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REVIEW ARTICLE

Surgical Stabilization of Rib Fractures: A Review of the Indications, Technique, and Outcomes

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ABSTRACT

Rib Fractures are a common injury in trauma patients and affect 10% of all injured patients who require admission to the hospital. Currently, there is no consensus on the most efficacious treatment for rib fractures with the debate comparing non-surgical versus surgical management. Medical management of rib fractures often requires admission to the intensive care unit with a focus on pain control to allow good pulmonary hygiene. Pain control involved a multimodal approach with current techniques including epidural anesthesia and paravertebral blocks. Although many patients recover with medical management alone, some patients may benefit from surgical stabilization of rib fractures as a means of augmenting pain control. Flail chest is the most evidence-based indication for surgical stabilization of rib fractures SSRF with many studies showing decreased days on mechanical ventilation, risk of pneumonia, intensive care unit length of stay, and hospital length of stay. Additionally, in patients with non-flail chest and ventilator dependent respiratory failure, surgical stabilization of rib fractures may provide an advantage over medical management for pain control. There are relatively few contraindications and complications associated with surgical stabilization of rib fractures. Therefore, with proper patient selection, surgical stabilization of rib fractures can improve outcomes in patients with rib fractures. Medical management with or without surgical intervention requires a multidisciplinary approach to prevent adverse clinical outcomes.

Keywords: Surgical stabilization of rib fractures, rib plating, rib fracture, flail chest, non-flail chest

Introduction

Rib fracture is one of the most common forms of chest injury in trauma patients. Approximately 400,000 patients sustain a rib fracture annually and 10% of all injured patients requiring admission to the hospital have rib fractures [1-4]. Despite the high frequency of rib fractures injuries, consensus on the most efficacious treatment is yet to be reached, and the debate between operative and non-operative management of such injuries remains ongoing.

Surgical stabilization of rib fractures (SSRF) has fluctuated in popularity ever since first gaining attention in the 1950s[5]. The modern era of SSRF emerged following the publication of the first SSRF randomized controlled trial (RCT), which demonstrated benefit in those undergoing operation, in 2002[6]. Since Tanaka et al.'s seminal work, the technology and research surrounding SSRF have undergone a renaissance, catapulting the interest in the operative management of rib fractures to unprecedented heights [7]. This renewed interest has shown an eight-fold increase in the use of SSRF as treatments for flail chest from 2007-2014 and a rise in SSRF-related publications from five peer-reviewed articles in 2005 to 229 in 2019 [8]. Of note, some of the SSRF-related research is funded by manufacturing companies, leading to potential bias of the articles.

In 2016 surgeons from around the world gathered with the mission of furthering our understanding of both the operative and non-operative care of patients with chest wall injury. This, in turn, further propelled the interest surrounding the use of SSRF in the treatment of chest wall injury. Despite the increase interest in SSRF, this treatment modality remains under-utilized, especially in critically injured patients where the procedure may be most beneficial [4].

Scope

This review article is intended to serve as a comprehensive, evidenced-based resource for clinicians who diagnose and manage patient with rib fractures and practice SSRF. The goal of the author group was to provide a detailed review of the most recent evidence regarding SSRF, including its indications, technique, and outcomes. We also aimed to contextualize the use of SSRF in the management of critically ill and injured patients who have sustained rib fractures through the discussion of non-operative alternatives. The writing of this article was author-initiated and free of either industry support or involvement.

Triage of Patients with Rib Fracture

The first decision point in treating a patient with multiple rib fractures involves determining who needs to be admitted to the ICU. Admission to the ICU allows for more aggressive pulmonary hygiene and may allow for better pain control if some parenteral medications are restricted to use in this setting. However, over-triage can result in unnecessary cost and challenges with capacity management/bed allocation. Patients over the age of 65 with three or more rib fractures have been shown to have a decreased mortality rate if admitted to the ICU [9]. This may be due to heightened multidisciplinary approach to pain control and pulmonary hygiene in the ICU. Various scoring systems, such as the RibScore [10] and Chest Trauma Score [11] , may be useful in identifying patients at risk for respiratory failure due to broken ribs. Kyriakakis et al proposed an algorithm to guide triage and various interventions in patients with rib fractures [12].

Management of Patients with Rib Fractures

The main goal in treatment of patients with rib fractures is pain control. This is needed in order to maintain good pulmonary hygiene and minute ventilation. Inability to meet this objective can result in progressive hypercapnic respiratory failure and/or pneumonia – either of which can lead to acute respiratory failure, need for mechanical ventilation, and in some instances, death. Since pain occurs with each breath, rib fracture patients instinctively reduce their tidal volume and force of breathing in order to minimize pain. Pain management is important both for patients who are treated operative and non-operatively, to ensure good pulmonary hygiene and ventilation.

PAIN MANAGEMENT

Broadly speaking, pain control in rib fracture patients can be classified as either systemic or regional. Systemic therapy is the more often used modality in the management of rib fractures. Historically, this was most commonly done using opioids. Opioid use for pain control, particularly in patients with rib fractures, has been shown to have multiple negative side effects, including decreased respiratory drive and delirium [13]. Current practice for pain control following blunt chest injury and rib fracture aims to reduce the overall opioid requirement. A multi-modal approach to pain control has been shown to reduce opioid consumption without compromising patient comfort when compared to single agents [14-16]. Many commonly used analgesic medications have an opioid sparing effect, and although patients with

severe chest wall injury may ultimately require opioids, they should not be considered first-line agents. As such, an escalating strategy of multi-modal analgesia that holds opioids as a therapy of last resort is preferred. Medications such as around-the-clock acetaminophen, NSAIDs, ketamine, lidocaine, gabapentinoids and alpha-2- agonists can be used in order to minimize narcotic need [17-25].

Regional analgesia is an attractive option to provide pain relief in patients with rib fractures, as it allows for targeted anesthesia that reduces the need for opioids and their associated systemic side effects. Common, proven techniques for regional anesthesia in rib fracture patients include thoracic epidural anesthesia [26,27], as well as paravertebral [27] and intercostal nerve blocks [26]. Epidural analgesia is associated with lower mortality in both young adult and elderly patients and therefore is beneficial in a multimodal approach to pain management [28]. However, epidural analgesia (EA) may not be feasible in patients who sustained multi trauma due to its effect on blood pressure, anticoagulation relative contraindication, or contraindication in patients with thoracic spine injury. These limitations can be mitigated by the use other regional anesthetic techniques such as paravertebral blocks (PVB), which have little to no impact on blood pressure, minimize the risks associated with thecal sack puncture, and allow patients to be discharged with the catheter in place. Compared to epidural anesthesia, paravertebral blocks have no significant difference in degree of pain control when used in the management of rib fractures [29]. Use of either epidural or paravertebral blocks is associated with better outcomes compared to no regional anesthesia [29]. Recently, myofascial nerve blocks in the serratus anterior and erector spinae planes have been described as potential alternatives, however, such techniques are not commonly used and there is debate regarding their efficacy[25,29]. There are limited data comparing the use of Erector Spinae (ESP) blocks to epidural or paravertebral blocks for pain management in patients with rib fractures. Interest in the use of ESP blocks has grown over the last 5 years and multiple prospective studies are ongoing to determine the efficacy of this technique in pain management.

MULTIDISCIPLINARY CLINICAL APPROACH

Following the initial evaluation and resuscitation of the rib fracture patient, early and aggressive pain control combined with pulmonary toilet via respiratory therapy and nursing interventions are crucial to patients' recovery. Education provided by all clinicians on reasonable expectation during recovery, pain management, pulmonary toileting such as incentive spirometry, the importance of adequate cough, and mobilization is an important component of recovery from chest wall injury. Multidisciplinary efforts in a structured rib fracture clinical pathway incorporating the above interventions improve outcomes, by lowering ICU length of stay, hospital length of stay, pneumonia and mortality [28,30-33]. Often, this is best accomplished in an ICU setting in patients with multiple fractures. Around one million patients experience ICU-acquired weakness every year while on mechanical ventilation. Although there is no direct evidence to support early mobilization in rib fracture patients in the ICU, studies have shown that early mobilization may decrease the incidence of ICU-associated weakness and improve functional capacity for patients in the ICU [34]. A study by Berry et al. suggested that early exercise may decreased the length of hospital stay in those with acute respiratory failure [35]. These findings support the intervention and collaboration with Physical Therapy for patients in the ICU following rib fractures.

Surgical Stabilization of Rib Fractures.

INDICATIONS FOR SURGERY AND PATIENT SELECTION

Although the majority of patients with rib fractures recover with good pain management and pulmonary hygiene alone such as those described above, some patients benefit from SSRF. On top of the managements listed above, surgical stabilization of rib fractures should be thought about mainly as a means to augment pain control when medical measures alone do not suffice. Rarely, SSRF is indicated for true chest wall instability and loss of bellows function, but this is much rarer as compared to respiratory failure from inadequate pain control. Recent studies have identified several indications for which SSRF may offer significant benefit compared to non-operative management.

FLAIL CHEST

Flail chest, especially with concomitant respiratory failure, is the most evidence-based indication for SSRF, with multiple studies suggesting numerous benefits in this population. Three randomized trials [36-38], one controlled prospective trial [2], and multiple cohort studies [2,8,38-47] have found that patients with flail chest managed with SSRF experience decreased pain, shorter duration of mechanical ventilation (MVD), decreased incidence of pneumonia (PNA), decreased rates of tracheostomy, and a reduction in both ICU length of stay (ICU LOS) and hospital length of stay (HLOS). Additionally, SSRF was also found to confer a mortality benefit in the setting of flail chest as well

as overall reduction in the cost of care [38,39,48]. These outcomes have been verified by seven meta-analyses [49-54]. SSRF appears to be most beneficial in patients who require mechanical ventilation due to the chest wall injury. The criticisms of these studies, however, include the use of outdated fixation technology in some of the studies (as the timespan of the studies extends almost 30 years), unblinded study design, inconsistent pharmacotherapy for pain management in the control group, and lack of long-term follow up. Furthermore, such findings have not been uniform; two cohort studies found that SSRF in flail chest conferred either no benefit or resulted in both longer hospitalization and ventilator duration [55] [56]

NON-FLAIL CHEST

There were two clinical trials and one observational study that helped further our understanding of the effects of SSRF in non-flail chest. Pieracci et al. conducted a 2-year prospective, controlled clinical trial comparing the early outcomes of SSRF against optimal medical management in critically ill trauma patients with severe rib fractures. In their evaluation of 70 patients, they concluded that SSRF, as compared with medical management, was associated with 76% and 82% decreases in the likelihood of respiratory failure and tracheostomy, respectively. SSRF was also associated with 5-day decrease in duration of mechanical ventilation with significant improvement in spirometry readings among the non-intubated patients [2]. Pieracci built on these findings shortly after with a multicenter, RCT examining the effects of SSRF in 110 patients with $\geq$ 3 ipsilateral displaced rib fractures without flail chest. In this trial, Pieracci et al. concluded that SSRF performed within 72 hours improved the primary outcome of numeric pain score (NPS) at 2-week follow-up and, subsequently, was associated with a trend towards reduced narcotic consumption [8]. Lastly, Majercik et al. concluded that SSRF was associated with low rates of chest wall deformity and chronic pain as well as patient satisfaction with the procedure[57].

VENTILATOR-DEPENDENT RESPIRATORY FAILURE DUE TO CHEST WALL INJURY

Most recently, Dehghan et al. conducted a multicenter randomized controlled trial of 207 patients with both flail and non-flail chest. 108 patients received SSRF while the remaining 99 received non-operative management. This was the first study to show the advantage of SSRF as compared to non-operative treatment in patients with ventilator-dependent respiratory failure due to either flail or non-flail chest wall injury [4]. Ventilated patients had fewer ventilator dependent days and shorter HLOS with operative treatment. Additionally, this study found a statistically significant difference in mortality between the operative and non-operative group. Of note, patients were not differentiated based on flail and non-flail chest when they were randomized to the operative versus non-operative group.

CONTRAINDICATIONS TO SURGICAL STABILIZATION

There are relatively few contraindications to surgical stabilization of rib fractures. As with any operation, proper patient selection is necessary to have a favorable outcome. Patients with severe concomitant injuries or those cannot tolerate surgery due to physiologic compromise would not be a good candidate for SSRF. Previously, severe pulmonary contusion was a contraindication for SSRF. One study of 405 patients with multiple trauma injuries found no benefit to surgical stabilization when patients had pulmonary contusions. [40] Of the group that had pulmonary contusion, only two patients were able to be extubated early and they were found to have respiratory insufficiency due to chest wall instability. However, a recent study found that the presence of pulmonary contusions was not associated with worse SSRF outcomes [58]. Additionally, Van Wijck et al found that SSRF was associated with better outcomes for patients with mild to moderate pulmonary contusions. A key difference between these two studies is improved use of multimodal pain control in addition to SSRF in the more recent study.

Previously, traumatic brain injury (TBI) along with multiple rib fractures would have been a contraindication to SSRF [8]. However, recently a multicenter retrospective study examining the outcome of SSRF in TBI patient showed a benefit in SSRF for moderate to severe TBI patients. In a study by Prins et al. patients with TBI and flail or non-flail pattern rib fractures were evaluated for the outcome of mechanical ventilation-free days. Four hundred forty-nine patients were included, 228 of whom sustained a non-flail chest injury. Of the non-flail group, the odds of pneumonia were lower in patients who underwent SSRF with an odds ratio of 0.29. In the flail chest group, patients who had SSRF had a significantly shorter ICU length of stay by 2.96 days. There was no negative impact on neurological recovery in the SSRF group [47].

PROCEDURAL PLANNING AND TECHNIQUE

The imaging modality of choice for preprocedural planning is computed tomography (CT). Some centers process these digital imaging into 3D reconstruction which can aid decisions regarding operative approach. However, standard 2D axial imaging offers the most sensitive means to identify a fracture line and to determine degree of

displacement [59]. Typically, ribs 3 through 10 are considered for surgical stabilization. Fractures of ribs 1 and 2 are difficult to reach surgically, rarely cause ongoing pain, and therefore are often left without fixation. Additionally, fractures of ribs eleven and twelve do not require stabilization, as they do not play an important function in respiration. A fracture within 3 cm of the transverse process of the spine is also traditionally left without fixation because the fracture segment is stabilized by the paraspinous muscles and there is not enough landing zone to fixate the plate to the rib. However, a relatively new intrathoracic plating system may offer a means to stabilize this segment should the need to do so be present.

Timing of surgery is another important factor when considering SSRF. Intervention within 48 hours of injury is associated with better post-operative pain relief as well as shortened hospital LOS and ICU LOS. Multiple factors, including concomitant injury and patient stability, more pressing operative needs, and operating room and surgeon availability, weigh into the decision regarding timing for operation. However, timing to operation should not be delayed more than 24-36 hours based solely on attempts to manage patients medically, particularly in those who are ventilator dependent due to flail chest or severely displaced fractures.

The approach most often used for SSRF is an open/extrathoracic technique based on the rib plating systems that are widely available. This technique places the implanted hardware on the anterior (outer) aspect of the rib. Video-assisted thoracoscopic surgery (VATS) can also be utilized to help with fracture localization and evacuation of retained hemothorax[60]. Although less commonly utilized, an intrathoracic approach applies hardware to the inner aspect of the rib. This procedure is relatively new and is performed under thoracoscopic guidance, thereby usually requiring single lung ventilation. There are few studies on this technique, but it may be useful in select instances such as very posterior or anterior fractures, where an extrathoracic approach may be technically challenging and offers a more muscle sparing option for fracture fixation, in general [61]. One recent study found a decreased LOS and operative time for patients with intrathoracic plating compared with extrathoracic plating in two cohorts which were matched for injury severity [62].

Nearly all plating systems use titanium plates that are somewhat rigid, though not entirely inflexible to allow for chest wall movement with respiration. The fixation systems for ribs are designed to match the curvature of the ribs. There are many different plating systems but there are no comparative studies that can suggest the superiority of one system over another. The decision on which plating system is used is based mostly on surgeon preference. Depending on the system that is chosen, the surgeon will need to drill holes prior to fixation, unless the system uses self-tapping screws. Regardless, the surgeon will measure the thickness of the rib in order to determine screw length. If the screws are too short, the plate fixation will not be strong and can lead to plate/screw migration or poor healing. Additionally, if the screws are too long, they can cause injury to the lung. The points of fixation should be 2-3 cm away from the fracture line in healthy bone. There is one commercially available system that does not require screw fixation, but this system is the least commonly used system, likely has the highest failure rate, and is rarely used in the United States.

SURGICAL COMPLICATIONS

Overall, complications from surgical stabilization of rib fractures are uncommon. Similar to any operation and especially operations that involve hardware implantation, there is always concern for post-operative infection. Junker et al. reported an infection rate of 3.5% in a cohort of 285 patients that were included in the study over a 9-year period [63]. Based on a retrospective review by Thiels et al., the rate of hardware infection in a cohort of 122 patients was 4.1% [64]. Infection following SSRF usually presents with erythema, induration, and drainage at the incision site however, the presentation may be more inconspicuous. Increased pain or evidence of a systemic infection might be the only presenting symptoms. Hardware infection is usually treated with antibiotics and/or hardware removal. Overall, there is a relatively low infection rate following surgical stabilization of rib fractures [64]. There is no need for prolonged, prophylactic antibiotic treatment and standard practice is to provide perioperative coverage targeting gram positive organisms, as with any other orthopedic implant operation.

Hardware failure is another potential complication of rib fixation. A retrospective study that included over 1200 patients showed hardware failure in 3% of the patients, with the most common cause being screw migration or plate fracture [65]. Hardware failure most commonly presents in a delayed fashion, weeks to months following the operation. Managing a patient with a hardware failure complication may not be different from those without complications. The study found that an equal number of patients were asymptomatic following hardware failure as those who had ongoing pain or

clicking. Patients with symptomatic failure may benefit from hardware removal if the clinical symptoms do not resolve or greatly affect their quality of life. Regardless of hardware failure, there are concerns for chronic pain and irritation from the implant. The risk of hardware failure might be as low as 3 to 4% in patients with SSRF [65,66]. Beks et al. showed that 13% of patients with SSRF due to flail chest had their implant removed because of persistent irritation [67].

Infection of implanted plates from an intrathoracic source, such as pneumonia or empyema, is rare. Case reports suggest that SSRF can be safely carried out in patients with known pneumonia or empyema, although such procedures likely carry a higher risk of hardware seeding as compared to those without an intrapleural infection [68,69].

Post-operative management in the ICU setting

The main goal of SSRF is to manage pain to avoid the need for mechanical ventilation and to expedite throughput in the hospital. As such, post-operative management following surgical stabilization of rib fractures focuses on pain control, thoracostomy tube management and timely extubation, if patient was left intubated. In the setting of the ICU, pain management will be important in both the operative and non-operative patient. As in the non-operative patient, multi-modal pain control should be used in post-operative patients, including NSAIDs, acetaminophen, ketamine, muscle relaxants, and local anesthetic nerve blocks. Fixation of the rib fractures will result in significant, immediate pain relief but it will not obviate all pain. Patients who undergo SSRF within 72 hours of admission have significantly decreased pain at the 2-week follow-up when compared with medical management of rib fractures [70].

Mechanical ventilator weaning is another goal in the management of ICU patients with multiple rib fractures. The current studies uniformly demonstrate decreased mechanical ventilator duration as shown in a meta-analysis where SSRF is associated with a shorter duration of mechanical ventilation as compared to those treated medically [71]. One study compared the number of ventilator days, need for tracheostomy and rate of pneumonia between patients who underwent VATS and SSRF versus those that only underwent VATS. This showed that the total MVD and the need for tracheostomy were lower in the rib fixation cohort[72]. Based on studies performed to date, weaning from mechanical ventilation should be pursued quickly following SSRF.

Conclusions

Management of patients with severely broken ribs starts with triage to ensure appropriate use of ICU resources. A predetermined, multimodal pain control strategy is key in mitigating the risk of respiratory failure in this cohort. Patients who have ongoing severe pain precluding pulmonary hygiene or appropriate ventilation despite medical therapy should be considered for SSRF.

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