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ORIGINAL SCIENTIFIC REPORT

# Outcomes of Complete Versus Partial Surgical Stabilization of Flail Chest

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**Abstract**

*Background* Rib fractures are common after chest wall trauma. For patients with flail chest, surgical stabilization is a promising technique for reducing morbidity. Anatomical difficulties often lead to an inability to completely repair the flail chest; thus, the result is partial flail chest stabilization (PFS). We hypothesized that patients with PFS have outcomes similar to those undergoing complete flail chest stabilization (CFS).

*Methods* A prospectively collected database of all patients who underwent rib fracture stabilization procedures from August 2009 until February 2013 was reviewed. Abstracted data included procedural and complication data, extent of stabilization, and pulmonary function test results.

*Results* Of 43 patients who underwent operative stabilization of flail chest, 23 (53 %) had CFS and 20 (47 %) underwent PFS. Anterior location of the fracture was the most common reason for PFS (45 %). Age, sex, operative time, pneumonia, intensive care unit and hospital length of stay, and narcotic use were the same in both groups. Total lung capacity was significantly improved in the CFS group at 3 months. No chest wall deformity was appreciated on follow-up, and no patients underwent additional stabilization procedures following PFS.

*Conclusion* Despite advances in surgical technique, not all fractures are amenable to repair. There was no difference in chest wall deformity, narcotic use, or clinically significant impairment in pulmonary function tests among patients who underwent PFS compared with CFS. Our data suggest that PFS is an acceptable strategy and that extending or creating additional incisions for CFS is unnecessary.

**Abbreviations**

| | |
|---|---|
| CFS | Complete flail chest stabilization |
| DLCO | Diffusing capacity of lung for carbon monoxide |
| $FEV_1$ | Forced expiratory volume in the first second of expiration |
| FVC | Forced vital capacity |
| LOS | Length of stay |
| PFS | Partial flail chest stabilization |
| TLC | Total lung capacity |

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## Introduction

Rib fractures are common and debilitating sequelae of chest wall trauma. Flail chest results when at least 2 consecutive ribs are fractured in at least 2 places [1, 2]. This anatomical dissociation may result in the flail segment moving paradoxically with respiration. Flail chest is a particularly morbid complication of blunt chest trauma, with mortality rates reported as high as 33 % [3]. Patients with flail chest often require prolonged periods of mechanical ventilation for ongoing respiratory dysfunction, leading to high rates of pulmonary infections [4]. In the era of modern critical care, the management of these patients is evolving. Previously described techniques of internal pneumatic stabilization with mechanical ventilation are being replaced by operative stabilization of flail chest injuries. Although the data are limited, recent studies have suggested a decrease in number of ventilator days [5], decreased development of pneumonia [6, 7], decreased pain [8], and decreased long-term disability [9] in flail chest patients managed with operative rib stabilization. Because of these findings, interest is increasing in rib fracture stabilization as a primary treatment of flail chest injuries. Recently revised Eastern Association for the Surgery of Trauma guidelines include surgical stabilization of flail chest as a viable treatment option [10].

Early attempts at fixation of rib fractures were limited because of the lack of appropriately engineered stabilization devices. Externally applied reduction clamps or internal wire and suture fixation were often used to brace the fractures, but the associated morbidity and failure furthered the belief that rib fracture fixation was inappropriate. These outdated techniques are being replaced by intramedullary fixation or plate stabilization. The most recent iteration of plate fixation uses "over the rib" plates, such as the RibLoc rib fracture plating system (Acute Innovations), or "on top of the rib" plate and screw fixation, such as the MatrixRIB fixation system (Synthes) [11, 12].

Despite significant improvements in the available materials and technique of rib fracture stabilization, not all rib fractures are amenable to operative fixation. Many techniques have been described to access fractures that are difficult to reach, including step ladder incisions, hanging scapula retractors, percutaneous trocar access, and use of a 90° drill and screwdriver [13, 14]. Although these maneuvers have extended the reach of rib fracture stabilization, often through a single incision, certain anterior, posterior, and cephalad rib fractures remain out of reach with the current instruments.

Anteriorly located fractures often require a counter incision for access and repair. Posteriorly located fractures often cannot be repaired because there is no adequate medial landing zone for the plate fixation technique. Cephalad fractures require additional maneuvers to elevate the scapula, and although they can be painful, contribute little to respiratory mechanics. Currently, surgeon preference determines whether to plate all the involved ribs or only the ribs easily amendable to rib stabilization. The decision is made on a case-by-case basis. For example, an 84-year-old blunt trauma victim with a flail segment of the right ribs 6 through 10 (Fig. 1) underwent successful surgical rib stabilization of his chest wall anterolaterally and posterolaterally (Fig. 2). However, a 68-year-old woman with a flail segment of the right ribs 6 through 11 (Fig. 3) underwent successful plate fixation and bridging of the lateral segment, but the posterior line of fractures, which did not have an appropriate landing zone for the plates, was not stabilized (Fig. 4). Anecdotally, both patients seemed to benefit from the stabilization procedures. A recent article suggests that fixing only 1 fracture per rib in a flail segment may be enough to avoid deformity; however, the authors concluded that ideally all fractures in the flail segment should be addressed [15].

**Fig. 1** Flail chest, right ribs 6 through 10. Computed tomography of the chest with 3-dimensional reconstruction shows flail chest amenable to complete stabilization of the flail segment

Thus, we sought to answer the following question: Does partial flail chest stabilization (PFS), compared with complete flail chest stabilization (CFS), result in satisfactory outcomes for patients? We hypothesized that aggressive maneuvers to access difficult-to-reach fractures are unnecessary and that patients undergoing PFS would have similar outcomes to those undergoing CFS.

## Methods

Our institution adopted surgical stabilization of rib fractures in selected patients in 2009. Patients met criteria if they had anatomically or physiologically defined flail chest.

**Fig. 2** Complete flail chest stabilization. Radiograph shows complete stabilization of the anterolateral and posterolateral fracture lines of the flail segment

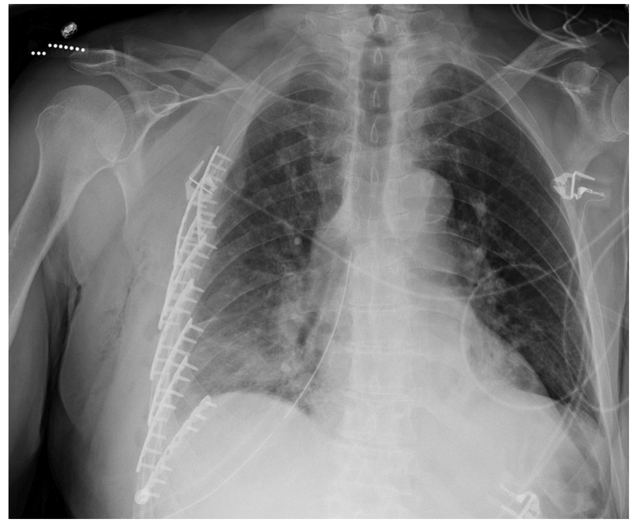

**Fig. 4** Partial flail chest stabilization. Radiograph shows partial stabilization of the flail segment, resulting in stabilization of the lateral segment and not the posterior line of fractures

**Fig. 3** Flail chest, right ribs 6 through 11. Computed tomography of the chest with 3-dimensional reconstruction shows flail chest amenable to partial stabilization of the flail segment

Multiple trauma surgeons performed the surgical stabilization procedures but were trained in the technique by a common trauma surgeon mentor with extensive experience in rib fracture fixation (coauthor B.D.K.). Our institution currently considers surgical stabilization if the patient meets 1 of the following criteria: (1) rib fractures with respiratory failure requiring mechanical ventilation; (2) nonintubated patient with deteriorating pulmonary function (with or without pulmonary contusion in association with rib fractures); (3) non-flail rib fracture(s) with or without significant ($\geq$1 rib width) displacement; (4) impalement of ribs into pulmonary parenchyma, other solid organs (e.g., hepatic or splenic parenchyma), or diaphragm; (5) significant and refractory patient pain in association with rib fractures; and (6) anticipated nonunion or malunion of rib fracture(s) or flail segment. However, we have multiple surgeons performing the procedure, so surgeon discretion and experience do lead to consideration of patients outside the protocol. We currently perform rib fracture stabilization procedures through a standard thoracotomy incision positioned over the most severely displaced fractures; we repair all fractures that are easily accessible through this approach and avoid additional incisions. No accessible fractures are left without fixation, and we typically plan our incision over the most severely fractured segments. Our institution's follow-up regimen for patients after surgical stabilization of flail chest includes a clinic visit at 1, 3, 6, and 12 months with posteroanterior and lateral chest radiographs and pulmonary function tests.

A prospectively collected and maintained database of all patients who underwent rib fracture stabilization procedures from August 2009 until February 2013 was reviewed after obtaining Mayo Clinic Institutional Review Board approval. Data included patient demographics, mechanism of injury, Injury Severity Score, complications, intensive care unit and hospital length of stay (LOS), and ventilator days. Time to follow-up, follow-up pulmonary function tests, narcotic use at the 1-month follow-up visit, and

**Table 1** Patient characteristics for complete flail chest stabilization (CFS) and partial flail chest stabilization (PFS) groups

| Characteristic | CFS ($n = 23$)[a] | PFS ($n = 20$)[a] | *P* |
|---|---|---|---|
| Age, years | 63 (30–85) | 58 (34–83) | .42 |
| Male | 12 (52 %) | 13 (65 %) | .39 |
| Operative time, min | 186 (110–293) | 183 (110–440) | .90 |
| ICU LOS, days | 1 (0–39) | 2 (0–26) | .72 |
| Hospital LOS, days | 10 (2–39) | 10 (4–36) | .85 |
| Flail ribs, no. | 3 (1–4) | 4 (3–6) | .01 |
| ISS | 20 (5–34) | 17 (9–27) | .50 |
| Pneumonia | 5 (22 %) | 4 (20 %) | .39 |
| Narcotic use at 1-month follow-up[b] | 10 (43 %) | 9 (45 %) | .86 |
| Time to follow-up, days | 196 (9–405) | 176 (30–472) | .76 |

*ICU* intensive care unit, *ISS* Injury Severity Score, *LOS* length of stay

[a] Continuous data are presented as median (interquartile range); categorical data, as number of patients (percentage of sample)

[b] Narcotic use at 1 month included any patients who reported ongoing use of any prescribed narcotic pain mediation at the initial follow-up visit

**Table 2** Pulmonary function test (PFT) results for complete flail chest stabilization (CFS) and partial flail chest stabilization (PFS) groups

| PFT | CFS ($n = 11$)[a] | PFS ($n = 13$)[a] | *P* |
|---|---|---|---|
| 1 month postoperatively | | | |
| TLC | 85.5 (50–99) | 82 (68–111) | .63 |
| VC | 73 (49–92) | 72 (41–104) | .89 |
| FVC | 72 (51–91) | 69 (45–103) | .68 |
| $FEV_1$ | 64 (39–90) | 65 (33–105) | .88 |
| $FEV_1$/FVC | 72 (60–90) | 75 (57–84.5) | .76 |
| DLCO | 79 (37–102) | 76 (55–99) | .47 |
| 3 months postoperatively | | | |
| TLC | 90 (83–108) | 72 (68–92) | .02 |
| VC | 86 (52–99) | 81 (43–98) | .61 |
| FVC | 83 (52–99) | 81 (39–98) | .61 |
| $FEV_1$ | 75 (43–97) | 81 (35–100) | .92 |
| $FEV_1$/FVC | 73 (57–82) | 75 (67–81) | .35 |
| DLCO | 78 (42–115) | 74 (63–103) | .57 |
| 6 months postoperatively | | | |
| TLC | 94 (79–101) | 75 (67–89) | .04 |
| VC | 86 (68–105) | 76 (49–107) | .36 |
| FVC | 85 (65–105) | 77 (44–107) | .40 |
| $FEV_1$ | 71 (53–99) | 78 (41–102) | .87 |
| $FEV_1$/FVC | 68 (56–82) | 74 (71–81) | .06 |
| DLCO | 74 (50–122) | 81 (58–108) | .85 |

*DLCO* diffusing capacity of lung for carbon monoxide, *$FEV_1$* forced expiratory volume in the first second of expiration, *FVC* forced vital capacity, *TLC* Total lung capacity, *VC* vital capacity

[a] Values are percentage of value as predicted by age (interquartile range)

patient- and provider-perceived chest wall deformity were recorded. Operative reports were reviewed to determine whether the flail segment was completely repaired or partially repaired; 79 % of patients had preoperative imaging with computed tomography of the chest with 3-dimensional reconstruction, and all patients had preoperative chest radiographs, which were reviewed. Pulmonary function test data, including total lung capacity (TLC), vital capacity, forced vital capacity (FVC), forced expiratory volume in the first second of expiration ($FEV_1$), $FEV_1$/FVC, and diffusing capacity of lung for carbon monoxide (DLCO), were collected at 1, 3, and 6 months postoperatively using the Jaeger testing system (CareFusion Corp). CFS was defined as operative stabilization of all fractures of all ribs involved in the flail segment. PFS included patients in whom all segments were not repaired because of inaccessibility. Results between the CFS and PFS groups were compared with the $\chi^2$ test for categorical data and nonparametric comparisons with Wilcoxon rank sums for continuous variables and presented as percentage and median (interquartile range) as appropriate. *P* values less than .05 were considered significant.

## Results

Forty-three patients underwent operative stabilization of flail chest. CFS was achieved in 23 patients (53 %), and the remaining 20 patients (47 %) underwent PFS. PFS ranged from 20 to 80 % of the fractures in the flail segment being repaired. Reasons for partial repair included anterior location in 9 patients (45 %), posterior location in 6 patients (30 %), cephalad location in 3 patients (15 %), and caudad location in 2 patients (10 %).

There were no statistically significant differences in age (63 vs. 58 years), sex (male 52 vs. 65 %), pneumonia (5 patients vs. 4 patients), intensive care unit LOS [1 day (0–39 days) vs. 2 days (0–26 days)], and hospital LOS [10 days (2–39 days) vs. 10 days (4–36 days)] between groups. There was no difference in operative times between groups [186 min (110–293 min) vs. 183 min (110–440 min)] (Table 1). There was one 30-day mortality in the CFS group secondary to a stroke and no deaths in the PFS group. Median follow-up was 190 days (9–472 days), with 84 % of patients having at least 6 months of follow-up. No difference was appreciated in overall narcotic use at the 1-month follow-up visit (10 patients vs. 9 patients). Twenty-four patients (56 %) underwent follow-up pulmonary function tests at 1, 3, and 6 months, and the results were compared across groups. There was no difference in pulmonary function (TLC, vital capacity, FVC, $FEV_1$, $FEV_1$/FVC, and DLCO) at 1 month ($P > .05$). TLC was significantly improved in the CFS group at 3 months (90 % predicted vs. 72 % predicted; $P = .02$) and 6 months (94 % predicted vs. 75 % predicted; $P = .04$), but there was no difference in the other measures of pulmonary function at 3 and 6 months (Table 2). No patients complained of chest wall deformities and no providers noted chest wall deformities during follow-up, and no patients underwent additional stabilization procedures.

## Discussion

Flail chest injuries are a debilitating consequence of chest wall trauma; surgical stabilization is a viable option to speed recovery [6, 16]. Certain anatomical configurations of flail chest injuries are not amenable to CFS, making PFS necessary. Whether the use of PFS affects patient outcomes is unknown, previous studies citing benefits of surgical stabilization in flail chest patients did not report on the completeness of the repair [6, 7, 9]. With the exception of an increase in TLC in the CFS group at 3 and 6 months, we found no significant differences in outcomes between PFS and CFS groups. No patients or providers noted significant chest wall deformity or paradoxical movement of the chest wall after PFS, suggesting that repair of the easily accessible fractures sufficiently restores overall chest wall anatomy.

The most common rationale for partial repair was anteriorly located rib fractures that were beyond the reach of surgical instruments through a standard posterolateral thoracotomy but were also not technically acceptable to stabilize given the proximity to the costal cartilage. At our institution, we have adopted the 90° drill and screwdriver from the Synthes MatrixMANDIBLE plating system. This has extended the reach of rib fracture stabilization, to allow higher ribs and more total ribs to be stabilized in an equivalent operative time [14]. Despite this improvement in technique, some anterior, posterior, and cephalad rib fractures remain out of reach. Both CFS and PFS appear to restore the 3-dimensional anatomy of the chest wall, aid in the alignment of remaining fractures, and convert a flail chest injury into a stable chest wall. We theorize that converting the flail chest into simple rib fractures is enough to sufficiently restore chest wall physiology, allowing the involved segment of chest wall to again participate in respiratory mechanics. Subjecting patients to the morbidity of additional incisions, prolonged operations, and aggressive maneuvers to access additional fractures may be unnecessary.

Although we are encouraged by these results and plan to incorporate our findings into practice at our institution, we recognize several potential sources of error. First, although the database was collected prospectively, this was a retrospective study, confounded by the multiply injured patients, and was subject to observer bias. Second, despite the relatively high prevalence of blunt trauma patients in our institution, the results are limited by our small sample size. Although we believe that, according to our data, CFS and PFS result in similar outcomes, our sample size limits our ability to prove noninferiority. Third, many patterns of rib fractures exist and conclusions can be difficult to draw because of the heterogeneity of the number and location of rib fractures.

Despite these obvious limitations of the study, we plan to incorporate our results into the practice of rib fracture stabilization at our institution. We routinely avoid additional incisions, repairing only those fractures that are readily accessible through the primary incision. From our presented evidence, we suggest that additional incisions or aggressive maneuvers to access all fractures are unnecessary and unwarranted.

**Compliance with ethical standards**

**Conflict of interest** None.

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