Curr Surg Rep (2019) 7:18
https://doi.org/10.1007/s40137-019-0238-9

Timing of Surgical Stabilization of Rib Fractures

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Published online: 28 June 2019

Abstract
Purpose of Review Surgical stabilization of rib fractures (SSRF) has a proven benefit in patients with flail chest. However, the timing of intervention is currently unclear. We aim to evaluate and summarize current evidence related to the time interval for the surgical stabilization of rib fractures.
Recent Findings Retrospective studies specifically addressing when to perform SSRF in patients with severely displaced rib fractures have reported a benefit for patients who underwent the procedure within 72 h of injury. There are currently no prospective trials specifically addressing timing of rib fixation. Delayed (i.e., months to years) SSRF may be indicated in highly select cases with both physical exam findings of "clicking" or instability and radiographic evidence of nonunion.
Summary For patients in whom there are no contra-indications, current evidence suggests that surgical stabilization of rib fractures should occur as early as possible, and ideally within 72 h of injury. The decision to perform delayed SSRF should be undertaken cautiously and on a case-by-case basis.

Keywords Surgical stabilization of rib fractures · Rib plating · Rib fixation · Flail chest · Chest wall trauma

This article is part of the Topical collection on *Trauma Surgery*.

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Introduction

Blunt thoracic trauma is a prevalent cause of trauma-related mortality. Of these injuries, rib fractures are most common [1–3]. There is a clear association between the number of fractured ribs and mortality, each fractured rib increases mortality by 19% in patients 65 years and older [4]. Furthermore, flail chest with associated pulmonary contusion carries a mortality rate of 42% [5, 6]. Even with improved critical care technology and widespread adoption of adjunctive pain management techniques, the outcomes in patients with multiple severe rib fractures has not significantly improved over the past 15 years [5]. The cause of death in these patients is most commonly due to pneumonia from inadequate pulmonary toilet secondary to hypoventilation, atelectasis, and inadequate pain control [5].

Efficacy of Surgical Stabilization of Rib Fractures

Surgical stabilization of rib fractures (SSRF) in trauma has gained a renewed interest over the past decade. This is likely due to several randomized controlled trials [7–9, 10•] and meta-analyses showing [11–17] benefit in those patients with flail chest, adoption of new techniques by trauma surgeons, consensus statements by the Eastern Association for the Surgery of Trauma (EAST) [18], the Chest Wall Injury Society (CWIS) [19], and the National Institute for Health and Care Excellence (NICE) [20], as well as the development of multiple industry-derived easily deployable rib fixation systems. Trials supporting SSRF in patients with flail chest have shown decreased rates of pneumonia, length of intensive care unit (ICU) stay, and mechanical ventilation [18, 19, 21]. It is also believed that these patients may avert the development of chronic pain

from fracture malunion months to years after their injury. Furthermore, studies are currently actively enrolling patients to address the role of SSRF in patients with severely displaced rib fractures without a flail segment [22, 23]. The incidence of SSRF nationally is rising exponentially [24].

Theoretical Advantages of Early SSRF

Although studies have shown benefit to SSRF as compared to nonoperative management, debate remains regarding the optimal timing of surgery [25]. Some believe that patients should only undergo SSRF once they have failed a prolonged trial of medical management and developed progressive pain or respiratory decompensation. Obvious benefits to this approach consist of the avoidance of an unnecessary procedure. Drawbacks include the development of pneumonia or empyema in patients in which these complications could have potentially been prevented. Furthermore, implantation of rib plates in patients who have had recent pneumonia or empyema may lead to devastating infected hardware which would then have to be removed.

Advocates of early SSRF believe that both patient physiology and fracture patterns can predict those patients who will ultimately fail nonoperative management [26]. Earlier fixation is also supported by data from orthopedic literature on the fixation of long bone fractures in which outcomes are improved in early fixation cohorts [27, 28]. Tissue inflammation and edema peaks at approximately 72 h post injury, and any surgeon who has operated on displaced ribs within 24 h of injury, as compared to 72 h after injury, will likely agree that the dissection is both bloodier and more challenging in the case of the later. Finally, early SSRF affords an opportunity to both clear the pleural space and place guided loco-regional anesthesia prior to the development of complications such as retained hemothorax, pneumonia, and respiratory failure [29–32]. Practice patterns among trauma surgeons appear to be shifting towards earlier SSRF. Among four high volume centers, we found a significant shift from late to early SSRF over the last decade [33••].

Data Addressing the Timing of Surgical Stabilization of Rib Fractures

There are several methodologic considerations that render interpretation of data addressing the optimal timing of SSRF problematic. The first is selection bias; the concept that patients who are selected for early SSRF, in general, are less severely injured as compared to those selected for late SSRF. In this case, any observed outcome benefit to early SSRF could in actuality be due to the patient's associated injuries (or lack thereof) rather than their rib fracture therapies. A second concern is attrition bias. In the case of SSRF timing, attrition bias is possible when patients are initially considered for surgery, observed, improved, and ultimately discharged not having undergone SSRF. Such patients are not included in comparisons of patients who undergo early vs. late SSRF because they never received the operation. By contrast, patients who deteriorate after a period of observation and ultimately undergo the surgery relatively late in their hospitalization represent the subset of "late" patients who did not improve. One important piece of information that is missing from the SSRF literature is a compilation of the reasons why patients underwent "late" surgery. Injury severity represents one such reason; however, surgeon and operating room availability, competing operations, and patient preference may all also contribute. In the case of the latter, a comparison of early versus late SSRF would theoretically be less subject to selection bias by injury severity.

The median time from injury to SSRF in the aforementioned RCTs ranged from 2 to 7 days, making it difficult to extrapolate any information from these studies regarding the optimal timing of surgery. Furthermore, time to surgery was not an a priori outcome in any of these studies. To date, there have only been three studies looking specifically at timing of SSRF (Table 1) [33••, 34•••, 35••••]. The earliest of these studies was published in 2011 by Althausen and colleagues. This was a retrospective case–control study looking at 22 patients who underwent SSRF compared to a matched cohort of 28 patients managed by maximal medical therapy. All patients evaluated in the study had flail chest requiring supplemental oxygen; however, reasons for stratification of early versus late SSRF cohorts were not provided. They found that patients who underwent SSRF had a significantly decreased intensive care unit length of stay (7.59 vs. 9.68 days), decreased overall length of stay (11.9 vs 19 days), decreased ventilatory days (4.41 vs 9.68), fewer tracheostomies (13.64 vs 39.29%), decreased incidence of pneumonia (4.55 vs. 25%), a decreased need for reintubation (4.55 vs 17.86%), and a decreased home oxygen requirement (4.55 vs 17.86%). More importantly, they also found on regression analysis that there was a statistically significant positive correlation between earlier SSRF and decreased ICU stay, hospital length of stay, and days of ventilatory support. The study was limited by a small sample size and its retrospective nature; however, it provided valuable insight and support for early SSRF [34•••].

The second study by Iqbal and colleagues was also a retrospective analysis of 102 patients who underwent SSRF and compared outcomes in those patients who underwent SSRF before and after 48 h from the time of injury.

Table 1 Studies addressing timing of SSRF

Author	Type	Study size	Timing	Major findings
Althausen et al. [34•••]	Retrospective case control	22	1–5 days	Decreased ICU and hospital LOS, decreased vent days correlated with earlier SSRF
Iqbal et al. [35••••]	Retrospective review	102	0–16 days	Compared outcomes of SSRF in < 48-h and > 48-h groups. Earlier SSRF had shorter ICU and hospital LOS, decreased vent days, less pneumonia, and decreased tracheostomy rate.
Pieracci et al. [33]	Multi-institutional retrospective review	551	0–10 days	Compared outcomes of SSRF in early (< 24 h), mid- (24-48 h), and late (> 48 h) groups. Early group had decreased pneumonia and shorter vent days. SSRF delay of 1 day increased pneumonia rate by 31%

Patients who had greater than 3 displaced rib fractures, flail chest, chest wall deformity, ineffective analgesic therapy, hemopneumothorax, or increased ventilatory support with concomitant rib fractures were evaluated for SSRF. A multidisciplinary team decided if patients should undergo SSRF and they aimed to perform the procedure as soon as possible after operative intervention was deemed appropriate. They found that patients who underwent earlier SSRF had a shorter duration of stay (11.5 vs. 17.3 days), a shorter ICU length of stay (3.3 vs. 7.1 days), decreased ventilatory days (2 vs 4.8 days), less pneumonia (17 vs 49%), and a decreased tracheostomy rate (6 vs 22%). Importantly, all-cause mortality in their study was not different between the two groups [35••••].

The final study, published by the authors, was a multicenter retrospective analysis of prospectively collected databases of patients who underwent SSRF at four major trauma centers in the United States [33]. This study analyzed the results of 551 patients between 2006 and 2016 who underwent SSRF and divided them into 3 groups based on the timing of their operative intervention—early (day 0), mid (days 1–2), and late (days 3–10). They found that time to surgery was significantly associated with the study site, year of surgery, age, body mass index, and mechanism of injury. Patients who underwent SSRF earlier in the analyzed time period tended to stratify to the late group indicating a significant trend towards earlier operative intervention. On univariate analysis, it was found that those patients who underwent earlier SSRF had a significantly decreased intensive care unit and hospital length of stay as well as decreased need for prolonged mechanical ventilation (> 24 h). Multivariate logistic regression also revealed that patients who underwent early SSRF had a significantly decreased rate of pneumonia and prolonged mechanical ventilation. Each day of prolonged SSRF was associated with a 31% increase in likelihood of pneumonia, a 27% increase in likelihood of prolonged mechanical ventilation, and a 26% increase in likelihood of tracheostomy [33].

Recent practice management guidelines for SSRF have been published by both the Chest Wall Injury Society and EAST [18, 19]. Both guidelines advocate for early operative fixation (within 72 h once other life-threatening injuries have been addressed) in order to theoretically decrease need for mechanical ventilation, ICU and hospital length of stay, incidence of pneumonia, and need for tracheostomy.

Delayed SSRF for Nonunion

The majority of rib fractures undergo ossification and healing within 6 months depending on severity and location. When this process is delayed or absent, fractures are deemed to be in "nonunion." Risk factors for nonunion are believed to be smoking, use of steroids, use of nonsteroidal anti-inflammatory drugs, alcohol abuse, diabetes, malnutrition, and vitamin D deficiency [36]. Overall, fracture nonunion rates range between 5 and 10%. This concurs with findings from Marsico and colleagues who found a rate of 13% nonunion in an assessment of nonfixed fractures in patients who underwent SSRF [37]. While scant data are available on the natural history and rate of nonunion of rib fractures, there have been numerous publications of patients who underwent SSRF for chronic nonunion [22, 23, 38–45]. Patients typically experience localized, persistent, and reproducible pain with an associated "clicking" sensation over the affected rib during activity [19]. These findings are supplemented by radiographic evidence of nonunion on CT. Based on these published reports, SSRF has been found to be an effective treatment modality. Prior to operative intervention, patients should have undergone physical therapy and maximal medical therapy. Preoperative counseling and addressing postoperative expectations regarding possible persistent pain is imperative. Operations were found to be safe with

Table 2 Contra-indications to early SSRF

1.	Hemodynamic instability
2.	Other high-priority injuries (e.g., spine fractures)[a]
3.	Intra-cranial hypertension
4.	Severe traumatic brain injury requiring prolonged ventilatory support
5.	Inability to properly position patient (e.g., open abdomen, pelvic fixator)
6.	Severe chest wall tissue loss

[a]The CWIS practice management guidelines advocate for a combined approach with a spine team in those patients with spine fractures that required operative fixation

patients reports improved pain scores and follow-up radiography showing complete healing in all patients [19].

Author's Experience

Our practice pattern is derived from the study by the author and includes early fixation, ideally within 24 h of injury if there are not contra-indications to early SSRF (Table 2). In fact, several of our patients with isolated, displaced rib fractures have been transported directly from the emergency department to the operating room for SSRF following their CT scans. This is dependent the availability of surgeons with operative expertise in rib fixation. Presumed additional benefits of early stabilization also include hemothorax evacuation. We routinely perform a bronchoscopy, pleural "washout" via a video-assisted thoracoscopic approach and injection of intrathoracic extended release local anesthetic. Our belief is that performing these adjunctive maneuvers will positively impact the patients' recovery and perhaps advert development of pneumonia and further respiratory failure. Anecdotally, we have found benefit to performing SSRF in patients up to 11 days from injury in whom such severe fractures exist, whose inability to wean pain medication leads to prolonged hospitalization. These cases are technically more challenging due to the development of ossification and scarring at the fracture site. While not common, there may be some benefit to stabilizing these fractures in the properly selected symptomatic patient.

Incidentally, we have also noticed patients with severe nondisplaced rib fractures who initially were not deemed to be candidates for rib fixation develop an interval displacement along the fracture line and thus increased chest wall instability (Fig. 1). We have found that this is commonly discovered in patients with multiple rib fractures by comparing sequential chest x-rays. A repeat a chest CT scan is usually obtained to quantify the newly discovered displacement and guide operative therapy. In cases such as these, we offer SSRF to be done as early as possible given the above parameters (Fig. 2).

Conclusion

Despite wide variability in practice patterns, new and increasing amounts of data are beginning to support early (within 72 h) SSRF in properly selected candidates as compared to salvage rib fixation. However, these data must be interpreted with caution and with attention to potential

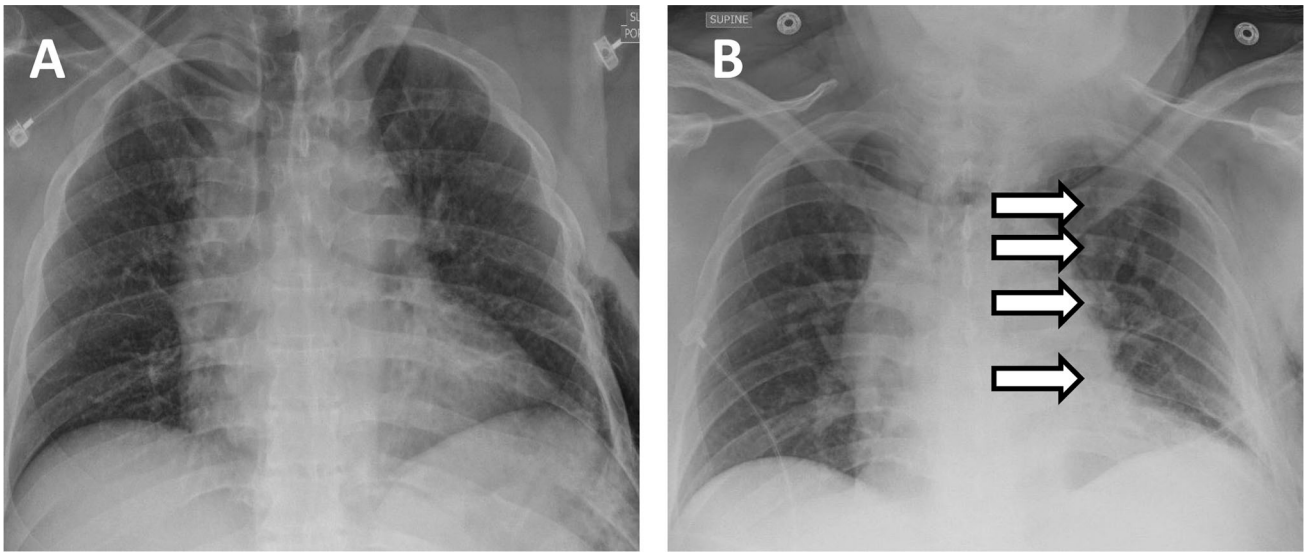

Fig. 1 Initial chest x-ray of a 55-year-old male who sustained left 4–9 rib fractures which were initially nondisplaced (**a**). Chest x-ray of the same patient 24 h post admission to the ICU (**b**). Arrows indicated the interval displacement

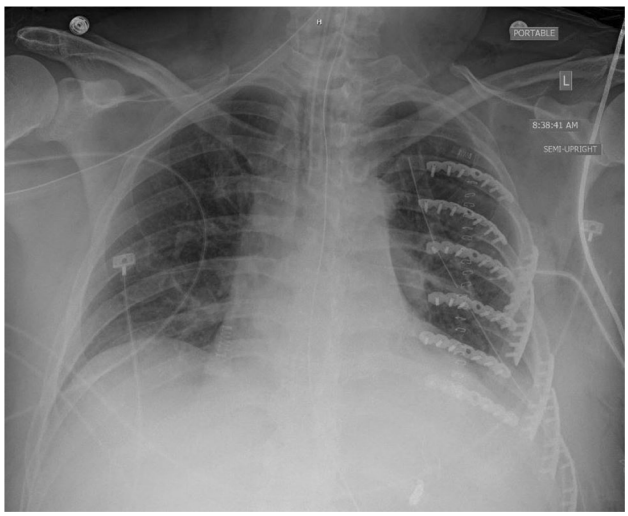

Fig. 2 continued

selection and attrition bias. Our own practice aims to perform the surgery as soon as possible and, ideally, within the first 24 h of injury. Delayed fixation (months to years after injury) should be performed only in highly selected cases, with the most important factor prognostic factor being a "clicking" sensation experienced either by the patient or elicited on physical exam, along with radiographic evidence of nonunion. The exponential increase in the number of SSRF cases being performed should afford the opportunity to perform large-scale outcomes analyses of the relationship between timing of surgery and both acute and long-term outcomes.

Compliance with Ethical Guidelines

Conflict of interest Michal Radomski declares no potential conflicts of interest. Fredric Pieracci is a paid educator and has received research funding from DePuy Synthes.

Human and Animal Rights This article does not contain any studies with human or animal subjects performed by any of the authors.

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