surgeon colleagues for video-assisted thoracoscopic procedures, diaphragmatic repair, placement of a thoracostomy tube, and postoperative patient management in the ICU.

We believe that fixation should involve as many of the ribs involved in the flail segment that can be safely accessed; however, there is still debate as to whether both sides of a flail segment require fixation. We tend to stabilize both sides of the flail segment when, after plating one side, clear instability or displacement still exists on the other side of the flail. Another factor that can influence the number of ribs to be repaired is the patient's physiologic ability to tolerate a longer surgery, based on associated injuries, comorbidities, and age.

We typically leave all intercostal tissue at the inferior margin of the rib undisturbed to avoid any damage to the neurovascular bundle. In addition, we perform very little, if any, superior soft-tissue dissection. We find that access to the fracture ends is adequate because of the soft-tissue disruption that takes place from the initial displacement of the fracture at the time of injury. After preparation of the fracture site, compression of the fracture ends is often accomplished by means of the inherent pull of the surrounding musculature, which tends to shorten the ribs with an internal rotational pull. Plates are placed on the extraperiosteal surface of the bone to avoid further soft-tissue stripping and are held in place with plate-reduction clamps that can be found in rib-specific plating systems or with threaded ball-tipped guidewires; these wires function as a push-pull device, which allows direct compression of the plate to the bony surface, rather than invasive clamps that require an intrathoracic position to clamp the plate to bone (Figure 5). Once adequate position has been established on both sides of the fracture, locking screws are placed in the plate, with a minimum of six cortices of purchase on each side of the fracture.

We routinely use precontoured locking plates for surgical stabilization. These systems include shorter eight-hole universal plates that fit well to most areas of the entire rib with minimal contouring necessary. We generally employ these plates for ease of placement on a shorter segment of rib; often, we use two plates per rib for each fracture of the flail segment rather than a single longer plate. If precontoured rib-specific systems are not available, we recommend 2.7- to 3.0-mm locking reconstruction plates that can be intraoperatively contoured to the rib surface.

Figure 5



Intraoperative photograph demonstrating the noninvasive nature of ball-tipped push-pull devices. Note that the plate is compressed to bone without invasive clamps.

Table 3

Evidentiary Results in Favor of Surgical Stabilization of Rib Fractures

Factor	Level I Studies	Level III Studies
Decreased no. of mechanical ventilator days	X	X
Decreased pneumonia	X	X
Decreased intensive care unit days	X	X
Decreased hospital days	X	X
Decreased tracheostomy	X	X
Decreased chest wall deformity	X	X
Improved respiratory function/long-term	X	X
Decreased medical costs	X	—
Decreased reintubation rates	—	X
Decreased home oxygen requirements	—	X
Decreased mortality rates	—	X
Decreased chronic pain	—	X

Level I = prospective randomized controlled trials, level III = retrospective comparative studies or case-control studies

Clinical Outcomes

Evidentiary results and clinical outcomes are summarized in Table 3.

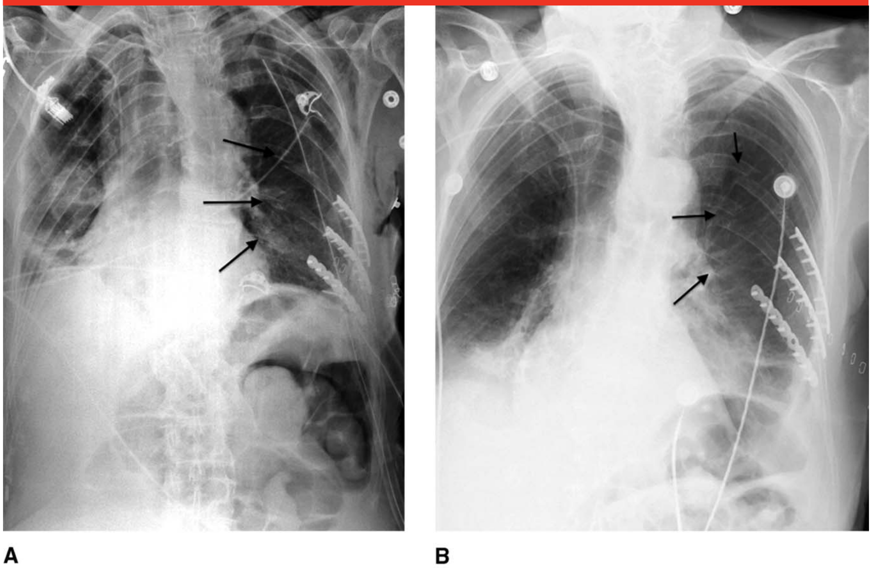
Flail Chest

Three prospective randomized controlled trials comparing surgical and nonsurgical management of flail chest injuries have been published to date. In 2002, Tanaka et al[6] randomized into two groups 37 patients who had a flail chest injury, acute respiratory failure, and failure to wean from the ventilator. The nonsurgical management group consisted of continued ventilator support, epidural and intravenous/oral analgesia, and respiratory physiotherapy; the surgical group was stabilized with Judet strut fixation devices at a mean of 8 days postinjury. The surgical group showed statistically significant favorable results in all areas measured, including rates of pneumonia (22% versus 90%), length of ventilation (10.8 versus 18.3 days), length of ICU stay (16.5 versus 26.8 days), need for tracheostomy (3 versus 15 patients), and lower medical expenses ($13,455 versus $23,423).[6] Patients were then followed for 1 year; surgical patients demonstrated improved forced vital capacity at 3, 6, and 12 months compared with nonsurgically treated patients. Subjectively, at 12 months, patients who were in the surgical group also reported less chest tightness, dyspnea, and thoracic pain.

In 2005, Granetzny et al[7] performed a prospective randomized control trial in 40 patients who were treated with traditional methods of nonsurgical management with adhesive bandage (ie, Elastoplast) taping of the chest wall compared with surgical treatment using a generally primitive method of K-wires and/or stainless steel wire. Similar to the results of Tanaka et al,[6] statistically significant results favored the surgical management group in length of ventilation (2 versus 12 days), mean ICU stay (9.6 versus 14.6 days), mean hospital stay (11.7 versus 23.1 days), chest infection (10% versus 50%), and chest wall deformity (5% versus 45%). In addition, forced vital capacity and total lung volume measurements were statistically significant in favor of the surgical treatment group as early as 2 months. Mortality rates between the two groups did not reach statistical significance.

In 2013, Marasco et al[21] published an evaluation of 46 patients with flail chest injuries who had been randomized to surgical treatment with bioabsorbable plates or to modern nonsurgical management. Similar to results in the previously cited studies, outcomes favored the surgical group in measures including length of ICU stay (317 versus 456

Figure 6



A, Immediate postoperative chest radiograph demonstrating mild displacement of the posterior fractures (arrows) of a laterally plated flail segment. **B,** Same patient as in panel A. One-week postoperative chest radiograph demonstrating significant displacement, shortening, and overlap of the posterior fractures (arrows) of the flail segment.

hours), rates of pneumonia (48% versus 74%), rates of tracheostomy (39% versus 78%), and duration of noninvasive ventilation (22 versus 67 hours). Notably, Marasco et al[21] were also able to demonstrate an initial cost savings of $14,443 per patient undergoing surgical fixation.

Several retrospective case-control and cohort studies have shown similar favorable results with surgical stabilization compared with nonsurgical management, including shorter periods requiring ventilator support;[4,5,17,28] shorter ICU[4,5,21] and hospital[5] lengths of stay; decreased rates of pneumonia,[5,17,28] mortality,[7,28] and tracheostomy;[5,17] and reduced need for reintubation and decreased home oxygen requirements.[5] A recent meta-analysis summarized the pooled results from prospective randomized controlled trials and found in favor of the surgical treatment of rib fractures in decreasing ventilator days and ICU days and decreasing rates of pneumonia.[34] Analysis of the retrospective studies found significant improvements with surgical intervention in regard to ventilation days, ICU and hospital lengths of stay, and rates of mortality, pneumonia, septicemia, tracheostomy, dyspnea, and chest deformity.[34]

Nonunion, Malunion, and Pain

The expectation that rib fractures will heal uneventfully, with patients returning to normal functional levels without surgical intervention, has now been extensively documented to be a false expectation.[11,15,16,24,25] Rib fractures treated nonsurgically can have a significant negative impact on a patient's quality of life. Fabricant et al[25] have recently documented that rib fractures treated nonsurgically can lead to prolonged chest wall pain and prolonged disability in 59% and 76% of patients, respectively. Interestingly, they found that one of the most significant predictors of prolonged disability and pain was the level of pain in the acute period after injury. Mayberry et al[11] performed a similar study investigating long-term morbidity, pain, and disability in patients who had had rib fractures surgically stabilized. Using the same McGill Pain Questionnaire (MQP) in both studies, patients with surgically stabilized rib fractures reported a mean MQP pain score of 6.7,[11] while rib fracture patients treated nonsurgically reported a mean MPQ pain score of 11.3.[25] Mayberry et al[11] also used the RAND-36 general health survey to compare patients after rib fracture fixation with the general healthy population; they found no differences in all categories measured, with the exception of a worse score in role limitations resulting from physical problems. This promotes the idea that, because of improvements in long-term functional outcome and pain scores, intractable pain inhibiting mobilization and respiratory effort is a relative indication for surgical fixation.

Nonunion of rib fractures has been well documented to cause chest wall deformity, nonphysiologic motion of the chest wall, dyspnea, and chronic debilitating pain.[2,11,15,23-25] Only levels IV and V evidence currently exists in the literature addressing nonunion of the ribs in the form of small case series and expert opinion. Nonunions, undoubtedly, are rare with nonsurgical management. However, when they occur, surgical treatment has proven to be successful in achieving bony union, pain relief, and stability of the chest wall.[2,23] Little exists in the literature on malunions and the benefit that is provided with osteotomy and deformity correction. It appears today that the best treatment of a malunion is to prevent them with surgical stabilization acutely.

Future Directions

Relatively speaking, the topic of rib fracture fixation has a paucity of high-quality evidence. Well-designed studies focusing on fine-tuning our surgical indications are sorely needed. Continued studies consisting of long-term follow-up to document functional outcomes for different surgical indications and/or approaches are also a needed area of study. Currently, it is the belief of the authors that stabilizing only one fracture of a flail segment is all that is necessary to gain the benefits achieved in many of the aforementioned studies. However, this style of fixation theoretically is prone to late displacement or nonunion and may be associated with worse outcomes (Figure 6). Comparative studies to determine any benefit from fixing both sides of a flail segment are warranted.

There is a myriad of different fixation constructs being studied that vary considerably with respect to surgical techniques and approaches, stiffness of the constructs, and complications. No studies to date have comparatively examined different fixation constructs or different chest wall fracture patterns.

The effect of the surgical approach on patient outcomes remains unknown despite its being a potentially crucial determinant. To analyze this, two of us (T.T.F., B.C.T.) are performing a multi-institution prospective trial comparing the outcomes of differing surgical approaches specific to rib fracture fixation.

Summary

Rib fracture treatment has changed considerably over the past two decades. With the advent of modern implants, as well as because of evolving surgical indications, treatment of severely injured patients with painful rib fractures and flail chest injuries has become the standard of care in many institutions. High-level evidence has demonstrated improvement in the length of mechanical ventilation, lengths of ICU and hospital stays, rates of pneumonia and tracheostomies, and improved mortality rates. Also notable in this era of awareness of cost control is that flail chest fixation has demonstrated a potentially significant financial benefit. Improvement in chronic pain levels, dyspnea, chest wall tightness, and instability can also be expected after fixation. Randomized controlled studies are needed to answer the many questions we still have about the surgical fixation of these injuries. However, this is an evolving technique that, when correctly used, appears to have a profound affect on the outcomes of these multiply injured patients.

References

Evidence-based Medicine: Levels of evidence are described in the table of contents. In this article, references 6, 7, 21, and 34 are level I studies. References 4, 5, 11, 17, and 28 are level III studies. References 1-3, 8, 12-16, 18, 20, 22-27, 29, 30, and 32 are level IV studies. References 9, 10, 19, 31, and 33 are level V expert opinion.

References printed in **bold type** are those published within the past 5 years.

1. Flagel BT, Luchette FA, Reed RL, et al: Half-a-dozen ribs: The breakpoint for mortality. *Surgery* 2005;138(4):717-723.
2. Slater MS, Mayberry JC, Trunkey DD: Operative stabilization of a flail chest six years after injury. *Ann Thorac Surg* 2001; 72(2):600-601.
3. Mayberry JC, Trunkey DD: The fractured rib in chest wall trauma. *Chest Surg Clin N Am* 1997;7(2):239-261.
4. Nirula R, Diaz JJ Jr, Trunkey DD, Mayberry JC: Rib fracture repair: Indications, technical issues, and future directions. *World J Surg* 2009;33(1):14-22.
5. **Althausen PL, Shannon S, Watts C, et al: Early surgical stabilization of flail chest with locked plate fixation. *J Orthop Trauma* 2011;25(11):641-647.**
6. Tanaka H, Yukioka T, Yamaguti Y, et al: Surgical stabilization of internal pneumatic stabilization? A prospective randomized study of management of severe flail chest patients. *J Trauma* 2002;52(4):727-732.
7. Granetzny A, Abd El-Aal M, Emam E, Shalaby A, Boseila A: Surgical versus conservative treatment of flail chest: Evaluation of the pulmonary status. *Interact Cardiovasc Thorac Surg* 2005;4 (6):583-587.
8. Ciraulo DL, Elliott D, Mitchell KA, Rodriguez A: Flail chest as a marker for significant injuries. *J Am Coll Surg* 1994; 178(5):466-470.
9. **Fitzpatrick DC, Denard PJ, Phelan D, Long WB, Madey SM, Bottlang M: Operative stabilization of flail chest injuries: Review of literature and fixation options. *Eur J Trauma Emerg Surg* 2010; 36(5):427-433.**
10. **Taylor BC, French BG, Fowler TT: Surgical approaches for rib fracture fixation. *J Orthop Trauma* 2013;27(7): e168-e173.**
11. Mayberry JC, Kroeker AD, Ham LB, Mullins RJ, Trunkey DD: Long-term morbidity, pain, and disability after repair of severe chest wall injuries. *Am Surg* 2009; 75(5):389-394.
12. Ali BA, Sanfilippo F: Management of flail chest in trauma: Analysis of risk factors affecting outcomes. *ANZ J Surg* 2007;77:A93.
13. Sirmali M, Türüt H, Topçu S, et al: A comprehensive analysis of traumatic rib fractures: Morbidity, mortality and management. *Eur J Cardiothorac Surg* 2003;24(1):133-138.
14. Wanek S, Mayberry JC: Blunt thoracic trauma: Flail chest, pulmonary contusion, and blast injury. *Crit Care Clin* 2004;20(1): 71-81.
15. Landercasper J, Cogbill TH, Lindesmith LA: Long-term disability after flail chest injury. *J Trauma* 1984;24(5): 410-414.
16. Beal SL, Oreskovich MR: Long-term disability associated with flail chest injury. *Am J Surg* 1985;150(3):324-326.
17. Ahmed Z, Mohyuddin Z: Management of flail chest injury: Internal fixation versus endotracheal intubation and ventilation. *J Thorac Cardiovasc Surg* 1995;110(6): 1676-1680.
18. Reber PU, Kniemeyer HW, Ris HB: Reconstruction plates for internal fixation of flail chest. *Ann Thorac Surg* 1998;66(6): 2158.
19. Mayberry JC, Ham LB, Schipper PH, Ellis TJ, Mullins RJ: Surveyed opinion of American trauma, orthopedic, and thoracic

surgeons on rib and sternal fracture repair. *J Trauma* 2009;66(3):875-879.

20. **Taylor BC, French BG: Successful treatment of a recalcitrant pleural effusion with rib fracture fixation. *HSS J* 2013;9(1): 96-99.**

21. **Marasco SF, Davies AR, Cooper J, et al: Prospective randomized controlled trial of operative rib fixation in traumatic flail chest. *J Am Coll Surg* 2013;216(5):924-932.**

22. **Boyles AD, Taylor BC, Ferrel JR: Posterior rib fractures as a cause of delayed aortic injury: A case series and literature review. *Inj Extra* 2013;44(5):43-45.**

23. Cacchione RN, Richardson JD, Seligson D: Painful nonunion of multiple rib fractures managed by operative stabilization. *J Trauma* 2000;48(2):319-321.

24. Kerr-Valentic MA, Arthur M, Mullins RJ, Pearson TE, Mayberry JC: Rib fracture pain and disability: Can we do better? *J Trauma* 2003;54(6):1058-1063.

25. **Fabricant L, Ham B, Mullins R, Mayberry J: Prolonged pain and disability are common after rib fractures. *Am J Surg* 2013;205(5):511-515.**

26. **Bottlang M, Long WB, Phelan D, Fielder D, Madey SM: Surgical stabilization of flail chest injuries with MatrixRIB implants: A prospective observational study. *Injury* 2013;44(2):232-238.**

27. Mayberry JC, Terhes JT, Ellis TJ, Wanek S, Mullins RJ: Absorbable plates for rib fracture repair: Preliminary experience. *J Trauma* 2003;55(5):835-839.

28. Voggenreiter G, Neudeck F, Aufmkolk M, Obertacke U, Schmit-Neuerburg KP: Operative chest wall stabilization in flail chest: Outcomes of patients with or without pulmonary contusion. *J Am Coll Surg* 1998;187(2):130-138.

29. Sillar W: The crushed chest: Management of the flail anterior segment. *J Bone Joint Surg Br* 1961;43(4):738-745.

30. Engel C, Krieg JC, Madey SM, Long WB, Bottlang M: Operative chest wall fixation with osteosynthesis plates. *J Trauma* 2005; 58(1):181-186.

31. Sales JR, Ellis TJ, Gillard J, et al: Biomechanical testing of a novel, minimally invasive rib fracture plating system. *J Trauma* 2008;64(5):1270-1274.

32. Nirula R, Allen B, Layman R, Falimirski ME, Somberg LB: Rib fracture stabilization in patients sustaining blunt chest injury. *Am Surg* 2006;72(4):307-309.

33. **Bottlang M, Helzel I, Long W, Fitzpatrick D, Madey S: Less-invasive stabilization of rib fractures by intramedullary fixation: A biomechanical evaluation. *J Trauma* 2010; 68(5):1218-1224.**

34. **Slobogean GP, MacPherson CA, Sun T, Pelletier ME, Hameed SM: Surgical fixation vs nonoperative management of flail chest: A meta-analysis. *J Am Coll Surg* 2013;216 (2):302-311.**