Early surgical stabilization of multiple rib fractures and flail chest is associated with better outcomes compared with nonoperative management

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BACKGROUND: Surgical stabilization of rib fractures (SSRF) is increasingly performed. Nationwide data comparing its outcomes with nonoperative management (NOM) and defining the best timing for SSRF are scarce.

METHODS: We analyzed data from the American College of Surgeons Trauma Quality Improvement Program, 2017–2021. Adults with three or more blunt rib fractures and no major extrathoracic injury were included. Surgical fixation was compared with risk-weighted NOM using inverse probability of treatment weighting. Primary outcome was in-hospital mortality. Secondary outcomes were hospital and intensive care length of stay, ventilator duration, ventilator-free days, acute respiratory distress syndrome, and ventilator-associated pneumonia. Subgroup analyses examined flail chest and the impact of timing of fixation, which was modeled as a continuous exposure with a generalized additive spline; its discriminatory performance was evaluated with receiver-operating-characteristic curve analysis to calculate the Youden's index.

RESULTS: A total of 3,806 patients underwent SSRF, and 3,753 weighted controls received NOM. After weighting, an association of SSRF with lower mortality (1.5% vs. 2.7%, $p < 0.001$) but longer hospital (median, 10 vs. 5 days) and intensive care stays (5 vs. 3 days, both $p < 0.001$) were observed. In the flail chest subgroup, SSRF was associated with a mortality of 4.2% compared with 10.1% with NOM ($p = 0.002$). In the nonflail group, mortality was 1.3% after SSRF versus 2.0% in NOM ($p = 0.003$). Early SSRF within 82 hours had similar mortality to delayed fixation (1.6% vs. 1.4%, $p = 0.647$). However, early SSRF was associated with lower rates of acute respiratory distress syndrome (0.5% vs. 1.5%), ventilator-associated pneumonia (0.9% vs. 2.3%), and shorter hospital stays compared with delayed SSRF.

CONCLUSION: Nationwide data demonstrated that SSRF is associated with higher survival, particularly in patients with flail chest, at the cost of increased resource utilization. Surgical stabilization of rib fractures performed within 82 hours is associated with higher survival, lower pulmonary morbidity, and additional resource utilization. (*J Trauma Acute Care Surg.* 2025;99: 859–867. Copyright © 2025 Wolters Kluwer Health, Inc. All rights reserved.)

LEVEL OF EVIDENCE: Therapeutic/Care Management; Level III.

KEY WORDS: Multiple rib fractures; flail chest; SSRF; trauma; pulmonary complications.

Rib fractures represent one of the most prevalent injuries in trauma, occurring in approximately 10% of all trauma patients and up to 55% of individuals with blunt chest trauma.[1] While mortality associated with isolated rib fractures has steadily declined over the past two centuries, a large-scale study by Jones et al.[2] reported that multiple rib fractures still carry a mortality rate of approximately 3%. Standard conservative management includes aggressive pain control, adequate pulmonary toilet, chest physiotherapy, and, if respiratory failure worsens, endotracheal intubation and mechanical ventilation are used.[3]

Although most rib fractures can be managed conservatively, patients with multiple rib fractures, including those with flail chest, are at higher risk for prolonged mechanical ventilation, prompting growing interest in the surgical stabilization of rib fractures (SSRF). Recent studies have shown that SSRF can prevent rib shortening and displacement, alleviate fracture pain, and reduce the risk of nonunion, thereby potentially contributing to better pain relief and functional recovery.[4,5] These benefits have led to an increasing trend in SSRF procedures nationwide.[6]

Despite this growth, the national utilization of SSRF varies significantly among centers. According to a recent analysis from the Chest Wall Injury Society collaborative centers, only about 7% of rib fracture patients underwent SSRF at dedicated centers.[7] This discrepancy likely reflects that SSRF is still largely driven by individual surgeons and institutions, and universal guidelines for

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patient selection and timing have not yet been established.[8] For instance, while numerous studies have demonstrated that patients with flail chest benefit from SSRF, there is ongoing debate regarding which subgroups of multiple rib fracture patients without flail chest derive a clear advantage.[4] Furthermore, the optimal timing of surgery has not been definitively established. Although early surgical intervention has been increasingly associated with a reduced need for prolonged mechanical ventilation, various studies use definitions of "early" and "delayed" SSRF arbitrarily, and the reported impact on clinical outcomes remains inconsistent.[9]

Importantly, there is a shortage of large-scale, generalizable data not constrained by geographic region, center type, or individual surgeon. Therefore, we conducted a study using a Trauma Quality Improvement Program (TQIP) database to compare clinically relevant outcomes in patients with multiple rib fractures managed either by SSRF or by nonoperative management (NOM). In particular, we aimed to determine the effect of flail chest on outcomes and to explore whether early versus delayed SSRF might influence key clinical endpoints, thereby providing clearer guidance on optimal timing and patient selection for SSRF.

PATIENTS AND METHODS

Data Source

We used the TQIP data set, developed by the American College of Surgeons. Trauma quality improvement program gathers nationwide trauma center data, providing risk-adjusted benchmarking to facilitate performance improvement. This data set includes detailed patient records submitted by participating centers, enabling comprehensive analysis and comparison of trauma care outcomes.[10]

Study Design

From 2017 through 2021, we performed a retrospective cohort analysis focusing on adult patients who presented with at least three rib fractures following blunt trauma. To select thoracic injuries, we excluded individuals with an Abbreviated Injury Scale (AIS) score of 3 or higher in other nonthoracic body regions. Patients who died in the ED or were discharged, transferred, or left against medical advice at ED disposition were excluded. Patients arriving as interfacility transfers were also omitted to maintain consistency in treatment pathways and data collection (Fig. 1).

Multiple rib fractures were determined using the following *International Classification of Diseases, Tenth Revision*, codes: S22.4 (multiple rib fractures; subcategories 41, 42, 43, and 49) and S22.5 (flail chest). In addition, flail chest patients were also identified using AIS predot codes (450209, 450211, 450212, 450213, 450214, 450260, 450262, 450264, 450266). Surgical stabilization of rib fractures was identified by procedure codes 0PS104Z, 0PS134Z, 0PS144Z, OPS204Z, 0PS234Z, and 0PS244Z. Subjects were categorized into SSRF and NOM groups, and outcomes were compared between these cohorts. Subgroup analyses stratified patients by the presence or absence of flail chest. Additionally, within the SSRF cohort, we further examined whether the timing of surgery affected clinical endpoints.

Variables and Outcomes

Key clinical information included demographic profile, Glasgow Coma Scale (GCS) score, region-specific AIS data,

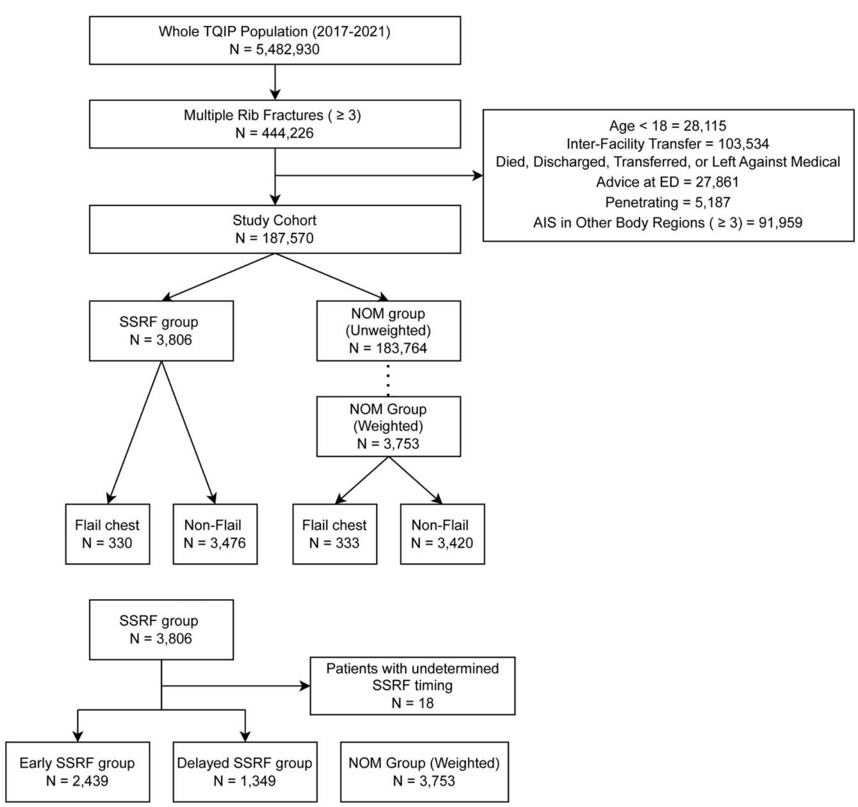

Figure 1. Study flowchart.

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and the overall Injury Severity Score (ISS). Admission vital signs and preexisting comorbidities were collected to address potential confounders. The primary outcomes were in-hospital mortality and health care resource utilization, encompassing total hospital length of stay, intensive care unit (ICU) length of stay, ICU-free days, duration of mechanical ventilation, and ventilator-free days. Ventilator-free days were calculated as 28 total ventilator days. Patients who stayed on a ventilator for >28 days or who experienced in-hospital mortality were assumed to have zero ventilator-free days. Secondary outcomes centered on pulmonary complications: acute respiratory distress syndrome (ARDS), ventilator-associated pneumonia (VAP). Acute respiratory distress syndrome and VAP were extracted from recorded hospital events.

Statistical Analysis

A comparison of patient characteristics and outcomes between multiple rib fracture patients undergoing SSRF and NOM was examined. Categorical variables were reported as counts and column proportions. χ^2 Analysis assessed categorical variables, while one-tailed Fisher's exact test was used to examine categorical variables with less than five incidences. Continuous variables were reported as medians and interquartile ranges and analyzed using Mann-Whitney *U* tests. Variables such as ISS were recategorized based on clinical impact: ISS <9, minor; 9 to 15, moderate; 16 to 24, severe; and 25+, very severe.

Missing Data

The Markov Chain Monte Carlo method imputed patient admission vitals such as systolic blood pressure, pulse rate, and respiratory rate. Patient demographics, comorbidities, and known respiratory complications were used to impute missing data patterns. Data were imputed in five iterations, and the fifth iteration was used for data analysis. Continuous variables missing more than 30% were deemed highly missing and thus removed from secondary analysis and not imputed.

Inverse Probability of Treatment Weighting

Inverse probability of treatment weighting was used to balance the NOM cohort and compare it to the SSRF group. A binomial logistic regression model examining risk factors for SSRF among multiple rib fracture adult patients was used to capture patients' probability of having rib fixation. Variable selection for the model included factors that were significantly different at admission between SSRF and NOM cohorts, including age, sex, white race, ISS, total GCS, thorax AIS, bilateral fracture, presence of flail chest, other body region injuries, and other significantly different comorbidities between the cohorts. The model's produced probabilities (p) were adjusted inversely and calculated into data point weights for the NOM cohort as ($p/1-p$). Surgical stabilization of rib fractures cohort patients' data points carried a weight of one to observe the average treatment effect on the treated. Outcomes were then examined using complex logistic regression, controlling for potentially unbalanced covariates in the newly weighted data.

Multilevel Logistic Regression

A multilevel logistic regression model was used to assess outcomes of interest while accounting for the potential nesting of outcomes within trauma centers. Facility identifiers were extracted from the database and categorized based on the number of rib fixations done within the extracted data. Trauma centers without recorded rib fixations in the data range 2017 to 2021 were excluded from the secondary analysis. Trauma centers were grouped by SSRF case volume during 2017 to 2021 into high (≥10 cases), medium (4–9 cases), and low (1–3 cases) volume categories. Mortality and presence of respiratory complication (ARDS/VAP) were assessed in the weighted data using complex sample generalized linear-mixed models (GLMMs) between SSRF and NOM while controlling for age, female sex, White race, chest AIS, ISS, presence of head injury, abdominal injury, spinal injury, fracture bilaterality, radiographic flail chest, total GCS, systolic blood pressure, and respiratory rate and accounting for the number of SSRF cases performed. Based on clinical relevance, confounders were included to ensure a balance between the two cohorts.

GAM and Receiver Operating Characteristic Analysis

Generalized additive models (GAMs) were used to examine unadjusted differences in outcomes based on time (hours) to SSRF. The GAM model identified an exponential association between complications (specifically ARDS and VAP) and time to SSRF. Receiver operating characteristic curve analysis was used to examine the outcomes of mortality, ARDS, VAP, and a composite complication variable (ARDS/VAP). The Youden's index was then used to determine the exact cutoff point to differentiate between early and delayed SSRF. Patients were then stratified into early versus delayed SSRF and compared with NOM to examine potential differences in mortality, hospital resource utilization, and respiratory complications.

Survival Analysis

Cox regression time-dependent models were also used to validate findings and assess hazard ratio differences between flail chest and nonflail chest patients while adjusting for potential risk factors associated with delayed SSRF. Variables in the Cox regression model were selected based on clinical significance: age, sex, flail chest, admission systolic blood pressure, respiratory rate, pulse rate, history of hypertension, chronic heart failure, chronic obstructive pulmonary disease, diabetes, functional dependency in health, total GCS, and categorized ISS. Generalized additive model analysis was conducted using XLSTAT 2024 Statistical Software for Excel (Lumivero, Denver, CO). All other statistical analyses were conducted using SPSS, V.29 (IBM Corp., Armonk, NY).

Ethical Considerations

Because the analysis was conducted using deidentified information from a publicly accessible database, the study was exempt from approval by the institutional review board. All study procedures and reporting conformed to the guidelines set forth by the STROBE. A completed STROBE checklist is provided as Supplemental Digital Content (Supplementary Data 1, http://links.lww.com/TA/E765).

RESULTS

A total of 3,806 patients underwent SSRF, compared with 183,764 unweighted NOM patients. After applying inverse

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probability of treatment weighting, the NOM cohort included 3,753 comparable patients. Key demographic and clinical data for these groups are summarized in Table 1.

Overall Comparison: SSRF and NOM

In the unweighted sample, the SSRF group contained a higher proportion of men and a slightly lower median age. After inverse probability of treatment weighting (IPTW), sex distribution no longer differed, whereas a small but statistically significant age difference persisted. Surgical stabilization of rib fractures patients had greater injury severity in the unweighted comparison, yet ISS distributions were well balanced after IPTW ($p = 0.720$). Mortality did not differ in the unweighted analysis (1.5% vs. 1.6%, $p = 0.581$) but was significantly lower among SSRF patients after weighting (1.5% vs. 2.7%, $p < 0.001$). Despite this survival advantage, SSRF was associated with increased resource utilization: median hospital length of stay was 10 days for SSRF versus 5 days for weighted NOM, and median ICU stay was 5 days versus 3 days (both $p < 0.001$). Surgical stabilization of rib fractures patients also required a higher number of mechanical ventilation days (median, 5 vs. 4 days; $p < 0.001$); however, because more SSRF patients survived through the study period, they experienced more ventilator-free days (25 vs. 23, $p < 0.001$). Regarding pulmonary complications, rates of ARDS were comparable after IPTW, whereas ventilator-associated pneumonia remained more frequent among SSRF patients (Table 1).

Stratified Analysis Comparing Flail and Nonflail Chest After IPTW

In the flail chest cohort (330 SSRF, 333 NOM), SSRF was associated with lower mortality (4.2% vs. 10.1%, $p = 0.002$). Surgical patients required greater resources, with longer median hospital stay (14 vs. 9 days, $p < 0.001$) and ICU stay (8 vs. 5 days, $p < 0.001$). Ventilator-free days favored SSRF (21 vs. 18 days, $p < 0.001$), whereas ICU-free days did not differ ($p = 0.077$). Acute respiratory distress syndrome rates were identical ($p = 0.945$), and the increase in VAP after SSRF did not reach statistical significance ($p = 0.055$) (Table 2).

In the nonflail cohort (3,476 SSRF, 3,420 NOM), SSRF similarly conferred a mortality reduction (1.3% vs. 2.0%, $p = 0.003$) but entailed longer hospital (10 vs. 5 days, $p < 0.001$) and ICU stays (5 vs. 3 days, $p < 0.001$). Intensive care unit–free days were comparable ($p = 0.940$). Surgical stabilization of rib fractures patients required more ventilator days (5 vs. 3 days, $p < 0.001$) yet still exhibited higher ventilator-free days overall ($p < 0.001$). Acute respiratory distress syndrome incidence remained low and similar between groups ($p = 0.067$), whereas VAP was more frequent following SSRF ($p < 0.001$) (Table 2).

TABLE 1. Comparison of Demographics and Outcomes Between SSRF and NOM Groups

	SSRF (n = 3,806)	NOM (UW) (n = 183,764)	NOM (W) (n = 3,753)	p** (UW)	p† (W)
Male, n (%)	2,797 (73.5)	120,989 (65.8)	2,773 (73.9)	<0.001	0.665
Age*	58 (48–68)	61 (48–73)	58 (45–70)	<0.001	0.003
ISS				<0.001	0.976
Minor (1–8), n (%)	0 (0)	0 (0)	0 (0)		
Moderate (9–15), n (%)	2,541 (66.8)	149,114 (81.1)	2,499 (66.6)		
Severe (16–24), n (%)	1,192 (31.3)	33,614 (18.3)	1,181 (31.5)		
Very severe (25–75), n (%)	73 (1.9)	1,036 (0.6)	73 (1.9)		
Median (interquartile range)	14 (10–17)	13 (10–14)	14 (10–17)	<0.001	0.720
GCS*	15 (15–15)	15 (15–15)	15 (15–15)	0.009	0.765
Systolic blood pressure*	136 (120–153)	140 (124–157)	136 (120–153)	<0.001	0.315
Pulse rate*	88 (75–101)	85 (73–97)	88 (76–101)	<0.001	0.501
Respiratory rate*	20 (18–24)	18 (17–20)	20 (18–22)	<0.001	0.810
Bilateral fractures, n (%)	635 (16.7)	28,630 (15.6)	618 (16.5)	0.063	0.738
Flail chest, n (%)	330 (8.7)	1,186 (0.6)	333 (8.9)	<0.001	0.723
Mortality, n (%)	58 (1.5)	3,011 (1.6)	101 (2.7)	0.581	<0.001
Discharged home, n (%)	2,594 (68.2)	133,818 (72.8)	2,689 (71.6)	<0.001	<0.001
Hospital LOS*	10 (8–14)	4 (3–7)	5 (3–8)	<0.001	<0.001
ICU LOS*	5 (3–9)	3 (2–5)	3 (2–6)	<0.001	<0.001
ICU-free days*	25 (21–27)	27 (25–28)	27 (23–28)	<0.001	0.012
Total ventilator days*	5 (3–11)	3 (2–8)	4 (2–10)	<0.001	<0.001
Ventilator-free days*	25 (18–27)	25 (0–28)	23 (0–28)	0.154	<0.001
ARDS, n (%)	33 (0.9)	522 (0.3)	26 (0.7)	<0.001	0.233
VAP, n (%)	52 (1.4)	482 (0.3)	28 (0.7)	<0.001	<0.001

*Median (interquartile range).

**Pearson's χ^2 test was used to analyze categorical variables, while Mann-Whitney U tests were used for continuous variables.

†Log transformations of the continuous variables were done to account for nonnormality and examined using generalized linear model tests, while complex sample χ^2 tests were used for categorical variables.

LOS, length of stay; UW, unweighted; W, weighted.

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TABLE 2. Stratified Analysis of Outcomes Between SSRF and NOM in Nonflail and Flail Chest Patients (Weighted Data)

	Flail Chest			Non-Flail Chest		
	SSRF (n = 330)	NOM (n = 333)	p**	SSRF (n = 3,476)	NOM (n = 3,420)	p**
Mortality, n (%)	14 (4.2)	34 (10.1)	0.002	44 (1.3)	67 (2.0)	0.003
Discharged home, n (%)	168 (50.9)	174 (52.1)	0.712	2,426 (69.8)	2,515 (73.5)	<0.001
Hospital LOS*	14 (10–21)	9 (6–15)	<0.001	10 (7–14)	5 (3–8)	<0.001
ICU LOS*	8 (5–15)	5 (3–11)	<0.001	5 (3–8)	3 (2–5)	<0.001
ICU-free days*	21 (13–25)	24 (12–27)	0.077	25 (21–27)	27 (24–28)	0.940
Total ventilator days*	9 (4–15)	6 (3–15)	0.071	5 (3–9)	3 (2–8)	<0.001
Ventilator-free days*	21 (13–26)	18 (0–26)	<0.001	25 (19–27)	25 (7–28)	<0.001
ARDS, n (%)	12 (3.6)	12 (3.6)	0.945	21 (0.6)	14 (0.4)	0.067
VAP, n (%)	23 (7.0)	14 (4.2)	0.055	29 (0.8)	14 (0.4)	<0.001

*Median (interquartile range).
**Log transformations of the continuous variables were done to account for nonnormality and examined using generalized linear model tests, while complex sample χ^2 tests were used for categorical variables.
LOS, length of stay.

GLMM of Predictors for Mortality and ARDS/VAP

A GLMM, clustered by facility, identified several independent predictors of hospital mortality and the composite pulmonary outcome (ARDS/VAP). Advanced age, male sex, elevated pulse and respiratory rates, lower systolic blood pressure, lower GCS score, and higher thoracic AIS were all associated with increased odds of death. Flail chest approached, but did not reach, statistical significance for mortality (p = 0.052), yet it was strongly associated with ARDS/VAP.

The effect of SSRF varied according to institutional case volume. Compared with NOM, SSRF performed in hospitals undertaking 10 or more procedures during the study period was associated with lower mortality (odds ratio [OR], 0.67; 95% confidence interval [CI], 0.46–0.97; p = 0.032). A greater survival advantage was observed at centers completing four to nine procedures (OR, 0.40; 95% CI, 0.20–0.81; p = 0.011), whereas no mortality difference was found in low-volume facilities performing one to three SSRF operations (p = 0.223). In contrast, SSRF undertaken at medium- and high-volume centers was linked to higher odds of ARDS/VAP (OR, 2.71 and 1.56, respectively; both $p < 0.05$), while the association was not significant in low-volume institutions (Fig. 2).

Together, these findings indicate that patient physiology, injury severity, and center-level operative experience all relate

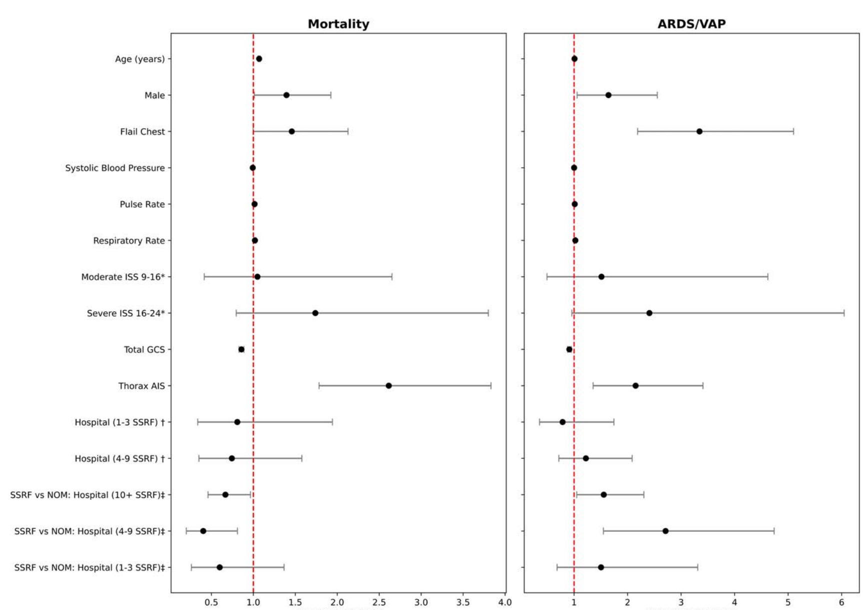

Figure 2. Comparison of risk factors associated with mortality and ARDS/VAP: a GLMM analysis. Adjusted ORs from the generalized linear mixed-effects model. Left, predictors of hospital mortality. Right, predictors of the composite pulmonary outcome (ARDS or VAP). Dots represent point estimates; horizontal bars show 95% CIs; the dotted line denotes an OR of 1 (no effect). *ISS 25+ is the reference category for injury severity; †high-volume hospitals (≥10 SSRF procedures during the study period) serve as the facility reference; ‡NOM is the treatment reference. Facilities reporting 0 SSRF cases were excluded from the model.

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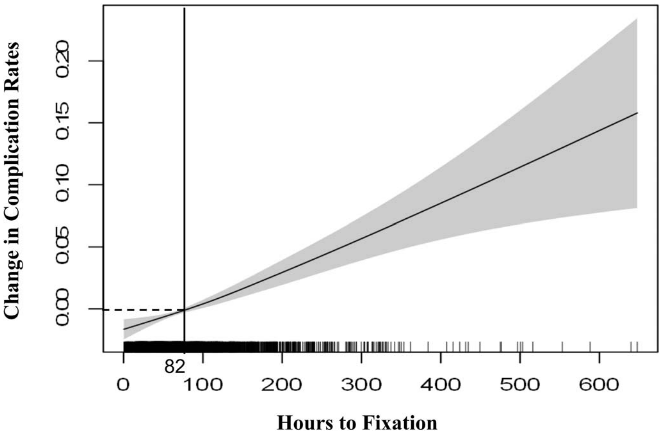

Figure 3. Generalized additive model assessing composite complications (ARDS/VAP) over hours to SSRF. Generalized additive model showing the adjusted change in ARDS/VAP risk as a function of hours from admission to surgical rib fixation. The solid line depicts the fitted spline, and the shaded band, its 95% CI; tick marks along the *x* axis indicate individual times of SSRF. The vertical line at 82 hours represents the data-derived threshold separating early and delayed surgery.

to outcomes, with the mortality benefit of SSRF limited to hospitals that perform the procedure with at least moderate frequency.

Timing-Threshold Analysis for Early Versus Delayed SSRF Using a GAM

A GAM was applied with "hours from admission to fixation" entered as a smoothed term. For the composite pulmonary end point (ARDS/VAP), the spline rose steadily once fixation was delayed beyond roughly 80 hours, and the 95% confidence band no longer included zero after 100 hours (Fig. 3). Receiver operating characteristic analysis identified 82 hours as the optimal cutoff point (Youden's index) for distinguishing early from delayed fixation. In contrast, the time-mortality curve followed a similar trajectory but did not reach statistical significance, indicating that the association between a potential time sensitive benefit of early SSRF may be related to less pulmonary complications instead of an association with improved survival (Fig. 3).

Timing of SSRF and Outcomes: Early SSRF, Delayed SSRF, and Weighted NOM

Among patients who underwent SSRF, 2,439 were treated within 82 hours of admission (early SSRF) and 1,349 after 82 hours (delayed SSRF); 3,753 weighted controls received NOM. Mortality did not differ between early and delayed fixation (1.6% vs. 1.4%, $p = 0.647$), but both surgical cohorts exhibited lower mortality than NOM (2.7%; $p = 0.001$ and 0.004, respectively). Early fixation was associated with the highest rate of discharge to home, significantly exceeding delayed SSRF (72.0% vs. 61.2%, $p < 0.001$) and comparable with NOM (71.6%). Increased surgical delay was associated with increased resource utilization. The median hospital and ICU length of stay were longest after delayed SSRF (13 and 7 days), intermediate with early SSRF (9 and 5 days), and shortest with NOM (5 and 3 days; all $p < 0.001$). Correspondingly, ICU-free and ventilator-free days decreased as SSRF was deferred, whereas total ventilator days increased. Pulmonary complications displayed a similar temporal pattern. Acute respiratory distress syndrome and VAP rates were lowest after early SSRF (0.5% and 0.9%), intermediate with NOM (0.7% and 0.7%), and highest after delayed SSRF (1.5% and 2.3%). Differences between early and delayed SSRF were significant for complications ($p \leq 0.003$). Delayed SSRF was associated with higher complication rates than NOM ($p \leq 0.001$), whereas early SSRF was not. Collectively, these findings indicate that SSRF performed within 82 hours is associated with a survival advantage, decreased pulmonary morbidity (ARDS, $p = 0.003$; VAP, $p < 0.001$), and reduced resource utilization ($p < 0.001$) compared with delayed surgery (Table 3).

DISCUSSION

In this study, SSRF was linked to a lower mortality rate compared with NOM but was also associated with increased hospital resource utilization, including longer hospital and ICU

TABLE 3. Comparison of Patient Demographics, Clinical Characteristics, and Outcomes Based on Timing of SSRF and Treatment Options (Weighted Data)

	Early SSRF (n = 2,439)	Delayed SSRF (n = 1,349)	NOM (W) (n = 3,753)	p** Early vs. Delayed	p† Early vs. NOM	p† Delayed vs. NOM
Mortality, n (%)	39 (1.6)	19 (1.4)	101 (2.7)	0.647	0.001	0.004
Discharged home, n (%)	1,757 (72.0)	826 (61.2)	2,689 (71.6)	<0.001	0.676	<0.001
Hospital LOS*	9 (7–12)	13 (10–18)	5 (3–8)	<0.001	<0.001	<0.001
ICU LOS*	5 (3–7)	7 (4–12)	3 (2–6)	<0.001	<0.001	<0.001
ICU-free days*	25 (23–27)	23 (18–26)	27 (23–28)	<0.001	<0.001	0.006
Total ventilator days*	4 (3–8)	7 (3–13)	4 (2–10)	<0.001	0.938	<0.001
Ventilator-free days*	26 (20–27)	23 (16–27)	23 (0–28)	<0.001	<0.001	<0.001
ARDS, n (%)	13 (0.5)	20 (1.5)	26 (0.7)	0.003	0.407	0.001
VAP, n (%)	21 (0.9)	31 (2.3)	28 (0.7)	<0.001	0.512	<0.001

*Median (interquartile range).
**Pearson's χ^2 test was used to analyze categorical variables, while Mann-Whitney *U* tests were used for continuous variables.
†Log transformations of the continuous variables were examined using generalized linear model tests, while complex sample χ^2 tests were used for categorical variables.
This table presents the results of the outcome analyses based on timing to fixation (≤ 82 hours or >82 hours) compared with NOM of patients with multiple rib fractures.
W, weighted; LOS, length of stay.

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stays. Notably, the mortality benefit of SSRF was mostly evident in patients with flail chest. Furthermore, early SSRF, in contrast to delayed SSRF, resulted in shorter hospital and ICU stays and a lower incidence of respiratory complications.

Mortality Outcomes of SSRF Versus NOM

Multiple studies confirm that SSRF can improve survival in patients with multiple rib fractures. A comprehensive meta-analysis of 33 studies found that surgical rib fixation roughly halved the risk of mortality compared with NOM.[11] This survival benefit is evident not only in the classic flail chest population but also in patients without flail segments. Large registry analyses echo these findings. For example, a Japanese nationwide study reported in-hospital mortality of 4.8% with SSRF versus 16.2% with NOM.[12] In geriatric trauma patients, SSRF has similarly been associated with lower mortality (4.2% vs. 7.3%).[13] These data align with our overall results and support the notion that operative management generally improves survival in the setting of severe chest trauma. Not all series, however, demonstrate a mortality difference. Two recent prospective studies with more limited patient samples observed no survival benefit to SSRF. A multicenter European cohort study reported very low mortality under NOM (overall ~1.5%) and found no significant outcome difference favoring fixation.[14] Similarly, a randomized trial in severe chest injury by Meyer et al.[15] noted zero deaths in either arm. The lack of a mortality advantage in these studies is likely attributable to patient selection and statistical power. In the European study, many patients had relatively mild chest trauma, yielding a low baseline mortality that could obscure any operative benefit. In the trial of Meyer et al.[15] (84 patients), the exclusion of the highest-risk chest trauma cases meant it was underpowered to detect a difference. In contrast, a recent multicenter randomized controlled trial by Dehghan et al.[16] reported a significantly lower in-hospital mortality rate in the surgical group compared with the nonoperative group (0% vs. 6%). However, the trial excluded patients with severe pulmonary contusions, which are frequently encountered in clinical cases of rib fractures, thereby limiting the generalizability of its findings to broader trauma populations. In contrast, our study analyzed a large, real-world trauma cohort inclusive of patients with pulmonary contusion and other severe injuries, used very strict and sophisticated statistical methodology, and still observed a clear survival benefit with SSRF after rigorous risk adjustment. This more representative evidence suggests that operative rib fixation confers a true mortality advantage in typical clinical practice, with the impact of SSRF being most pronounced in higher-risk populations, whereas, in lower-risk patients, good supportive care can achieve similarly low mortality outcomes.

Flail Chest Versus Nonflail Chest: Who Benefits From SSRF?

Surgical stabilization of rib fractures is an accepted standard for flail chest injuries, especially with respiratory failure.[17–20] Early trials showed that operative fixation improves pulmonary outcomes and reduces ventilator days compared with conventional treatment.[21] Our findings confirm that flail chest patients benefit from SSRF. Recent evidence indicates that nonflail patients may also benefit in select cases. A meta-analysis noted improved survival with SSRF in patients without flail chest.[11] Surgeons have demonstrated SSRF efficacy in multiple nonflail fractures, although gains tend to be smaller given the lower injury severity.[17] Pieracci et al.[22] NONFLAIL trial found no difference in hospital metrics but showed that SSRF reduced pleural space complications (0% vs. 10%) and improved pain relief and respiratory function compared with NOM. In that study, mortality and pulmonary complications were low in both groups, confirming that nonflail patients have a lower baseline risk. The NONFLAIL trial demonstrated that SSRF patients reported lower pain scores by 2 weeks and required fewer opioids at follow-up. Similarly, Marasco et al.[23] found higher return-to-work rates with SSRF in nonflail, nonventilated patients, despite no difference in pain or quality of life. Even without flail segments, certain patients experience meaningful improvements with rib fixation. Treatment decisions should be individualized, weighing outcome differences against pain, disability, and recovery trajectory. Our results suggest a smaller yet significant mortality reduction with SSRF in nonflail patients, supporting expanded indications in select cases.

Timing of Rib Fixation: Early Versus Delayed SSRF

The timing of intervention appears critical to SSRF outcomes. Previous studies used arbitrary cutoffs to define “early” versus “delayed” rib fixation.[24] Iqbal et al.[25] categorized SSRF within 48 hours as “early,” comparing it with later intervention, while another analysis used a 3-day postinjury threshold.[26] These cutoffs were selected by convention rather than outcome data. In contrast, our study determined optimal timing through statistical modeling, using a GAM to identify when outcomes worsen with surgical delay. This established an evidence-based threshold for early SSRF. Our definition of early SSRF (within 3–4 days) aligns with the trauma literature. Forrester et al.[27] analyzed timing in a TQIP cohort, stratifying rib fixation within 2 days, 2 to 3 days, and >3 days. Patients who underwent SSRF after 3 days had threefold higher complication rates and longer ICU and hospital stays compared with those operated on within 48 hours. Delaying surgery beyond 72 hours led to a 4-day longer hospitalization.[27] Similarly, Simmonds et al.[28] observed that early SSRF improves outcomes versus delayed fixation. These studies suggest that prompt rib stabilization improves recovery by preventing pain-related inflammation and pulmonary complications.

Some earlier studies reported reasonable outcomes even with longer delays to SSRF. The randomized controlled trial of Tanaka et al.[29] in 2002 performed rib plating at 5 to 7 days after injury and yet showed benefit in flail chest patients. Belaroussi et al.[30] analyzed delayed SSRF and found that it led to longer hospital stays (18 vs. 11 days), without significantly increasing pneumonia rates, compared with early SSRF. Their late group trended toward more pneumonias, but the difference was not statistically significant, possibly because of a small sample size. These findings suggest that early fixation could potentially be associated with shorter recovery and decreased complications. However, delayed SSRF may still benefit select patients requiring ventilator weaning or those with persistent pain. Our data, defining early as within 82 hours, align with the body of evidence in the current literature advocating for early fixation. We observed an association between delayed surgery beyond 4 days and worse outcomes. Standardizing an “early SSRF” window as a quality metric may improve chest injury care.[31]

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This study has several important limitations. First, the retrospective cohort design introduces a risk of selection bias and confounding. Patients were not randomized to SSRF or NOM, so differences in injury severity or patient characteristics could have influenced the treatment choice and outcomes. Although matching and multivariable adjustments were performed, unmeasured confounders may still exist. Second, there are limitations inherent to the data available. The analysis used a large trauma registry database that may contain coding errors and missing data. Certain clinical details were not recorded, including the specifics of NOM, such as analgesia protocols or respiratory support, and key physiologic measures, such as preoperative ventilation status. This could introduce bias from unmeasured factors. Third, the data set does not contain information that would allow us to differentiate between clinical and radiographic flail chest, forcing us to rely on *International Classification of Diseases, Tenth Revision*, and AIS predot codes, which may incur misclassification bias. Fourth, TQIP does not contain patient-reported outcomes data, which limits the impact of our results, as patients' preferences regarding the treatment type are unknown. Fifth, the external validity of our findings is limited. The patient population and setting of this study may not represent all contexts. Our cohort included adult trauma patients treated at trauma centers participating in TQIP, where management practices and patient demographics may vary across institutions and regions. Therefore, caution is warranted when generalizing these results to other settings, especially those with different patient populations or institutional protocols. Nonetheless, these limitations do not diminish the overall significance of the results; they underscore the need for careful interpretation while still affirming the valuable insight this study provides into the outcomes of SSRF compared with NOM.

In conclusion, our study adds to the growing body of literature showing the benefits of SSRF in multiple rib fracture patients. Surgical stabilization of rib fractures was associated with reduced mortality in patients with severe chest injury. Early SSRF, occurring within approximately 3 to 4 days of injury (around the 82-hour threshold), was associated with fewer complications and shorter hospital stays. In contrast, delays in SSRF seem to reduce these advantages.

Our results provide additional evidence in support of early SSRF in suitable candidates, tempered by judicious patient selection, including flail chest and select nonflail chest patients with multiple displaced fractures or with respiratory compromise. We showed that early operation was associated with improved survival and fewer complications.

AUTHORSHIP

R.C. and J.K. contributed in the concept and design. R.C., J.K., and B.Z. contributed in the acquisition, analysis, and initial interpretation of data. R.C., J.K., and B.Z. contributed in the drafting of the manuscript. B.C.C. and B.S. contributed in the critical review of the manuscript for important intellectual content. B.Z. and J.K. contributed in the statistical analysis. R.C. and B.C.C. contributed in the administrative, technical, or material support. R.C. contributed in the supervision.

DISCLOSURE

Conflicts of Interest: Author Disclosure forms have been supplied and are provided as Supplemental Digital Content (http://links.lww.com/TA/E764).

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