Treatment of Chest Wall Implosion Injuries Without Thoracotomy: Technique and Clinical Outcomes

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Background: Chest wall implosion injuries secondary to side impact are unusual but devastating injuries. The purpose of this series is to describe the clinical entity, present a surgical technique to reduce and repair the thoracic cage deformity without thoracotomy, and report outcomes in nine patients.
Study: Institutional review board approved retrospective case series, surgical technique.
Setting: Level I Trauma Center.
Methods: Twenty-two patients were admitted during 7-year period with thoracic cage implosion injuries and multiple segmental rib fractures from a side impact mechanism. All patients' required mechanical ventilation and had an implosion deformity along the posterolateral thoracic cage, pulmonary contusion, and clavicular fractures. Nine patients underwent repair of rib fractures through a paramidline posterior approach without thoracotomy using standard 2.4-mm titanium plates. Seven patients with similar fracture pattern treated nonoperatively were used as a historical control. Total intubation time, intensive care unit (ICU) length of stay (LOS), and final shoulder function using the Constant Murley scoring system were compared between the two groups.
Results: Average age, male to female ratio, and injury severe score were comparable for both cohorts ($p > 0.6$). Average follow-up was 16 months versus 12 months for the operative and nonoperative groups, respectively, ($p = 0.11$). In the operative group, 8 of 9 (89%) patients were extubated within 24 hours of surgery; 3 of 9 (33%) were extubated in the operating room. In the operative group, seven patients underwent internal fixation of the clavicle and progressed to union with a mean Constant score of 93. Nine patients had nonoperative treatment of the clavicle with a mean Constant score of 75 ($p = 0.04$). Total intubation time (1.9 days) was significantly shorter in the operative group than the nonoperative controls at 13.3 days ($p < 0.01$) and length of ICU stay was also shortened at 5.7 (4–8) days versus 16.7 (10–26) days, respectively, ($p < 0.01$).
Conclusion: Chest wall implosion injuries with fixed deformities of the thoracic cage, multiple segmental rib fractures, and clavicular injury are a distinct clinical entity, which can be effectively managed with a posterior paramidline approach without thoracotomy. Reduction of the deformity and repair of the rib fractures led to a dramatic reduction in time to extubation, ICU LOS, and in-hospital complications including pneumonia and sepsis. Repair of the clavicular fracture appeared to be beneficial.

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Blunt chest wall trauma is a major cause of morbidity and mortality in multiple injured patients.[1–7] Flail chest injuries are defined as fractures of four or more ribs in two or more locations with paradoxical motion of the flail segment during inspiration.[3,8,9] These injuries are commonly caused by frontal impact of the thoracic cage on the steering column in motor vehicle collisions (MVC).[8,9] Patients with flail chest injuries require aggressive pulmonary toilet, pain control, and often prolonged mechanical ventilation to maintain adequate gas exchange.[7–13] Mortality is partly caused by associated injuries; however, the primary cause of in-hospital morbidity is a combination of barotrauma, pulmonary contusion, pneumonia, and sepsis stemming from prolonged mechanical ventilation.[10–17] Surgical management of these injuries through an extended thoracotomy has been described in the literature with decrease in total time on ventilatory support, intensive care unit (ICU) length of stay (LOS), and sepsis complications.[3,7,8–16,18,19]

Improvements in secondary automotive restraints have led to a decrease in anterior flail chest injuries but the incidence of patients surviving high-energy side impact injuries has dramatically increased.[20–26] Patients involved in side impact MVCs often sustain lateral chest wall injuries; however, thoracic cage injuries from lateral compression mechanism have not been distinguished as a separate clinical entity from classic anterior flail chest injuries. Aside from multiple displaced rib fractures, there is little data to guide surgeons as to when surgical intervention is beneficial in implosion deformities of the chest wall.[8,14] The purpose of this study is to describe a group of patients with multiple segmental rib fractures and a fixed implosion deformity of the posterolateral thoracic cage, to describe a paramidline posterior approach without thoracotomy to reduce and stabilize the displaced rib segments, and to report the outcomes in 16 patients during a 7-year period.

PATIENTS AND METHODS

Thirty-one patients with thoracic cage trauma and multiple segmental rib fractures treated between January 2000 and June 2007 were studied retrospectively. Inclusion criteria were high-energy blunt chest wall trauma with side impact mechanism and radiographically documented superolateral

implosion deformity of the thoracic cage. Exclusion criteria were displaced anterior flail chest injuries, less than 12 months clinical follow-up, or patients with severe closed head injury with initial presenting Glasgow Coma Scale score of 10 or less. Institutional Review Board approval was obtained for a retrospective review of the patient records and radiographs. Twenty-two (71%) patients sustained a posterolateral chest wall implosion deformity secondary to side impact mechanism. A total of six patients (27%) were excluded: three patients (14%) had incomplete follow-up, and three patients (14%) had severe head injury requiring prolonged mechanical ventilation and tracheostomy. Before March 2004, these patients were managed nonoperatively, and 10 patients (32%) were treated in an ICU setting with ventilatory pneumatic stabilization of the flail segments. After March 2004, surgical repair was attempted whenever possible, and 12 patients (39%) underwent surgical repair through a paramidline posterior approach without thoracotomy using 2.4-mm titanium plates. Treatment selection was not randomized.

Nine patients met inclusion criteria in the operative group; seven in the nonoperative group were included. Treatment groups (operative vs. nonoperative) were not concomitant and did not overlap. In the operative group, patients were repaired surgically within 48 hours of presentation. Postoperatively, all patients were monitored in the surgical ICU for a minimum of 24 hours after extubation and received 24 hours of IV antibiotics for prophylactic coverage. Decision for extubation was made according to the standardized ICU protocol. Thoracostomy tubes were kept to suction for the first 24 hours postsurgery and then to water seal with serial chest X-rays performed daily while the tube was in place. Tubes were discontinued after resolution of the hemo or pneumothorax and a minimum of 24 hours without air leak. Patients were transferred out of the ICU when they had stable or improving pulmonary function without mechanical ventilation for a minimum of 24 hours. After discharge from the hospital, patients were followed at 3 and 6 weeks and every 3 months thereafter.

Outcome measurements included total time on mechanical ventilation, time from surgical repair to extubation, length of ICU stay, time patients required a chest tube, and final Constant-Murley score in the involved shoulder at the latest follow-up using active range of motion. Statistical analysis was performed using a Student's two tailed t test, Mann-Whitney (Wilcoxon rank sum) test, or Fisher's Exact test. Level of significance was set to $p \leq 0.05$.

Illustrative Case

A 38-year-old male was transported to the Emergency Department after a high-speed side impact MVC with significant passenger space intrusion. He presented with dyspnea, a Glasgow Coma Scale score of 15 and severe left-sided chest pain. His initial chest X-ray revealed multiple adjacent segmental rib fractures, left-sided thoracic cage implosion deformity and hemothorax without pneumothorax or tracheal deviation (Fig. 1). Initial physical examination revealed respiratory splinting, labored breathing, internal rotation of the involved forequarter, and clavicle fracture, but paradoxical

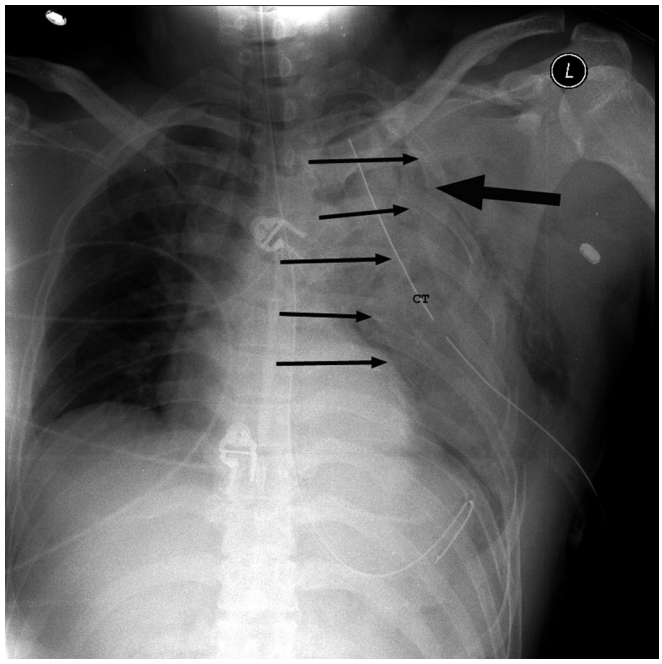

Figure 1. Initial chest X-ray showing thoracic cage implosion and multiple posterior rib fractures.

motion of the chest wall was not appreciated. Associated injuries included an ipsilateral lateral compression pelvic ring fracture and a contralateral closed tibial shaft fracture. A 36 French thoracostomy tube was placed with immediate return of 255 mL of sanguineous drainage. Computed tomography imaging of the chest showed multiple segmental posterior rib fractures (ribs 2–8), implosion of the superolateral thoracic cage (Figs. 2 and 3). Because of his inability to maintain adequate oxygenation, he was intubated and mechanically ventilated. He subsequently underwent surgical repair 28 hours after initial presentation.

The patient was placed prone on a radiolucent flat top table with the ipsilateral arm adducted to the side. Skin incision performed approximately 5 cm lateral to the spinous process from the superior border of the scapula to T10 (Fig. 4). The rhomboids and trapezius muscles were released off of the medial border and spine of the scapula and retracted medially along with the erector spinae group. None of the muscles were transected during this approach. The scapulothoracic bursa was incised, and the scapula was retracted laterally giving access to the posterior thoracic cage. The fractures of the posterior rib segments and thoracic cage deformity from ribs 3 to 8 were visualized (Fig. 5). Reduction was carried out by a combination of distraction at the fracture and outward traction on the rib with bone forceps. Fixation was carried out using 2.4-mm nonlocking titanium implants (Fig. 6). We were unable to gain surgical access above the third rib. Once the posterior fractures were reduced and repaired, palpation of the fracture in the midaxillary line was undertaken to assess reduction. Intraoperative fluoroscopy was used to verify the position of the plates as well as the reduction of the ribs (Fig. 7). The wound was closed in a

Figure 2. Axial computed tomography scan of the chest showing posterior rib fracture with thoracic cage implosion deformity.

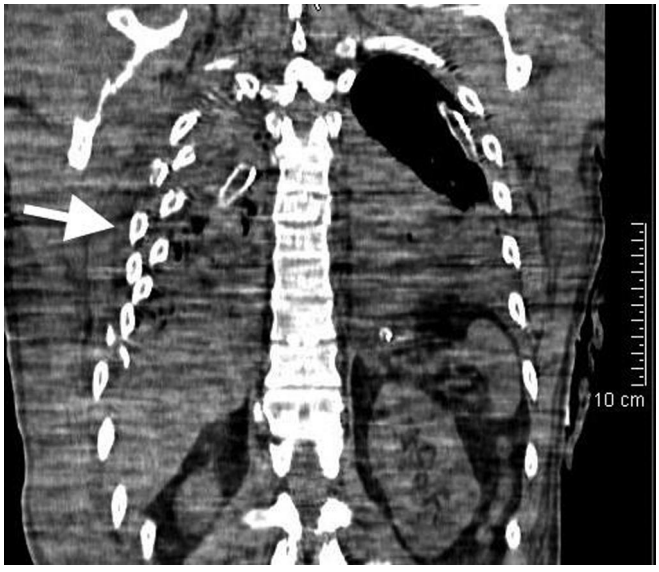

Figure 3. Coronal reconstruction computed tomography showing overlap of the rib fractures.

layered fashion over a small suction drain. The patient was then repositioned and repair of the ipsilateral clavicular shaft fracture or acromioclavicular (AC) joint was performed via a separate anterior approach.

RESULTS

Group demographics including age, follow-up, injury severe score, and sex were comparable between the two groups and outlined in Table 1. In the operative group, 8 of 9 (89%) patients were extubated within 24 hours of surgery and 3 of 9 (33%) were extubated postoperatively in

Figure 4. Skin incision along the medial border of the scapula.

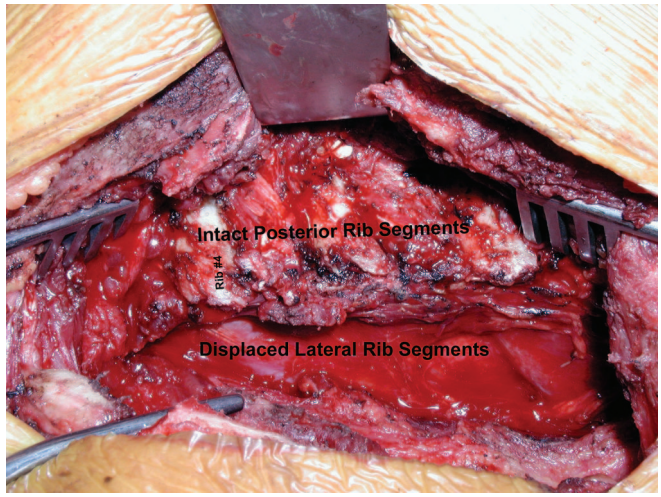

Figure 5. Visualization of the rib fracture step off, intact posterior segment, and displaced lateral segment.

the operating room. Time from injury to repair averaged 18 (6–42) hours, and all the patients were repaired within 48 hours of injury. Total ventilation time after surgical repair averaged 19 (0–36) hours with an average ICU LOS of 5.4 (4–9) days. There were no superficial infections, deep wound infections, or hardware failure of either the rib or clavicular fixation. Three patients (33%) in the operative group developed mild pulmonary contusions. None of these patients developed consolidation of the contusion, pneumonia, or sepsis.

Two patients had displaced scapular body fractures that were concomitantly repaired. All patients had clavicular fractures; five were shaft fractures and four AC joint fracture/dislocations. Seven patients underwent surgical repair of the clavicular fracture or AC joint disruption and went on to union with a mean Constant score of 93. Two patients had nonoperative management of their clavicle fractures after rib repair and both developed hypertrophic nonunion requiring intervention with a mean Constant score of 78 ($p = 0.12$). Shoulder function in the rib plating group, overall, was

Figure 6. Photograph of the same rib segment stabilized with 2.4-mm titanium plates.

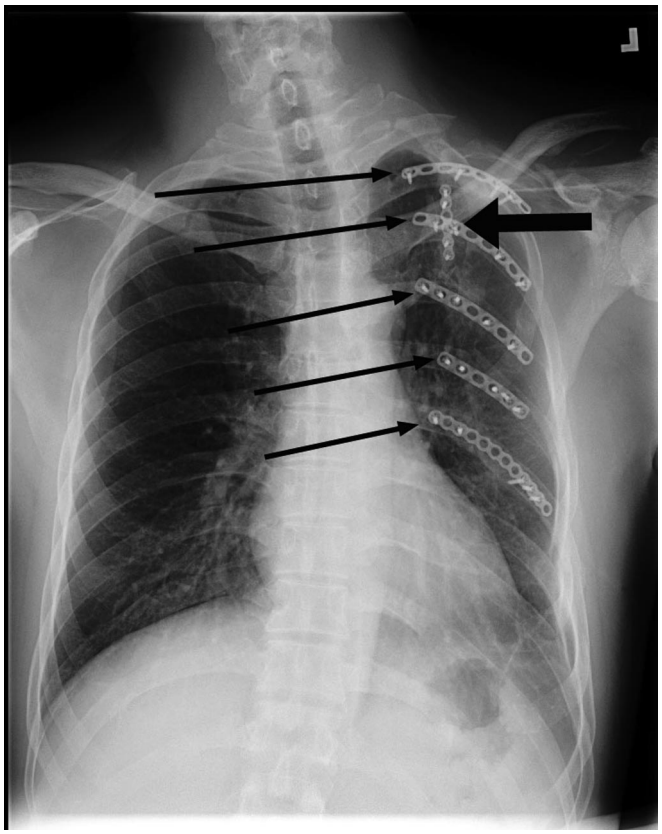

Figure 7. Anteroposterior chest X-ray showing the location of the plates on ribs 3 to 7 as well as a small plate on the scapular body.

excellent with an overall Constant score of 88 (68–96) versus 75 (55–82) for the nonoperative cohort ($p = 0.01$).

In the nonoperative group, total intubation time averaged 13.3 (6–22) days with an average ICU LOS of 21 (3–41) days. Average chest tube duration in this group was 16.8 (±5.1) days. Of the patients treated nonoperatively (7), five (71%) developed pulmonary contusions, three (43%) developed consolidation of the contusion with pneumonia, and two (29%) developed blood culture positive bacteremia.

Total intubation time was significantly shorter for the operative group (1.9 days) than nonoperative treatment (13.3 days) ($p < 0.01$). Length of ICU stay was reduced from 21.0 (3–41) days to 5.4 (4–9) days in groups undergoing repair of implosion chest deformity ($p = 0.01$). Total duration of thoracostomy tube was likewise decreased from 16.8 (10–26) days to 5.7 (4–8) days with operative stabilization ($p < 0.01$; Table 2).

TABLE 1. Patient Characteristics of the Operative and Conservative Patients

	Operative Group	Conservative Group	*p*
Number	9	7	
Age	38.8 (±16.7) yr	41.1 (±13.0) yr	$p = 0.75$
F/U	16.1 (±6.7) mo	12.0 (±2.3) m	$p = 0.11$
Male/female	6/3	5/2	
ISS	24.9 (±6.5)	24.8 (±6.2)	$p = 0.99$

TABLE 2. Clinical Outcomes

	Operative Repair	Nonoperative Treatment	*p*
Total intubation time	1.9 (±1.1) d	13.3 (±5.3) d	<0.001
ICU LOS	5.4 (±1.5) d	21 (±13.6) d	0.01
Chest tube duration	5.6 (±1.2) d	16.8 (±5.1) d	0.001
Constant score	87.6 (±5.4)	74.6 (±9.75)	0.01

DISCUSSION

Flail chest injuries are defined fractures of four or more ribs in two or more locations with paradoxical motion of the flail segment during inspiration.[3,8,9] Nonoperative management has been associated with high rates of in-hospital complications and prolonged mechanical ventilatory requirements.[7,10–13,15] Long-term morbidity from loss of pleural space volume and chronic pain has also been reported.[1,2,4–6] Several authors have reported experience with repair of flail chest injuries using a variety of methods including plates, cables, fixators, and intramedullary nails through a thoracotomy approach.[7–13,15,16,18,19] Significant decreases in ICU LOS, ventilatory requirements, and in-hospital infection rates with rib reduction and stabilization have been documented.[4,8,11,13,15,16,18,19]

Classic anterior flail chest injuries are less common with improved secondary automotive restraints, whereas lateral compression thoracic cage injuries from side impact mechanisms are more common in trauma patients.[20–26] Aside from a flail rib segment, indications for repair of multiple rib fractures include severe displacement and overriding rib fractures,[3,8,14,16] pleural cavity volume decrease of more than 30%,[3,7,16] and pulmonary instability preventing ventilator weaning.[7,10,13,14] There is no current consensus, however, as

to the appropriate timing or surgical approach to address multiple segmental rib fractures from lateral compression injuries.

Our series describes a clinically distinct subset of patients with multiple segmental rib fractures from a side impact mechanism. Typical symptoms of respiratory splinting, labored breathing, and impaired oxygenation were evident, but paradoxical chest wall motion was not appreciated as the involved area is under the patient, covered by the scapula and several muscles. This group of patients had a relatively fixed implosion deformity of the posterolateral thoracic cage, displaced rib fractures near the posterior midline and fracture or dislocation involving the clavicle or AC joint. Rib fractures in the midaxillary line, which are typically widely displaced in anterior flail chest injuries, were minimally or nondisplaced in this group.

A standard or extended thoracotomy has been described as the preferred surgical approach for repair of flail chest injuries in several series.[3,7–14,16,18,19] The advantages of this approach include the ability to access the pleural space and lung parenchyma; however, exposure is limited in the posterior thorax and long-term shoulder impairment using this approach has been reported.[7,13,16,18] In our series, rib displacement was most pronounced in the posterior paramidline area; an area relatively inaccessible using a thoracotomy approach. The use of a paramidline posterior approach allowed access to the displaced rib segments below the second rib while iatrogenic trauma to the periscapular stabilizers was minimized by the surgical technique. We felt that after the repair of the paramidline posterior fractures had been performed, the rib displacement at the midaxillary line was negligible and did not warrant additional dissection. Moreover, the paradoxical rib segment motion, which was appreciated with mechanical ventilation intraoperatively, was eliminated after repair of the primary (posterior) fracture line.

All patients in our series had some type of injury involving the clavicle or AC joint. Clavicular failure seems to be a critical prerequisite for the genesis of this clinical syndrome as the clavicle functions as the only mechanical strut resisting medialization of the scapula against the thoracic cage. Failure of the clavicle can occur when significant force is applied laterally on the shoulder, leading to medialization of the scapula and direct implosion of the superolateral thoracic cage. A seated position places the clavicle in a flexed and slightly offset position relative to the sternoclavicular joint and may explain why the clavicle typically failed in the lateral 1/3 of the shaft or at the AC joint instead of closer to the sternoclavicular joint, which is proposed when the scapula is retroverted.[27–31] Moreover, failure to stabilize the clavicular strut in two patients in the operative group resulted in impairment of shoulder function with overall medialization of the scapula requiring secondary intervention.

Limitations of the paramidline posterior approach included an inability to explore the pleural space and evaluate the lung parenchyma for clot accumulation or need for resection. In addition, we did not use a dual lumen endotracheal tube to deflate the involved lung during repair and cannot comment of the possibility of iatrogenic lung injury from drill puncture. However, the lack of persistent air leak from the chest tube and short time from surgical repair to extubation would argue against this.

CONCLUSION

Chest wall implosion injuries represent a distinct clinical entity characterized by multiple displaced segmental rib fractures, clavicle fracture or dislocation, and a fixed implosion deformity of the superolateral thoracic cage. Unlike classic flail chest injuries, chest wall implosion injuries are secondary to side impact mechanisms and do not have characteristic paradoxical motion of the involved segment on physical examination. A paramidline posterior approach without thoracotomy allowed exposure and repair of the displaced posterior rib fractures below the second rib and dramatically reduced duration of chest tube, time of intubation, in-hospital infection rates, and ICU LOS compared with nonoperative management. Medium-term shoulder function is excellent provided surgical stabilization of the clavicle is performed concomitantly with rib repair.

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EDITORIAL COMMENT

Rib fractures are a common and painful injury for which the majority of patients admitted to trauma centers require supportive therapy only. Current accepted treatment focuses on pain control, respiratory therapy, and prevention or management of secondary pulmonary complications such as pneumonia and delayed respiratory failure.[1] Historically, operative therapy for rib fractures has been considered controversial and potentially meddlesome. Thus, even the most severe chest wall injuries, such as flail chest, have in a majority of centers in the past several decades been treated nonoperatively. Consequently most active, academic trauma surgeons in the United States have neither performed nor observed a rib fracture repair.[2] Several centers, however, have recently reported a rich operative experience with chest wall fracture repair with the stated goal of the prevention of not only acute morbidity and but also long-term disability.[3–6] The reported experience can be summarized as encouraging and therefore, chest wall fracture repair has been recently and succinctly described as "underused."[6]

Similarly, this report by Solberg et al. on the results of surgical fixation of a particular subset of severe chest wall injury challenges the traditional nonoperative approach. The eloquently named "chest wall implosion" results from massive blunt force to the upper posterior chest wall that not only fractures and displaces several ribs but also the clavicle and frequently the scapula. In this series, fixation of the rib, clavicle, and scapula fractures were performed within 48 hours of injury with the patient prone and without entry into the pleural space. Compared with a historical cohort of similarly injured patients treated without operative intervention, the operative cohort endured less time on mechanical ventilation and had improved outpatient shoulder function. Solberg et al. are to be commended not only for being the first in modern times to describe this peculiar and instantly recognizable injury but also for devising an ingenious and effective surgical approach.

This series is also unique because orthopedic and general surgeons cooperated in the selection of patients and in the conduct of their surgery. Because most general trauma surgeons are not familiar with the techniques and potential pitfalls of rib fracture repair, this is an excellent example to emulate. Orthopedic and thoracic surgeons are recommended partners for general trauma surgeons seeking to learn rib fracture repair.[2]

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