# A multicenter evaluation of the optimal timing of surgical stabilization of rib fractures

**Fredric M. Pieracci, MD, MPH, Julia Coleman, MD, MPH, Francis Ali-Osman, MD, Alicia Mangram, MD, Sarah Majercik, MD, MBA, Thomas W. White, MD, Elan Jeremitsky, MD,** *and* **Andrew R. Doben, MD***, Denver, Colorado*

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**BACKGROUND:** The optimal timing of surgical stabilization of rib fractures (SSRF) remains debated. We hypothesized that (1) demographic, radiologic, and clinical variables are associated with time to surgery and (2) shorter time to SSRF improves acute outcomes.

**METHODS:** Prospectively collected SSRF databases from four trauma centers were merged and analyzed (2006–2016). The independent variable was days from hospital admission to SSRF (early [<1 day], mid [1–2 days], and late [3–10 days]). Outcomes included length of operation, number of ribs repaired, prolonged (>24 hours) mechanical ventilation, pneumonia, tracheostomy, length of stay, and mortality. Multivariable logistic regression was used to control for significant differences in covariates between groups.

**RESULTS:** Five hundred fifty-one patients were analyzed. The median time to SSRF was 1 day (range, 0–10); 207 (37.6%) patients were in the early group, 168 (30.5%) in the midgroup, and 186 (31.9%) in the late group. There was a significant shift toward earlier SSRF over the study period. Time to SSRF was significantly associated with study center ($p < 0.01$), year of surgery ($p < 0.01$), age ($p = 0.02$), mechanism of injury ($p = 0.04$), and body mass index ($p = 0.02$). Injury severity was not associated with time to surgery. Despite repairing the same median number of ribs (4; range, 1–13), median length of surgery was 68 minutes longer for the late as compared to the early group ($p < 0.01$). After controlling for the aforementioned significant covariates, each additional hospital day before SSRF was independently associated with a 31% increased likelihood of pneumonia ($p < 0.01$), a 27% increased likelihood of prolonged mechanical ventilation ($p < 0.01$), and a 26% increased likelihood of tracheostomy ($p < 0.01$).

**CONCLUSION:** Surgical stabilization of rib fractures within 1 day of admission is associated with certain demographic and physiologic variables. After controlling for confounding factors, early SSRF was accomplished using less operative time, and was associated with favorable outcomes. When indicated and feasible, SSRF should occur as early as possible. (*J Trauma Acute Care Surg.* 2018;84: 1–10. Copyright © 2017 Wolters Kluwer Health, Inc. All rights reserved.)

**LEVEL OF EVIDENCE:** Therapy, level III.

**KEY WORDS:** Rib fractures; surgical stabilization of rib fractures; outcomes.

The practice of surgical stabilization of rib fractures (SSRF) for the treatment of severe chest wall injuries has increased exponentially over the last 10 years.[1] The reasons for this proliferation are many, including the development of rib-specific fixation systems,[2,3] publication of favorable prospective trials,[4–6] and consensus statements,[7,8] and a general improvement in the exposure of trauma surgeons to the technique of rib repair.[9,10]

The vast majority of clinical investigations related to SSRF involve assessment of acute outcomes in patients with flail chest, as compared with optimal medical management.[11–14] Although these studies have provided a foundation supporting the overall effectiveness of SSRF in this patient population, the study groups have consisted of a relatively heterogeneous population of patients with respect to associated injuries, fracture patterns, and days to surgery.

The optimal timing of SSRF remains debated and has not been studied prospectively. Proponents of delayed repair argue for a period of maximal medical therapy, during which certain patients will "declare themselves" as failures (and thus candidates for surgery) as evidenced by either progressive pain or respiratory decompensation. By contrast, advocates of early repair postulate that certain demographic, clinical, and radiographic parameters present on or close to admission can reliably predict subsequent failure of non-operative management. In this case, delaying surgery serves only to increase the likelihood of adverse outcomes, including prolonged mechanical ventilation, pneumonia, and retained hemothorax.[15] The median time to SSRF in published trials varies widely, from 2 days[14] to 9 days.[11]

Few contemporary data are available to elucidate the factors influencing timing of SSRF. Whereas, anecdotally, severity of injury (both chest wall and associated) is believed to be the primary driving factor, additional considerations, including operating room and surgeon availability, varying periods of non-operative management trials, and patient preference, may also be important. The objectives of this study were to: (1) identify variables associated with time to SSRF and (2) evaluate the relationship between timing of SSRF and acute outcomes. We hypothesized that shorter time to SSRF is associated with improved outcomes.

## METHODS

A retrospective review of prospectively maintained SSRF databases from four American College of Surgeon-certified Level I trauma centers was conducted. The four centers were: (1) Denver Health Medical Center, Denver, CO (lead study center); (2) Baystate Medical Center, Springfield, MA; (3) Intermountain Medical Center, Salt Lake City, UT; and (4) Honor Health Medical Center, Phoenix, AZ. These four centers were identified based on a professional relationship between investigators, data collection over similar periods, comparable indications for SSRF, volume of cases, and perioperative management protocols, and a relatively limited number of surgeons performing the operation and caring for the patients in the intensive care unit (ICU). Institutional review board approval was obtained at each study center, and data sharing agreements were executed between the lead study center and each satellite center.

The study sample consisted of patients who underwent SSRF from 2006 to 2016. Indications for surgery were ≥ 1 of

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From the Denver Health Medical Center (F.M.P., J.C.), Denver, Colorado; Honor Health (F.A.-O., A.M.), Pheonix, Arizona; Intermountain Medical Center (S.M., T.W.W.), Salt Lake City, Utah; and Baystate Medical Center (E.J., A.R.D.), Springfield, Massachusetts

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Address for reprints: Fredric M. Pieracci, MD, Trauma Medical Director, Denver Health Medical Center, Associate Professor of Surgery, University of Colorado School of Medicine, 777 Bannock St, MC0206, Denver, CO 80206; email: fredric.pieracci@dhha.org.

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the following: (1) radiographic or clinical flail chest, (2) three or more bicortically displaced fractures, (3) greater than 30% volume loss of a hemithorax, and (4) failure of optimal medical management. Although in the ICU, pain control and respiratory status were monitored at least hourly by nursing staff, and failure of medical management was defined as 4 hours to 6 hours or longer with two or more of the following deranged variables: (1) numeric pain score greater than 5, (2) incentive spirometry less than 50% predicted, (3) poor cough (as determined by the respiratory therapist), and (4) respiratory rate greater than 20. A typical scenario for a patient who failed medical management, but did not meet any other anatomic indications for surgery, involved a painful clicking sensation at the fracture site with respiration.

The independent variable was time from hospital admission to surgery. This variable was operationalized as both continuous (days from admission), and categorical, divided into three periods: early (day 0), mid (days 1–2), and late (days 3–10). These temporal cutoffs were selected based on the intertercile range of the variable's distribution. Both the date and time of admission and surgery were used to stratify patients into the three groups, such that patients in the "early group" underwent surgery within 24 hours of admission. For example, a patient who was admitted at 12 noon and underwent surgery the next day at 10:00 AM would be in the "early group," whereas a patient who was admitted at 12 noon and underwent surgery the next day at 2:00 PM would be in the "mid" group.

Demographic covariates included age (years), sex, race, body mass index (BMI, kg/m$^2$), former or current tobacco use, chronic obstructive pulmonary disease, and mechanism of injury (motor vehicle collision/motorcycle crash, auto vs. pedestrian, fall, and other). Severity of rib fractures was captured using the number of rib fractures, presence of radiographic flail chest, and the RibScore.[16] The RibScore assigns one point to each of six radiographic variables as demonstrated on admission CT chest—flail chest, first rib fracture, bilateral fractures, six or more fractures, one or more fracture in each anatomic location (anterior, lateral, posterior), and three or more severely (bicortical) displaced fractures—and is associated significantly with adverse pulmonary outcomes. Additional injuries abstracted included the Injury Severity Score (ISS), admission Glasgow Coma Scale (GCS) score (operationalized as both continuous and categorical ≤13), pneumothorax on admission, hemothorax on admission, degree of pulmonary contusion, as measured by the Blunt Pulmonary Contusion 18 score[17]], clavicle fracture, scapula fracture, and spine fracture.

All patients were prescribed pulmonary toilet regiments implemented by certified respiratory therapists, and received locoregional pain control in the perioperative period with either thoracic epidural catheter or paraspinous, percutaneous indwelling pain catheter pump.

Although the technique of SSRF evolved at each center over the study period, standardized components included repair of fractures of ribs 3 to 10, both fracture series in the case of flail chest whenever possible, repair of posterior fractures longer than 3 cm from the transverse process, muscle-sparring exposure, concomitant drainage of retained hemothorax, and pleural drainage with a chest tube.[10] Intraoperative variables abstracted included the length of operation (minutes), the number of ribs repaired, and the use of fiberoptic bronchoscopy. Outcomes included prolonged (>24 hours) mechanical ventilation, ventilator days, pneumonia,[18] tracheostomy, mortality, hospital length of stay (LOS), and ICU LOS.

All statistical analyses were performed using SAS version 9.0 (SAS, Inc., Carey, NC). Statistical significance was defined as $p$ less than 0.05. Continuous variables were tested for normality using the Kolmogorov-Smirnov D statistic. Non-normally distributed variables are listed as median (range) and were analyzed using the nonparametric Wilcoxon Rank Sum test.

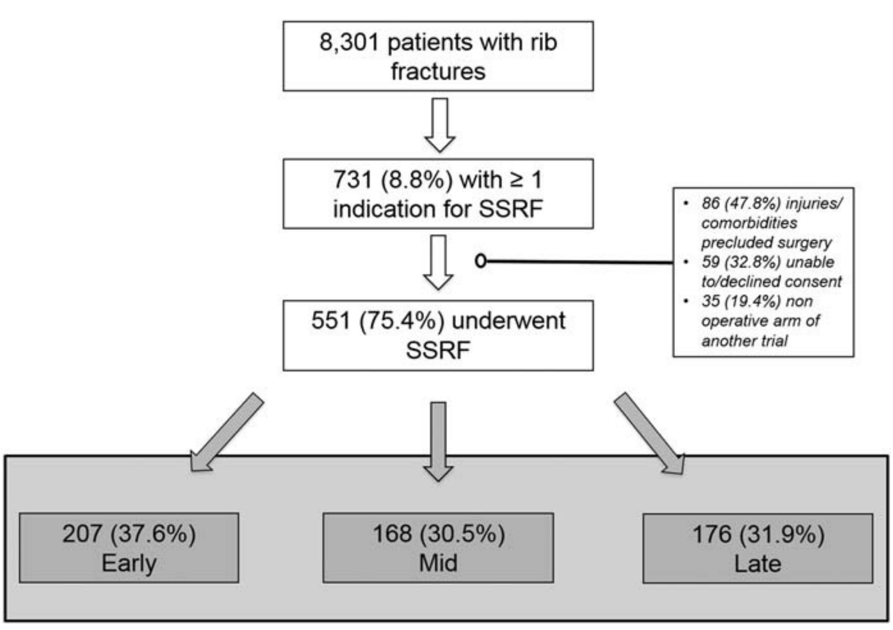


**Figure 1.** Flow diagram depicting derivation of the final sample.

 

Categorical variables are listed as number (%), and were compared using the $\chi^2$ test, unless expected cell counts were less than 10, in which case the Fischer's exact test was used.

Covariates that were associated with time to SSRF (categorical) at the $p \leq 0.05$ level by univariate analysis were selected for multivariable logistic regression modeling. These variables were added in a forward selection, stepwise fashion based upon their level of significance in univariate analysis. Time to SSRF was added to the models as both as a categorical variable (early, mid, late, with the early group as the reference category) and continuous variable (days to surgery). Logistic regression models were created for the outcomes of prolonged mechanical ventilation, pneumonia, and tracheostomy; mortality was not examined because it was too rare. Model fit was assessed using the Hosmer Lemishow goodness-of-fit test. Power was calculated to reduce the possibility of model overfitting. We decided a priori that a minimum of 10 outcomes per variable included was necessary.

## RESULTS

Derivation of the sample is shown in Figure 1. A total of 551 patients were available for analysis; 207 (37.6%) in the early group, 168 (30.5%) in the mid group, and 176 (31.9%) in the late group. Baseline characteristics of the three groups are shown in Table 1. Time to surgery was significantly associated with study site, year of surgery, age, BMI, and mechanism of injury. There was no difference between groups in number of ribs fractured, presence of flail chest, and RibScore. There was no difference between groups in associated injuries, although both ISS and admission GCS trended toward statistical significance ($p = 0.06$ and 0.05, respectively), with the late group being more severely injured.

Annual volume of SSRF increased significantly over the 10-year study period, from five total cases in 2006 to 135 cases in 2016. Furthermore, there was a significant temporal shift towards early SSRF over the study period (Fig. 2). Before 2012, 62.5% of SSRF cases occurred in the late window, whereas only 19.3% of SSRF cases occurred in the late window in 2016. By contrast, before 2012, only 21.9% of SSRF cases occurred in the early window. By 2016, over one half of SSRF cases (51.5%) occurred in the early window.

Operative variables are shown in Table 2. The median days to surgery for the entire sample was 1 (range, 0–10) and varied significantly by group. This variable was not distributed normally, with the majority of operations clustered in the first 5 days (Fig. 3). The median time to SSRF in the late group was 4 days (range, 3–10), 82% of patients in this group underwent SSRF within 6 days of admission, and 97% of patients underwent SSRF within 7 days of admission.

Length of surgery varied significantly by group, was shortest for the early group (median, 133 minutes), and longest for the late group (median, 201 minutes) ($p < 0.01$). There was no difference between groups in the number of ribs repaired during surgery (median, 4; range, 1–13). All patients underwent pleural drainage during the operation, and approximately one third of patients underwent intra-operative bronchoscopy: 78 (37.7%) in the early group, 57 (33.9%) in the mid group, and 75 (42.6%) in the late group ($p = 0.25$).

Univariate analysis of outcomes is shown in Table 3. Mortality was rare and did not vary by group. Incidence of prolonged mechanical ventilation, hospital LOS, and ICU LOS each increased significantly moving from the early to the late group. There was no association between either pneumonia or tracheostomy and time to SSRF.

The results of multivariable logistic regression are shown in Table 4. The following covariates were included: (1) study site, (2) year of surgery, (3) age, (4), BMI, and (5) mechanism of injury. Patients in the late group were 2.37 times as likely to develop pneumonia as compared to the early group (95% confidence interval [CI], 1.21–4.65, $p = 0.01$). Furthermore, each additional day to SSRF was associated with a 31% increased likelihood of pneumonia (95% CI, 1.14–1.51, $p < 0.01$).

**TABLE 1.** Sample Demographics

| Variables | Early n = 207 (37.6%) | Mid n = 168 (30.5%) | Late n = 176 (31.9%) | *p* |
|---|---|---|---|---|
| Study site | | | | <0.01 |
| 01 | 50 (48.1%) | 39 (37.5%) | 15 (14.4%) | |
| 02 | 22 (19.8%) | 14 (12.6%) | 75 (67.6%) | |
| 03 | 73 (40.1%) | 76 (41.8%) | 33 (18.1%) | |
| 04 | 62 (40.3%) | 39 (25.3%) | 53 (34.4%) | |
| Age, y | 55 (16–97) | 57 (21–92) | 60 (18–91) | 0.02 |
| Male | 148 (71.5%) | 124 (73.8%) | 118 (67.1%) | 0.37 |
| White | 176 (85.4%) | 138 (82.6%) | 159 (90.3%) | 0.11 |
| BMI, m/kg$^2$ | 27.2 (12–50) | 28.4 (18–60) | 29.0 (18–55) | 0.02 |
| Tobacco use | 70 (34.3%) | 52 (31.5%) | 67 (38.3%) | 0.70 |
| COPD | 10 (4.8%) | 12 (7.1%) | 12 (6.8%) | 0.59 |
| Mechanism | | | | |
| MVC/MCC | 77 (37.2%) | 73 (43.7%) | 88 (50.1%) | 0.04 |
| Fall | 54 (26.0%) | 50 (29.9%) | 54 (29.2%) | |
| Auto-ped | 20 (9.7%) | 15 (9.0%) | 14 (7.8%) | |
| Other | 56 (27.0%) | 29 (17.3%) | 23 (12.4%) | |
| ISS | 17 (4–75) | 17 (0–50) | 20 (1–66) | 0.06 |
| Admission GCS score | 15 (3–15) | 15 (3–15) | 15 (3–15) | 0.05 |
| Admission GCS score < 14 | 22 (10.7%) | 19 (11.3%) | 26 (14.9%) | 0.42 |
| No. rib fractures | 7 (2–21) | 7 (2–19) | 8 (2–23) | 0.12 |
| RibScore | 3 (0–6) | 3 (0–6) | 3 (0–6) | 0.99 |
| Indications for surgery* | | | | |
| Flail chest | 120 (60.9%) | 95 (57.6%) | 100 (56.8%) | 0.69 |
| ≥3 displaced fractures | 149 (72.0%) | 121 (72.0%) | 133 (75.6%) | 0.68 |
| ≥30% volume loss | 13 (6.3%) | 8 (4.8%) | 7 (4.0%) | 0.58 |
| Failure of nonoperative** | 11 (5.3%) | 9 (5.4%) | 6 (3.4%) | 0.61 |
| Pneumothorax | 141 (70.5%) | 109 (65.7%) | 125 (71.0%) | 0.49 |
| Hemothorax | 110 (55.3%) | 100 (60.2%) | 95 (54.0%) | 0.47 |
| BPC 18 | 3 (0–18) | 4 (0–15) | 3 (0–14) | 0.62 |
| Clavicle fracture | 35 (16.9%) | 30 (17.9%) | 39 (22.2%) | 0.39 |
| Scapula fracture | 41 (19.8%) | 22 (13.1%) | 30 (17.1%) | 0.23 |
| Spine fracture | 54 (26.1%) | 49 (29.2%) | 46 (26.1%) | 0.76 |

* Categories may sum to > 100% if patients had ≥ 1 indication for surgery.
** This group represents only those patients who had none of the other three anatomic indications for surgery.
BPC 18, Blunt Pulmonary Contusion 18; COPD, chronic pulmonary obstructive disease; MVC/MCC, motor vehicle crash/motorcycle crash.

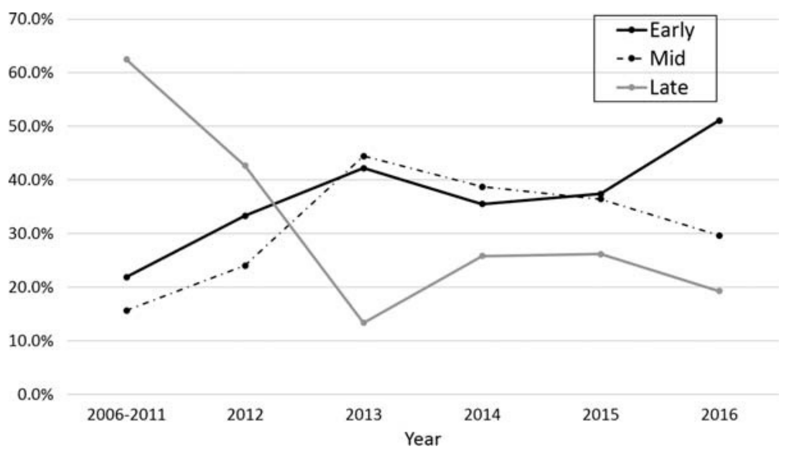


**Figure 2.** Temporal trends in timing of SSRF. A significant shift toward early SSRF was observed over the study period ($p < 0.01$).

Patients in the late group were 3.24 times as likely to require prolonged mechanical ventilation as compared with the early group (95% CI, 1.89–5.56; $p = 0.01$). A trend was also observed toward patients in the midgroup being more likely to require prolonged mechanical ventilation as compared with the early group ($p$ = 0.07). Finally, each additional day to SSRF was associated with a 27% increased likelihood of prolonged mechanical ventilation (95% CI, 1.12–1.43; $p < 0.01$).

Although tracheostomy was a relatively rare outcome (n = 48, 8.7%), the logistic regression model maintained acceptable goodness of fit (Hosemer-Lemeshow $\chi^2$, 8.25; $p = 0.41$). A trend was also observed toward patients in the late group being more likely to require tracheostomy as compared with the early group ($p = 0.07$). Finally, each additional day to SSRF was associated with a 26% increased likelihood of tracheostomy (95% CI, 1.06–1.50; $p = 0.01$).

We next repeated the logistic regression analyses after the addition of both ISS and admission GCS score, as these variables approached, but did not reach statistical significance in their association with time to SSRF in univariate analysis. The addition of these variables did not add substantially to the model predictability, nor did they change the association between time to SSRF and outcomes. As compared with early surgery, late surgery remained associated with a higher likelihood of both prolonged mechanical ventilation (odds ratio [OR], 2.99; 95% CI, 1.60–5.57; $p < 0.01$) and pneumonia (OR, 1.83; 95% CI, 0.97–3.81; $p = 0.06$).

Finally, we repeated the regression analyses in the subgroup of patients without flail chest (n = 205, 37.2%). As compared with early surgery, late surgery remained associated with a higher likelihood of both prolonged mechanical ventilation (OR, 4.34; 95% CI, 1.55–12.12; $p = 0.01$) and pneumonia (OR, 2.84; 95% CI, 1.00–9.64; $p = 0.05$). Tracheostomy occurred too rarely in this subgroup to perform a meaningful regression (n = 13).

**TABLE 2.** Operating Room Variables

| Variables | Early (≤24 h) n = 207 | Mid (24–48 h) n = 168 | Late (>48 h) n = 186 | *p* |
|---|---|---|---|---|
| Days to surgery | 0 (0–0) | 2 (1–2) | 4 (3–10) | <0.01 |
| Length of operation, min | 133 (32–540) | 122 (14–503) | 201 (54–854) | <0.01 |
| No. ribs repaired | 4 (1–11) | 4 (1–12) | 4 (2–13) | 0.83 |

## DISCUSSION

In this multicenter analysis of prospectively maintained SSRF databases, we identified a significant shift from late to early surgery over the last 10 years. Furthermore, in general, patients who underwent surgery within 24 hours of admission tended to be younger, have a lower BMI, and were less likely to be injured by motor vehicle crashes. We observed only mild, non-significant differences in overall injury severity between groups, and no differences in either the severity of rib fractures or associated thoracic injuries. Finally, surgery undertaken during the early window took significantly less time and was independently associated with favorable pulmonary outcomes.

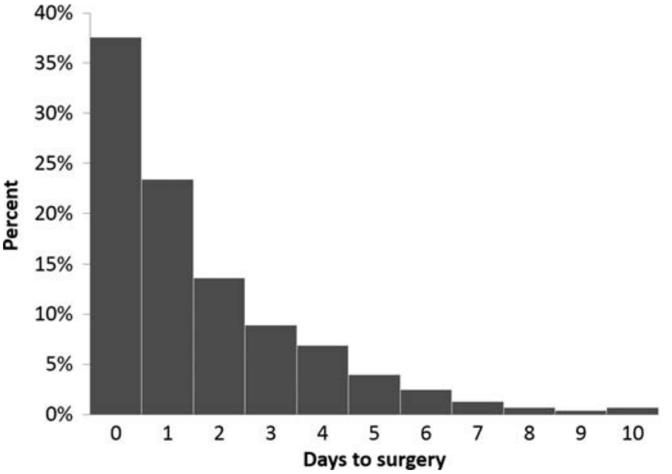


**Figure 3.** Histogram of days from admission to SSRF. The variable was not distributed normally (mu =0.87). Within the late group (SSRF 3–10 days from admission), 82% of patients underwent surgery within 6 days of admission, and 97% of patients underwent surgery within seven days of admission.

 

**TABLE 3.** Univariate Outcomes

| Variables | Early (≤24 h) n = 207 | Mid (24–48 h) n = 168 | Late (>48 h) n = 186 | *p* |
|---|---|---|---|---|
| Mortality | 2 (1.0%) | 1 (0.6%) | 4 (2.3%) | 0.35 |
| Hospital LOS | 9 (1–725) | 10 (3–68) | 13 (5–58) | <0.01 |
| ICU LOS | 3 (1–376) | 4 (1–28) | 6 (1–54) | <0.01 |
| Pneumonia | 22 (10.6%) | 21 (12.5%) | 28 (15.9%) | 0.30 |
| Mechanical ventilation > 24 h | 51 (24.6%) | 58 (34.5%) | 113 (64.2%) | <0.01 |
| Ventilator days (among those ventilated > 24 h) | 6 (1–32) | 3 (1–23) | 3 (1–35) | 0.25 |
| Tracheostomy | 16 (7.9%) | 15 (9.1%) | 17 (9.7%) | 0.82 |

Although many prospective studies have examined the effectiveness of SSRF as compared with nonoperative management,[4–6] no data are available comparing operative groups according to the timing of surgery. Time to surgery is theoretically an important variable as the main benefits of SSRF are believed to result from increased chest wall stability leading to both improved pain control and pulmonary mechanics. The sooner this stability is achieved, the less time the patient is exposed to secretion accumulation, atelectasis, and hypoventilation. Additional benefits to early surgery may include improvement of atelectasis secondary to intraoperative positive pressure ventilation, clearance of secretions via flexible bronchoscopy, evacuation of retained hemothorax,[15] and early placement of directed analgesic catheters. The results from multivariable analysis of our study support this general hypothesis by providing evidence that early surgery is independently associated with a decreased likelihood of prolonged mechanical ventilation, pneumonia, and tracheostomy.

Because patients were not randomized to early versus late surgery, it is likely that the observed associations were confounded by additional covariates. One particular concern is that patients were selected for late surgery because of both increased injury severity and comorbidities, both of which would also increase the risk of adverse pulmonary outcomes. However, we found no significant differences in pulmonary comorbidities, ISS, GCS, number of fractures, flail chest, degree of pulmonary contusion, and associated fractures. Furthermore, observed differences in age and BMI were controlled for in the regression modeling. Even when the nonsignificant ISS and GCS variables were added to the models, there remained a significant association between time to SSRF and outcomes. Finally, in general, moderate to severe traumatic brain injury was relatively rare in this cohort of patients, as evidenced by a low percentage of patients with admission GCS score of 13 or less (n = 67, 12.2%). This parameter also did not differ significantly as a function of time to surgery.

Important differences in systems-related parameters were also observed between groups, including study site and year of surgery. The significant variability in time to SSRF observed between these four high volume, experienced centers underscores the lack of consensus as to the optimal timing of the operation. Year of operation also likely confounded the relationship between time to surgery and outcomes, as there may have been a general improvement in the care of the patient with severe chest wall injury over the last 10 years. However, after measuring and controlling for these variables, time to SSRF remained an independent predictor of outcomes.

To date, prospective studies of SSRF have been limited by relatively small sample sizes, with randomized trials including less than 30 patients in the operative arm.[11–13] By contrast, retrospective studies of SSRF using the National Trauma Database[1,19] have not contained detailed information on injury patterns. Furthermore, these studies are comprised of SSRF patients from hundreds of relatively low-volume centers, which introduces a substantial level of variability of care. The current study allows for a large enough sample size to conduct an adequately-powered regression analysis while also minimizing both missing data and confounding by differences in perioperative management.

Despite abstracting the aforementioned variables, our regression models explained only approximately one third of the variability in the time to surgery. Additional considerations may have been competing operative injuries (e.g., pelvic and long bone fractures), surgeon and operating room availability, and patient preference. The authors' anecdotal experience is that limited number of both surgeons who can perform the operation and operating room availability are major factors influencing the time to surgery. These factors, in and of themselves, should not influence the relationship between time to surgery and outcomes.

It may be argued that patients in the late group simply represent those who did not improve with optimal medical management, and thus were ultimately selected for surgery. By contrast, those patients who improved without surgery did not undergo SSRF and thus are not represented in this study. However, we believe that this reasoning further underscores the benefits of early surgery, such that patients are not given the "opportunity" to fail medical management, thereby creating a group of late surgery patients who are at very high risk of pulmonary morbidity. As further research refines indications for surgery, our current approach is to offer this low-risk surgery to patients who meet

**TABLE 4.** Multivariable Logistic Regression Models

| Variable | OR | Lower, 95 CI | Upper, 95 CI | *p* | HL, $\chi^2$ | HL, *p* |
|---|---|---|---|---|---|---|
| Pneumonia (71 outcomes) | | | | | | |
| Late vs. early | 2.37 | 1.21 | 4.65 | 0.01 | 7.44 | 0.49 |
| Mid vs. early | 1.19 | 0.62 | 2.29 | 0.60 | | |
| Days to surgery | 1.31 | 1.14 | 1.51 | <0.01 | 5.73 | 0.68 |
| Mechanical ventilation (222 outcomes) | | | | | | |
| Late vs. early | 3.24 | 1.89 | 5.56 | <0.01 | 6.95 | 0.54 |
| Mid vs. early | 1.61 | 0.97 | 2.69 | 0.07 | | |
| Days to surgery | 1.27 | 1.12 | 1.43 | <0.01 | 5.98 | 0.65 |
| Tracheostomy (48 outcomes) | | | | | | |
| Late vs. early | 2.27 | 0.95 | 5.28 | 0.07 | 7.41 | 0.49 |
| Mid vs. early | 1.16 | 0.51 | 2.6 | 0.73 | | |
| Days to surgery | 1.26 | 1.06 | 1.5 | 0.01 | 8.25 | 0.41 |

All models controlling for study site, year of surgery, age (years), BMI ($kg/m^2$), and mechanism of injury. HL, Hosmer Lemishow goodness-of-fit.

either physiologic or fracture pattern criteria early on in their hospital course.

One additional finding in this study was that, despite repairing the same number of ribs, surgery in the late window took over an hour longer as compared with the early window. Although callous formation is unlikely to occur within 14 days of fracture, tissue inflammation peaks at approximately 72 from injury (between the mid and late windows in this study) and causes increased friability, obscuring of planes, and increased bleeding. This phenomenon may explain the increased time necessary to complete SSRF in the late window and offer an additional advantage to early surgery.

Using our four proposed indications for SSRF, an early determination of eligibility for surgery should almost always be possible. The first three indications are radiographic and thus available immediately. The fourth indication—failure of optimal medical management—although more subjective, may be quantified to the extent that we have described and, in our experience, determined within 24 hours of observation. In this study, a minority of patients (n = 26, 4.7%) was operated on solely based on this forth criterion.

As mentioned previously, our study is limited because it was not randomized. Furthermore, detailed, day-to-day physiologic parameters, such as vital signs, arterial blood gases, and blood product requirements, were not abstracted. Detailed pulmonary function measurements, including incentive spirometry, cough effort, and narcotic requirements, were also not included. Variability across study sites and time, although controlled for in the regression models, likely contributed partially to differences in observed outcomes. Although the four study sites used similar indications for SSRF and perioperative management protocols, certain decisions, such as that of tracheostomy, remained at least partially subjective. Hospital costs were not collected. Finally, outcomes were limited to the index hospitalization.

In conclusion, SSRF was performed approximately equally within early, mid, and late windows. However, almost all of the surgeries occurred within one week of admission, with a significant shift toward earlier surgery over the study period. Rib fracture pattern, degree of pulmonary contusion, and associated thoracic injuries did not appear to influence time to surgery. After controlling for available covariates, early surgery was associated with shorter operative time and improved pulmonary outcomes. Based on these data, we recommend that SSRF, when indicated, should occur as early as possible after admission, and preferably within 24 hours.

## AUTHORSHIP

F.M.P. participated in the study concept, study design, data collection, data analysis, article drafting, and critical revisions. J.C. participated in the data collection, data analysis, and critical revisions. F.A. participated in the study concept, data collection, and critical revisions. A.M. participated in the critical revisions. S.M. participated in the study concept, study design, data collection, critical revisions. T.W. participated in the critical revisions. E.J. participated in the data collection and critical revisions. A.D. participated in the study concept, study design, data collection, and critical revisions.

## DISCLOSURE

F.P., T.W., and F.A.O. are paid speakers for DePuy Synthes. Andrew Doben is a paid consultant for DePuy Synthes and Zimmer Biomet. F.P. has received research funding from DePuy Synthes.

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## Self-Assessment Questions

1. Over the 10-year study period (2006–2016), the following trend was observed:
   a. **In later years, surgical stabilization of rib fractures was performed sooner after admission.**
   b. In later years, surgical stabilization of rib fractures was performed longer after admission.
   c. There was no association between study year and time from admission to surgical stabilization of rib fractures.
   d. The data abstracted were not sufficient to analyze this relationship.

2. A 40-year-old obese man is involved in a motorcycle crash and sustains a left sided flail chest. According to the data presented, surgical stabilization of his rib fractures within 24 hours of admission (as compared to > 24 hours from admission), is associated with a decreased likelihood of each of the following, EXCEPT:
   a. Pneumonia
   b. Prolonged mechanical ventilation
   c. Hospital length of stay
   d. **Mortality**

## DISCUSSION

**Dr. Martin D. Zielinski** (Rochester, Minnesota): Drs. Coimbra, Spain, members. Thanks for the opportunity to review this paper. Dr. Pieracci, thank you for getting the manuscript to me on time for review.

Dr. Pieracci and his colleagues have presented a multi-institutional, observational study on surgical stabilization of rib fractures. This is a hot topic, garnering national interest.

But as the authors point out, we have relatively few answers regarding the optimal patient population, optimal fracture patterns, and optimal timing, the current aim of this study.

Of course, all of these unknowns are highly interrelated and dependent on one another. And that will bias any sort of study, short of a randomized, controlled, clinical trial.

Nevertheless, the authors have undertaken the next-best study design. They collected prospective data on 551 patients from eight participating centers over a ten-year period. And they aimed to discern whether or not the duration of time from admission to fixation had an impact on clinical outcomes.

The patients were equally distributed among the three groups in the early, mid, and late groups with a shift towards earlier intervention over the study period.

The authors determined that the operative duration was greater in the late group, and that with each passing day without an operation, the risk of pneumonia, mechanical ventilation, and tracheostomy were all increased.

I do have several questions and comments.

First, the authors tout, at least in the paper, that this was a prospective study. And in the presentation today presented a retrospective review of a prospective database. So I was just curious as to why that changed in the nomenclature.

Secondly, you defined the three groups using intertercile ranges and you present ANOVA statistics showing differences among the groups but do not follow this up with individual comparisons when there were statistical differences.

Therefore, there must be some differences between the early and the late groups. But what about between the early and the mid and the mid and the late groups? Are there really differences in those two categories?

If there are no statistically significant differences between the early and the middle groups, shouldn't the early group really be defined as zero to two days and the mid group eliminated?

You state the general indications for the fixation, the fourth of which was failure of optimal medical management – and that's very subjective. Are the protocols at each site similar for who would be an appropriate candidate?

The timing to fixation was highly associated with the contributing institution which also likely introduced a significant bias from institutional factors, such as weekend OR availability and surgeon willingness to provide surgical repair of rib fractures.

In your multivariate models you didn't control for preoperative mechanical ventilation, despite having a huge influence on the outcomes of pneumonia, need for post-operative mechanical ventilation, and tracheostomy. Why not?

I certainly agree with the conclusion that if you know when a patient will need indications for fixation you should repair them as soon as possible. This makes inherent sense. Isn't it really the crux of the issue, however, that we can't really predict with any sort of accuracy who will benefit from fixation?

I find it telling that no data regarding patients who did not undergo fixation was presented. Perhaps those who did not undergo fixation actually did better?

Thank you for the opportunity to discuss this paper. Advancing our knowledge in the field of rib fracture fixation is necessary. And we hope that this initial experience will prompt a randomized, controlled trial. Thank you.

**Dr. Eileen M. Bulger** (Seattle, Washington): A very interesting paper. My question relates to associated injuries. I know you tried to control for ISS in one of the models but I'm not sure that's good enough.

If you think about the decision-making that goes into who you're going to operate on early and who you're going to operate on late, it seems like a lot of the other injuries, particularly brain injury as you alluded to, would factor into that decision making and make the groups potentially very different. You won't pick that up using ISS alone.

Can you comment on how you decide what other injuries take priority that might delay your surgery? Do you have protocols to define that? Is there anything in the data that would help us clarify how that may factor into your results? Thank you.

**Dr. Carl J. Hauser** (Boston, Massachusetts): Thank you. Carl Hauser, Boston. I'd like to note first of all, that bone films, whether they are plain films or CTs, don't tell us whether a patient has a flail. And that is because static films completely ignore the viscoelastic properties of the chest wall.

We've all seen frail older patients who flail like crazy with a small number of rib fractures and muscular young men who don't flail at all with the same fractures.

So the question we need to ask here is "how did you determine who really had a flail?" Was it the radiologist's report (and I try to discourage this) which said that the patient has a flail because they have "three ribs fractured in two places"? Or did you actually have some other measure, whether it was clinical exam or something more objective?

I would strongly suggest that the way we need to do this is with dynamic CT scanning, just as is done for people with tracheo-bronchial malacia, scanning in both inhalation and exhalation to actually visualize asymmetric movement of the chest wall. Until we do that, I don't think we'll be able to apply these operations to appropriate populations and get to verifiably improved outcomes.

**Dr. Matthew Delano** (Ann Arbor, Michigan): Matt Delano, University of Michigan. My question is brief. I know the authors advocated for a muscle-sparing incision and you definitely can get to the fifth or sixth ribs.

But for posterior rib segments that are fractured or flail, and for superior segments two, three, four, which are up under the scapula, doing a muscle-sparing incision, even with right-angle equipment, is not always possible. How would they suggest to get around those barriers?

**Dr. Walter L. Biffl** (La Jolla, CA): red, that's a nice study and, as you know, the recent WTA guidelines suggest that we should be doing this earlier to prevent the mechanical ventilation associated complications. So a couple of questions.

There seems to be a pretty sharp change in practice in 2012. So I wonder why you don't restrict the analysis to patients since 2012 because then there was about a 50/50 early versus late.

In the more recent years the timing issue may be more related to patient selection and the reason the surgeon waits. Were they getting a TEVAR on the first day and a pelvic fracture fixation the second day? So could you talk about that a little? Thanks.

**Dr. Babak Sarani** (Washington, D.C.): Babak Sarani from George Washington University. Fred, excellent study, as expected. The question is your study essentially shows that patients who may ultimately require an operation do better when that operation is offered early.

My question is how do you determine who these patients are? Who, in fact, would benefit from an operation in the first place?

**Dr. Frederic M. Pieracci** (Denver, Colorado): Thank you all for your comments. Very quickly, the reviewers as well as my discussant astutely noted that this – to clarify – this is not truly a prospective study; it is a retrospective review of prospectively collected data. And I changed that in the presentation based on the reviewer's comments.

Whether we should really have done two groups instead of three groups, I think that would have been okay except that we did find a blip between the middle and the early group, even though it wasn't statistically significant.

And we also found relationships when analyzing the variable continuously. So I don't think it's as simple as just one cutoff. I think it's either two or three or four groups. But that point is well taken.

Most of the patients in the study had one of the three anatomic criteria for surgery: flail chest – which I'll get to the definition of in a second; volume loss or displaced fractures.

About 5 percent of patients had none of those anatomic criteria but still failed non-operative management. And almost all of those patients had one or two fractures and complained of a "clicking" sensation when they were breathing.

And I think many of us have treated a patient like that who you can give all the narcotics and epidurals in the world but they say, "It hurts right here every time I breath," again, a minority of patients in that group.

The next question related to why we didn't control for preoperative mechanical ventilation. And I thought about this one for a while but it's really an issue of is that a confounder or is that an outcome variable?

Because if you haven't had your surgery for five days and you get intubated and get pneumonia on Day 3, I would argue that's a consequence of a delayed surgery, not something that should be controlled for.

And then, finally, there was, or, I'm sorry, not finally, there was a question asked about ISS not really being sufficient to control for what was going on. And I agree with that.

The TBI rate was relatively low in this study. We're in the process right now of diving deeper in to the data and getting things like blood transfusion requirements and long-bone surgeries. In general, open abdomens, pelvis fractures are things that would keep us from doing the surgery.

But, to be perfectly honest with you, when we set out to do this study we noticed across the four centers that one of the common reasons that we would be waiting an extra day or two would be surgeon and OR availability.

And so, unfortunately, that's harder to control for but that was one of the things that got us going in the first place.

I hate the definition of flail chest because I think it is mostly a radiographic one. And I'm somewhat embarrassed to say that is what we used in this study because that is what we had available to us.

I think there is too much variability in what I think is a flail chest and what someone else thinks is a flail chest.

So I think it's really a matter of the radiographic fracture pattern and then how the patient looks clinically and physiologically. And part of that includes things like beside PFTs and the appreciation of paradoxical motion.

Dr. Biffl, your comment about taking out 2012 on is a good one. I will do that.

Someone asked about how we approach posterior rib fractures, we developed the triangle of asculatation and raised flaps under the trapisius and the latisimisus in the prone position and can usually get quite high that way.

But what I really think is going to be an interesting and an exciting way to do it is to put the plates on the inside thorascopically but we're just not there with the technology yet.

And then Babak your final question was how do we pick the patients in the first place. And I think that is the, quite literally, billion dollar question.

And I just wanted to emphasize that the point of this study was to look at patients who were already selected for surgery so that's already a group that is selected and see if there was a relationship between the timing and outcoms.

The goal was not to take this highly-select group that we thought needed surgery and compare them to a group that doesn't get surgery. That's been done before. It's being done right now. It will be done again. But I didn't want that to be the focus of this study. Thank you.