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Trauma/Critical Care

Surgical stabilization of rib fractures is associated with improved survival but increased acute respiratory distress syndrome



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ABSTRACT

Background: How the surgical stabilization of rib fractures after trauma affects the development of acute respiratory distress syndrome and impacts survival has yet to be determined in a large database. We hypothesized that surgical stabilization of rib fractures would not decrease the incidence of acute respiratory distress syndrome.

Methods: The National Trauma Data Bank was queried for all traumatic rib fractures in 2016. Patients were divided into groups with single rib fractures, multiple rib fractures, and flail chest. Nonoperative therapy was compared with stabilization of rib fractures of 1 to 2 ribs or 3+ ribs.

Results: There were 114,972 total patients with rib fractures meeting inclusion criteria, with 5,106 (4.4%) having flail chest, 24,726 (21.5%) having single rib fractures, and 85,140 (74.1%) having multiple rib fractures. Those with flail chest (15.9%) were most likely to get rib plating in comparison to multiple rib fractures (0.9%) and single rib fractures (0.2%); $P < .001$. On logistic regression, surgical stabilization of rib fractures 1 to 2 ribs (odds ratio: 0.17, 95% confidence interval: 0.10–0.28) or 3+ ribs (odds ratio: 0.17, 95% confidence interval: 0.11–0.28), with nonoperative therapy as the reference was associated with survival. Variables associated with mortality included increasing age, male sex, increasing injury severity score, decreased Glasgow coma scale, requirement of transfusions, and hypotension on admission. Surgical stabilization of rib fractures 3+ ribs (odds ratio: 2.30, 95% confidence interval: 1.58–3.37) was associated with acute respiratory distress syndrome but not 1 to 2 ribs (odds ratio: 1.55, 95% confidence interval: 0.97–2.48). On logistic regression of only patients with flail chest, stabilization of rib fractures was associated with decreased mortality but not increased risk of acute respiratory distress syndrome.

Conclusion: The increased risk of acute respiratory distress syndrome should be considered in the pre-operative assessment for stabilization of rib fractures.

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Introduction

Traumatic rib fractures are extremely common, occurring in approximately 10% of all trauma patients. Over 350,000 patients

sustain rib fractures in the United States annually, and approximately 70% of these are a result of blunt trauma.¹ Rib fractures are a vexing problem with high complication rates. Patients have a high rate of pneumonia, acute respiratory distress syndrome (ARDS), sepsis, and death.^{1,2} Mainstays of rib fracture treatment include adequate analgesia and clearance of pulmonary secretions. In particular, epidural analgesia has been shown to decrease complication rates and need for mechanical ventilation after rib fractures.³ Recent studies also suggest adjuvant ketamine to be associated with greater pain relief and reduced oral opiate use in rib-fracture patients.^{4,5}

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Surgical stabilization of rib fractures (SSRF) refers to the reduction and fixation of broken ribs. Proponents of this technique believe that it restores chest wall stability and decreases pain after rib fractures. In addition, it may help prevent nonunion of broken ribs and decrease respiratory failure. While the number of patients with rib fractures receiving SSRF has increased in recent years, the number of patients undergoing the procedure remains relatively small. Cheema et al estimated 5.8% of patients with flail chest (FC) undergo SSRF.^{1,6} Consensus guidelines recommend SSRF for patients with flail chest, citing improved pain control and pulmonary function.^{2,7–9}

The use of SSRF in patients with traumatic rib fractures without FC remains controversial. Recent studies have shown that SSRF may be helpful in patients with rib fractures without flail chest.¹⁰ One study demonstrated that early SSRF (<72 hours) for patients with 3 or more ipsilateral, severely displaced rib fractures without FC had decreased numeric pain scores.¹⁰ However, the way in which SSRF influences the development of an important trauma-induced morbidity such as ARDS has yet to be studied using a large, national database. We hypothesized that SSRF would not decrease incidence of ARDS.

Methods

An exemption was obtained from the Tulane University School of Medicine Institutional Review Board (IRB). The National Trauma Data Bank (NTDB) research dataset is an aggregation of trauma registry data submitted from over 700 trauma centers in the United States and contains standardized information for over 7.5 million deidentified cases.¹¹ The dataset includes variables from emergency medical services and hospital sources, including categories such as demographics, International Classification of Disease, Tenth Revision (ICD-10) codes, general facility information, discharge information, vital signs, complications, and comorbidities. We performed a retrospective cohort study using ICD-10 codes within the 2016 dataset to identify adults age 18 or older with rib fractures. Patients were divided into 6 study groups: (1) those with single rib fractures treated nonoperatively, (2) multiple rib fractures (MR) treated nonoperatively, (3) FC treated nonoperatively, (4) single rib fractures treated with SSRF, (5) MR treated with SSRF, and (6) FC treated with SSRF. Patients receiving nonoperative therapy were compared with those receiving SSRF. Among those receiving SSRF, we examined those receiving plating of 1 to 2 ribs and those receiving plating of 3 or more ribs, as this is what is available in the database by using ICD-10 codes. Entries with unknown age were excluded. Primary outcomes examined were mortality and development of ARDS. Secondary outcomes included duration of stay, intensive care unit (ICU) duration of stay, ventilator days, and development of any complications.

Statistical analysis

Missing data were treated as missing at random and imputed using multivariate imputation by chained equations in order to reduce bias and increase precision.^{12,13} All results were compared with those generated from the original dataset with dropped missing variables. We examined demographic and injury pattern data using Pearson χ^2 statistic for categorical variables and 1-way analysis of variance or Wilcoxon-Kruskal-Wallis test for continuous variables when appropriate. To test the association between SSRF status and outcomes, we used multiple logistic regression and coded all dependent variables as binary variables. For multiple

regression, significant variables were selected using stepwise selection with Bayesian information criterion.^{14,15} *P* values <.05 were considered statistically significant. All analyses were conducted in R version 3.6.1 (R Foundation for Statistical Computing, Vienna, Austria).¹⁶

Logistic regression was carried out to examine variables associated with mortality and ARDS. For subset analysis, we performed logistic regression to examine the association of SSRF with outcomes for patients with FC alone. For this analysis, patients with SSRF 1 to 2 ribs and 3 or more ribs were combined owing to small sample size.

Results

As seen in Fig 1, there were a total of 114,972 total patients age 18 and over with rib fractures, with 5,106 (4.4%) having FC, 24,726 (21.5%) having a single rib fracture (SR), and 85,140 (74.1%) having MR. A total of 113,306 (98.6%) were treated nonoperatively, while 1,666 (1.4%) were treated with SSRF. Of those treated with SSRF, 746 (44.8%) had SSRF of 1 to 2 ribs, and 920 (55.2%) had SSRF of 3 or more ribs.

Baseline patient characteristics

A comparison of baseline patient characteristics is shown in Table I. Patients with FC were older (57.0 years) than those with MR (56.0 years) and SR (50.0 years); *P* < .001. Patients with FC were most likely to receive SSRF (15.9%), with 354 (6.9%) receiving SSRF of 1 to 2 ribs and 459 (9.0) receiving SSRF of 3 or more ribs. Patients with MR (*n* = 84,316, 90.0%) and SR (*n* = 24,697, 99.9%) were much more likely to receive nonoperative treatment; *P* < .001. Patients with FC (14.0) had the highest injury severity score (ISS), followed by MR (11.0) and by SR (9.0); *P* < .001. Patients with FC appeared to have more severe associated injuries as they had the highest head, thorax, abdomen/pelvis, upper extremity, and lower extremity abbreviated injury score (AIS) as shown in Table I. Patients with FC were more likely to be privately insured (44.1%) when compared with MR (42.1%) and SR (39.2%); *P* < .001. Patients with MR were more likely to have Medicare (26.5%) compared with FC (23.7%) and SR (21.7%); *P* < .001.

In-hospital outcomes and disposition

A comparison of in-hospital outcomes stratified by types of rib fractures is shown in Table II. Duration of stay (12.0 days, *P* < .001), ICU duration of stay (6.0 days, *P* < .001), and ventilator days (7.0 days; *P* < .001) were highest in the FC group as compared with the MR and SR groups. Patients with FC were most likely to develop any complication (34.8%; *P* < .001). Rates of required transfusions (*n* = 1,240, 24.3%), ventilator associated pneumonia (*n* = 243, 4.8%), acute kidney injury (*n* = 167, 3.3%), and surgical site infections (*n* = 65, 1.3%) were highest in the FC group when compared with MR and SR.

A comparison of disposition status is shown in Table III. Patients with FC were least likely to be discharged to home (*n* = 1,876; 36.7%). Patients with FC were most likely to be discharged to inpatient rehab (*n* = 838, 16.4%) as compared with MR (11,082, 13.0%) and SR (*n* = 2,750, 11.1%) (*P* < .001). Patients with FC were also most likely to be discharged to skilled nursing facility (*n* = 601, 11.8%).

Nonoperative management versus SSRF

A comparison of baseline patient characteristics for patients receiving nonoperative therapy and those receiving SSRF is shown

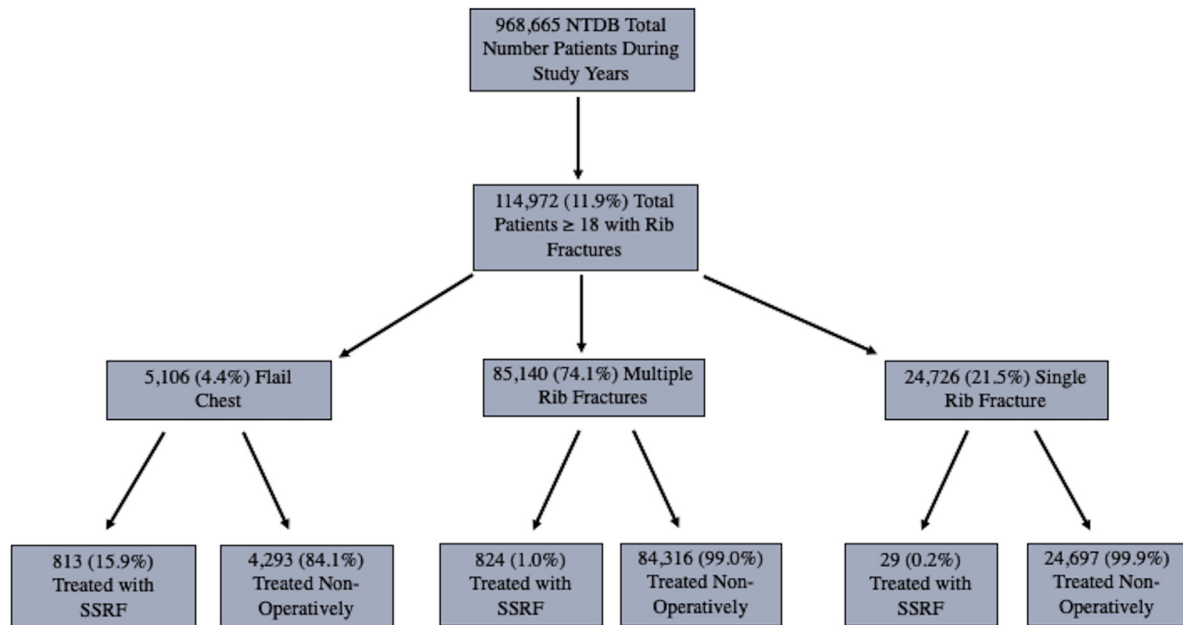


Fig 1. Flow chart showing patient selection and those treated with surgical stabilization of rib fractures.

in [Table IV](#). Patients receiving SSRF were less likely to be female (31.8% vs 26.2%; $P < .001$) and less likely to be Black or African American (10.7% vs 6.0%; $P < .001$) and Hispanic/Latino (10.1% vs 7.5%; $P < .001$). Patients receiving SSRF were more likely to have FC (3.8% vs 48.8%; $P < .001$), more likely to be privately insured (41.5% vs 48.4%; $P < .001$), and less likely to be self-pay (10.5% vs 8.9%; $P < .001$). Patients receiving SSRF had higher ISS (14.0 vs 19.0; $P < .001$), were more likely to require supplemental oxygenation on presentation (30.4% vs 49.9%; $P < .001$), and were more likely to receive blood transfusion (12.8% vs 27.3%; $P < .001$). Patients receiving SSRF had higher AIS for thorax (2.6 vs. 3.4; $P < .001$) and upper extremity (1.7 vs 1.8; $P < .001$) but lower AIS for head (2.4 vs 2.2; $P = .002$) and spine (2.2 vs 2.1; $P < .001$).

A comparison of in-hospital outcomes for those receiving nonoperative management and receiving SSRF is shown in [Table V](#). Patients receiving nonoperative management had higher mortality than those receiving SSRF (4.8% vs 2.5%; $P < .001$). Patients with SSRF had longer duration of stay (5.0 vs 13.0 days; $P < .001$), longer ICU stay (4.0 vs 8.0; $P < .001$), and were more likely to require mechanical ventilation (19.5% vs 52.7%; $P < .001$). Patients with SSRF had higher complication rates (19.5% vs 40.6%; $P < .001$), higher incidence of ARDS (1.0% vs 3.1%; $P < .001$), and were more likely to receive blood transfusions (27.3% vs 12.8%; $P < .001$). In addition to ARDS, transfusion-related acute lung injury represents an important complication of blood transfusions. However, there was only one patient with transfusion-related acute lung injury in our cohort.

ARDS

As shown in [Table II](#), the FC cohort was most likely to develop ARDS ($n = 151$, 3.0%) when compared with MR ($n = 815$, 1.0%) and SR ($n = 166$, 0.7%). Logistic regression examining variables associated with developing ARDS is shown in [Table VI](#). FC (odds ratio [OR]: 1.95, 95% confidence interval [CI]: 1.53–2.48; $P < .001$) and MR (OR 1.20, 95% CI: 1.01–1.42; $P = .04$), regardless of fixation, were associated with ARDS. Patients receiving SSRF of 3 or more ribs (OR: 2.00, 95% CI: 1.37–2.94; $P < .001$) were more likely to develop ARDS

as compared with nonoperative therapy. SSRF of 1 to 2 ribs was not associated with increased risk of ARDS (OR 1.55, 95% CI: 0.97–2.48; $P = .07$). Other variables associated with increased ARDS included male sex, transfusion of any blood component, and increasing ISS, as shown in [Table VI](#). Variables associated with decreased ARDS included higher Glasgow coma scale (GCS). On subset analysis of patients with FC alone, transfusion (OR 1.38, 95% CI 1.12–1.72; $P = .003$), but not SSRF (OR 1.40, 95% CI: 0.93–2.10; $P = .11$), was associated with ARDS ([Supplemental Table S1](#)).

[Supplemental Tables S2 to S3](#) demonstrate the results using our original dataset and omitting, not imputing, missing cases and is available online. There were no differences in conclusions between our imputed and original datasets.

Mortality

As shown in [Table II](#), mortality was highest in patients with FC (15.9%) as compared with MR (6.9%) and SR (4.7%); $P < .001$. Logistic regression examining variables associated with mortality is shown in [Table VII](#). Surgical stabilization of 1 to 2 ribs (OR: 0.17, 95% CI: 0.10–0.28; $P < .001$) or 3 or more ribs (OR: 0.17, 95% CI: 0.11–0.28; $P < .001$) was associated with decreased mortality when compared with nonoperative therapy. Having FC or MR was not associated with mortality. Variables associated with increased mortality included age, male sex, higher ISS, hypotension on presentation, requirement of transfusions, being uninsured, and having Medicare. Higher GCS was associated with decreased mortality, as shown in [Table VII](#). On logistic regression of patients with FC alone, SSRF was associated with decreased mortality ([Supplemental Table S4](#)). Significant variables in this model were not different when compared with our model without transfusion. There were no differences in conclusions between our imputed and original datasets ([Supplemental Tables S5–S6](#), available online).

Discussion

While SSRF remains controversial, recent guidelines and consensus statements have suggested that it can be an effective

Table 1
Baseline patient characteristics

	Flail chest (n = 5,106)	Multiple ribs fractured (n = 85,140)	Single rib fracture (n = 24,726)	P value
Age, median (IQR)	57.0 (33–79)	56.0 (28–84)	50.0 (17–83)	<.001
Sex (n, %)				<.001
Female	1,270 (24.9)	27,473 (32.3)	7,719 (31.2)	
Missing	1 (0.0)	7 (0.0)	6 (0.0)	
Race (n, %)				<.001
White	4,039 (79.1)	66,661 (78.3)	17,656 (71.4)	
American Indian	52 (1.0)	635 (0.7)	201 (0.8)	
Asian	63 (1.2)	1,512 (1.8)	434 (1.8)	
Black or African American	478 (9.4)	7,991 (9.4)	3,804 (15.4)	
Native Hawaiian or Other Pacific Islander	12 (0.2)	236 (0.3)	74 (0.3)	
Other Race	328 (6.4)	6,056 (7.1)	2,043 (8.3)	
Missing	134 (2.6)	2,049 (2.4)	514 (2.1)	
Plating (n, %)				<.001
Nonoperative treatment	4,293 (84.1)	84,316 (99.0)	24,697 (99.9)	
1–2 ribs	354 (6.9)	378 (0.4)	14 (0.1)	
3 or more ribs	459 (9.0)	446 (0.5)	15 (0.1)	
Method of payment (n, %)				<.001
Private insurance	2,250 (44.1)	35,852 (42.1)	9,692 (39.2)	
Medicaid	574 (11.2)	10,085 (11.8)	3,860 (15.6)	
Medicare	1,210 (23.7)	22,535 (26.5)	5,364 (21.7)	
Other insurance	328 (6.4)	5,837 (6.9)	1,778 (7.2)	
Self-pay	566 (11.1)	8,266 (9.7)	3,267 (13.2)	
Missing	178 (3.5)	2,565 (3.0)	765 (3.1)	
Injury severity score				<.001
Median (IQR)	22.0 (14.0)	14.0 (11.0)	9.0 (12.0)	
Missing (n, %)	2 (0.0)	64 (0.0)	27 (0.1)	
Abbreviated injury score* (mean, SD)				
Head	2.5 (1.3)	2.4 (1.2)	2.3 (1.2)	<.001
Face	1.4 (0.5)	1.3 (0.5)	1.3 (0.5)	.170
Neck	1.7 (0.9)	1.7 (1.0)	1.7 (1.0)	.998
Thorax	3.7 (0.7)	2.8 (0.6)	1.8 (1.0)	<.001
Abdomen/pelvis	2.4 (1.2)	2.2 (1.1)	2.2 (1.1)	<.001
Spine	2.2 (0.7)	2.2 (0.7)	2.2 (0.7)	.686
Upper extremity	1.8 (0.4)	1.7 (0.5)	1.6 (0.5)	<.001
Lower extremity	2.1 (1.0)	2.0 (0.9)	1.9 (0.9)	<.001
Blood pressure				
Presenting systolic median (IQR)	130.0 (39.0)	135.0 (34.0)	134.0 (33.0)	<.001
Hypotensive (n, %)	590 (11.8)	4,627 (5.5)	1,128 (4.6)	<.001
Missing (n, %)	128 (2.5)	1,837 (2.2)	478 (1.9)	
Presenting pulse				<.001
Median (IQR)	91.0 (32.0)	87.0 (26.0)	88.0 (27.0)	
Missing (n, %)	128 (2.5)	1,769 (2.1)	460 (1.9)	
Presenting respiratory rate				<.001
Median (IQR)	20.0 (7.0)	18.0 (5.0)	18.0 (4.0)	
Missing (n, %)	283 (5.5)	3,055 (3.6)	843 (3.4)	
Presenting oxygen saturation				<.001
Median (IQR)	96.0 (7.0)	97.0 (4.0)	98.0 (4.0)	
Missing (n, %)	353 (6.9)	4,557 (5.3)	1,159 (4.7)	
Supplemental oxygen required on presentation (n, %)				<.001
(n, %)	2,500 (49.0)	26,335 (30.9)	6,432 (26.0)	
Missing (n, %)	448 (8.8)	6,625 (7.8)	1,783 (7.2)	
Presenting GCS				<.001
Median (IQR)	15.0 (3.0)	15.0 (0.0)	15.0 (0.0)	
Missing (n, %)	159 (3.1)	3,272 (3.8)	832 (3.4)	

GCS, Glasgow coma scale; IQR, interquartile range; SD, standard deviation.

* For patients with recorded abbreviated injury scores in the region of interest.

method to treat rib fractures.² While the use of SSRF in trauma patients with rib fractures remains relatively low nationwide,⁶ there has been considerable increase in usage.¹⁷ Patients with rib fractures are known to develop a significant number of pulmonary complications.^{1,18} This study used a large, national database to examine whether SSRF was associated with the development of ARDS and mortality in trauma patients with rib fractures.

Our study demonstrated that there is an association with SSRF and ARDS. This association appears to be stronger with a greater number of ribs being plated as trauma patients with 3 or more ribs undergoing SSRF had a higher OR for ARDS (OR: 2.00, 95% CI: 1.37–2.94; $P < .001$). This is the first study to make this finding, as prior studies have found that there is no association between SSRF

and ARDS.¹⁹ Patients who received SSRF do appear to be a more severely injured group of patients because they had higher ISS and higher thoracic AIS. This may, at least in part, explain the increased observation of ARDS in the SSRF cohort, as prior studies have shown that severity and extent of pulmonary contusion correlates with development of ARDS.²⁰ Another potential explanation for this increased risk of ARDS with patients receiving SSRF is that the timing of surgery is not being optimized. A multicenter trial showed that when SSRF is performed within 1 day of admission, there are more favorable outcomes. While this study did not examine the incidence of ARDS, the likelihood of pulmonary complications such as pneumonia and prolonged mechanical ventilation increased with each additional hospital day before SSRF.

Table II
In-hospital outcomes

	Flail chest (n = 5,106)	Multiple ribs fractured (n = 85,140)	Single rib fracture (n = 24,726)	P value
Mortality	814 (15.9)	5,838 (6.9)	1,154 (4.7)	<.001
Duration of stay, median (IQR)	9.0 (12.0)	5.0 (7.0)	4.0 (5.0)	<.001
ICU days, median IQR	6.0 (11.0)	4.0 (6.0)	3.0 (4.0)	<.001
Required mechanical ventilation	2,224 (43.6)	16,692 (19.6)	4,017 (16.2)	<.001
Ventilator days (median, IQR)	7.0 (12.0)	4.0 (9.0)	3.0 (6.0)	<.001
Any complication	1,775 (34.8)	16,925 (19.9)	4,060 (16.4)	<.001
ARDS	151 (3.0)	815 (1.0)	166 (0.7)	<.001
Ventilator associated pneumonia	243 (4.8)	1,142 (1.3)	211 (0.9)	<.001
Acute kidney injury	167 (3.3)	1,034 (1.2)	168 (0.7)	<.001
Surgical site infection	65 (1.3)	471 (0.6)	170 (0.7)	<.001
Transfusion required	1,240 (24.3)	10,958 (12.9)	2,808 (11.4)	<.001

ARDS, acute respiratory distress syndrome; ICU, intensive care unit; IQR, interquartile range.

Table III
Comparison of disposition location

	Flail chest (n = 5,106)	Multiple ribs fractured (n = 85,140)	Single rib fracture (n = 24,726)	P value
Home	1,876 (36.7)	43,052 (50.6)	13,700 (55.4)	<.001
Home with home health services	364 (7.1)	6,451 (7.6)	1,699 (6.9)	<.001
Psychiatric facility	10 (0.2)	316 (0.4)	158 (0.6)	<.001
Short-term inpatient hospital	122 (2.4)	1,444 (1.7)	339 (1.4)	<.001
Intermediate care facility	31 (0.6)	318 (0.4)	70 (0.3)	<.001
Long-term care hospital	210 (4.1)	1,253 (1.5)	214 (0.9)	<.001
Inpatient rehab	838 (16.4)	11,082 (13.0)	2,750 (11.1)	<.001
Hospice	32 (0.6)	461 (0.5)	104 (0.4)	<.001
Skilled nursing facility	601 (11.8)	9,748 (11.5)	2,176 (8.8)	<.001
Left against medical advice	24 (0.5)	700 (0.8)	287 (1.2)	<.001
Discharge to court of law enforcement	9 (0.2)	374 (0.4)	219 (0.9)	<.001
Other discharge location	39 (0.8)	736 (0.9)	184 (0.7)	<.001

Our study did not evaluate the timing of SSRF. ARDS develops owing to the release of inflammatory cytokines in the alveolar space.²¹ Cytokines such as TNF- α , IFN- γ , and Interleukin-6 play a key role in the inflammatory process that drives ARDS. These cytokines are generally increased in patients who undergo surgery.^{22–24} In addition, general anesthesia also increases the release of these inflammatory mediators.^{25,26} The combination of general anesthesia, the resulting tissue trauma from surgery, and a patient population already at increased risk of ARDS owing to chest trauma may drive the release of cytokines that further increases risk of ARDS after SSRF. More studies are needed to determine if SSRF may worsen or trigger the development of these inflammatory mediators.

In our study, blood transfusions were found to be associated with the development of ARDS. This is consistent with several other studies that have shown that transfusion increases the risk of developing ARDS.^{27,28} Our study also corroborated that patients with more severe chest wall injuries were associated with ARDS.²⁹ We found that patients with FC were most likely to

Table IV
Comparison of patients receiving nonoperative therapy or SSRF

	No SSRF (n = 113,292)	SSRF (n = 1,667)	P value
Age, (median, IQR)	55.0 (30.0)	55.0 (20.0)	.773
Sex (n, %)			<.001
Female	36,025 (31.8)	437 (26.2)	
Missing	14 (0.0)	0 (0.0)	
Race (n, %)			<.001
White	86,958 (76.7)	1,398 (83.9)	
American Indian	865 (0.8)	23 (1.4)	
Asian	1,991 (1.8)	18 (1.1)	
Black or African American	12,173 (10.7)	100 (6.0)	
Pacific Islander	321 (0.3)	1 (0.1)	
Other race	8,329 (7.4)	98 (5.9)	
Missing	2,669 (2.4)	28 (1.7)	
Ethnicity (n, %)			<.001
Hispanic/Latino	11,482 (10.1)	125 (7.5)	
Missing	7,118 (6.3)	71 (4.3)	
Fracture type (n, %)			<.001
Single rib fracture	24,697 (21.8)	29 (1.7)	
Flail chest	4,293 (3.8)	813 (48.8)	
Multiple rib fractures	84,316 (74.4)	824 (49.5)	
Method of payment (n, %)			<.001
Private insurance	46,987 (41.5)	807 (48.4)	
Medicaid	14,338 (12.7)	181 (10.9)	
Medicare	28,762 (25.4)	347 (20.8)	
Other	7,819 (6.9)	124 (7.4)	
Self-pay	11,950 (10.5)	149 (8.9)	
Missing	3,450 (3.0)	58 (3.5)	
Injury severity score			<.001
Median (IQR)	14.0 (10.0)	19.0 (13.0)	
Missing (n, %)	93 (0.0)	0 (0.0)	
Abbreviated injury score (mean, SD) [*]			
Head	2.4 (1.2)	2.2 (1.1)	.002
Face	1.3 (0.5)	1.3 (0.5)	.833
Neck	1.7 (1.0)	1.7 (0.9)	.657
Thorax	2.6 (0.9)	3.4 (0.7)	<.001
Abdomen/pelvis	2.3 (1.1)	2.3 (1.1)	.063
Spine	2.2 (0.7)	2.1 (0.5)	<.001
Upper extremity	1.7 (0.5)	1.8 (0.4)	<.001
Lower extremity	2.0 (0.9)	2.0 (0.9)	.249
Blood pressure			
Presenting systolic, median (IQR)	135.0 (34.0)	130.0 (38.0)	<.001
Hypotensive on arrival (n, %)	6,236 (5.5)	109 (6.5)	.074
Missing (n, %)	2,408 (2.1)	35 (2.1)	
Presenting pulse			<.001
Median (IQR)	88.0 (27.0)	94.0 (29.0)	
Missing (n, %)	2,305 (2.0)	52 (3.1)	
Presenting respiratory rate			<.001
Median (IQR)	18.0 (5.0)	20.0 (6.0)	
Missing (n, %)	4,122 (3.6)	59 (3.5)	
Presenting oxygen saturation			<.001
Median (IQR)	97.0 (4.0)	96.0 (6.0)	
Missing (n, %)	5,994 (5.3)	75 (4.5)	
Supplemental oxygen given at presentation (n, %)	34,436 (30.4)	831 (49.9)	<.001
Missing (n, %)	8,719 (7.7)	137 (8.2)	
Presenting GCS			.01
Median (IQR)	15.0 (0.0)	15.0 (1.0)	
Missing (n, %)	4,223 (3.7)	40 (2.4)	

GCS, Glasgow coma scale; IQR, interquartile range; SSRF, surgical stabilization of rib fractures.

^{*} For patients with recorded abbreviated injury scores in the region of interest.

develop ARDS, followed by those with MR, regardless of surgical fixation. In addition, we found that SSRF of 1 to 2 ribs was not associated with ARDS, while 3+ was. While this observation needs further investigation, it is possible that fixation of more ribs results in greater tissue trauma and longer duration of general anesthesia, which may increase the release of inflammatory mediators that drive ARDS. Interestingly, our logistic regression of patients solely with FC showed that SSRF was not

Table V
In-hospital outcomes for patients receiving nonoperative therapy or SSRF

	No SSRF (n = 113,292)	SSRF (n = 1,666)	P value
Mortality	5,438 (4.8)	42 (2.5)	<.001
Duration of stay, median (IQR)	5.0 (7.0)	13.0 (11.0)	<.001
ICU d, median IQR	4.0 (6.0)	8.0 (11.0)	<.001
Required mechanical ventilation	22,055 (19.5)	878 (52.7)	<.001
Ventilator days (median, IQR)	7.8 (9.7)	10.1 (9.1)	<.001
Any complication	22,083 (19.5)	677 (40.6)	<.001
ARDS	1,080 (1.0)	52 (3.1)	<.001
Ventilator associated pneumonia	1,505 (1.3)	91 (5.5)	<.001
Acute kidney injury	1,309 (1.2)	60 (3.6)	<.001
Surgical site infection	664 (0.6)	42 (2.5)	<.001
Transfusion required	14,551 (12.8)	455 (27.3)	<.001

ARDS, Acute respiratory distress syndrome; ICU, intensive care unit; IQR, interquartile range; SSRF, surgical stabilization of rib fractures.

Table VI
Logistic regression examining variables associated with ARDS

	Odds ratio	95% confidence interval	P value
Plating (reference: nonoperative)	-	-	-
1–2 ribs	1.55	0.97–2.48	.07
3 or more ribs	2.00	1.37–2.94	<.001
Male sex	1.78	1.53–2.06	<.001
Injury severity score	1.03	1.03–1.04	<.001
Presenting Glasgow coma scale	0.96	0.95–0.97	<.001
Transfusion	3.33	2.92–3.79	<.001
Injury type (ref: single rib fracture)	-	-	-
Flail chest	1.95	1.53–2.48	<.001
Multiple ribs fractured	1.20	1.01–1.42	.04

ARDS, Acute respiratory distress syndrome.

associated with ARDS. This may help explain why patients with FC appear to benefit the most from SSRF when compared with other patient populations.^{2,7–9}

This study observed that SSRF was associated with improved survival, a finding that has not been demonstrated in prior studies. One potential explanation is that there has been a considerable increase in knowledge and improvement in techniques with SSRF, leading to improved outcomes not seen in prior studies. While studies are beginning to show a benefit in early SSRF,³⁰ patients who receive early rib plating are unlikely to have severe injuries that place the patient at risk for death, making it difficult to demonstrate a survival advantage. Further studies are needed to examine whether there is a subset of patients with rib fractures who may actually have improved survival with SSRF. Other variables found to be associated with increased mortality in this study were consistent with prior research, such as being uninsured. These health disparities have been well documented in the trauma literature.^{31–34}

Patients with 3 or more rib fractures have increased pulmonary complications, leading some authors to conclude that patients with 3 or more rib fractures should be hospitalized.³⁵ While patients with 3 or more rib fractures could not be specifically identified in the NTDB, patients with MR, but not FC, clearly had worse outcomes than those with SR. We found these patients to have higher total complication rates and to be independently associated with mortality. These findings, along with other studies,³⁵ suggest that hospitalization should be considered for patients with more than 1 rib fracture.

Interestingly, this study showed that SSRF patients have longer hospital and ICU duration of stay. However, this is likely a marker of more severe injury as these patients were more likely

Table VII
Logistic regression examining variables associated with mortality

	Odds ratio	95% confidence interval	P value
Plating (ref: nonoperative)	-	-	-
Rib plating 1–2 ribs	0.17	0.10–0.28	<.001
Rib plating 3 or more ribs	0.17	0.11–0.28	<.001
Age	1.04	1.04–1.05	<.001
Male sex (ref: female)	1.20	1.12–1.29	<.001
Injury severity score	1.07	1.07–1.07	<.001
Hypotension on presentation	3.94	3.63–4.27	<.001
Presenting Glasgow coma scale	0.77	0.77–0.78	<.001
Transfusion	1.56	1.45–1.67	<.001
Injury type (ref: single rib fracture)	-	-	-
Flail chest	0.98	0.85–1.13	.78
Multiple ribs fractured	0.92	0.85–1.00	.05
Method of payment (ref: private insurance)	-	-	-
Uninsured	2.26	2.05–2.50	<.001
Medicaid	0.92	0.83–1.03	.13
Medicare	1.39	1.28–1.52	<.001
Other insurance	1.10	0.96–1.25	.17

to have FC and had higher ISS. Prior studies have shown that early SSRF leads to decreased chest tube time, shorter time in the ICU,³⁶ and decreased pleural space complications.³⁰ While the NTDB could not be used to specifically measure pain control, previous work has suggested that SSRF may result in improved pain for patients with rib fractures. More specifically, SSRF resulted in decreased use of epidurals.⁶ For patients who do not have FC, early rib plating resulted in decreased numeric pain score at 2 weeks.³⁰ Further studies are needed to determine which patient population with rib fractures may have improved pain control with SSRF and optimal timing for SSRF to reduce pain and minimize duration of stay.

This study was not without limitations, including those related to retrospective analysis of large, administrative databases. Such large data sets rely on accurate reporting and coding. While we cannot confirm that the data is devoid of coding errors, any such errors are likely random and unlikely to create bias with such a large sample size. In addition, information on mortality is limited to the initial hospitalization, which prevents any long-term survival analysis. The NTDB does not have detailed information on timing of SSRF, so we could not determine which patients had early SSRF and whether there was any benefit. Another limitation is the use of ISS to adjust for injury severity. In addition, using ICD-10 codes allows for identification of patients who have had 1 to 2 ribs undergoing SSRF or 3 or more ribs undergoing SSRF and does not provide any further detail about number of ribs undergoing SSRF. Finally, the NTDB does not allow us to examine the temporal relationship between the development of ARDS and SSRF surgery.

In conclusion, SSRF was associated with improved survival for patients with rib fractures. However, SSRF appears to be associated with ARDS, a finding most pronounced in patients with SSRF of 3 or more rib fractures. Patients with rib fractures receiving blood transfusion were associated with higher incidence of ARDS. Further studies are needed to determine if SSRF leads to inflammatory changes that can lead to ARDS.

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Supplementary Materials

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