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Current Status of Rib Plating: Hardware Failure When and How?

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Abstract
Purpose of Review Surgical stabilization of rib fractures (SSRF) has been shown to decrease morbidity and mortality in patients with multiple rib fractures. This has led to a concomitant increase in the procedure, but the complications are just now being described in the literature. The purpose of this review is to focus on the current understanding of hardware failure after rib fixation.
Recent Findings A recent study from the Chest Wall Injury Society (CWIS) found that hardware failure is relatively rare and often asymptomatic thus not requiring routine postoperative imaging or reoperation. When hardware failures occur, they tend to occur on the lateral and posterolateral columns. Patients who undergo fixation for chronic fractures may be at higher risk for complications.
Summary Hardware failure is a rare complication of SSRF and rarely requires reoperation. Postoperative imaging should be based on symptoms.

Keywords Surgical stabilization of rib fractures · Rib plating · Hardware failure · Flail chest · Flail segment

Introduction

Chest wall injury is extremely common resulting in roughly 200,000 admissions per year [1, 2]. Rib fractures result in extreme pain, difficulty breathing, decreased secretion mobilization, and, in very severe cases such as flail chest, inherent chest wall/bellows failure. The sequelae of this injury pattern vary greatly but these patients can develop hypoventilation and require prolonged mechanical ventilation with associated nosocomial pneumonia.

The vast majority of rib fractures are treated non-operatively with aggressive pain control and early mobilization. Current pharmacologic therapies include NSAIDs, acetaminophen, ketamine and lidocaine infusions, gabapentinoids, opioids and local analgesia such as intercostal nerve blocks and axial anesthesia. Although multimodal combinations of these various modalities are helpful, patients with severely displaced fractures often have pain that remains refractory to medical management alone.

Rib fractures are commonly considered to be a benign injury, but the consequences can be severe. Bulger et al. showed that patients 65 years and older have twice the morbidity and mortality of those younger than 65 years old, and the mortality increases by nearly 20% for each additional rib fracture [3•]. These patients often require aggressive pain control and early mobilization to minimize morbidity and mortality. Patients with flail chest or multiple, displaced non-flail rib fractures benefit from SSRF as a means to optimize pain control and chest wall function [4•].

These patients with flail chest and non-flail, multiple displaced rib fractures have been shown to have improved outcomes with SSRF and the incidence of this procedure has increased over 35% from 2007 to 2014 [5••, 6]. There has also been an increased usage in patients with multiple,

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displaced fractures and those who are unable to be weaned from mechanical ventilation. Indications for SSRF remain controversial, particularly in patients without flail chest injury. Similarly, there is no universal agreement on which ribs and how many fracture segments should be repaired in patients undergoing SSRF. It is generally agreed that the first two ribs do not significantly contribute to respiration and exposure for repair is challenging. Ribs eleven and twelve are also generally not repaired for similar reasons. In a study of 156 patients undergoing rib plating, there was a Gaussian distribution of the fractures that were plated with the apex at the sixth rib and most authors agree that repairing fractures on ribs 4–8 confers the most benefit [7].

While this has led to an increased understanding of indications of SSRF, questions remain regarding the complications of this procedure, particularly infection and hardware failure. This review will summarize the current literature on SSRF and complications thereof.

Complications of Rib Fixation

Bone Failure

As with any surgical intervention, surgical stabilization of rib fractures (SSRF) is not without its complications. Ribs are classified as membranous bones with a thin layer of cortex and soft marrow that allows for maximum elastic bending. The cortex should not be used as a lever to reduce the fracture. Doing so risks creating a new fracture line. As well, the angle of curvature of the rib varies depending on rib number and which area of the rib is undergoing fixation. Because of this, implanted hardware should be contoured to sit comfortably against the bone lest a periprosthetic fracture occur at points where the plate is anchored to the bone.

Hardware Failure

Because of the inherent difficulties in the surgical management of rib fractures, multiple techniques have been developed. These include the placement of titanium plates with locking screws, cerclage wires, intramedullary fixation, and the Judet strut. Although there are no head-to-head studies comparing outcomes among various systems, most authors recommend against cerclage wires, intramedullary fixation, and the Judet strut. As such, the most commonly utilized SSRF systems utilize a titanium, low-profile, malleable plate that is secured in place with locking screws.

Variations in system design that may impact the probability of failure of fixation of a plate to the bone include the type of plate implanted (U-plate vs anterior plate) and type of screw fixation used (bicortical vs unicortical). Theoretically, a U-plate design with a bicortical, locking screw should provide the most stable fixation, but this may also result in the most rigid construct. As well, unicortical fixation of an anterior plate may have the most ability to move with the ribs (thereby lessening pain and a sense of "stiffness") but may be most likely to dislodge, especially in osteoporotic bone. However, because there are no studies comparing these systems against one another, all of these concerns remain theoretical. Aside from method of fixation, currently available plates also differ in terms of density and ability to withstand sheer stress. Engineering models upon which these systems are based utilize cadaveric bone or synthetic materials designed to replicate ribs and then subject the plate to thousands of cycles of force to emulate movement and stress associated with breathing. However, this design is artificial at best since the forces of breathing differ based on the degree of physical activity (resting v exercise) and state of health (coughing v breathing comfortably). Thus, there are no clinically applicable studies which can be used to select one system over the other or that can be used to suggest needed modifications to currently available systems.

Unsurprisingly, there are differing rates of hardware failure depending on the type of system utilized. Marasco et al. studied failure rates in absorbable plates [8]. They found that of 44 plated ribs, there were 10 failures (23%). Notably all 4 posterior plates had failed and 6 of 36 lateral plates had failed. This is likely due to the inherently weaker nature of these plating systems over time. Marasco also investigated outcomes in intramedullary fixation of rib fractures [9]. This cohort included 15 patients with 35 splints and follow-up at 3 and 6 months. There were no hardware failure events but 2 patients (6%) did have failures at the rib/splint interface requiring explantation of the hardware. Another system, MatrixRIB implant, was studied by Bottlang et al. [10]. The study group included 19 patients of which included 91 plates, 15 splints, and 605 screws. They describe no hardware failures at 6-months and 1 wound infection requiring explantation.

Nirula et al. performed a large-scale review of SSRF studies from 1975 [11]. In this series, a total of 704 SSRF were examined. General complications, including 14 superficial wound infections (2%), 4 chronic wound drainages without infection (0.6%), 2 pleural empyema (0.3%), 1 hematoma, and 1 persistent pleural effusion, are rare. Fixation failures, which include plate loosening, wire migration or fracture nonunion, also represented a small number of cases. Nirula et al. also describes the incidence of plate loosening or wire migration in 9 patients (1.3%). Additionally, 9 patients (1.3%) required plate removal due to postoperative chest wall stiffness, rigidity or pain. There was also one case of rib osteomyelitis due to

Staphylococcus aureus that was attributed to contamination from a preoperative chest tube. It is important to note that SSRF systems used today differ significantly from those used in the past, particularly regarding thickness and rigidity.

Most recently, a multinational retrospective study sponsored by the Chest Wall Injury Society analyzed the outcomes of SSRF from 2010 to 2017 [12•]. This study included 1,224 patients, which represents a much larger sample size than previous reports and highlights the increased use of this technique. A total of 38 patients, involving 233 rib fractures in 279 distinct fracture segments, met criteria for having hardware failure, defined as migration of implanted hardware or fracture of the implanted plates. The 3% incidence of hardware failure noted demonstrates that this is still a rare event.

In this data set, forty percent of patients with hardware failure were asymptomatic. The failed hardware was only detected on routine chest x-ray. Surgeon preference dictated if postoperative images are obtained, and it is likely that the incidence of failure was under-appreciated. However, assuming that the incidence of symptomatic failure would be unchanged (since symptomatic patients would most likely get an X-ray), this study suggests that routine postoperative imaging may not be necessary. Ongoing pain (42%) and persistent clicking while breathing or coughing (13%) were the two most common presenting signs of hardware failure with infection only representing 8%. Of all the cases of hardware failure, 55% required explant of the hardware with only 10% of patients requiring subsequent reimplantation of hardware. This suggests that despite the hardware failure, the majority of fractures had healed.

According to location, posterolateral rib fractures and lateral rib fractures had the highest numbers of fixation failures of 58% and 42%, respectively, while anterior rib fractures had the lowest at 13%. This failure rate is may be because rib fractures are most common in the lateral region of the rib cage and/or because the rib cage moves the most in this area, thereby putting stress on the implanted hardware.

The mechanism by which hardware was noted to fail in this study is also noteworthy. The incidence of screw migration and plate fracture was nearly equal, and both were almost double the rate of plate migration. From a technical standpoint, screw migration should be a very rare event since the screws and plates are designed to fit together and lock. This observation suggests that the screws and plates were not properly tightened, lending itself to the possibility of technical error.

It is more curious that plate fractures occurred at similar rates to screw migrations. Many of the principles of rib plating have been extrapolated from orthopedic practice. It is known that metal fatigue and fracture will result if a large gap across a fracture line is traversed. Plates should not be placed across a gap that exceeds 1 cm and typically at least 2.5 cm of healthy bone is required to fixate the plate [13]. Violating these principles causes the plate to bear the full stress across the defect and can result in metal fatigue due to the constant movement of the chest wall. Billé et al. first showed this in 2012 after multiple events of hardware failure occurred with large defects in the chest wall [14]. In 2016, Sawan et al. describe a case report in which a patient underwent multiple rounds of SSRF with multiple episodes of hardware failure due to a large chest wall defect [15]. During each reoperation, the fractured hardware was removed, autologous bone grafts were placed, as well as new hardware. Each rib that had a hardware fracture healed without complication after bone grafting and replacement of the implant. This strategy is appealing for those patients with large chest wall defects and should be considered during the initial surgery in those with large chest wall defects. Ultimately, one must remember the orthopedic principle that the implanted hardware should be "load sharing, not load bearing".

Hardware Infection

Infection is always a concern with implantation of any synthetic product into the body. There have been several case series of this complication in the setting of SSRF with hardware infections having a range of 0–10%. When infection of implanted hardware occurs, the standard of care is explantation of the foreign material and temporary stabilization of the fracture segment (often externally) to allow the bone to heal while decreasing the bacterial load. Unfortunately, the latter is not possible for ribs due to constant movement of the chest wall.

Thiels et al. examined 122 patients who underwent SSRF from 2009 to 2014 [16]. Of this cohort, there were 5 patients (4.1%) who were found to have hardware infection. The hardware infections on average were diagnosed on postoperative day 12, required 2–3 returns to the operating room, and one patient had hardware explantation during the initial hospital stay. The remainder of the patients underwent wound debridement/irrigation, negative pressure wound therapy, as well as placement of antibiotic beads. This treatment algorithm is novel in that the hardware is left in place until there is fracture union. The authors recommend that if hardware is removed early, it should be partially removal. Unfortunately, the authors did not describe which portion of the hardware should be removed specifically regarding the portions traversing the fracture and how the remaining plates are anchored.

In 2018, Junker et al. performed a follow-up study of 285 patients who underwent SSRF [17]. Of this cohort,

there were 10 patients (3.5%) who developed hardware infection. Risk factors for development of infection included the following: chest wall lacerations that were in close proximity to the SSRF surgical site, pre-hospital tube thoracostomy, pre-operatively diagnosed pneumonia, hemorrhagic shock, and increasing BMI—with the last 2 factors being statistically significant. The authors proposed an algorithm which depended mainly on use of antibiotic beads and negative pressure therapy as an attempt to salvage the hardware prior to hardware removal. The patients with diagnosed hardware infection tolerated the antibiotic bead placement well and had a median of 182 days (range 97–190) until hardware removal. Although this algorithm has shown promising results for patients with hardware infection after SSRF, it needs to be validated using a prospective, appropriately powered study design.

Recently, there have been 2 case reports of successful SSRF in a known infected field. In each instance, SSRF was done due to inability to extubate the patient due to flail chest injury. Ju et al. described a case where SSRF was performed in the setting of *C. albicans* colonization of the pleural space and mediastinum [18]. Once the procedure was performed, the patient's narcotic requirement decreased quickly, and the patient was weaned from the ventilator in less than a week. The patient completed a 28-day course of antifungal therapy and there were no complications from the procedure. Allen et al. describe a similar situation in which SSRF was performed in the setting of empyema [19]. The patient had initially been admitted with diaphragmatic and gastric rupture secondary to blunt trauma as well as left flail chest. The patient developed a left empyema requiring a decortication on hospital day 7. After multiple failed attempts at weaning the ventilator, she was taken for SSRF on hospital day 19. Intraoperative cultures isolated multiple bacteria and a biofilm was present at the time that hardware was implanted. The patient was successfully extubated 9 days thereafter. The patient completed a 2-month course of antibiotics and had no complications from SSRF. Hardware did not have to be explanted in either case. Both case reports identify an area of opportunity for SSRF that should be further studied.

Taken in amalgam, it appears that hardware is more likely to become infected due to subcutaneous infection/surgical site infection as opposed to being seeded from an internal source, such as pneumonia. However, this statement is based on the very few, low-quality studies noted above and should not be taken to assume that implantation of hardware into a known infected field is safe in all instances. Until better quality studies are available, SSRF should be avoided in infected fields unless the benefits are truly felt to outweigh the risks.

Conclusion

Rib fractures are a common injury pattern among trauma patients. SSRF has been shown to be efficacious and beneficial in select patients. Recent data regarding hardware failure show that it is a rare complication which rarely requires reintervention. The risk of hardware infection following SSRF in a contaminated or colonized wound has yet to be fully determined but preliminary studies that this may be safe in select cases. Overall, it appears that SSRF is a safe procedure.

Compliance with Ethical Standards

Conflict of interest Dr. Babak Sarani serves as a consultant for Acute Innovations, LLC. The other authors do not have any conflicts of interest to declare.

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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