

Salvage of rib stabilization hardware with antibiotic beads[☆]Michelle S. Junker^{*}, Alex Kurjatko, Matthew C. Hernandez, Stephanie F. Heller, Brian D. Kim, Henry J. Schiller

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ABSTRACT

Background: Surgical stabilization of rib fractures (SSRF) can be used to improve pulmonary mechanics; however, hardware infection is a morbid complication. Antibiotic impregnated beads have been used to suppress infection in orthopedic practices. We aimed to determine the efficacy of antibiotic beads for infected and at-risk SSRF hardware.

Methods: This is a single institution retrospective review of adults (18 years or older) that received SSRF between 2009 and 2017. Infected and at-risk hardware were managed with antibiotic beads. The primary outcome was bony union of rib fractures.

Results: There were 285 SSRF patients. Infection rate was 3.5%. Antibiotic beads were placed in 17 patients – 9 for infected hardware and 8 for prophylaxis. Increased body mass index ($p=0.04$) and hemorrhagic shock at admission ($p=0.03$) were risk factors for infection. There was 100% bony union post-operatively.

Conclusion: SSRF hardware infection is morbid. Antibiotic beads can salvage SSRF hardware until bony union.

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Introduction

Approximately 10% of all patients that sustain blunt trauma will have rib fractures.¹ Due to pain and impaired pulmonary toilet, patients are at an increased risk of developing pneumonia and respiratory failure.² Surgical stabilization of rib fractures (SSRF) has been utilized in patients with flail segments, fracture nonunion, or pain which may exacerbate poor pulmonary hygiene.^{1,2} In select patients, SSRF has also been associated with reduced intensive care unit/hospital duration of stay, duration of mechanical ventilation, rates of pneumonia, and need for tracheostomy.^{1,3–8}

Although indications for SSRF are not uniform, this technique is being increasingly utilized. Implantation of SSRF hardware is not without risk. Development of hardware infection is a challenging

and morbid complication following SSRF. Typically, infection in the presence of a foreign body mandates removal, which in the setting of incompletely healed rib fractures may complicate pulmonary hygiene.⁹ In the field of orthopedic surgery, management of prosthetic joint infections incorporates the use of antibiotic-impregnated cement beads.^{10,11} These antibiotic beads provide sustained, locally high concentrations of antibiotics that cannot be achieved parenterally.¹² In accordance with this concept, antibiotic beads reduce bacterial burden and promote fracture union.

Previously, we demonstrated that in a single institution the SSRF hardware infection rate was 4.1%; however, the rates of successful bony union were not evaluated.¹³ We assessed the use of antibiotic beads in patients with SSRF hardware infections, hypothesizing that the addition antibiotic beads would suppress infection and permit bony union.

Methods

This was a single institution retrospective review and institutional review board approval was obtained prior to data collection. Consent was waived.

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Patient cohort

At the study institution, the SSRF technique was adopted in 2009.¹³ Indications for SSRF include presence of a flail segment defined as two or more adjacent ribs fractured in at least two separate locations, fracture displacement greater than or equal to one rib width, mobile rib fractures (i.e. “clicking”), poor respiratory function as demonstrated by progressive atelectasis on serial chest radiographs, and inadequate pain control refractory to multimodal therapy. Patients were identified from the electronic medical record. Those included were aged 18 years or older that also underwent SSRF for traumatic injuries from August 2009 to May 2017.

Operative management

The operative strategy was uniform and SSRF was routinely performed using a single thoracotomy incision. In rare cases, several small thoracotomies were used for multiple anterior fractures. The need for multiple incisions has diminished with the advent of the 90° drill and driver. Two SSRF systems were used in this study - MatrixRIB Fixation System (Synthes, West Chester, PA, USA) and RibLoc Rib Fracture Plating System (Acute Innovations, Hillsboro, OR, USA). The MatrixRIB system utilizes an anteriorly placed plate on the rib that spans the fracture site and secured in place with bicortical screws. The RibLoc system is comprised of a U-shaped plate that is affixed anteriorly and posteriorly with a bicortical screw.

Hardware Infection Management Algorithm

A previously described SSRF infected hardware management algorithm¹³ was used. Patients with deep space wound infection, exposed hardware due to wound dehiscence, abscess, soft tissue infection, or surgical site infection were managed with the algorithm. Initially, the infected wound was explored operatively and infection was confirmed by identifying purulence in proximity to the SSRF hardware, which was subsequently cultured. Debridement, irrigation, antibiotic bead implantation, and vacuum-assisted temporary closure were performed. Serial wound washouts and vacuum-assisted closure were repeated until the wound appeared grossly clean for delayed closure. At each washout, the antibiotic beads were exchanged for a new set in order to provide the highest concentration of antibiotic to the wound. In rare situations, antibiotic beads were exchanged when culture results provided specific bacterial antibiotic sensitivities. As the management utilizing the algorithm evolved, attempts to decrease the number of operations (serial washouts) were made by definitively closing the chest wall with antibiotic beads left in place, seen in Fig. 1. An incisional vacuum closure dressing was applied sterilely and superficial to the closed wound, not in communication with the thoracic cavity. This dressing does not affect antibiotic concentrations as it is not in communication with the deeper tissues, but rather, was utilized to promote more rapid epithelialization of the incision. Additionally, patients remained on suppressive systemic parenteral antibiotic therapy, often at the direction of the infectious disease specialists. This included initial therapy with IV antibiotics for a mean of 30 days, followed by oral therapy until hardware removal. After dismissal, patients were followed at regular intervals (1–3 months) with chest radiography and pulmonary function testing. Chest computed tomography (CT) was performed to demonstrate fracture healing, as evidenced by callus formation and to rule out radiographic evidence of persistent infection prior to consideration for antibiotic bead removal.

Once the patient no longer demonstrated evidence of infection, the hardware and antibiotic beads were removed at a single

operation and the wound closed primarily. This was performed either as an outpatient procedure or overnight observation, depending on the extent of dissection. A chest tube was placed only if the pleural cavity was violated during the bead and hardware removal. Both hardware and antibiotic beads were removed due to concern for delayed presentation of infection, as there are, as of yet, no effective methods to overcome bacterial biofilm adherent to rib plates.

Antibiotic bead implantation as a prophylactic strategy

Regarding SSRF hardware infection, several factors were considered to increase risk. These included patients who underwent prehospital chest tube placement that also traversed fracture segments, demonstrated a preoperative diagnosis of pneumonia, sustained soft tissue wounds in proximity to fractures, and/or required additional thoracotomy after SSRF. In patients with these risk factors, prophylactic antibiotic beads were placed at the time of SSRF in order to prevent future hardware infection. Conversely, these patients were not placed on suppressive parenteral or enteral antibiotics. Chest CT was performed at three months post-operatively to evaluate for fracture healing as evidenced by callus formation. Both hardware and antibiotic beads were subsequently removed after bony union was demonstrated as previously described.

Formation of antibiotic beads

Antibiotic beads were made at the time of implantation. The standard formulation requires a full-dose of polymethyl methacrylate (PMMA) bone cement (Surgical Simplex^R P, Howmedica Osteonics Corp, Mahwah, NJ), 2 g vancomycin powder, and 2.4 g gentamicin powder. After the bone cement polymerized, powdered antibiotics were added and mixed together. Beads were fashioned to an approximate diameter of 1.5–2 cm and strung on 0-prolene suture. The number of beads implanted depended on the size of the wound cavity, ensuring that beads were in proximity to all SSRF hardware.

Timing for antibiotic bead and hardware removal

Postoperatively, chest CT was performed at 3 months to assess for bony union. The timing was based upon anticipated length of time for expected bony union and literature proposing that PMMA beads can elute antibiotics for up to three months.^{10–12,14} Once the fracture callus was demonstrated, antibiotic bead removal was offered based on patient convenience.

Outcomes

The primary outcome in this study was demonstration of bony union. For patients who had antibiotic beads implanted for SSRF infection, secondary outcomes in this study included need for additional operations, hospital and ICU duration of stay, and duration of systemic antibiotic therapy.

Data abstraction

Data were abstracted from the electronic medical record. Demographics included age, sex, injury severity score (ISS), height (cm), weight (kg), and body mass index (BMI). Pre-existing medical conditions abstracted included history of asthma, chronic obstructive pulmonary disease (COPD), tobacco use, hypertension, diabetes mellitus, chronic kidney disease, chronic liver disease, and chronic immunosuppression (steroids, transplant, autoimmune

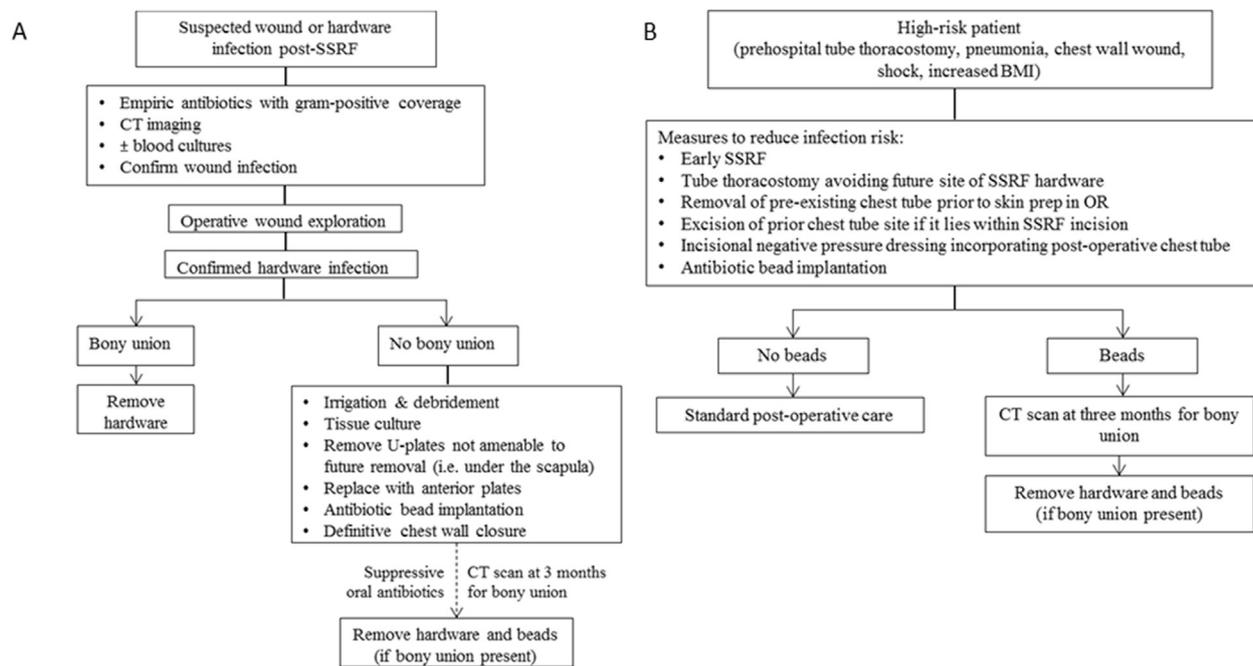


Fig. 1. Ssrf hardware infection management algorithm (A) and infection prophylaxis algorithm (B).

disease). The characteristics of the rib fractures were evaluated. The number of ribs fractured, total number of fractures, presence of flail segment (as diagnosed by two or more contiguous rib levels with fractures in two locations on computed tomography scan), concomitant scapula, spine, and/or clavicle fractures, pneumothorax, hemothorax, hemorrhagic shock (sustained systolic blood pressure <90 mmHg and/or massive blood transfusion) present on admission, blood transfusion requirement, and need for a chest tube, including timing of placement and whether it was placed in the pre-hospital setting, were collected. Additional data included chest tube duration post-SSRF, intensive care unit (ICU) and hospital duration of stay (days), duration of mechanical ventilation (days), need for tracheostomy, administration of intravenous (IV) and/or enteral antibiotics and duration of therapy (days), and sputum culture data. The dates of bead and hardware implantation and removal were also collected.

Statistical analysis

Three distinct comparisons were performed: patients with or without antibiotic beads, infected versus non-infected hardware, and prophylactically placed beads versus therapeutically placed beads. Normally distributed data were compared using Student's t-test and reported using mean with standard deviation (\pm SD). Data not normally distributed were analyzed using Wilcoxon nonparametric test and reported using medians with interquartile range [IQR]. Categorical data were analyzed using Fisher's exact test. Statistical significance was considered at $p < 0.05$.

Results

There were 285 patients who underwent Ssrf and the mean age was 61 ± 17 years. Sixty-eight percent of the population was male. Hypertension was the most frequent comorbidity ($n = 112$, 39%). Additional comorbidities are demonstrated in Table 1. Flail segment was common ($n = 177$, 62%) and pneumothorax was present in nearly two-thirds of patients ($n = 179$, 63%). One-hundred twelve

patients (39%) required tube thoracostomy prior to Ssrf, of which 27 (24%) were performed in the prehospital setting. The median tube thoracostomy dwell time prior to Ssrf was 1 [0–3] day. The duration of time from injury to Ssrf was 4 [2–5] days. Post-operatively, the median tube thoracostomy dwell time was 3 [2–4] days. Forty-seven patients were diagnosed with perioperative pneumonia. Mechanical ventilation was required in 41% of patients ($n = 146$) with a median of 2 [0–4] ventilator days. The overall duration of hospital stay was 10 [8–15] days and ICU duration of stay was 4 [0–8] days. In-hospital mortality was 1.8% ($n = 5$). Mortality was due to withdrawal of organ support in the setting of chronic respiratory failure ($n = 4$) and cerebrovascular accident ($n = 1$).

Table 2 compares patients that developed hardware infection ($n = 10$, 3.5%) and patients that did not ($n = 275$, 96.5%). Patients with an increased BMI were associated with a higher infection rate (34 ± 6 vs. 30 ± 6 , $p = 0.04$). The presence of hemorrhagic shock on admission was also more common in patients who developed Ssrf infection compared to those who did not ($n = 5$, 50% vs. $n = 50$, 18%, $p = 0.03$). In patients with Ssrf infection, the duration of ICU stay (8 [5–14] days vs. 4 [0–8], $p = 0.03$) and hospital stay (25 [10–37] days vs. 10 [8–15], $p = 0.01$) was prolonged compared to those without infection. There was no statistically significant difference in mortality between groups. The rate of pneumonia was higher in patients with hardware infection (40% vs. 16%, $p = 0.06$) but was not statistically significant. Culture data was available in 9 patients with an Ssrf infection. Organisms identified included: *Methicillin-sensitive Staphylococcus aureus*, *Methicillin-resistant Staphylococcus aureus*, *Methicillin-resistant Staphylococcus epidermidis*, *Finogoldia magna*, and *Enterococcus faecalis*.

Table 3 compares all patients that underwent placement of antibiotic beads ($n = 17$, 6%) with those that did not ($n = 268$, 94%), demonstrating that there were no considerable differences between patients that received antibiotic beads and those that did not. Table 4 compares receipt of antibiotic beads for prophylaxis ($n = 8$, 47%) and those placed for established infection ($n = 9$, 53%). Overall, there were no differences between each group. No patients

Table 1
Overall patient characteristics in those receiving surgical stabilization of rib fractures.

	SSRF Cohort (n = 285)
Patient Characteristics, n (%)	
Age	61 ± 17
Male	194 (68)
BMI	30 ± 6
Smoker	64 (23)
Asthma	42 (15)
COPD	33 (12)
Diabetes	41 (14)
Hypertension	112 (39)
CKD	20 (7)
CLD	12 (4)
Immunosuppression	19 (7)
Injury Characteristics	
ISS	17 (10–23)
# ribs fractured	7 (5–9)
# fractures	11 (7–15)
Flail segment, n (%)	177 (62)
Pneumothorax, n (%)	179 (63)
Hemothorax, n (%)	112 (39)
Scapula fracture, n (%)	49 (17)
Spine fracture, n (%)	102 (36)
Clavicle fracture, n (%)	57 (20)
Hemorrhagic shock, n (%)	55 (19)
Blood Transfusion, n (%)	113 (40)
Pre-OR intubation, n (%)	81 (28)
Chest tube characteristics	
Pre-hospital chest tube, n (%)	27 (9)
CT prior to SSRF, n (%)	112 (39)
CT pre-OR, days	1 (0–3)
SSRF characteristics	
Days to plating	4 (2–5)
# of ribs plated	5 (3–6)
# of plates	5 (4–7)
Chest tube, days	3 (2–4)
Pneumonia, n (%)	47 (16)
ICU LOS, days	4 (0–8)
Hospital LOS, days	10 (8–15)
Mechanical Ventilation, n (%)	146 (51)
Ventilator, days	2 (0–4)
Tracheostomy, n (%)	21 (7)
IV antibiotics, days	0 (0–4)
PO antibiotics, days	0 (0–0)
Mortality, n (%)	5 (1.8)

Injury Severity Score (ISS), Chronic Obstructive Pulmonary Disease (COPD), Chest Tube (CT), Surgical Stabilization of Rib Fractures (SSRF).

Values were expressed as medians with (IQR) and means ± SD unless specified.

developed *Clostridium difficile* infection related to antibiotic therapy. Five patients developed acute kidney injury (AKI). There was a 100% bony union rate during the follow up period for all patients receiving antibiotic beads.

In patients that received antibiotic beads placed for infection, the median number of washouts prior to delayed primary closure was 2.0. To date, seven patients have had both beads and hardware removed at a median of 182 days post SSRF, outlined in Table 5. Patients demonstrated rib fracture union on CT scan at a median of 96 days. Following bead and hardware removal, the median duration of stay was 3 [0–4] days. One patient required chest tube placement at the time of hardware removal. Two patients have hardware remaining in place - one patient lost to follow-up and the other is in the process of evaluation for hardware removal.

In the prophylactic antibiotic bead group, 5 patients have had both beads and hardware removed at a median of 167 (range: 110–213) days from SSRF. Patients demonstrated fracture healing on CT scan at a median of 126 days. Following bead and hardware removal, the median duration of stay was 1 [0–1] days. One patient required a chest tube post-operatively. Two patients have had their beads removed, but hardware remains in place secondary to

difficult access for removal (U-plates that are deep to the scapula). One patient preferentially elected to keep both beads and hardware in place. None of the patients with beads and/or hardware remaining in place experienced infectious related complications.

Discussion

Surgical stabilization of rib fractures, while not adopted universally, is increasingly practiced by surgeons. Despite considerable concern regarding benefits of the operation, the risk of hardware infection exists and these patients will require management. In patients who developed hardware infection, there was a statistically significant longer hospital and ICU duration of stay which highlights the morbidity of this complication. Since fracture non-union and infection are serious SSRF complications, this technique can be employed to minimize the need for SSRF hardware removal and achieve bony union with near perfect results at three months.

In patients without bony union, hardware removal results in poorer outcomes.⁹ Similarly, SSRF plate removal might result in non-union and destabilization of the chest wall. The present study demonstrates that antibiotic bead implantation in the setting of infection can be used to suppress infection which can permit bony union and salvage of the SSRF plate(s). Antibiotic beads provide increased local tissue concentrations beyond levels achievable with systemic antibiotics alone. Pharmacokinetic studies demonstrated that beads release antibiotics locally several months after implantation, with the highest concentrations achieved in the first few days.^{10–12,15,16} Gentamicin is typically utilized due to its gram positive and negative coverage, low rate of hypersensitivity, and rare bacterial resistance.^{14,16} The surface area and porosity of the bead determines the local concentration and duration that the antibiotic is released into the surrounding tissue.¹⁵ Several *in vitro* and *in vivo* models demonstrated improved bactericidal efficacy with systemic and local antibiotic therapy administration in comparison to either route alone to prevent infection for open fractures.^{16–19} Ostermann et al. found a statistically significant decrease in the infection rate from 12% to 3.7% for open fractures when both IV and local antibiotic therapy were utilized in comparison to IV antibiotic therapy alone.¹⁹ The safety of antibiotic impregnated beads also has been well described. Several *in vivo* models and clinical studies demonstrated that systemic levels of antibiotics did not achieve toxic levels.¹⁶ In our study, no patients demonstrated systemic effects related to the antibiotic beads. Additionally, during the follow-up period, all patients achieved bony union and did not experience any further infectious related complications.

Given the safety and efficacy of antibiotic beads and the associated morbidity of SSRF hardware infection (additional operations, prolonged hospital/ICU duration of stay, prolonged course of systemic antibiotics), we hypothesized that prophylactic antibiotic bead administration would be of benefit. We began to identify patients considered high risk based on clinical gestalt, with a focus on patients with open wounds that approximated the SSRF repair, pre-hospital tube thoracostomy, and pre-operatively diagnosed pneumonia. In this interim analysis, these risk factors did not demonstrate any correlative infection association in the prophylactic group. This was likely due to small sample size and the infrequency of infection. Increased patient BMI and the presence of hemorrhagic shock at admission, however, were the only factors associated with developing an infection. These risk factors have been previously demonstrated in several traumatically injured populations. As the data does not support utilization of prophylactic antibiotic beads in high risk patients, we plan to discontinue this practice with the exception of patients in whom hardware

Table 2
Comparison of patients with and without hardware infection.

	No Infection (n = 275)	Infection (n = 10)	p
Patient Characteristics, n (%)			
Age	61 ± 17	59 ± 17	0.65
Male gender	188 (68)	6 (60)	0.73
BMI	30 ± 6	34 ± 6	0.04
Smoker	64 (23)	0 (0)	0.12
Asthma	40 (15)	2 (20)	0.65
COPD	32 (12)	1 (10)	1.00
Diabetes	39 (14)	2 (20)	0.64
Hypertension	108 (39)	4 (40)	1.00
Chronic kidney disease	19 (17)	1 (10)	0.52
Chronic liver disease	11 (4)	1 (10)	0.35
Immunosuppression	19 (7)	0 (0)	1.00
Injury Characteristics			
ISS	17 (9–22)	21 (14–35)	0.13
# ribs fractured	7 (5–9)	7.5 (6–9)	0.85
# fractures	11 (7–15)	12 (9–16)	0.65
Flail segment, n (%)	169 (62)	8 (80)	0.33
Pneumothorax, n (%)	171 (62)	8 (80)	0.33
Hemothorax, n (%)	107 (39)	5 (50)	0.52
Scapula fracture, n (%)	46 (17)	3 (30)	0.38
Spine fracture, n (%)	98 (36)	4 (40)	0.75
Clavicle fracture, n (%)	55 (20)	2 (20)	1.00
Hemorrhagic shock, n (%)	50 (18)	5 (50)	0.03
Blood Transfusion, n (%)	108 (39)	5 (50)	0.53
Pre-OR intubation, n (%)	78 (28)	3 (30)	1.00
Chest tube characteristics			
Pre-hospital chest tube, n (%)	25 (9)	2 (20)	0.24
CT prior to SSRF, n (%)	107 (39)	5 (50)	0.52
CT pre-OR, days	1 (0–3)	3 (1–3)	0.19
SSRF characteristics			
Days to plating	4 (2–5)	3.5 (3–4)	0.82
# of ribs plated	5 (3–6)	4.5 (3–6)	0.78
# of plates	5 (4–7)	5 (4–7)	0.82
Chest tube, days	3 (2–4)	4 (3–7)	0.23
Pneumonia, n (%)	43 (16)	4 (40)	0.06
ICU LOS, days	4 (0–8)	8 (5–14)	0.03
Hospital LOS, days	10 (8–15)	25 (10–37)	0.01
Mechanical Ventilation, n (%)	139 (51)	7 (70)	0.34
Ventilator, days	2 (0–4)	2.5 (0–12)	0.19
Tracheostomy, n (%)	20 (7)	1 (10)	0.54
IV antibiotics, days	0 (0–4)	30 (10–39)	< 0.0001
PO antibiotics, days	0 (0–0)	61 (42–181)	< 0.0001
Mortality, n (%)	5 (1.8)	0 (0)	1.00

Injury Severity Score (ISS), Chronic Obstructive Pulmonary Disease (COPD), Chest Tube (CT), Surgical Stabilization of Rib Fractures (SSRF), Intensive Care Unit (ICU), Length of stay (LOS).

Values were expressed as medians with (IQR) and means ± SD unless specified.

infection would be a devastating complication (i.e. mechanical aortic valve).

While antibiotic beads have been integral to the management of hardware infection, we have also been conscientious about our SSRF plate selection. The rationale is the need to maintain awareness for the potential of future SSRF plate removal. Of the two systems utilized in this study, experience has shown that the U-shaped RibLoc plate is challenging to explant. The struts connecting the anterior and posterior portions of the U-plate tend to fracture during attempts at removal which requires the posterior portion be removed as a separate piece. While full removal of the system can be accomplished, there is concern about plate removal in areas where the superior edge of the rib cannot be visualized, such as deep to the scapula. To address these concerns, RibLoc U+ plates are modified by cutting off the struts to the posterior portion of the U-plate, thereby converting this to an anterior plate. With this modification, the RibLoc U+ system can still be utilized while affixing anterior plates. Since making this change, no hardware failures have occurred and the modified plates appear to be easier to remove. Regardless of the SSRF system utilized, surgeons who are performing SSRF should maintain caution and consider one's ability to safely remove hardware in the event of infection.

Early in this experience, the impression was that removal of previously infected hardware was well-tolerated with short hospital duration of stay (initially 0–2 days). Due to this observation, it was thought that the morbidity of hardware infection could be avoided by placement of prophylactic antibiotic beads. Later, experience with removal of infected hardware demonstrated longer hospital duration of stay (median 3 days), which was, in part, secondary to technically challenging hardware removal (U-plates deep to the scapula). Patients with prolonged hospital stay demonstrated persistent air leak from the chest tube, bleeding from the surgical site, and postoperative delirium. No patients required ICU level care. In contrast, hardware removal in prophylactic patients was associated with low morbidity and short hospital duration of stay (median 1 day). In these patients, it remains unclear if SSRF hardware removal was necessary, as no patients developed clinical infection. However, the procedure appeared to be well-tolerated with low morbidity and thus hardware removal was pursued.

We acknowledge several limitations in this work, foremost the single center retrospective review of a small patient cohort which demonstrated low incidence of hardware infection. This work also contains a selection bias with respect to the utilization of

Table 3
Comparison of patient characteristics receiving no beads versus beads.

	No Beads (n = 268)	Beads (n = 17)	p
Patient Characteristics, n (%)			
Age	60 ± 17	58 ± 13	0.46
Male gender	182 (68)	12 (71)	1.00
BMI	30 ± 6	31 ± 5	0.22
Smoker	61 (23)	3 (18)	0.77
Asthma	38 (14)	4 (24)	0.29
COPD	31 (12)	2 (12)	1.00
Diabetes	38 (14)	3 (18)	0.72
Hypertension	107 (40)	5 (29)	0.45
Chronic kidney disease	18 (7)	2 (12)	0.34
Chronic liver disease	10 (4)	2 (12)	0.16
Immunosuppression	18 (7)	1 (6)	1.00
Injury Characteristics			
ISS	17 (10–22)	17 (13–34)	0.24
# ribs fractured	7 (5–9)	7 (5–9)	0.96
# fractures	11 (7–16)	11 (5.5–14)	0.60
Flail segment, n (%)	168 (63)	9 (53)	0.45
Pneumothorax, n (%)	167 (62)	12 (71)	0.61
Hemothorax, n (%)	106 (40)	6 (35)	0.80
Scapula fracture, n (%)	47 (18)	2 (12)	0.75
Spine fracture, n (%)	95 (35)	7 (41)	0.61
Clavicle fracture, n (%)	54 (20)	3 (18)	1.00
Hemorrhagic shock, n (%)	48 (18)	8 (42)	0.03
Blood Transfusion, n (%)	102 (38)	11 (65)	0.04
Pre-OR intubation, n (%)	73 (27)	8 (47)	0.10
Chest tube characteristics			
Pre-hospital chest tube, n (%)	22 (8)	5 (29)	0.02
CT prior to SSRF, n (%)	103 (38)	9 (53)	0.31
CT pre-OR, days	1 (0–3)	3 (1–3.5)	0.04
SSRF characteristics			
Days to plating	4 (2–5)	4 (2.5–5)	0.78
# of ribs plated	5 (3–6)	4 (3–7)	0.76
# of plates	5 (4–7)	5 (3–7)	0.84
Chest tube, days	3 (2–4)	4 (2–5.5)	0.34
Pneumonia, n (%)	37 (14)	10 (59)	< 0.0001
ICU LOS, days	3 (0–8)	6 (5–14)	0.01
Hospital LOS, days	10 (8–14)	19 (10–31)	0.01
Mechanical Ventilation, n (%)	134 (50)	12 (71)	0.13
Ventilator, days	2 (0–3)	4 (0–12)	0.05
Tracheostomy, n (%)	18 (7)	3 (2)	0.12
IV antibiotics, days	0 (0–4)	9.5 (4–28)	< 0.0001
PO antibiotics, days	0 (0–0)	9 (0–61)	< 0.0001
Mortality, n (%)	5 (1.9)	0 (0)	1.00

Injury Severity Score (ISS), Chronic Obstructive Pulmonary Disease (COPD), Chest Tube (CT), Surgical Stabilization of Rib Fractures (SSRF), Intensive Care Unit (ICU), Length of stay (LOS).

Values were expressed as medians with (IQR) and means ± SD unless specified.

prophylactic antibiotic bead implantation given the lack of clear risk factors for SSRF hardware infection. This study is underpowered to assess mortality differences and requires further investigation, potentially in a multi-institutional format in order to evaluate the efficacy of antibiotic bead placement when compared to no bead placement. The initial stages of our practice were subject to inter-provider variation which we attempted to standardize using a management algorithm.

Conclusion

Antibiotic bead implantation may be a viable strategy for treatment of hardware infection in SSRF patients and appears well tolerated. Based on the results of this study, we cannot advise the utilization of antibiotic beads for prophylaxis, as we have been unable to identify statistically significant risk factors to guide patient selection. Further studies need to be conducted to identify the efficacy of this treatment method for the management of and prophylaxis against SSRF infection.

Table 4

Comparison of characteristics in patients receiving prophylactic beads versus beads for infection.

	Prophylaxis (n = 8)	Infected (n = 9)	p
Patient Characteristics, n (%)			
Age	58	58	0.99
Male	6 (75)	6 (66.7)	1.00
BMI	29.47 ± 3.59	33.63 ± 5.68	0.08
Smoker	3 (37.5)	0 (0)	0.08
Asthma	2 (25)	2 (22.2)	1.00
COPD	1 (12.5)	1 (11.1)	1.00
Diabetes	1 (12.5)	2 (22.2)	1.00
Hypertension	2 (25)	3 (33.3)	1.00
Chronic kidney disease	1 (12.5)	1 (11.1)	1.00
Chronic liver disease	1 (12.5)	1 (11.1)	1.00
Immunosuppression	1 (12.5)	0 (0)	0.47
Injury Characteristics			
ISS	30 (26–33)	33 (28–39)	0.09
# ribs fractured	8 (5–9)	7 (6–10)	0.96
# fractures	8 (5–13)	12 (7–17)	0.39
Flail segment, n (%)	2 (25)	7 (78)	0.06
Pneumothorax, n (%)	5 (62)	7 (78)	0.62
Hemothorax, n (%)	1 (12)	5 (56)	0.13
Scapula fracture, n (%)	0 (0)	2 (22)	0.47
Spine fracture, n (%)	3 (37)	4 (44)	1.00
Clavicle fracture, n (%)	1 (12)	2 (22)	1.00
Hemorrhagic shock, n (%)	3 (38)	4 (44)	1.00
Blood Transfusion, n (%)	6 (75)	5 (56)	1.00
Pre-OR intubation, n (%)	5 (62)	3 (33)	0.35
Chest tube characteristics			
Pre-hospital chest tube, n (%)	3 (37)	2 (22)	0.62
CT prior to SSRF, n (%)	4 (50)	5 (56)	1.00
CT pre-OR, days	3 (1–4)	3 (1–3)	0.52
SSRF characteristics			
Days to plating	5 (3–6)	3 (3–4)	0.26
# of ribs plated	5 (3–7)	4 (3–6)	0.51
# of plates	5 (3–9)	5 (3–6)	0.91
Chest tube, days	2.5 (2–5)	4 (3–7)	0.24
Pneumonia, n (%)	6 (75)	4 (44)	0.34
ICU LOS, days	6 (5–13)	11 (4–14)	0.92
Hospital LOS, days	14 (8–22)	27 (14–39)	0.12
Mechanical Ventilation, n (%)	6 (75)	6 (67)	1.00
Ventilator, days	4 (0–11)	2 (0–12)	0.73
Tracheostomy, n (%)	2 (25)	1 (11)	0.58
IV antibiotics, days	6 (2–10)	25 (9–36)	0.02
PO antibiotics, days	0 (0–1)	59 (42–196)	0.01
Mortality, n (%)	0 (0)	0 (0)	1.00

Injury Severity Score (ISS), Chronic Obstructive Pulmonary Disease (COPD), Chest Tube (CT), Surgical Stabilization of Rib Fractures (SSRF), Intensive Care Unit (ICU), Length of stay (LOS).

Values were expressed as medians with (IQR) and means ± SD unless specified.

Table 5

Comparison of outcomes in patients receiving prophylactic beads versus beads for infection.

	Prophylaxis (n = 8)	Infected (n = 9)	p
Days to fracture healing	126 (95–150)	96 (93–189)	0.87
Beads removed, n (%)	7 (88)	9 (100)	0.47
Hardware removed, n (%)	5 (63)	7 (78)	0.62
Days to hardware removal	167 (110–213)	182 (97–190)	1.00
Chest tube post-explant, n (%)	1 (20)	1 (14)	1.00
Duration-of-stay post removal	1 (0–1)	3 (0–4)	0.06

Values expressed as median with (range) unless otherwise specified.

Duration is based upon initial date of SSRF.

Conflicts of interest

The authors have no conflicts of interest (internal or external) for the generation of this manuscript.

Summary

Although infected rib stabilization hardware occurs

infrequently, it is a morbid complication with increased hospital and ICU duration of stay. Antibiotic bead placement can salvage infected hardware until bony union is achieved.

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