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Intrathoracic plates versus extrathoracic plates: a comparison of postoperative pain in surgical stabilization of rib fracture technique

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ABSTRACT

Background Surgical stabilization of rib fractures (SSRF) has been shown to improve outcomes, yet there is an absence of studies comparing SSRF techniques. An intrathoracic system that minimizes incision length has recently been developed and adopted by multiple institutions. We hypothesized that SSRF with an intrathoracic system plus intercostal nerve cryoneurolysis (IC) leads to improved pain control compared with an extrathoracic system plus IC.

Methods A single-center, retrospective chart review was performed comparing intrathoracic SSRF versus extrathoracic SSRF, and included patients undergoing SSRF from 2015 to 2021 at a level 1 trauma center. Patients who did not undergo intercostal nerve cryoablation were excluded. The primary outcome was opioid consumption based on morphine milligram equivalent (MME) consumption. We collected Rib score, Blunt Pulmonary Contusion 18 Score, number of rib fractures, number of ribs plated, and Injury Severity Score (ISS) to compare baseline characteristics of each group.

Results A total of 112 patients were evaluated for study inclusion. Thirty-one patients were excluded due to missing outcomes data and/or lack of cryoablation. There was no difference in ISS or Rib Score between the intrathoracic (n=33) and extrathoracic (n=48) groups. At 7-day follow-up, the median MME requirement was significantly lower in the intrathoracic group (21.25) versus the extrathoracic group (46.20) (p=0.02).

Conclusion Intrathoracic SSRF was associated with a lower postoperative MME consumption compared with extrathoracic SSRF. These data support the use of intrathoracic SSRF to improve pain control compared to extrathoracic SSRF.

Level of evidence III.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Surgical stabilization of rib fracture (SSRF) is an important treatment for patients with severe chest injuries, but there are limited data comparing patient outcomes with surgical stabilization via an extrathoracic approach versus an intrathoracic approach.

WHAT THIS STUDY ADDS

⇒ Patients who underwent SSRF via an intrathoracic approach used significantly less narcotics during 7 days postoperatively compared with patients who underwent SSRF via an extrathoracic approach.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ SSRF performed intrathoracically may lead to less postoperative pain compared with SSRF performed extrathoracically.

BACKGROUND

Surgical stabilization of rib fractures (SSRF) has become a critical treatment for patients with severe chest injuries.[1–3] SSRF has been shown to have significant benefits over non-operative management in multiple clinical outcomes, resulting in improved postoperative pain, decreased risk of pneumonia and re-admission, and decreased hospital and intensive care unit (ICU) length of stay (LOS).[4–8] Currently, the Chest Wall Injury Society (CWIS) recommends SSRF for non-flail fractures if there are three or more ipsilateral consecutive or non-consecutive ribs with 50% displacement on axial CT.[9] Although the indications for SSRF are becoming well understood, there are limited data comparing patient outcomes with different SSRF techniques. Currently, trauma surgeons are treating severe rib fractures and simultaneously choosing the best technique available.

During the last 5 years, our level 1 trauma center performed SSRF using an extrathoracic system. In early 2020, we adopted the minimally invasive intrathoracic SSRF system. A newer development in SSRF, the intrathoracic system has shown promise in terms of improved patient outcomes. Intrathoracic SSRF requires a video-assisted thoracoscopic surgical (VATS) approach. VATS SSRF addresses many of the shortcomings of more invasive, open approaches like those used for extrathoracic SSRF (eg, open thoracotomy), and retaining the biomechanical advantages conferred by rib fracture stabilization.[10] VATS aids in more complete visualization of the thoracic cavity and fractured ribs, and provides access to the pleural space, which can improve elimination of hemothorax.[11] Further, VATS helps directly guide nerve blocks (eg, paraspinal blocks), and blunt diaphragm injuries are more readily diagnosed.[12 13] One of the primary goals of SSRF is to improve pain. By reducing the likelihood and number of injuries to chest wall structures and nerves, and in creating significantly smaller incisions, intrathoracic SSRF may improve postoperative pain scores.[10 13] In a recent prospective study, patients who underwent intrathoracic

SSRF had decreased LOS and operative time compared with patients who underwent traditional extrathoracic plating.[14] Intrathoracic plating has also been demonstrated to have a biomechanical advantage over extrathoracic plating.[15] In a study using cadavers to evaluate the biomechanical differences between the two plating types, Mischler *et al* reported significantly higher construct stiffness after intrathoracic plating, indicating superior plate support compared with extrathoracic plating.[15]

In addition to SSRF, we routinely perform intercostal nerve cryoneurolysis (IC), which many centers use for SSRF and other thoracic operations, and which helps alleviate postoperative pain.[16–18] A recent study demonstrated that SSRF in conjunction with IC significantly lowers postoperative opioid requirements (as measured by morphine milligram equivalent (MME)) compared with SSRF alone.[16] IC was first described in 1974 for post-thoracotomy pain,[19] and patients who undergo either extrathoracic and intrathoracic SSRF at our hospital typically also undergo IC.

The objective of this study was to investigate the efficacy of an intrathoracic system versus the extrathoracic system and control for IC. The CWIS NONFLAIL Study evaluated postoperative Numeric Pain Score (NPS) and opioid consumption (OC) to compare operative and non-operative groups, reporting a significant difference in NPS at 2 weeks follow-up.[7] Since the accuracy of NPS has been questioned due to its subjective nature,[20] we evaluated postoperative OC as the primary outcome. We hypothesized that intrathoracic SSRF, as compared with extrathoracic SSRF, would improve pain control and reduce OC.

METHODS

In this Institutional Review Board (IRB)-approved study, we retrospectively reviewed all patients who underwent rib plating at our level 1 trauma center between January 1, 2015 and March 22, 2021. Patient data were extracted from our institution's trauma registry, and 112 patients were evaluated for study inclusion. Patients who did not undergo IC, or whose records were missing data on postoperative OC (as measured by MME), were excluded from the study. Rib fracture pattern was not considered in the exclusion criteria due to the retrospective nature of the data collection. None of the patients included in this study had cardiopulmonary resuscitation (CPR) performed, were pregnant, or were prisoners. This study abides by the Strengthening the Reporting of Observational Studies in Epidemiology guidelines.

The independent variable was SSRF. In general, our institution uses CWIS criteria for patient selection; however, surgeon discretion was used prior to CWIS guidelines. Surgeon's preference was a component in both patient selection for surgical intervention, as well as technique (extrathoracic vs intrathoracic). The extrathoracic technique consisted of open reduction and internal fixation with external plates. We were unable to evaluate exposure techniques including muscle-sparing versus muscle-splitting. All extrathoracic plates were fixed with monocortical locking screws using KLS Martin L1 Rib System. VATS was performed at the surgeon's discretion. The intrathoracic technique consisted of open reduction and internal fixation with internal plates using the Zimmer Ribfix Advantage . VATS was performed in every patient to assist with fixation. IC was performed in all patients, regardless of technique. We routinely perform cryoablation of intercostal nerves 3–7, and sometimes 8. The size, quantity, and location of chest tubes were at the surgeon's discretion; however, all patients received at least one chest tube.

We queried our trauma registry to capture all patients of "rib plating". From that set, we identified 112 patients who underwent SSRF. We excluded 31 patients who did not undergo IC, and/or whose records were missing data on postoperative OC (as measured by MME), giving us a final patient sample size of 81. Of those 81 patients, 33 underwent intrathoracic fixation and 48 underwent extrathoracic fixation.

The primary outcome was pain control. We examined OC to evaluate the primary outcome. OC was assessed by measuring 24-hour MMEs. We calculated 24-hour MME consumption starting on the preoperative day up until postoperative day 7. If a patient was discharged prior to postoperative day 7, we stopped collecting MME use data at the day of patient discharge. We were able to compare the average postoperative MME to the preoperative MME. Additional outcome variables included ICU LOS and hospital LOS. Covariates included age, sex, smoking status, chronic obstructive pulmonary disease (COPD)/asthma, body mass index (BMI)>30, mechanism of injury (fall, motor vehicle crash), Injury Severity Score (ISS), admission Glasgow Coma Scale (GCS) Score, intracerebral hemorrhage (ICH), facial fracture, spine fracture, pelvis fracture, long bone fracture, solid organ injury, blunt cerebrovascular injury (BCVI), hemothorax, pneumothorax, chest tube insertion<24 hours, clavicle fracture, and scapula fracture. Rib fracture severity was measured using the RibScore.[21] The degree of lung injury was measured using the Blunt Pulmonary Contusion 18 (BPC18) Score. The BPC18 Score was created by Tyburski *et al* to quantify the extent of a pulmonary contusion.[22] Thus, higher scores signify more lung injury, which may lead to clinical deterioration and need for ventilator assistance. We also collected the number of ribs fractured and repaired. No patient in our cohort received thoracic epidural catheters, para vertebral blocks, continuous intercostal blocks, or liposomal bupivacaine rib blocks.

Discrete variables were reported as N (%) and tested using χ^2 test or Fisher's exact test for small sample sizes (n<5). Normal distribution was assessed by the Shapiro-Wilk test and visual inspection of histograms. Continuous variables were reported as median (IQR) when skewed and were tested using the Wilcoxon rank-sum test. To test the association between SSRF types and pain control, we used a multiple linear regression model, with log-transformed consumption in MME as the dependent variable, SSRF types as the independent variable, and controlled for statistically or clinically significant demographic and other pain-related variables. We applied stepwise selection to evaluate which variables to include in the linear regression model, and elected to run the regression model with relevant pain-related covariates. The linear regression was controlled for variables including gender, ISS, number of ribs fractured, BPC18, and admission GCS type (mild, moderate, or severe). Values of $p<0.050$ were considered statistically significant. All analyses were performed using R statistical software (R Foundation for Statistical Computing, V.4.0.2, Vienna Austria).

One of the surgeons is a paid consultant for Zimmer Biomet. This surgeon was not involved in data abstraction and analysis.

RESULTS

Between the years 2015 and 2021 a total of 112 patients underwent SSRF at our institution and were evaluated for study inclusion. Ultimately 31 patients were excluded who did not undergo IC, and/or whose records were missing data on postoperative OC, for a final pool of 81 patients. Of those included, 33 (41%) patients had SSRF performed using the intrathoracic system and 48 (59%) using the extrathoracic system. Table 1 summarizes

Table 1 Demographic, characteristics comparison

Comparison of patients receiving intrathoracic or extrathoracic SSRF			
	Intrathoracic (n=33)	**Extrathoracic (n=48)**	**P value**
Patient characteristics			
Age, median (IQR)	59 (52, 66)	56.5 (43.5, 65.25)	0.70
Gender, N (%)			0.062
Female	4 (12.12)	15 (31.25)	
Male	29 (87.88)	33 (68.75)	
Current smoker, N(%)			0.84
Yes	9 (27.27)	12 (25.00)	
No	15 (45.45)	26 (54.17)	
NA	9 (27.27)	10 (20.83)	
COPD or asthma, N (%)			0.18
Yes	4 (12.12)	2 (4.17)	
No	19 (57.58)	38 (79.17)	
NA	10 (30.30)	8 (16.67)	
BMI>30, N(%)			1
Yes	12 (36.36)	16 (33.33)	
No	20 (60.61)	29 (60.42)	
NA	1 (3.03)	3 (6.25)	
Fall, N (%)			0.14
Yes	11 (33.33)	8 (16.67)	
No	22 (66.67)	40 (83.33)	
MVC, N (%)			0.20
Yes	21 (63.64)	38 (79.17)	
No	12 (36.36)	10 (20.83)	
Time from arrival to SSRF (hours), median (IQR)	73.22 (52.35, 120.73)	95.59 (63.48, 138.50)	0.36
ISS, median (IQR)	17 (13, 22)	20.5 (14, 26.25)	0.20
Admission GCS Score, median (IQR)	15 (15, 15)	15 (14, 15)	0.39
Admission GCS type, N (%)			0.33
Mild (13–15)	31 (93.94)	39 (81.25)	
Moderate (9–12)	1 (3.03)	4 (8.33)	
Severe (3–8)	1 (3.03)	5 (10.42)	
ICH, N (%)			0.30
Yes	6 (18.18)	4 (8.33)	
No	27 (81.82)	44 (91.67)	
Facial fracture, N (%)			1
Yes	29 (87.88)	40 (83.33)	
No	4 (12.12)	7 (14.58)	
Spine fracture, N (%)			1
Yes	9 (27.27)	14 (29.17)	
No	24 (72.73)	33 (68.75)	
Pelvis fracture, N (%)			0.26
Yes	4 (12.12)	11 (22.92)	
No	29 (87.88)	37 (77.08)	
Long bone fracture, N (%)			0.75
Yes	4 (12.12)	8 (16.67)	
No	29 (87.88)	40 (83.33)	
Solid organ injury, N (%)			0.18
Yes	10 (30.30)	23 (47.92)	
No	23 (69.70)	25 (52.08)	
BCVI, N (%)			0.56
Yes	2 (6.06)	1 (2.08)	
No	31 (93.94)	47 (97.92)	
Number of ribs repaired, median (IQR)	4 (3, 5)	5 (4, 6)	0.0040
Number of ribs fractured, median (IQR)	6 (5, 8)	8 (5.75, 10.25)	0.055
RibScore, median (IQR)	3 (2, 3)	3 (2, 5)	0.11
BPC18, median (IQR)	1 (0, 4)	3 (0.5, 9)	0.030

Continued

Table 1 Continued

Comparison of patients receiving intrathoracic or extrathoracic SSRF			
	Intrathoracic (n=33)	Extrathoracic (n=48)	P value
Hemothorax, N (%)			0.38
Yes	16 (48.48)	18 (37.50)	
No	16 (48.48)	30 (62.50)	
Pneumothorax, N (%)			0.042
Yes	20 (60.61)	40 (83.33)	
No	13 (39.39)	8 (16.67)	
Chest tube <24 hours from admit, N (%)			1
Yes	16 (48.48)	24 (50.00)	
No	17 (51.52)	23 (47.92)	
Clavicle fracture, N (%)			0.90
Yes	5 (15.15)	9 (18.75)	
No	28 (84.85)	39 (81.25)	
Scapula fracture, N (%)			0.99
Yes	6 (18.18)	10 (20.83)	
No	27 (81.82)	38 (79.17)	
Isolated chest injury, N (%)			0.41
Yes	1 (3.03)	0 (0)	
No	32 (96.97)	48 (100)	
Mortality, N (%)			1
Yes	1 (3.03)	1 (2.08)	
No	32 (96.97)	47 (97.92)	

BMI, body mass index; BPC18, Blunt Pulmonary Contusion 18; GCS, Glasgow Coma Scale; ISS, Injury Severity Score; MVC, motor vehicle crash; NA, not assayed; SSRF, surgical stabilization of rib fracture.

the demographics, characteristics, and outcomes of these 81 patients, by SSRF group. Table 2 summarizes the type of SSRF by year.

We found no significant differences in age, sex, smoking status, COPD/asthma, BMI>30, mechanism of injury, median time between hospital arrival and SSRF, ISS, RibScore, admission GCS, ICH, facial fractures, spine fractures, pelvic fractures, long bone fractures, solid organ injury, BCVI, hemothorax, pneumothorax, chest tube insertion<24 hours, clavicle fracture, isolated chest wall injury, or scapula fracture between the two groups. The overall mortality was the same for both groups (one patient death in each group).

The extrathoracic group had more mean rib fractures compared with the intrathoracic group, with the mean rib fractures being eight and six, respectively. The average number of ribs repaired was five in the extrathoracic group and four in the intrathoracic group. The median BPC18 Score was higher in the extrathoracic group compared with the intrathoracic group, with the median BPC18 Scores being 3 and 1, respectively (p=0.030).

The primary outcome was pain control, as measured by MME use up to 7 days postoperatively; table 3 lists outcomes including average postop MME, hospital LOS, and ICU LOS by SSRF group. We found that during seven postoperative days, the median 24-hour MME requirement was significantly lower in the intrathoracic group (21.25) versus the extrathoracic group (46.20) (p=0.020) (table 3; figure 1). The mean 24-hour MME requirements during 7 days postoperatively were also lower in the intrathoracic group (38.38) compared with the extrathoracic group (94.81) (table 3; figure 2).

On multivariable analysis (see table 4), the average MME requirements during 7 days postoperatively were significantly (37.84%) less in the intrapleural group compared with the extrapleural group (p=0.035). The linear regression controlled for gender, ISS, number of ribs fractured, BPC18, and admission GCS type.

LOS were not significantly different in the two groups (see table 3). As the distributions of these variables were skewed, we examined differences in medians. The median hospital LOS was 16 days for the intrathoracic group compared with 18.5 days for the extrathoracic group (p=0.32). The median ICU LOS for the intrathoracic group was 5 days, and the extrathoracic group was 8 days (p=0.091).

Table 2 SSRF type by year

	Intrathoracic (n=33)	Extrathoracic (n=48)
2018	0	6
2019	0	24
2020	28	18
2021	5	0

SSRF, surgical stabilization of rib fracture.

DISCUSSION

Currently, trauma surgeons are faced with multiple techniques and systems to treat severe rib fractures. Although recent data support an intrathoracic SSRF approach to reduce LOS and operative time, published data comparing postoperative pain control in patients who underwent intrathoracic SSRF or extrathoracic SSRF are less clear. A recent prospective study reported patients who underwent extrathoracic SSRF had similar MME Scores to the patients who underwent intrathoracic SSRF, but were also more likely to have epidural anesthesia and intercostal nerve blocks.[14] In this study, we investigated whether the intrathoracic SSRF technique improves patients' postoperative pain and demonstrated that patients who underwent intrathoracic

Table 3 Outcome comparison

n=81	Intrathoracic (n=33)	Extrathoracic (n=48)	P value
Outcomes			
Avg postop MME, median (IQR)	21.25 (14.38, 60.09)	46.20 (19.89, 106.91)	0.020
Hospital length of stay, median (IQR)	16 (10, 24)	18.5 (12.75, 33.25)	0.32
ICU lenth of stay, median (IQR)	5 (2, 8)	8 (3, 15.25)	0.091

ICU, intensive care unit; MME, morphine milligram equivalent .

SSRF used significantly less opioids than patients who underwent extrathoracic SSRF. After controlling for varying characteristics in the patient groups via multivariable analysis the differences in postoperative pain remained significant between the extrathoracic and intrathoracic groups, underscoring the validity of this finding.

Although we saw differences between the two groups with the number of rib fractures and differences in BPC18 Scores, with the extrathoracic group tending to have more rib fractures, all other injury patterns were the same in both groups including ISS, long bone fractures, spinal fractures, solid organ injuries, and facial fractures.

We surmise that there was less MME use in the intrathoracic group due to the intrathoracic system technique itself—namely, a minimally invasive procedure with smaller incisions and less damage to chest wall structures required to complete the operation, direct visualization of the thoracic cavity, fractured ribs, and the neurovascular bundle, and the restoration of chest wall physiology that occurs when pulling the intrathoracic plates into place.

Cryoablation of the intercostal nerve bundle was performed in all patients included in this study. Recent studies on the use of cryoablation in combination with SSRF have shown decreased postoperative OC and decreased hospital LOS.[17 23] These studies used the extrathoracic system for SSRF, and few studies have examined comparative outcomes for the intrathoracic and extrathoracic systems in conjunction with cryoablation. Our study is among the first of its kind showing a postoperative pain control benefit with intrathoracic rib plating in conjunction with cryoablation.

Although the extrathoracic group tended to have more rib fractures than the intrathoracic group, there is evidence that traumatic rib fractures lead to chronic pain with the number of rib fractures being unrelated and/or a poor predictor.[24 25] If pain does not increase in direct correlation with number of fractures, we do not think that two additional rib fractures would account for twice as much MME use in the extrathoracic group compared with the intrathoracic group.

Among the limitations of this study are that we did not evaluate incision and exposure type, or incision length. Extrathoracic plating is typically associated with larger incisions with muscle splitting technique. However, there is some evidence indicating that incision type does not affect acute and chronic postoperative pain.[26]

There was not a standardized analgesia regimen during the study period, and we were also unable to obtain patient history of opioid use and chronic pain, or of in-hospital administration of intravenous (IV) ketamine, IV lidocaine, nonsteroidal anti-inflammatory drugs (NSAIDs), acetaminophen or gabapentinoids. These are all factors which could have potentially affected MME data. Future studies would ideally be able to be performed prospectively with a more clearly delineated or controlled postoperative analgesia regimen, and to control for differences in dosing and patient history.

Additional data we did not collect that could have impacted MME data include ventilator days, sedation on ventilation, size and number of chest tubes, surgical site infections, unplanned returns to operating room for hemorrhage or hardware issues, possible increased surgeon expertise over time, and differences by individual surgeons. Due to unanticipated institutional data access issues, we were unable to collect those data elements.

Another issue to consider is that all intrathoracic SSRF is performed via VATS, whereas all extrathoracic SSRF is performed via an open approach. Separating out the nuanced impacts of VATS itself versus intrathoracic plating on postoperative opioid use and pain has potential for future research endeavors. Future studies could also include functional and quality of life data as useful, more long-term outcomes.

Finally, the study is limited by its retrospective design that used registrar-extracted data. Registry-based data may contain data

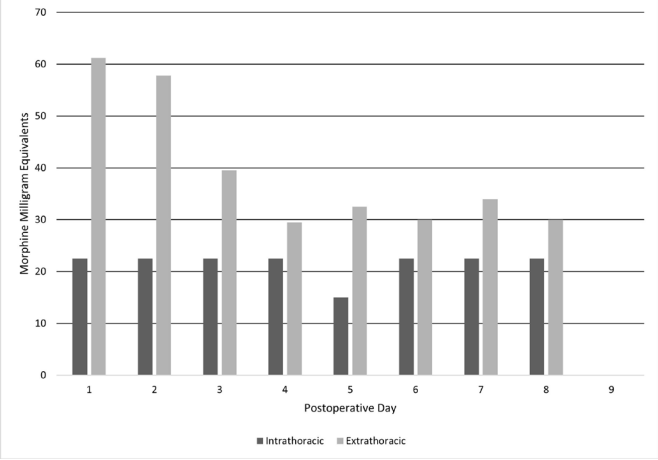

Figure 1 Median postoperative morphine milligram equivalent use.

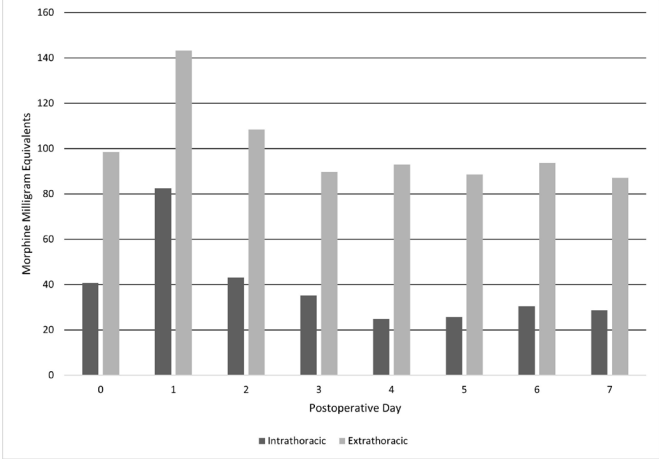

Figure 2 Mean postoperative morphine milligram equivalent use.

Table 4 Multiple linear regression for MME outcome

Predictor	Comparison/reference	Percent change	P value
SSRF group	Intrathoracic/extrathoracic	37.84	0.035
Gender	Male/female	113.04	0.0040
ISS	–	1.24	0.32
Number of ribs fractured	–	8.09	0.026
BPC18	–	1.22	0.60
GCS type	Moderate/severe	362.48	0.0010
	Mild/severe	392.72	<0.0010

BPC18, Blunt Pulmonary Contusion 18; GCS, Glasgow Coma Scale; ISS, Injury Severity Score; MME, morphine milligram equivalent ; SSRF, surgical stabilization of rib fracture.

entry errors and registrar-dependent coding variability; though registrars are trained in medical coding, they are not trained as clinical practitioners and may be prone to differences in clinical chart data interpretation. Further, registry data are based on what is available/entered into the medical record and missing or incomplete data fields in the medical record will typically cause missing data fields in the registry data, as well. In addition, CWIS guidelines were published in 2019. Therefore, most of the extrathoracic SSRF was performed at surgeon discretion which could have led to selection bias.

We also did not control for the size and quantity of chest tubes placed during the operation. According to Yi *et al*,[27] a smaller pleural catheter, when used for hemothorax evacuation, was associated with decreased analgesic treatment.

Notwithstanding these limitations, our findings are among the first to report that intrathoracic SSRF with IC is associated with decreased opioid use compared with extrathoracic SSRF with IC, and add to the growing body of evidence supporting an intrathoracic SSRF approach for rib fracture management for improved patient outcomes.

CONCLUSION

SSRF has become an important tool for treatment of rib fractures, and currently, there is a lack of data comparing outcomes for the two primary techniques, intrathoracic SSRF and extrathoracic SSRF. This study demonstrates that the use of the intrathoracic system with IC was associated with decreased postoperative opioid use and improves patient outcomes, compared with the use of the extrathoracic system with IC. Although recent studies have demonstrated the utility of SSRF in improving pain and other patient outcomes, and demonstrated that intrathoracic SSRF compared with extrathoracic SSRF leads to decreased hospital LOS and operative time, this is the first study to show a difference in postoperative MME between the two approaches. A large prospective study that uses a more standardized approach is needed to further confirm our results.

Contributors MT planned the study, collected and cleaned data, and drafted and revised the article. LBR drafted and revised the article. CW, JR, PP, MF designed and planned the study. NP collected and cleaned data. XT designed and performed statistical analyses, and drafted and revised the article. JH designed and planned the study, monitored data collection, and drafted and revised the article. He is the guarantor of the study.

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Competing interests CW is a paid consultant for Zimmer Biomet.

Patient consent for publication Not applicable.

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Provenance and peer review Not commissioned; externally peer reviewed.

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