ISSN: 2684-1320
Journal of Pain Management & Medicine

OPEN ACCESS Freely available online

Research Article

Early Surgical Stabilization of Rib Fractures Leads to Favorable Short-Term Outcomes of Flail Chest Injuries: A Retrospective Study

Shun-Mao Yang[1*], Po-Keng Su[1], Ying-Hao Su[2], Chun-Hsiung Huang[3], Alban Don Wang[4], Guan-Been Chen[4], Hsiung Tu[4], Meng-Kan Chen[5]

[1]Department of Thoracic Surgery, National Taiwan University Hospital, Taipei, Taiwan;[2]Department of Orthopedics, National Taiwan University Hospital, Taipei, Taiwan;[3]Department of Trauma Surgery, National Taiwan University Hospital, Taipei, Taiwan;[4]Department of Emergency Medicine, National Taiwan University Hospital, Taipei, Taiwan;[5]Department of Family Medicine, National Taiwan University Hospital, Taipei, Taiwan

ABSTRACT

Background: The optimal timing for Surgical Stabilization of Rib Fractures (SSRF) in the Flail Chest (FC) has not been established. This study was designed to study the effects of different timing for SSRF in patients with FC and analyze the subgroup of patients with an FC who can have maximal benefit.

Methods: We retrospectively analyzed the data of patients with FC, who underwent SSRF between May, 2016 and February, 2020. The enrolled patients were divided into the early (operation ≤ 48 h after injury) and late (operation>48 h after injury) SSRF groups. The primary outcome measures were the Duration of Mechanical Ventilation (DMV), duration of Intensive Care Unit stay (ICU stay) and Duration of Hospital Stay (HLOS). The secondary outcome measures were the incidence of pneumonia, tracheostomy and mortality.

Results: One hundred and twenty-seven patients with FC who underwent SSRF were included in the study of these, 89 were men and 38 were women, with mean ages of 62.50 and there were 75 patients and 52 patients in the early and late SSRF groups, respectively. Univariate and multivariate linear regression analyses revealed that the factors associated with late SSRF and Respiratory Failure (RF) may affect primary outcomes. The early and late SSRF groups showed significantly different DMV (2.63 ± 3.59 *vs.* 5.58 ± 9.50, P=0.0367), ICU stay (4.32 ± 4.41 *vs.* 7.83 ± 9.41, P=0.0147) and HLOS (10.63 ± 4.73 *vs.* 15.83 ± 10.45, P=0.0013). The early (41 cases) and late (16 cases) SSRF subgroups of the RF group (57 cases) significantly different DMV (3.85 ± 4.42 *vs.* 14.44 ± 13.49, P=0.0071), ICU stay (5.51 ± 5.62 *vs.* 16.50 ± 13.14, P=0.0049) and HLOS (11.90 ± 5.80 *vs.* 24.63 ± 14.61, P=0.0049). Pearson's correlation coefficients revealed significant positive correlations between surgical timing and DMV (r=0.671, p<0.001), ICU stay (r=0.631, p<0.001) and HLOS (r=0.700, p<0.001) in the RF group. Surgical timing and RF did not affect secondary outcomes.

Conclusion: This Research revealed that late SSRF and RF significantly affected the primary outcome of FC injuries. Patients who underwent early SSRF had significantly shortened DMV, ICU stay and HLOS, especially in the RF subgroup. SSRF within 48 h after injury is recommended for FC injuries.

Keywords: Flail chest; Surgical stabilization of rib fracture; Respiratory failure; Flail chest; Intensive care unit

Abbreviations: COPD: Chronic Obstructive Pulmonary Disease; DMV: Duration of Mechanical Ventilation; FC: Flail Chest; HLOS: Duration of Hospital Stay; ICU: Intensive Care Unit; ISS: Injury Severity Score: RF: Respiratory Failure; SSRF: Surgical Stabilization of Rib Fractures; TBI: Traumatic Brain Injury.

INTRODUCTION

Thoracic injuries, including chest wall contusions, rib fractures, traumatic pneumo-hemothorax and pulmonary contusions, are complex and diverse; thoracic injury is the second most common cause of trauma-related mortality after traumatic brain injury. Rib

Correspondence to: Shun-Mao Yang, Department of Thoracic Surgery, National Taiwan University Hospital, Taipei, Taiwan, E-mail: mutayang@gmail.com

Received: 22-Oct-2024, Manuscript No. JPMME-24-27238; **Editor assigned:** 25-Oct-2024, PreQC No. JPMME-24-27238 (PQ); **Reviewed:** 08-Nov-2024, QC No. JPMME-24-27238; **Revised:** 15-Nov-2024, Manuscript No. JPMME-24-27238 (R); **Published:** 25-Nov-2024, DOI: 10.35248/2684-1320.24.10.296

Citation: Yang SM, Su PK, Su YH, Huang CH, Wang AD, Chen GB, et al. (2024). Early Surgical Stabilization of Rib Fractures Leads to Favorable Short-Term Outcomes of Flail Chest Injuries: A Retrospective Study. J Pain Manage Med. 10:296.

fractures are common thoracic injuries that account for 10% of all trauma-related admissions [1-4]. Flail Chest (FC) is a segmental rib fracture involving at least three consecutive ribs that leads to instability of the chest wall. It may be characterized by paradoxical respiratory movement and subsequent pneumonia or respiratory failure requiring mechanical ventilation support and prolonged Intensive Care Unit (ICU) stay, which leads to a mortality rate of up to 16% [1,2].

In recent decades, three randomized controlled trials have demonstrated that Surgical Stabilization of Rib Fracture (SSRF) for FC is superior to conservative treatment [5-7]. Some meta-analyses have shown that SSRF can improve the Duration of Mechanical Ventilation (DMV), ICU stay and duration of hospital stay (HLOS). It can also decrease the rate of pneumonia and the need for tracheostomy in patients with FC [8-10]. Several studies have also reported that patients with multiple fractures of displaced ribs, rib fracture with intractable pain after conservative treatment, chest wall deformity and failed weaning from the ventilator are candidates for SSRF [11,12]. The practice guidelines for the management of rib fractures recommend that SSRF in adult patients with FCs is superior to conservative management after blunt trauma [13,14]. However, the optimal timing of SSRF in patients with FCs has not been established. Recent studies have revealed that early fixation of rib fractures may improve the short-term outcomes of complex rib fractures [15-17]. However, the inclusion criteria for SSRF in these studies included patients with and without FC. In this retrospective study, only the patients with FC were included.

We hypothesized that early surgical stabilization (surgery within 48 hours of injury) in patients with FC can shorten the DMV, ICU stay and HLOS reduce the incidence of pneumonia and the need for tracheostomy. Therefore, we conducted a single-center retrospective study to investigate the effects of different surgical timing in patients with FC and determine the subgroup of patients with FC who can have maximal benefits.

MATERIALS AND METHODS

Study design and patients

A retrospective review of trauma registries and databases was conducted between May, 2016 and June, 2020 at our institute. Our indications for SSRF were as follows: (a) FC; (b) ≥3 rib fractures with bicortical displacement; (c) rib fractures associated with RF; (d) rib fractures associated with inability to cough or intractable pain (visual analog scale of >6) after adequate pain control and (e) rib fractures associated with pneumothorax or hemothorax requiring surgical intervention for the repair of intrathoracic injuries. We excluded patients with Traumatic Brain Injury (TBI) who had a Glasgow coma scale score of <13, patients younger than 18 years, pregnant women and massive hemothorax with shock requiring emergent thoracotomy. FC was diagnosed using chest Computed Tomography (CT) with three-dimensional reconstruction to confirm the locations and patterns of segmental fracture of at least three consecutive ribs or in patients with the paradoxical movement of the chest wall during inspiration and expiration. A three-step inclusion method was adopted in this study: (i.) All hospitalized trauma patients with evidence of rib fracture were eligible for inclusion review; (ii.) patients with indications for SSRF were eligible for inclusion review and (iii.) patients with FC who underwent SSRF were eligible for the final analysis (Figure 1). The study was approved by the Institutional Board Review of the National Taiwan University Hospital Hsin-Chu Branch (approval number: 110-132-E) and individual patient consent was waived.

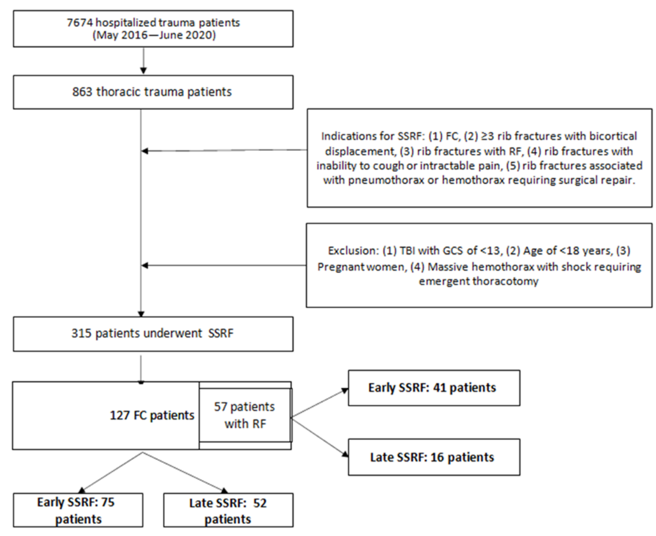

Figure 1: Flowchart of patient enrolment in the study.

All patients were admitted to the emergency department or referred from peripheral hospitals. Management priority in the emergency department was based on the Advanced Trauma Life Support guidelines [18]. RF was defined as paradoxical movement during respiration with respiratory distress, PaO_2 of <60 mmHg or $PaCO_2$ of >60 mmHg after use of O_2 or a non-invasive ventilator, respiratory rate of >30 times per minute even after use of O_2 supply, risk of aspiration or unconsciousness requiring endotracheal intubation to maintain respiratory function [18].

The charts and medical records were reviewed and the following patient data were collected: Age, sex, mechanism of trauma, referral history from a peripheral hospital; current smoking status, history of Chronic Obstructive Pulmonary Disease (COPD), history of diabetes mellitus, associated injuries, Injury Severity Score (ISS), chest abbreviated injury score, ribScore, rib fracture score, chest trauma score, blunt pulmonary contusion 18 score, number of fractured ribs, number of plated fractured ribs, stabilization index (number of plated fractured ribs/number of fractured ribs), time to surgery (the interval between injury and operation), RF, ICU stay, DMV, HLOS, pneumonia, tracheostomy and mortality [19-22]. The recorded time of injury depended on the recording by the emergency medical technician or the recall of conscious patients.

The enrolled patients were divided into the early (operation ≤ 48 h after injury) and late (operation >48 h after injury) SSRF groups for comparison. Our primary outcome measures were DMV, ICU stay and HLOS. The secondary outcome measures were the incidence of pneumonia, tracheostomy and mortality.

Statistical analyses

Statistical analysis was performed using the SAS software (version 9.4; SAS Institute Inc., Cary, NC, USA). All continuous variables were summarized as the mean (standard deviation) for normally distributed variables. Group comparisons were conducted using the two-sample independent t-test for distributed continuous variables and the Fisher's exact or chi-squared test for dichotomous or categorical variables depending on the sample size. Multiple linear regression analysis was used to evaluate the correlations between the associated variables and primary outcomes. A two-sample independent t-test was also used to compare the groups and subgroups for the RF analysis. The association between surgical timing and primary outcomes of the RF group was assessed using Pearson's correlation coefficient. All p-values were two-tailed and statistical significance was set at $p < 0.05$.

RESULTS

A total of 127 patients with FC who underwent SSRF met the inclusion criteria and were enrolled in this study. The clinical and demographic characteristics of patients are shown in Table 1. The 127 patients, 89 were men and 38 were women; their mean age was 62.50 ± 15.54 (22-92 range) years and 62 patients were older (≥65 years). Seventy-five and 52 patients were included in the early and late SSRF groups, respectively. The mean times to surgery for the early and late SSRF groups were 25.39 ± 14.55 and 155.1 ± 129.40 hours, respectively. The mean ISS, RibScore, rib fracture score, chest trauma score and blunt pulmonary contusion 18 were 22.82 ± 7.20, 2.83 ± 0.96, 10.81 ± 6.88, 6.50 ± 1.40 and 2.76 ± 2.34, respectively. Eight hundred and sixty-one fractured ribs were identified by chest CT and the mean number of fractured ribs per person was 6.78 ± 2.34. Four hundred and eighteen fractured ribs were fixed and the mean number of ribs fixed per person was 3.29 ± 1.11. The mean stability index was 0.51 ± 0.18. Only nine patients had bilateral FC.

The most common mechanism of trauma was motorcycle accidents (66.93%), followed by falls (23.62%). Eighty-nine (70.08%) of 127 patients had associated injuries. The incidence of clavicular fracture, TBI, scapular fracture and lower limb fracture were 31.5%, 18.11%, 17.32% and 14.96%, respectively. The two groups showed similar data for most variables. Regarding the exceptions, the mean number of plated ribs and the incidence of RF were higher for the early SSRF group; the incidence of referral was higher for the late SSRF group (Table 1). The early and late SSRF groups showed statistically significant differences in DMV (2.63 ± 3.59 *vs.* 5.58 ± 9.50, P=0.0367), ICU stay (4.32 ± 4.41 *vs.* 7.83 ± 9.41, P=0.0147) and HLOS (10.63 ± 4.73 *vs.* 15.83 ± 10.45, P=0.0013). However, there were no significant differences between the secondary outcomes of the two groups (Table1). The incidence of tracheostomy and mortality were 0.79% and 3.15%, respectively. Only one patient required tracheostomy; four patients died after surgery and three of them were older than 75 years.

Table 1: Baseline characteristics of patients who received early (within 48 hours after injury) and late (>48 hours after injury) SSRF.

Variable	ALL (N=127)	Early SSRF (N=75)	Late SSRF (N=52)	p-value
Age	62.50 ± 15.54	62.04 ± 15.74	63.17 ± 15.38	0.6879
Sex (%)	-	-	-	0.539
F	38 (29.92)	24 (32.00)	14 (26.92)	-
M	89 (70.08)	51 (68.00)	38 (73.08)	-
Time to surgery, hour	78.51 ± 104.91	25.39 ± 14.55	155.1 ± 129.40	<0.0001**
RibScore	2.83 ± 0.96	2.95 ± 1.03	2.67 ± 0.83	0.1137
ISS	22.82 ± 7.20	22.23 ± 6.72	23.67 ± 7.84	0.2676
Chest AIS (%)	-	-	-	1
4	120 (94.49)	71 (94.67)	49 (94.23)	-
5	7 (5.51)	4 (5.33)	3 (5.77)	-
RFS	10.81 ± 6.88	10.60 ± 8.46	11.12 ± 3.56	0.6389
CTS	6.50 ± 1.40	6.49 ± 1.46	6.52 ± 1.32	0.919
BPC 18	2.76 ± 2.34	2.85 ± 2.31	2.62 ± 2.39	0.5744
Pneumothorax (%)	43 (33.86)	29 (38.67)	14 (26.92)	0.1691
Hemothorax (%)	121 (95.28)	70 (93.33)	51 (98.08)	0.3995
Respiratory failure (%)	57 (44.88)	41 (54.67)	16 (30.77)	0.0078**
Number of plated ribs	3.29 ± 1.11	3.55 ± 1.22	2.92 ± 0.81	0.0008***
Number of fractured ribs	6.78 ± 2.34	6.88 ± 2.39	6.63 ± 2.27	0.5626
Stabilization index	0.51 ± 0.18	0.54 ± 0.18	0.48 ± 0.19	0.0837
Referral (%)	51 (40.16)	23 (30.67)	28 (53.85)	0.0088**
COPD	26 (20.47)	15 (20.00)	11 (21.15)	0.8741
Current smoker	47 (37.01)	27 (36.00)	20 (38.46)	0.7775
DM	36 (28.35)	25 (33.33)	11 (21.15)	0.1342
Mechanism (%)	-	-	-	0.1697
motorbike	85 (66.93)	54 (72.00)	31 (59.62)	-
fall, ≥ 3m	18 (14.17)	11 (14.67)	7 (13.46)	-
fall, <3m	12 (9.45)	4 (5.33)	8 (15.38)	-
MVC	2 (1.57)	2 (2.67)	0 (0.00)	-
Pedestrian	4 (3.15)	1 (1.33)	3 (5.77)	-
heavy mental compression	1 (0.79)	1 (1.33)	0 (0.00)	-
bicycle	5 (3.94)	2 (2.67)	3 (5.77)	-
Associated injury (%)	89 (70.08)	52 (69.33)	37 (71.15)	0.8256
Cervical spinal injury (%)	4 (3.15)	3 (4.00)	1 (1.92)	0.6439
Lumbar spinal injury (%)	6 (4.72)	2 (2.67)	4 (7.69)	0.2259
Thoracic spinal injury (%)	5 (3.94)	2 (2.67)	3 (5.77)	0.3992
Clavicular fracture (%)	40 (31.50)	24 (32.00)	16 (30.77)	0.8833
Sternal fracture (%)	3 (2.36)	3 (4.00)	0 (0.00)	0.2688

Scapular fracture (%)	22 (17.32)	11 (14.67)	11 (21.15)	0.3422
Upper limb fracture (%)	12 (9.45)	9 (12.00)	3 (5.77)	0.357
Lower limb fracture (%)	19 (14.96)	10 (13.33)	9 (17.31)	0.5369
TBI (%)	23 (18.11)	11 (14.67)	12 (23.08)	0.2262
Splenic laceration (%)	6 (4.72)	6 (8.00)	0 (0.00)	0.0806
Liver laceration (%)	5 (3.94)	2 (2.67)	3 (5.77)	0.3992
Kidney laceration (%)	3 (2.36)	2 (2.67)	1 (1.92)	1
Aortic dissection or Major	-	-	-	-
vessel injury (%)	3 (2.36)	1 (1.33)	2 (3.85)	0.5672
Pelvic fracture (%)	8 (6.30)	4 (5.33)	4 (7.69)	0.7154
Bilateral flail chest (%)	9 (7.09)	6 (8.00)	3 (5.77)	0.7363
Primary outcomes	-	-	-	-
DMV	3.83 ± 6.80	2.63 ± 3.59	5.58 ± 9.50	0.0367*
ICU stay	5.76 ± 7.09	4.32 ± 4.41	7.83 ± 9.41	0.0147*
HLOS	12.76 ± 8.00	10.63 ± 4.73	15.83 ± 10.45	0.0013**
Secondary outcomes	-	-	-	-
Pneumonia (%)	24 (18.90)	10 (13.33)	14 (26.92)	0.0544
Tracheostomy (%)	1 (0.79)	0 (0.00)	1 (1.92)	0.4094
Mortality (%)	4 (3.15)	1 (1.33)	3 (5.77)	0.3042

Note: Differences between groups were evaluated using the χ^2 test, Fisher's exact test and two-sample independent t-test p-value: *<0.05; **<0.01; ***<0.001; ISS: Injury Severity Score; Chest AIS: Chest Abbreviated Injury Score; RFS: Rib Fracture Score; CTS: Chest Trauma Score; BPC 18: Blunt Pulmonary Contusion score 18; COPD: Chronic Obstructive Pulmonary Disease; DM: Diabetes Mellitus; MVC: Motor Vehicle Collision; TBI: Traumatic Brain Injury; DMV: Duration of Mechanical Ventilation; HLOS: Hospital Length of Stay.

The univariate analysis of the primary outcomes is shown in Table 2. A higher RibScore (>3) was associated with prolonged DMV and ICU stay. A higher ISS (≧ 25) was associated with prolonged DMV, ICU stay and HLOS. Early SSRF was associated with shortened DMV, ICU stay and HLOS. RF was associated with prolonged DMV, ICU stay and HLOS. Referral was associated with prolonged DMV, ICU stay and HLOS. Clavicular fractures were associated with shortened DMV, ICU stay and HLOS. Scapular fractures were associated with prolonged ICU stay. Lower limb fractures were associated with prolonged DMV, ICU stay and HLOS. TBI was associated with prolonged ICU stay and HLOS. COPD was associated with prolonged DMV, ICU stay and HLOS and current smoking was associated with prolonged ICU stay.

The results of the multiple linear regression analysis of the primary outcomes are shown in Table 3. Late SSRF was associated with prolonged DMV (3.79 days, Standard Error (SE) SE=1.11, P=0.0009), ICU stay (3.69 days, SE=1.10, P=0.0011) and HLOS (5.29 days, SE=1.27, P<0.0001). RF was associated with prolonged DMV (5.15 days, SE=1.08, P<0.0001), ICU stay (4.35 days, SE=1.07, P<0.0001) and HLOS (5.15 days, SE=1.24, P<0.0001). Clavicular fractures were associated with shortened ICU stay (2.51 days, SE=1.10, P=0.0240). Scapular fractures were associated with prolonged ICU stay (3.12 days, SE=1.32, P=0.0198). Lower limb fractures were associated with prolonged HLOS (3.62 days, SE=1.71, P=0.0358). TBI was associated with prolonged ICU stay (4.52 days, SE=1.42, P=0.0019) and HLOS (5.03 days, SE=1.67, P=0.0032). COPD was associated with prolonged DMV (2.54 days, SE=1.25, P=0.0446).

The 57 patients with RF in this study were further categorized into two groups (early SSRF, 41 patients *vs* late SSRF, 16 patients). There were statistically significant differences in DMV (3.85 ± 4.42 *vs* 14.44 ± 13.49, P=0.0071), ICU stay (5.51 ± 5.62 *vs* 16.50 ± 13.14, P=0.0049) and HLOS (11.90 ± 5.80 *vs* 24.63 ± 14.61, P=0.0049) between the early and late SSRF groups (Table 4). There were also significant positive correlations between surgical timing and DMV (r=0.671, p<0.0001), ICU stay (r=0.631, p<0.0001) and HLOS (r=0.700, p<0.0001) in the RF subgroup.

DISCUSSION

FC injury is a severe condition that results in pulmonary contusion, intrathoracic injuries and paradoxical motion of the chest wall. Some patients develop respiratory failure with higher morbidity and mortality after blunt chest trauma [1,2]. The benefits of SSRF are the correction of an unstable chest wall, restoration of respiratory mechanics and the reduction of unstable chest wall-related pain [3,4,11,12]. Previous randomized controlled trials have shown that patients with FC who undergo SSRF can have shorter DMV, duration of ICU stay and HLOS and lower mortality rate, incidence of pneumonia and tracheostomy rate than those who undergo non-operative management [5-7]. Rib fixation occurred earlier and the patient had recovery from intractable pain, lung atelectasis, hypoventilation or pneumonia [13,15]. However, in these two prospective randomized studies, the surgical timing varied from 2 to 5 days after endotracheal intubation with mechanical ventilation, which created a longer interval between injury and operation [5,6]. Early surgical intervention for rib fracture was investigated by some centers [15-17,23]. In this retrospective study, we reviewed our trauma registry and analyzed different surgical timing for stabilizing patients with FC, which could affect acute outcomes. In this baseline analysis, the two groups were similar for the variables assessed, except that the rate of referral from peripheral hospitals was higher in the late SSRF group. The univariate analysis showed that higher ISS, higher Ribscore, RF, referral, associated injury, TBI, COPD, current smoking and late SSRF were associated with worse acute outcomes. Multiple linear regression analysis showed that late SSRF and RF had significant adverse effects on DMV, ICU stay and HLOS. Late SSRF was associated with prolonged DMV (3.79 days), ICU stay (3.69 days) and HLOS (5.29 days); RF was also associated with prolonged DMV (5.15 days), ICU stay (4.35 days) and HLOS (5.15 days) (Table 3).

Table 2: Univariate analysis of primary outcomes.

Variables	DMV			ICU stay		HLOS	
	N	Mean ± SD	p-value	Mean ± SD	p-value	Mean ± SD	p-value
Age	-	-	0.0961	-	0.1289	-	0.1285
<65	65	2.85 ± 5.75	-	4.82 ± 6.01	-	11.69 ± 6.63	-
≥ 65	62	4.87 ± 7.66	-	6.74 ± 7.99	-	13.87 ± 9.14	-
Sex	-	-	0.6395	-	0.8156	-	0.6312
F	38	4.37 ± 9.30	-	6.03 ± 2.94	-	13.37 ± 10.21	-
M	89	3.61 ± 5.45	-	5.64 ± 4.40	-	12.49 ± 6.90	-
Stabilization index	-	-	0.7438	-	0.375	-	0.631
≤ 0.5	72	4.00 ± 7.75	-	6.22 ± 8.09	-	13.06 ± 8.55	-
>0.5	55	3.62 ± 5.38	-	5.15 ± 5.52	-	12.36 ± 7.27	-
Ribscore	-	-	0.0104*	-	0.0232*	-	0.07
≤ 3	103	3.10 ± 5.41	-	4.95 ± 5.45	-	12.14 ± 7.14	-
>3	24	7.00 ± 10.53	-	9.21 ± 11.31	-	15.42 ± 10.74	-
ISS	-	-	0.0446*	-	0.0167*	-	0.0160*
<25	91	2.76 ± 4.03	-	4.44 ± 4.32	-	11.42 ± 6.28	-
≥ 25	36	6.56 ± 10.68	-	9.08 ± 10.81	-	16.14 ± 10.61	-
Pneumothorax	-	-	0.321	-	0.4237	-	0.4769
no	84	3.36 ± 5.95	-	5.35 ± 5.97		3.36 ± 5.95	-
yes	43	4.77 ± 8.21	-	6.56 ± 8.91		4.77 ± 8.21	-
Associated injury	-	-	0.3887	-	0.1969	-	0.2697
no	38	3.16 ± 4.83	-	4.68 ± 5.21	-	11.55 ± 8.15	-
yes	89	4.12 ± 7.49	-	6.21 ± 7.73	-	13.27 ± 7.93	-
Clavicular fracture	-	-	0.0016**	-	0.0029**	-	0.0299*
no	87	4.75 ± 7.99	-	6.66 ± 8.35	-	13.54 ± 9.30	-
yes	40	1.85 ± 1.66	-	3.80 ± 1.71	-	11.05 ± 3.40	-
Scapular fracture	-	-	0.4249	-	0.0416*	-	0.0615
no	105	3.27 ± 4.90	-	5.06 ± 5.41	-	12.02 ± 6.56	-
yes	22	6.55 ± 12.22	-	9.09 ± 11.93	-	16.27 ± 12.46	-
Upper limb fracture	-	-	0.6246	-	0.6659	-	0.6949
no	115	3.77 ± 6.75	-	5.63 ± 6.81	-	12.63 ± 7.92	-
yes	12	4.50 ± 7.60		6.92 ± 9.63	-	14.00 ± 8.99	-
Lower limb fracture	-	-	0.0056**	-	0.0046**		0.0005***
no	108	3.56 ± 6.30	-	5.43 ± 6.59	-	12.12 ± 7.47	-
yes	19	5.37 ± 9.23	-	7.63 ± 9.44	-	16.37 ± 9.98	-

TBI	-	-	0.1288	-	0.0093**	-	0.0020**
no	104	2.80 ± 3.62	-	4.56 ± 3.86	-	11.52 ± 5.88	
yes	23	8.52 ± 13.25	-	11.17 ± 13.44	-	18.35 ± 12.82	-
COPD	-	-	0.0039**	-	0.0076**	-	0.0104*
no	101	3.04 ± 6.20	-	4.90 ± 6.26	-	12.10 ± 7.91	-
yes	26	6.92 ± 8.17	-	9.08 ± 9.06	-	15.31 ± 7.99	-
Current smoking	-		0.0521	-	0.0499*	-	0.1519
no	80	2.94 ± 6.60	-	4.81 ± 6.70	-	11.98 ± 7.72	-
yes	47	5.36 ± 6.94	-	7.36 ± 7.50	-	14.09 ± 8.37	-
DM	-	-	0.9781	-	0.8405	-	0.8792
no	91	3.82 ± 7.26	-	5.82 ± 7.71	-	12.82 ± 8.20	-
yes	36	3.86 ± 5.58	-	5.58 ± 5.27	-	12.58 ± 7.57	-
Time to surgery, hour	-	-	0.0367*	-	0.0147*	-	0.0013**
≤48	75	2.63 ± 3.59	-	4.32 ± 4.41	-	10.63 ± 4.73	-
>48	52	5.58 ± 9.50	-	7.83 ± 9.41	-	15.83 ± 10.45	-
Respiratory failure	-	-	<.0001***	-	0.0002***	-	0.0014**
no	70	1.40 ± 1.23	-	3.44 ± 1.91	-	10.54 ± 3.59	-
yes	57	6.82 ± 9.26	-	8.60 ± 9.67	-	15.47 ± 10.70	-
Referral	-	-	0.0184*	-	0.0129*	0.0101*	0.0101*
no	76	2.46 ± 3.12	-	4.25 ± 3.33	-	11.04 ± 4.62	-
yes	51	5.88 ± 9.74	-	8.00 ± 10.07	-	15.31 ± 10.87	-

Note: Differences between groups of primary outcomes were evaluated by two sample independent t-test. p-value: *<0.05; **<0.01; ***<0.001; DMV: Duration of Mechanical Ventilator, HLOS: Hospital Length of Stay, ISS: Injury Severity Score, TBI:

Table 3: Multiple linear regression analysis of primary outcomes.

Risk factor	DMV			ICU stay			HLOS		
	β	SE	p-value	β	SE	p-value	β	SE	p-value
Ribscore, >3 (ref: ≤ 3)	2.52	1.34	0.0636	2.46	1.33	0.0659	-	-	-
ISS, ≥ 25 (ref: <25)	1.38	1.2	0.2514	0.45	1.27	0.7209	0.14	1.48	0.9264
Time to surgery, hour, >48 (ref: ≤ 48)	3.79	1.11	0.0009***	3.69	1.1	0.0011**	5.29	1.27	<0.0001***
Respiratory failure (ref: No)	5.15	1.08	<0.0001***	4.35	1.07	<0.0001***	5.15	1.24	<0.0001***
Referral (ref: No)	1.84	1.07	0.0887	1.69	1.06	0.1139	2.22	1.23	0.075
Clavicular fracture (ref: No)	2	1.09	0.0708	2.51	1.1	0.0240**	1.94	1.28	0.1327
Scapular fracture (ref: No)	-	-	-	3.12	1.32	0.0198**	-	-	-
Lower limb fracture (ref: No)	0.79	1.46	0.5913	1.27	1.45	0.3848	3.62	1.71	0.0358*
TBI (ref: No)	-	-	-	4.52	1.42	0.0019**	5.03	1.67	0.0032**
COPD (ref: No)	2.54	1.25	0.0446*	2.47	1.31	0.0606	1.68	1.45	0.2502
Smoking (ref: No)	-	-	-	0.62	1.1	0.5738	-	-	-

Note: p-value: *<0.05; **<0.01; ***<0.001; DMV: Duration of Mechanical Ventilator; HLOS: Hospital Length of Stay; ISS: Injury Severity Score; TBI: Traumatic Brain Injury; COPD: Chronic Obstructive Pulmonary Disease.

The above findings have also been reported by previous studies. Iqbal et al., reported that early surgical stabilization of complex chest wall injuries within 48 hours of injury leads to improve acute outcomes, indicating that early SSRF can shorten HLOS (5.8 days), ICU stay (3.8 days) and DMV (2.8 days) and decrease the incidence of pneumonia (32%) and tracheostomy (16%) [17]. Pieracci et al., suggested that early SSRF (within 24 hours of admission) for multiple rib fractures can lead to favorable outcomes (shortened HLOS, ICU stay and DMV) and shorter operative time in a multicenter study [15]. In our previous study, Su et al. revealed that patients with severe rib fractures and RF who underwent early SSRF (within 72 hours of injury) may have shortened DMV (54 h), ICU stay (107 h), HLOS (6 days) and lower medical costs [16]. However, the enrolled patients in the above three studies on timing for SSRF had FC and three or more bicortically displaced fractures and optimal medical management had failed. Only patients with FC were included in this study. Higher ISS and Ribscore were not associated with primary outcomes in the multiple linear regression analysis; however, clavicular fractures, TBI, scapular fractures, lower limb fractures and COPD partially affected the primary outcomes. In this series, patients with FC-associated clavicular fractures had a shorter ICU stay. Most patients with clavicular fractures were in the early SSRF group in this study. We performed simultaneous SSRF and internal fixation of clavicular fractures and clavicular fractures did not adversely affect respiratory function.

FC injuries with TBI require neurologic monitoring in the ICU for at least 24 hours-72 hours depending on the judgement of the neurologic surgeon in the institute; this prolongs the ICU stay and HLOS. For the management of FC-associated lower limb fractures, we consulted an orthopedic surgeon in our trauma team, which led to the prolongation of HLOS. The management of FC with scapular fractures was difficult and we performed SSRF for FC; however, only some scapular fractures were fixed simultaneously, thus persistent chest pain and impaired respiratory motion led to prolonged ICU stay. More experience is required to manage FC injuries with scapular fractures. The comorbidity of COPD can influence respiration and weaning of the ventilator, leading to prolonged DMV.

In this study, an early intervention did not affect secondary outcomes, but the incidence of pneumonia tended to be lower in the early SSRF group (Table 1). We further analyzed the effect of different surgical timing on acute outcomes in the subgroup of FC patients with RF. Early SSRF was associated with shorter DMV (10.59 days), ICU stay (10.99 days) and HLOS (12.73 days) than late SSRF in this RF group (Table 4).

Table 4: The analysis of the primary outcomes of the RF subgroups of the early and late SSRF groups.

Primary outcomes	Respiratory failure (N=57)		
	Early SSRF (N=41)	Late SSRF (N=16)	p-value
DMV	3.85 ± 4.42	14.44 ± 13.49	0.0071*
ICU stay	5.51 ± 5.62	16.50 ± 13.14	0.0049**
HLOS	11.90 ± 5.80	24.63 ± 14.61	0.0049***

Note: Differences between groups were evaluated by two sample independent t-test. p-value: *<0.05; **<0.01; ***<0.001; DMV: Duration of Mechanical Ventilator; HLOS: Hospital Length of Stay.

FC patients with RF who underwent SSRF within 48 hours could gain more of the primary outcome than the whole group that underwent early SSRF. We also found moderate to high positive correlations between the time to surgery and primary outcomes (Figure 2). In patients with FC, instability of the chest wall can compromise respiratory mechanics, which may lead to respiratory failure. Stabilizing the chest wall early was associated with earlier recovery from lung atelectasis, paradoxical movement and hypoventilation; thus, early SSRF can lead to better primary outcomes, especially in the RF subgroup. This result is different from those of other studies.

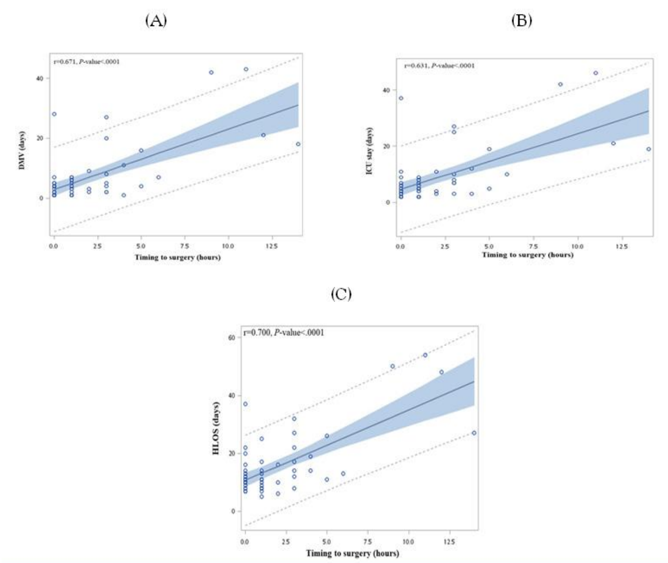

Figure 2: Pearson's correlation between time to surgery and primary outcomes. **Note:** (A) Correlation between time to surgery and DMV; (B) Correlation between time to surgery and ICU stay; (C) Correlation between time to surgery and HLOS.

This study had several limitations. First, the patients were not randomized and the patients in the two groups were not equal. Second, we attempted early surgical stabilization in patients with FC in our unit, but factors such as operation room availability, patient preference and referral from peripheral hospitals delayed SSRF. Third, several trauma patients may have sustained concurrent injuries such as splenic rupture, hepatic rupture, TBI, long bone fracture, pelvic fracture or spinal fracture; however, splenic rupture, hepatic rupture, spinal fracture or pelvic fracture may have been given higher priority than be flail chest, which delayed the timing of SSRF.

CONCLUSION

In conclusion, our study revealed that late SSRF and RF were major prognostic factors affecting the outcomes of FC injuries. Patients who underwent early SSRF had significantly shorter DMV, ICU stay and HLOS, especially in the RF subgroup. SSRF should be performed within 48 h of injury and is recommended for FC injuries.

These findings suggest that surgical intervention should be prioritized within 48 hours post-injury to optimize outcomes and reduce healthcare burdens. While secondary outcomes like incidence of pneumonia, tracheostomy and mortality were not significantly affected, a trend toward reduced pneumonia in the early SSRF group was observed, potentially reflecting quicker respiratory stabilization. This study supports the recommendation of SSRF as an effective early intervention for FC injuries, particularly in patients at high risk of RF and highlights the importance of timely surgery to enhance clinical recovery and minimize complications. Further research, ideally with randomized controlled trials, is recommended to confirm these findings and refine guidelines for optimal surgical timing.

DECLARATIONS

Ethical committee consent

The study was approved by the Institutional Board Review of the National Taiwan University Hospital Hsin-Chu Branch (approval number: 110-132-E) and individual patient consent was waived.

Consent for publication

Data collections, coding and analysis were in accordance with the legal data protection policy.

Availability of data and materials

The data supporting the conclusions of this study are included within the article.

Author contributions

Huan-Jang Ko acquired and analyzed the data and drafted the manuscript. Ying-Hao Su, Meng-Kan Chen and Shun-Mao Yang participated in designing the study and analyzing the data. Chun-Hsiung Huang, Alban Don Wang, Guan-Been Chen and Hsiung Tu participated in collecting data and reviewing the literature. Huan-Jang Ko, Shun-Mao Yang and Meng-Kan Chen oversaw the study. All authors read and approved the final manuscript.

Acknowledgement

We thank the staff of the Biotechnology R&D Center, National Taiwan University Hospital, Hsin-Chu Branch, for their assistance with the statistical analysis.

REFERENCES

1. Dehghan N, De Mestral C, McKee MD, Schemitsch EH, Nathens A. Flail chest injuries: A review of outcomes and treatment practices from the National Trauma Data Bank. J Trauma Acute Care Surg. 2014;76(2):462-468.
2. Ziegler DW, Agarwal NN. The morbidity and mortality of rib fractures. J Trauma Acute Care Surg. 1994;37(6):975-979.
3. Qasim Z, Gwinnutt C. Flail chest: Pathophysiology and management. Trauma. 2009;11(1):63-70.
4. Lafferty PM, Anavian J, Will RE, Cole PA. Operative treatment of chest wall injuries: Indications, technique and outcomes. J Bone Joint Surg Am. 2011;93(1):97-110.
5. Tanaka H, Yukioka T, Yamaguti Y, Shimizu S, Goto H, Matsuda H, et al. Surgical stabilization of internal pneumatic stabilization? A prospective randomized study of management of severe flail chest patients. J Trauma. 2002;52(4):727-732.
6. Granetzny A, Abd El-Aal M, Emam E, Shalaby A, Boseila A. Surgical *vs.* conservative treatment of flail chest. Evaluation of the pulmonary status. Interact Cardiovasc Thorac Surg. 2005;4(6):583-587.
7. Marasco SF, Davies AR, Cooper J, Varma D, Bennett V, Nevill R, et al. Prospective randomized controlled trial of operative rib fixation in traumatic flail chest. J Am Coll Surg. 2013;216(5):924-932.
8. Leinicke JA, Elmore L, Freeman BD, Colditz GA. Operative management of rib fractures in the setting of flail chest: A systematic review and meta-analysis. Ann Surg. 2013;258(6):914-921.
9. Slobogean GP, MacPherson CA, Sun T, Pelletier ME, Hameed SM. Surgical fixation *vs.* nonoperative management of flail chest: A meta-analysis. J Am Coll Surg. 2013;216(2):302-311.
10. Coughlin TA, Ng JW, Rollins KE, Forward DP, Ollivere BJ. Management of rib fractures in traumatic flail chest: A meta-analysis of randomized controlled trials. Bone Joint J. 2016;98(8):1119-1125.
11. Nirula R, Diaz JJ, Trunkey DD, Mayberry JC. Rib fracture repair: Indications, technical issues and future directions. World J Surg. 2009;33(1):14-22.
12. Pieracci FM, Lin Y, Rodil M, Synder M, Herbert B, Tran DK, et al. A prospective, controlled clinical evaluation of surgical stabilization of severe rib fractures. J Trauma Acute Care Surg. 2016;80(2):187-194.
13. Pieracci FM, Majercik S, Ali-Osman F, Ang D, Doben A, Edwards JG, et al. Consensus statement: Surgical stabilization of rib fractures rib fracture colloquium clinical practice guidelines. Injury. 2017;48(2):307-321.
14. Kasotakis G, Hasenboehler EA, Streib EW, Patel N, Patel MB, Alarcon L, et al. Operative fixation of rib fractures after blunt trauma: A practice management guideline from the Eastern Association for the Surgery of Trauma. J Trauma Acute Care Surg. 2017;82(3):618-626.
15. Pieracci FM, Coleman J, Ali-Osman F, Mangram A, Majercik S, White TW, et al. A multicenter evaluation of the optimal timing of surgical stabilization of rib fractures. J Trauma Acute Care Surg. 2018;84(1):1-10.
16. Su YH, Yang SM, Huang CH, Ko HJ. Early *vs.* late surgical stabilization of severe rib fractures in patients with respiratory failure: A retrospective study. PLoS One. 2019;14(4):e0216170.
17. Iqbal HJ, Alsousou J, Shah S, Jayatilaka L, Scott S, Scott S, et al. Early surgical stabilization of complex chest wall injuries improves short-term patient outcomes. J Bone Joint Surg Am. 2018;100(15):1298-1308.
18. Subcommittee AT, International ATLS Working Group. Advanced trauma life support (ATLS®): The ninth edition. J Trauma Acute Care Surg. 2013;74(5):1363-1366.
19. Chapman BC, Herbert B, Rodil M, Salotto J, Stovall RT, Biffl W, et al. RibScore: A novel radiographic score based on fracture pattern that predicts pneumonia, respiratory failure and tracheostomy. J Trauma Acute Care Surg. 2016;80(1):95-101.
20. Maxwell CA, Mion LC, Dietrich MS. Hospitalized injured older adults: Clinical utility of a rib fracture scoring system. J Trauma Nurs. 2012;19(3):168-174.
21. Chen J, Jeremitsky E, Philp F, Fry W, Smith RS. A chest trauma scoring system to predict outcomes. Surgery. 2014;156(4):988-994.
22. De Moya MA, Manolakaki D, Chang Y, Amygdalos I, Gao F, Alam HB, et al. Blunt pulmonary contusion: Admission computed tomography scan predicts mechanical ventilation. J Trauma. 2011;71(6):1543-1547.
23. Fokin AA, Wycech J, Weisz R, Puente I. Outcome analysis of surgical stabilization of rib fractures in trauma patients. J Orthop Trauma. 2019;33(1):3-8.