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Rib fixation for flail chest physiology and the facilitation of safe prone spinal surgery: illustrative case

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BACKGROUND Spine fractures are frequently associated with additional injuries in the trauma setting, with chest wall trauma being particularly common. Limited literature exists on the management of flail chest physiology with concurrent unstable spinal injury. The authors present a case in which flail chest physiology precluded safe prone surgery and after rib fixation the patient tolerated spinal fixation without further issue.

OBSERVATIONS Flail chest physiology can cause cardiovascular decompensation in the prone position. Stabilization of the chest wall addresses this instability allowing for safe prone spinal surgery.

LESSONS Chest wall fixation should be considered in select cases of flail chest physiology prior to stabilization of the spinal column in the prone position. Further research is necessary to identify patients that are at highest risk to not tolerate prone surgery.

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KEYWORDS spine surgery; trauma; prone; rib fracture; rib plating

Timing of spinal stabilization, particularly in the absence of neural element compression, favors earlier intervention.[1–8] Spine fractures are commonly associated with other injuries.[1,2,9] Medical stabilization is recommended prior to surgical stabilization.[4,10] A multidisciplinary approach between trauma surgeons, spine surgeons, and other specialists can help determine the appropriate timing of surgery.

Chest wall trauma is the third most common injury in trauma patients,[11] with rib fractures occurring in upwards of 10% of trauma admissions.[12] While most fractures may not pose a significant issue for spinal fixation, flail chest physiology can present a management dilemma. Found in 7% of patients with fib fractures, flail chest is defined as 3 or more consecutive ribs broken in at least 2 locations.[13–16] This also extends to 3 or more bilateral consecutive rib fractures, or 3 rib fractures in conjunction with a sternal fracture. These fracture patterns can produce chest wall instability that may result in asynchronous or paradoxical chest wall motion. Complications due to flail chest injuries include pneumonia, acute respiratory distress syndrome, pneumothorax, hemothorax, pulmonary contusion, chronic pain, chest wall deformity, and atelectasis.[13] The overall mortality rate for flail chest has been described with an incidence ranging from 10% to 36%.[15] Surgical stabilization of rib fractures (SSRF) has increased significantly over the past decade to restore the integrity of the chest wall and reverse the physiological changes of flail chest. SSRF of patients with these injuries has resulted in improvements in mortality, length of stay, and pulmonary complication rates.[17]

There is a paucity of literature regarding the management of flail chest in the setting of spine fractures.[18,19] Prone positioning in the setting of an unstable chest wall can increase intrathoracic pressure, ultimately compromising venous return, increasing intraoperative blood loss, and reducing cardiac output, creating an additional challenge for spine surgical repair. Pennington et al.[19] described utilizing the ventral aspect of a thoracolumbar sacral orthosis (TLSO) to place the patient prone and successfully complete spinal fixation in the setting of flail chest physiology. Separately, Alvi et al.[18] published the sole article assessing rib fixation in the setting of unstable spinal fractures. Here, we present a case of flail chest physiology associated with unstable

ABBREVIATIONS CT = computed tomography; EAST = Eastern Association for the Surgery of Trauma; ICU = intensive care unit; MRI = magnetic resonance imaging; NICE = National Institute for Health and Care Excellence; POD = postoperative day; SSRF = surgical stabilization of rib fractures; TLSO = thoracolumbar sacral orthosis.

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cervical and thoracic fractures that tolerated prone positioning only after rib fixation.

Illustrative Case

A 63-year-old male was evaluated in the emergency department after falling from a roof. He reported diffuse spine and chest wall pain. On initial neurosurgical evaluation the patient was C4 American Spinal Cord Injury Association Impairment Scale grade D, with arm weakness that was more pronounced distally, consistent with central cord. The patient had no deficits in the lower extremities or long tract signs. His body mass index was recorded as 30.6 kg/m^2. The primary survey was notable for the following injuries: C1 Jefferson fracture, C2 lamina fracture, left C5–7 lateral mass fractures, and T1 3-column injury (Fig. 1). Chest computed tomography (CT) revealed extensive bilateral anterior rib fractures (right 2–7, left 2–7), segmental fractures of the right 5th and 6th ribs with additional fractures in the lateral position, and a minimally displaced sternal body fracture (Fig. 2). This injury constellation resulted in a flail chest involving the right/left ribs and sternum. The patient was hemodynamically stable and initially maintaining adequate oxygenation on nasal cannula. Cervical magnetic resonance imaging (MRI) revealed punctate hemorrhages within the spinal cord at C3 and C4, apical, alar, and transverse ligamentous injury, T1–3 supraspinous and interspinous ligament injury (Fig. 1). He was admitted to the surgical trauma intensive care unit (ICU).

The patient was scheduled to undergo occipital-cervical-thoracic fusion the following day. His oxygen requirement gradually increased prior to surgery, requiring 50% F_{IO_2} on nonrebreather at 10 L/min. The patient was brought to the operating room and placed under general anesthesia. Next, the patient was placed in prone position, and shortly after he developed hemodynamic instability refractory to norepinephrine and epinephrine pressor therapy. The decision was made to place the patient supine and abort the spinal fixation; the patient's hemodynamic instability promptly resolved. The neurosurgery team notified the trauma surgery team who performed rib plating for fixation to stabilize the chest wall. Instrumented segments included right 5th and 6th ribs, the left 5th rib, and sternum, placing a right chest tube at the completion of surgery (Fig. 3). The patient remained intubated postoperatively and return to the intensive care unit. He was weaned off vasoactive medications on postoperative day (POD) 2 and on minimal ventilator settings by POD 3. On POD 3 he returned to the operating room with the neurosurgery team and successfully underwent occipital to T3 posterior surgical fusion without hemodynamic instability. He has not had any hardware complications from the SSRF. The patient ultimately was discharged to acute rehabilitation.

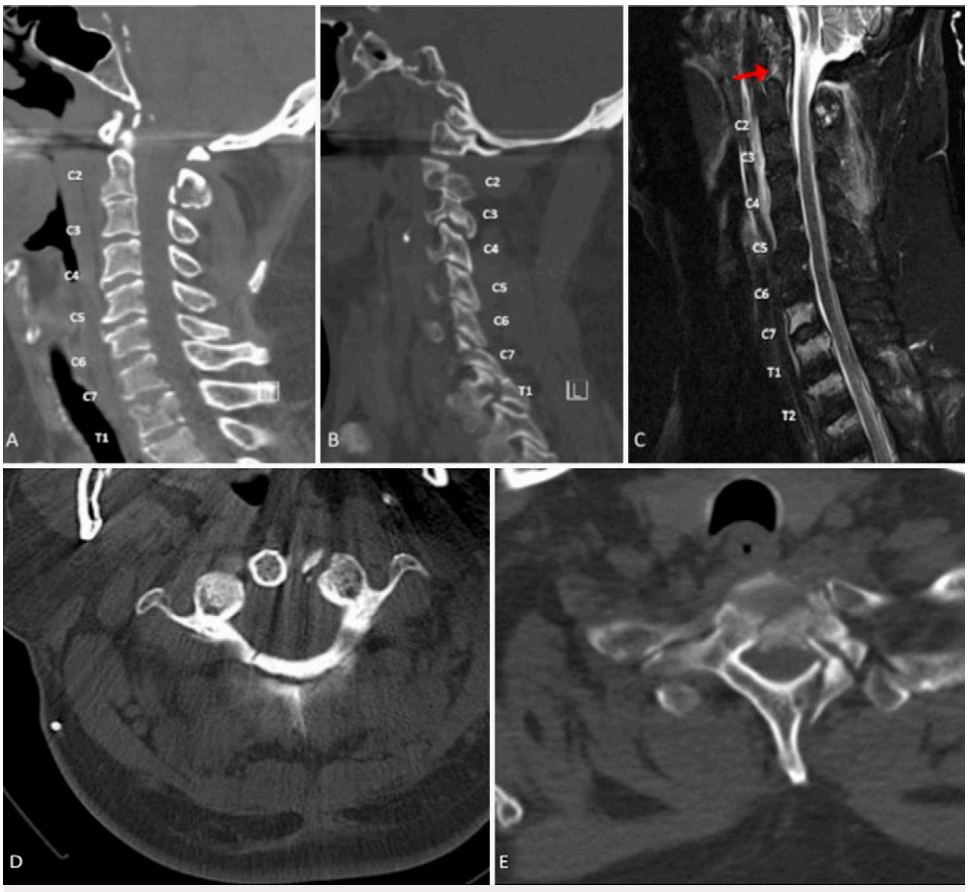

FIG. 1. A: Midsagittal CT showing C2 posterior arch disruption and comminuted T1 vertebral body. **B:** Left parasagittal view showing C3, C7, and T1 later mass fractures. **C:** Sagittal short tau inversion recovery (STIR) MRI showing increased signal within the transverse ligament. **D:** Axial CT demonstrating C1 Jefferson fracture. **E:** Axial CT demonstrating T1 comminuted vertebral body fracture with extension into the left pedicle and lamina.

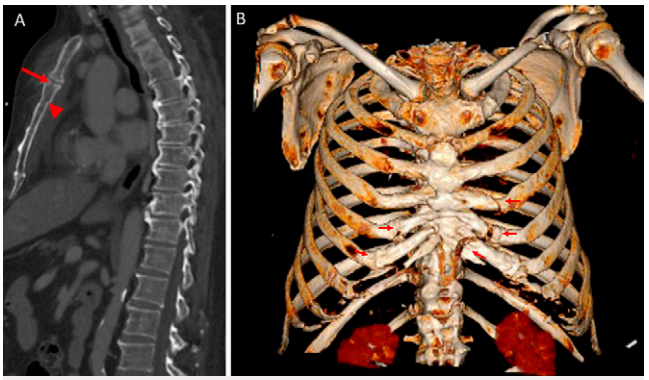

FIG. 2. A: Sagittal CT demonstrating sternal fracture (*arrow*) with subtle posterior displacement (*arrowhead*). **B:** Three-dimensional chest CT reconstruction showing numerous rib fractures. *Multiple arrows* highlight a subset of the patient's fractures.

Discussion

Surgical rib fixation is becoming increasingly popular given that early intervention is associated with shorter duration on the ventilator, shorter ICU stays, shorter overall length of stay, and lower rates of pneumonia and tracheostomies.[3,20–23] There are various cited indications for rib fixation.[14,24,25] Currently, Eastern Association for the Surgery of Trauma (EAST) and the National Institute for Health and Care Excellence (NICE) guidelines give a conditional or weak recommendation for rib fixation in the setting of flail chest. They note that additional and/or stronger recommendations cannot be made at this time.[26,27] Given multiple recent publications on the subject, the EAST guidelines are in revision.

Observations

It is typically recommended to perform fixation of the unstable spine prior to rib fixation, especially in the presence of incomplete spinal cord injury.[1,2,28–31] The decision of whether to perform rib or spinal fixation first is not well documented in the setting of flail chest injuries. Pennington et al.[19] published two cases of flail chest where patients were unable to tolerate the prone position. Both patients were later placed prone on a TLSO brace and were then able to tolerate posterior spinal instrumentation. Although this technique is viable, it does not address the flail chest beyond the operation. Additionally, an inflexible brace may alter patient positioning and spinal alignment creating added kyphosis that may be undesirable for spine fixation. Additionally, bracing in the prone position for prolonged periods of time intraoperatively predispose to pressure ulcers. In a series of 57 patients with unstable spinal fractures and concomitant segmental rib fractures, Alvi et al.[18] retrospectively evaluated outcomes of patients who underwent spinal fixation. In their study, 4 patients decompensated while being placed in the prone position for surgery. Seven patients underwent rib fixation, with only one undergoing rib fixation prior to spinal fixation, and this patient tolerated prone positioning without any significant events. Given their findings, the authors astutely advise careful consideration to rib fixation prior to spinal stabilization.

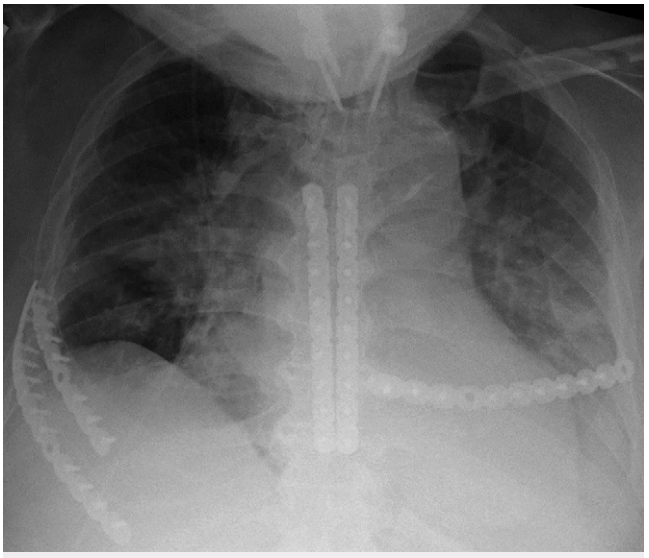

FIG. 3. Postoperative chest radiograph demonstrating rib fixation of the right 5th and 6th ribs, left 5th rib, and sternum.

In our case, the patient declined and became hemodynamically unstable once placed in the prone position before the surgical incision was made. Although flail chest physiology may be relatively rare, accounting for less than 5% of the patients in the cohort of Alvi et al.,[18] its consequences are severe and can be rapidly fatal. Our patient's decline is suspected to be secondary to increased intrathoracic pressure, right ventricular compression, and subsequent decreased venous return, which only improved upon return to the supine position. The decision of whether to treat the spine or the flail chest first remains unclear, due to a lack of literature on this subject. This is in large part due to considerable heterogeneity in the trauma population.[19,27] It is also unclear which patients would benefit most from rib fixation prior to surgery. We believe that spinal stabilization, especially in the setting of incomplete or progressive spinal cord injury, should not be delayed. However, in patients that are without impending neurological catastrophe, strong consideration of rib fixation first should be given.

Careful consideration of positioning should be discussed between the spine and trauma teams. Patient factors including body mass index and overall habitus must also be included, as this may further complicate positioning. SSRF often requires significant patient positioning that may not be feasible with an unstable spine fracture. Anterior/anterior lateral rib fractures as well as sternal fractures can be surgically stabilized in a supine position. Lateral and posterior-lateral fractures are best repaired through lateral positioning. Posterior rib fractures are often best repaired in a prone position. The location of the fractures must be considered in positioning and the risks of positioning for SSRF. It is the opinion of the authors that multiple anterior or anterior-lateral rib fractures bilaterally are the highest risk for the development of hemodynamic compromise with prone positioning. This is secondary to a loss of sternal wall integrity that is at greater risk the closer these fractures are to their sternal insertion. At this time, it remains unclear how to predict which patients will decline upon prone positioning.

Lessons

The interest in rib fixation has gained increased popularity due to favorable outcome data reported in the literature. Although many polytrauma patients with concomitant rib fractures and spinal fractures may safely undergo spinal fixation, a subset of patients may not tolerate surgical positioning. The primary limitation is identifying which patients are appropriate for rib stabilization prior to spinal surgery. Future studies are necessary to establish which subset of patients stand to improve with early intervention

and the correct order of surgical intervention. Here we demonstrate a case where surgical rib fixation for flail chest physiology allows for safe spine surgery. Accordingly, trauma and spine surgical teams should consider rib fixation prior to spine surgery in select cases particularly if the patient exhibits hemodynamic instability with prone positioning.

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Disclosures

Dr. Eriksson reported personal fees from DePuy Synthes outside the submitted work. Dr. Kalhorn reported personal fees from MUSC Zucker Institute (ZI) outside the submitted work; in addition, Dr. Kalhorn had a patent for WO2021041889A1 issued. No other disclosures were reported.

Author Contributions

Conception and design: all authors. Acquisition of data: Wessell, Pereira. Analysis and interpretation of data: Wessell, Pereira, Kalhorn. Drafting the article: Wessell, Pereira, Eriksson. Critically revising the article: Pereira, Eriksson, Kalhorn. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Wessell. Statistical analysis: Wessell. Study supervision: Kalhorn.

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