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ORIGINAL ARTICLE

Evaluation of efficacy and indications of surgical fixation for multiple rib fractures: a propensity-score matched analysis

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Abstract

Purpose The purpose of this study was to assess the effects of recent surgical rib fixation and establish its indications not only for flail chest but also for multiple rib fractures.

Methods Between 2007 and 2015, 187 patients were diagnosed as having multiple rib fractures in our institution. After the propensity score matching was performed, ten patients who had performed surgical rib fixation and ten patients who had treated with non-operative management were included. Categorical variables were analyzed with Fischer's exact test and non-parametric numerical data were compared using the Mann–Whitney *U* test. Wilcoxon signed-rank test was performed for comparison of pre- and postoperative variables. All statistical data are presented as median (25–75 % interquartile range [IQR]) or number.

Results The surgically treated patients extubated significantly earlier than non-operative management patients (5.5 [1–8] vs 9 [7–12] days: $p = 0.019$). The duration of continuous intravenous narcotic agents infusion days (4.5 [3–6] vs 12 [9–14] days: $p = 0.002$) and the duration of intensive care unit stay (6.5 [3–9] vs 12 [8–14] days: $p = 0.008$) were also significantly shorter in surgically treated patients. Under the same ventilating conditions, the postoperative values of tidal volume and respiratory rate improved significantly compared to those values measured just before the surgery. The incidence of pneumonia as a complication was significantly higher in non-operative management group ($p = 0.05$).

Conclusions From the viewpoints of early respiratory stabilization and intensive care unit disposition without any complications, surgical rib fixation is a sufficiently acceptable procedure not only for flail chest but also for repair of severe multiple rib fractures.

Keywords Flail chest · Multiple rib fractures · Operative result · Surgical rib fixation · Non-operative management

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Abbreviations

CT	Computed tomography
AIS	Abbreviated Injury Scale
GCS	Glasgow Coma Scale
NOM	Non-operative management
ICU	Intensive care unit
IQR	Interquartile range

Introduction

Among the blunt chest injuries, multiple rib fractures are one of the most common injuries, and their influences on patient morbidity and mortality are not negligible. Past strategies for treatment of multiple rib fractures, including flail chest were external fixation or pneumatic fixation using mechanical ventilation [1–5], but as previously reported, up to 60 % of patients experienced some kind of morbidity, such as nosocomial pneumonia, prolonged respiratory instability, prolonged number of ventilation days, and a resulting long-term hospital stay [6]. Because of chest wall pain or deformity, 40–60 % of these patients cannot return to full-time employment [7–10]. Furthermore, in addition to long-term chest wall pain, patients with flail chest or multiple rib fractures and pulmonary contusion often suffer from residual respiratory impairment [7, 11].

Recently, open reduction and internal fixation for multiple rib fractures have been performed in limited special trauma centers, and several satisfactory results have been obtained [12–15]. However, these studies supporting surgical rib fixation still had study limitations and comprised a pooling of primarily small numbers of patients, the background propensity of the patients in the retrospective study was not the same, and the indications for surgical fixation were mainly just the presence of flail chest.

Despite the measurable potential for surgical rib fixation in patients who suffer from uncontrollable pain or a prolonged hospital stay, indications for the repair of multiple rib fractures and the effect on the patients compared to conservative therapy have not been established. Therefore, the purpose of this study was to assess the effects of recent surgical fixation for rib fractures not only for flail chest but also for multiple rib fractures.

Materials and method

Our treatment strategies for the patients with multiple rib fractures

This study was performed in the Department of Trauma and Critical Care of Osaka City University Hospital. We retrospectively sought to enroll all patients aged 16 years or older who were admitted to our institution with a diagnosis of multiple rib fractures due to trauma from April 2007 through March 2015. Because there is no universal definition of multiple rib fractures, we defined the term to be fractures of at least more than two ribs either unilaterally or bilaterally.

All patients who had clinical findings or suspicion of rib fractures underwent a computed tomography (CT) scan with 3-dimensional reconstruction to assess the type of fractures at the time of admission or after the vital signs became stable enough to allow scanning. Following the strategies for the multiple rib fractures in our institution, if the patients had a flail segment at their injury site, they were intubated and operative fixation was the priority for repair of the segment. For the patients who did not have flail segments, we preferred to perform surgical rib fixation for massive fractured rib dislocations, such as ribs lacerating the lung or when overlapping of fractured ribs was >15 mm, or the patients could not be tapered from continuous intravenous narcotics or could not start rehabilitation due to the severe pain caused by the fractured ribs. The patients with none of these clinical findings were treated non-operatively.

Previously, there have been no defined consensuses about the appropriate indications and the timing of surgical rib fixation, but several favorable case reports describing surgical rib fixation have appeared since the beginning of 2013 [12, 13]. Therefore, during the latter part of the study period compared with the earlier years, we tended to perform surgical treatment as quickly as possible if the patients had the indications detailed above and the hemodynamic conditions of the patients were prepared enough for the operation.

Patient selection

During the study period, 187 patients were diagnosed as having multiple rib fractures. Patients who had died from severe brain, abdominal, spinal, or pelvic injury as indicated by their Abbreviated Injury Scale (AIS) score of more than five were excluded. We also excluded patients with severe brain injury who had not recovered during hospital admission, as indicated by not attaining a Glasgow Coma Scale (GCS) of >8, and those with spinal or pelvic injury for which a lateral decubitus position for surgery was difficult or contraindicated. Furthermore, patients with open rib fractures and contaminated or infected wounds were also excluded from this study.

The remaining patients were divided into those who underwent surgical rib fixation and those who underwent non-operative management (NOM). Propensity score matching was performed according to the baseline covariates of the patients. Propensity scores were estimated from a logistic model and matched against a caliper of .25.

Surgical strategy for patients with multiple rib fractures

The operations were performed under general anesthesia and differential lung ventilation. Surgical access to the fractured ribs was via muscle sparling incision or if the dislocation of the fractured ribs were huge, minimally thoracotomy was performed as we could confirm the lung or other intra pleural injuries. Depending on the number of fractures to be repaired, several types of skin incisions were performed. As Fig. 1 shows, the three or four most dislocated or flailed segment ribs were fixed by locking screws and plates (Synthes©, Oberdorf, Switzerland) or KANI titanium devices (USCI Japan Ltd., Tokyo, Japan) in all cases. After fixation, a 28 Fr intercostal drainage tube and 10 Fr subcutaneous drainage tube were inserted.

NOM strategy for patients with multiple rib fractures

Patients in the NOM group were treated with traditional external fixation or were intubated and supported by current best-practice invasive mechanical ventilator management if needed. These patients tend to have treated during the earlier part of the study period because there had been no reliable surgical fixation devices obtained.

Weaning from invasive mechanical ventilation was undertaken if the PaO_2 and $PaCO_2$ values and lactate levels of the arterial blood gases were within the permissive range and the patient was not suffering from excruciating pain during spontaneous breathing. If the patient's respiratory rate was >20 breaths per minute or the arterial blood gas values were outside of the permissive range, appropriate sedation and mechanical ventilation were continued for an additional 24 h.

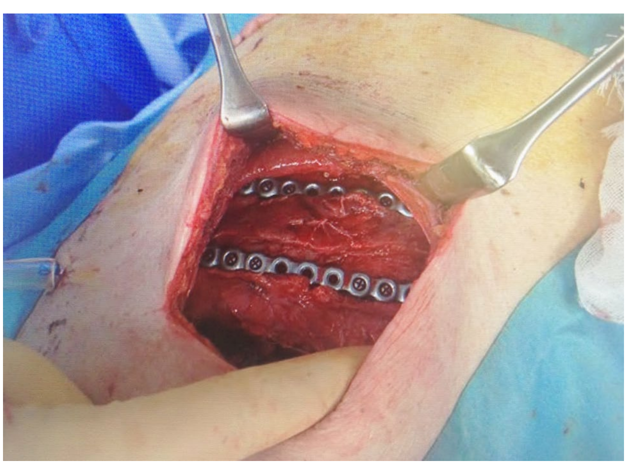

Fig. 1 Rib fixation for flailed segment using locking screws and plates (Synthes©, Oberdorf, Switzerland)

Comparison of therapeutic effects

To clarify the effects of surgical fixation of multiple rib fractures, we retrospectively reviewed the operative indications. As the primary endpoint, the duration of invasive mechanical ventilation days, the number of days in the intensive care unit (ICU), the number of days of continuous administration of intravenous narcotic agent, and the rate of complications, such as pneumonia were compared between the surgical fixation group and the NOM group.

Furthermore, in the surgical fixation group, we evaluated the differences between pre- and postoperative respiratory functions, including respiratory rate, changes in arterial blood gas values, pre- and postoperative pain levels, ventilation-associated pneumonia or other complications of surgery to assure the efficacy of the surgical rib fixation. In the patients who no longer required mechanical ventilator assistance or who were extubated, the respiratory rate during spontaneous respiration was compared between the pre-and postoperation. Tidal volume was compared under the same ventilator conditions in the patients who required pre- and postoperative ventilatory support.

Statistical analysis

All statistical data are presented as median (25–75 % interquartile range [IQR]) or number. Categorical variables were analyzed with Fischer's exact test. Non-parametric numerical data (presented as median with IQR) were compared using the Mann–Whitney *U* test. Propensity matching of patients was performed to balance baseline characteristics. The variables used for matching were age, sex, and AIS score of thoracic injury. The Wilcoxon signed-rank test was performed for comparison of pre- and postoperative variants. A value of $p < 0.05$ was considered statistically significant. Data were analyzed using IBM SPSS Statistics, version 22 (SPSS Inc., Chicago, IL).

Results

During the study period, 187 patients were diagnosed as having multiple rib fractures by CT scan on admission or after their vital signs became stable enough to allow them to undergo pan-CT scanning. Of the patients, 51 were initially excluded because of death caused by other severe injuries or severe brain injury with a GCS that did not recover to >8 during the hospital admission. Of the remaining 136 patients, 21 patients were treated with surgical rib fixation, and the other 115 patients were treated with NOM. After propensity score matching was performed according to the baseline covariates of the patients, ten patients who underwent surgical rib fixation and ten patients who

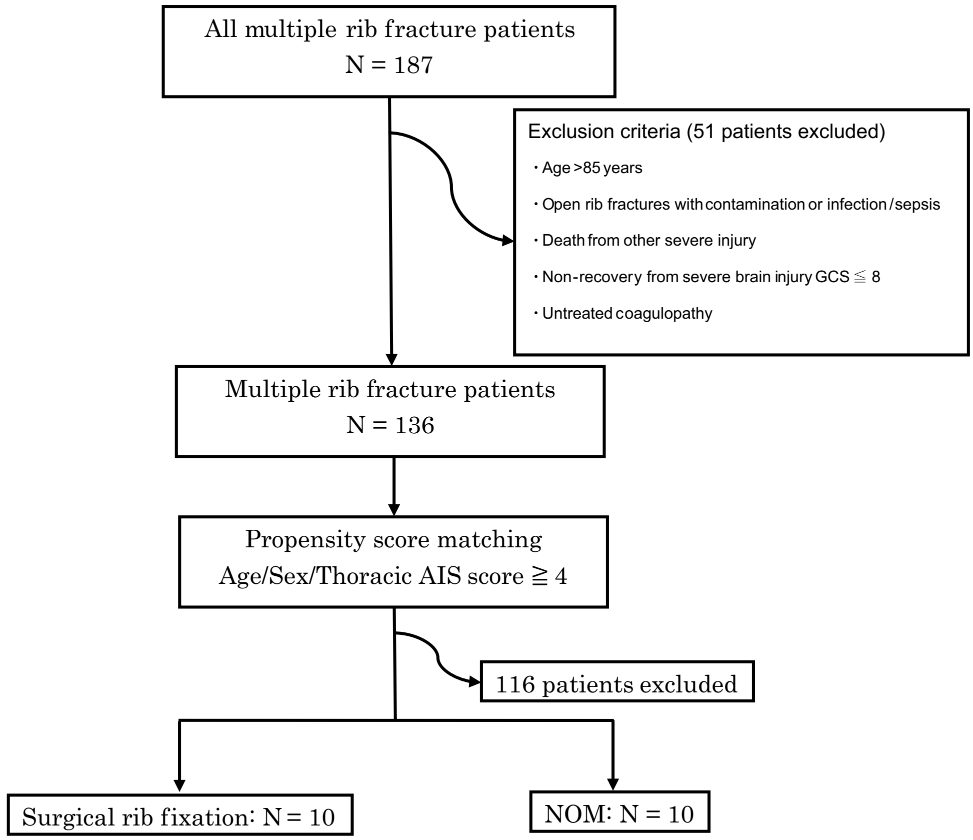

Fig. 2 Of the 187 patients diagnosed as having multiple rib fractures, 51 patients were excluded. Of the remaining 136 patients, 20 underwent propensity score matching at baseline and were included into this study. Ten patients underwent surgical rib fixation, and ten patients were treated with non-operative management (NOM). *AIS* Abbreviated Injury Scale, *GCS* Glasgow Coma Scale

underwent NOM were included and their clinical results were compared in this study (Fig. 2).

The epidemiologic characteristics and initial clinical presentation of the patients in both groups are shown in Table 1. The mechanisms of injury in all patients were blunt injuries received from a traffic accident, fall or some other unexpected injuries. There were no significant differences between the two groups in the presence of pneumothorax or hemothorax. The indications for surgical rib fixation were flail chest in six patients, suspected lung laceration caused by fractured ribs in two patients, overlap of the fractured ribs of more than 15 mm causing intolerable pain in two patients, and inability to wean from mechanical ventilation or continuous intravenous administration of analgesic drugs.

The injuries of the patients are listed in Table 2. Because the presence of flail chest is one of our indications for surgical rib fixation, the number of the fractured ribs consisting of flail chest segments was significantly different between the two groups. There were no significant differences between the two groups in the number of fractured ribs or the anterior or posterior component of fractured ribs. The disposition or amounts of overlap of fractured ribs were also not significantly different.

The overall outcomes of the patients are shown in Table 3. Despite the presence of flail chest or severe

Table 1 Demographic data

	Surgical fixation *N* = 10	NOM *N* = 10	*p* value
Sex, male/female	7/3	7/3	1.0
Age, years	63 (51–72)	57 (53–75)	0.88
Thoracic AIS	4.8 (4–5)	4.8 (4–5)	1.0
Mechanism of injury			
Motor vehicle accident	6	5	
Fall from height	1	3	
Other unexpected injury	3	2	
Additional injury			
Lung contusion	7	7	1.0
Mild (1 quadrant)	3	4	
Moderate (2–3 quadrants)	4	3	
Severe (4 quadrants)	0	0	
Pneumothorax	8	6	0.63
Hemothorax	5	4	1.0
Cranial injury (GCS > 8)	1	2	1.0
Abdominal injury	2	1	1.00
Pelvic injury	0	0	0.47
Bony spinal injury	0	1	1.0

Statistical data are presented as median (25–75 % IQR) or number

NOM non-operative management, *AIS* Abbreviated Injury Scale, *GCS* Glasgow Coma Scale

Table 2 Injury description

	Surgical fixation $N = 10$	NOM $N = 10$	p value
Number of fractured ribs	5 (4–6.5)	4 (2–7)	0.672
Site of rib fracture			
Anterior	4.5 (3–6)	5 (0–7)	0.879
Posterior	5 (4–6)	4 (2–7)	0.516
Number of fractured ribs consisting of flail segments	3 (2–3)	0.5 (0–2)	0.025
Maximum overlap of fractured ribs (mm)	17.5 (14–20)	16.5 (14–18)	0.286

Statistical data are presented as median (25–75 % IQR)

NOM non-operative management

Table 3 Overall outcomes

	Surgical fixation $N = 10$	NOM $N = 10$	p value
Total duration of IMV (days)	5.5 (1–8)	9 (7–12)	0.019
Total duration of ICU stay (days)	6.5 (3–9)	12 (8–14)	0.008
Pneumonia onset during admission	2	9	0.005
Tracheostomy	1	3	0.58
NIV post-extubation	1	4	0.30
Duration of intravenous narcotics (days)	4.5 (3–6)	12 (9–14)	0.002
Failed extubation	0	3	0.21
Patients requiring blood transfusion	3	4	1.00
Duration of intrapleural drainage (days)	6.5 (4–10)	9 (8–10)	0.043
In-hospital mortality	0	0	1.00

Statistical data are presented as median (25–75 % IQR) or number

NOM non-operative management, *IMV* invasive mechanical ventilation, *ICU* intensive care unit, *NIV* noninvasive ventilation

respiratory dysfunction in the patients preoperatively, almost all of the surgically treated patients obtained stabilization of respiratory function and were extubated significantly earlier than the NOM patients. The duration of continuous intravenous narcotics infusion and the duration of ICU stay were also significantly shorter in the surgically treated patients. The incidence of pneumonia in the NOM group was significantly higher than that in the surgical fixation group. For the surgical fixation patients, the number of days of intrapleural drainage was also significantly shorter than that of the NOM patients. There was a tendency for more patients in the NOM group to fail extubation and to require reintubation because of subsequent respiratory disorder. There were no infections, lung injury, or any other complications associated with the surgery, and there were no surgical deaths during the study period.

The respiratory functions on admission are shown in Table 4. All of the patients except one in the NOM group were treated under the control of invasive mechanical ventilation and continuous intravenous administration of narcotic agents. The values of respiratory rate and $PaCO_2$ and the P/F ratio on admission were not significantly different between the two groups.

In the group of surgical rib fixation, the operation was performed on the basis of indications detailed before at the timing of 4 (1–7.5) days after admission. In addition, the pre- and postoperative outcomes in the surgical fixation group are outlined in Table 5. Under the same ventilation conditions, the postoperative values for tidal volume and respiratory rate improved significantly compared to those determined just before the surgery. The number of fixed ribs was three or four in all patients, and all patients could be extubated in the operating room or within 24 h after surgery (1.0 [0.2–1.0] days) and also could be withdrawn from continuous administration of intravenous narcotic agents within 48 h after surgery (1.0[0.5–1.5] days). Furthermore, all of the patients treated by surgical rib fixation could be discharged from ICU within 48 h after surgery (1.0 [1.0–1.5] days).

There were no surgical complications, such as lung injury, bleeding, infection, or adhesions at the surgical site. One patient had atelectasis of the lung on the surgical side caused by muscle pain from the surgical incision, but as the patient began to ambulate, the atelectasis resolved on its own within a couple of days.

Discussion

The control of multiple rib fractures certainly requires delicate handling and adequate management of oxygenation or ventilation for pain control and respiratory stabilization [10, 16]. Previously, several reports were published that showed the clinical benefits of surgical rib stabilization, but they were small studies and almost all addressed stabilization of only the flail chest [17, 18]. Presently, there are no guidelines for treatment of multiple rib fractures, but some previous reports noted that longer durations of mechanical ventilation and ICU stay are significantly related to the increased risk of mortality and morbidity especially in elderly patients over 65 years old [19]. Even if the pain in these patients is improved non-operatively, sometimes they continue to suffer from chronic tenderness that affects their long-term quality of life [20, 21].

This study showed that the patients who underwent surgical rib fixation could be promptly weaned from mechanical ventilation and could be extubated within 24 h after

Table 4 Respiratory function testing on admission

	Surgical fixation $N = 10$	NOM $N = 10$	*p* value
Number of patients requiring mechanical ventilatory assistance	10	9	1.0
Number of patients requiring narcotic administration	10	10	1.0
RR on admission (breaths/min)	22.5 (15–27)	24 (19–28)	0.676
P/F ratio on admission	185 (179–191)	218 (173–258)	0.384
$PaCO_2$ on admission (mmHg)	43.8 (38.4–45.7)	45.1 (41.0–46.1)	0.45

Statistical data are presented as median (25–75 % IQR) or number

NOM non-operative management, *RR* respiratory rate, *P/F ratio* ratio of arterial oxygen partial pressure to fractional inspired oxygen

Table 5 Data changes pre- and postoperation

	Pre-operative	Post-operative	*p* value
Respiratory rate (breaths/min)	25.5 (20–28)	15 (14–15)	0.005
$PaCO_2$ (mmHg)	40.4 (37.7–47.0)	39.4 (38.7–41.4)	0.086
Tidal volume (ml)	400 (400–450)	480 (466–542)	0.008

Statistical data are presented as median (25–75 % IQR)

surgery. Furthermore, the respiratory functions of not only the patients with flail chest but also those with multiple rib fractures improved significantly. Because we could gain early improvement of respiratory functions and early extubation in the patients who underwent surgical rib fixation, subsequent complications, such as ventilator-associated pneumonia or aspiration pneumonia were significantly reduced. Furthermore, all of the surgically treated patients could be smoothly transferred out of the ICU within 48 h after the surgery.

As de Moya et al. noted, another important benefit of surgical rib fixation is the reduction of pain [17]. The surgically treated patients experienced a significant reduction in analgesic requirements, and these drugs were terminated within 48 h after the surgery in all patients.

Tanaka et al. [10] and Granetzny et al. [16] independently reported in their randomized trials for flail chest patients that surgical rib fixation contributes to reducing the number of mechanical ventilation days, the ICU stay, and the total number of hospital days. Even if propensity score matching was performed in the present study to normalize the baseline of the patients, we also showed significant differences in the durations of both mechanical ventilation and ICU stay between the two groups not only in the patients with flail chest but also in those with multiple rib fractures. Furthermore, we could directly observe intrapleural injuries, such as lung lacerations or contusions during surgery in all of the surgically treated patients, which made us confident in removing the intrapleural drainage tube after surgery. This contributed to the significantly short duration of intrapleural drainage days in these patients.

Of the greatest importance, we could wean almost all of the patients from mechanical ventilation within 24 h after the surgery. This indicates that surgical rib fixation for multiple rib fractures could shorten the number of mechanical ventilation days and result in significantly earlier transfer of these patients out of the ICU compared with the NOM patients. Furthermore, from the viewpoint of pain control for these patients, the number of days of continuous intravenous administration of a narcotic agent and the intolerable pain that the patients suffered could also be shortened with surgical rib fixation. These results showed the measurable potential of rib fixation for multiple rib fractures to shorten the number of days of ICU stay and invasive mechanical ventilation and eventually to reduce the intolerable pain experienced by these patients if we could perform early fixation.

In our limited experience in this study, no surgical or postoperative complications occurred in any of the patients who underwent surgical rib fixation. We conclude that surgical rib fixation could be a safe and effective procedure for the repair of not only flail chest but also severe multiple rib fractures that cause lung injury or intolerable pain in these patients.

Limitations

Although the present study is a small preliminary report with good follow-up, it is a single-center study, and the number of patients is too small to establish significant advantage and conclusive proof of the benefits of surgical fixation. We surely have to plan further multi-institutional, prospective and randomized trials on the basis of this study, and need to assess whether the indications for surgical fixation are adequate in patients with multiple rib fractures.

Conclusions

Surgical rib fixation not only for flail chest but also for multiple rib fractures is an acceptable procedure from the viewpoints of realizing early respiratory stabilization and early extubation for the patients who suffer from intolerable pain. The results of this study reaffirm the appropriateness of the operative indications for the treatment of multiple rib fractures.

Compliance with ethical standards

Conflict of interest The all authors declare that there are no conflicts of interest in relation to this manuscript.

Informed consent Written informed consent was obtained from the patients for publication of this report and any accompanying images.

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