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Original Research

The advantages of adding rib fixations during VATS for retained hemothorax in serious blunt chest trauma – A prospective cohort study

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ABSTRACT

Background: Serious blunt chest trauma usually induces hemothorax, pneumothorax, and rib fracture. Early video-assisted thoracoscopic surgery (VATS) to evacuate retained hemothorax is one commonly used treatment. In this study, a new strategy was implemented to combine VATS with fractured rib fixation simultaneously.

Methods: This prospective observational study was performed from January 2013 to April 2018. All patients were aged 18 years or older and had blunt chest trauma with displaced fractures in more than three ribs. No patients had acute respiratory failure within 24 h after trauma. Patients with retained hemothorax who received VATS constituted the study cohort. Subsequently, patients who received rib fixation during VATS procedures were compared with those who did not. Clinical outcomes such as dose of analgesics, and length of hospital stay were recorded.

Results: During the study period, 128 patients were enrolled. Available demographic characteristics of the 2 groups were compared, and no statistical differences were observed. The rates of shorter temporary ventilator dependence after operations were lower in the rib fixation group (0% vs. 24.7%, $P = 0.017$). Persistent air leakage more than 5 days after operations were also lower in the rib fixation group (0% vs. 10.4%, $P = 0.001$). The length of stay in overall hospital stay were longer for patients who received VATS without rib fixation (9.29 ± 2.51 days vs. 12.39 ± 4.65, $P = 0.001$). Furthermore, the rib fixation group were administered much lower doses of opiates during their hospital stays (52.45 ± 15.67 mg vs. 77.24 ± 50.42 mg, $P = 0.001$).

Conclusion: Adding rib fixation during VATS in the management of retained hemothorax can contribute to shorten whole treatment courses. Rib fixation can also reduce pain, thus reducing dependence on analgesics.

1. Introduction

In cases of severe blunt chest trauma, rib fractures are common with hemothorax and pneumothorax [1]. Past treatment of blunt thoracic injury usually focused on hemothorax and pneumothorax drainage through tube thoracostomy. If chest tubes were obstructed, retained hemothorax would require further surgical intervention [17,18]. Conventionally, rib fracture fixation is not routine because the ribs are not weight-bearing bones and can heal with analgesic use and sufficient rest, wherein patients avoid lifting heavy objects. However, untreated rib fractures can exacerbate hemothorax through continual bleeding from the fractured ends or injury to the intercostal vessels [2]. In addition, the fractured ribs may directly penetrate the lung parenchyma. Severe pain derived from fractured ribs is another grave post-trauma complication that can induce acute respiratory failure or even pneumonia [3]. Nonunion of a rib fracture may also induce chronic pain that reduces both work ability and activities of daily living [4].

Recently, because several instruments have been specifically developed for rib fixation, the clinical outcomes of these new orthopedic materials applied to rib fixation have been evaluated [7–12]. Several studies have demonstrated the benefits of rib fixation, which include shortening ventilator dependence and decreasing the duration of

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hospital admission [13,14]. Although rib fixation has some advantages, the necessity of this procedure remains controversial, especially the definite applications and indications of this operation [5,6,15,16].

In our previous studies, early evacuations of retained pleural effusion through video-assisted thoracoscopic surgery (VATS) have been shown to improve clinical outcomes [19]; however, the next logical step for clinicians is to investigate whether rib fracture fixation should be combined with VATS. In this study, a new prospective treatment model was developed in our hospital, combining rib fixation with evacuations of retained pleural effusion. We hypothesized that this new strategy could improve clinical outcomes. The main purpose of this study was to identify and evaluate the effectiveness of rib fixation with VATS in serious blunt chest trauma.

2. Methods

2.1. Patients

This prospective observational study was conducted in a level 1 trauma medical center in southern Taiwan that receives approximately 14,000 emergency trauma visits per year. The protocol for this study was established in October 2012 with the approval of the hospital's ethics committee. The patient enrollment period was from January 2013 to April 2018. Patients were 18 years old or older and had blunt force trauma mainly to the chest region. All patients presented with three or more fractured ribs combined with hemothorax, pneumothorax, or both. The fractured ends in these patients' injuries were displaced at least half the width of the ribs. The abbreviated injury scores (AISs) for the chest injuries were equal to 3 or 4, denoting serious or severe injuries according to the 2008 edition of the scale, respectively. Injuries in other regions were evaluated during a secondary survey in the emergency department (ED). Patients were excluded if their AISs for other regions were higher than 3 or exceeded their chest AISs, as this could have interfered with outcomes. Patients with acute respiratory failure within 24 h after trauma who required positive pressure ventilator support that may prolong admission courses were excluded. Patients with hemodynamic instability indicated with emergent thoracotomy were also excluded. Finally, patients with severe medical diseases, such as chronic heart failure, liver cirrhosis, end-stage renal disease, chronic obstructive pulmonary disease, or cancer of any stage, were excluded as well.

All patients underwent chest computed tomography (CT) in the ED. The number of ribs fractured, displacements of the fractured ends, and hemothorax or pneumothorax volume were estimated according to CT images [20]. In patients who exhibited hemothorax with a volume of > 300 mL was diagnosed, tube thoracostomy by chest tube was indicated in initial treatment [20,21]. After detailed evaluations, patients were admitted to the intensive care unit (ICU) for further care. In our hospital, patients with blunt trauma usually receive intravenous morphine for pain control. Forty milligrams of morphine is added to 500 mL of normal saline dripped through an infusion autopump. Nursing staff regularly record patients' 10-point pain scores during their hospital stay, with the dosage at nursing staff's discretion.

Routine chest X-ray was performed daily in ICU to assess the condition of the injured chest. In patients whose daily chest X-rays revealed increasing density, retained hemothorax was highly suspected. Bedside sonography or secondary chest CT was used to identify these post-trauma complications and to estimate volumes. VATS was indicated for patients with retained hemothorax of more than 300 mL (Fig. 1A). Once VATS had been indicated, trauma surgeons provided detailed explanations of adding rib fixations to the patients [22,23]. Fig. 2 illustrates the treatment plan in this study, which was approved by the institutional review board (IRB) of our hospital. All patients were eligible for rib fixation based on retained hemothorax where VATS was indicated; Group 1 included patients who agreed to fixation, whereas patients who refused it were placed in Group 2. All VATS procedures with or without ribs fixations were performed within 6 days after trauma. According to routine procedure, patients each received an infusion of 1 dose of prophylactic antibiotics before VATS.

2.2. VATS and surgical fixation of fractured ribs

In the present study, all VATS with or without rib fixation were performed in an operating room under general anesthesia. Our trauma team members include nine trauma surgeons, among whom two subspecialize as orthopedic surgeons and two as cardiothoracic surgeons. These four subspecialized surgeons have completed simulation-based training programs involving animals and cadavers. All rib fixations were performed by them. Titanium plates with locking screws (TPLSs) were selected for rib fixation; they were applied to the outer surfaces of the ribs (Fig. 1B). The surgical wound incisions were designed according the fracture sites of the ribs that were localized by VATS. The fractured sites were approached using the chest wall muscle sparing method of Hasenboehler [5].

2.3. Postoperative care

After the operations, patients' endotracheal tubes were removed immediately when general anesthesia were finished. For patients who did not have sufficient oxygen saturation after their operations, a ventilator was applied until they reached optimal oxygen saturation. All patients received VATS only or VATS with rib fixation underwent postoperative chest tube drainage. The chest tubes were connected to low-pressure suction (-15 cm; H_2O) to reduce the residual pleural space and to prevent the early formation of blood clots. Chest tubes were removed when the absence of air leaks was confirmed, fluid drainage was less than 100 mL per day, and the lung had completely expanded. Routine follow-up chest X-rays and close observations for wounds were performed after operations. Residual pleural effusions after operations were managed with secondary VATS.

2.4. Data collection

Demographic data of all patients were collected, including age, sex, number of fractured ribs, pulmonary contusion score [24], and trauma mechanism. The AIS of each associated injury was also collected, and injury severity score (ISSs) were calculated [25]. Duration of post-operation ventilator use, duration of chest tube use, rates of infection, and total dose of analgesics were recorded as primary outcomes. The lengths of ICU and hospital stays were recorded as secondary outcomes. When fever occurred, sputum and blood samples were collected immediately and over the following 3 days for analysis of microbial cultures. Additionally, cultures from chest fluid were collected intraoperatively. Total doses of morphine were also calculated and recorded. This work has been reported in line with the STROCSS criteria [26].

2.5. Statistical analysis

An initial descriptive analysis was performed on all variables to determine the frequencies and averages in the two groups. Numerical variables are presented as means ± standard deviation (SD). The chi-squared and Fisher's tests were used to evaluate the categorical and proportional variables, respectively, between the groups. Continuous variables were compared using analysis of variance. We considered $P < 0.05$ as statistically significant. All data were analyzed using SPSS 20.0. This study had a 0.99 power to detect a significant difference in hospital length of stay between patients and controls (two-sided equality, two-sample) by using a sample size of 128 patients ($\alpha = 5\%$; sampling ratio = 0.66). Multivariate logistic regression was used to assess the associated variables of rib fixation. Confounders were controlled using a running entry model of logistic regression analysis.

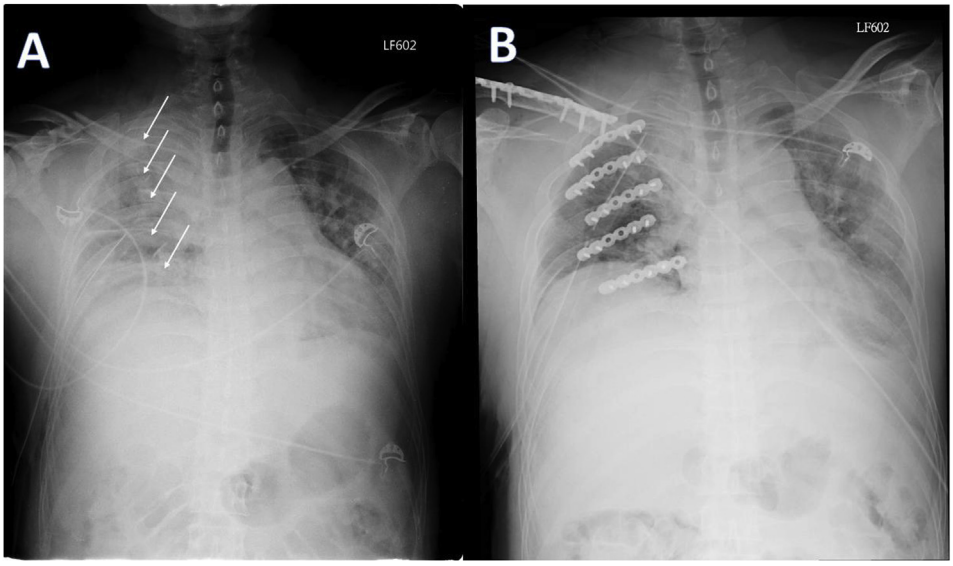
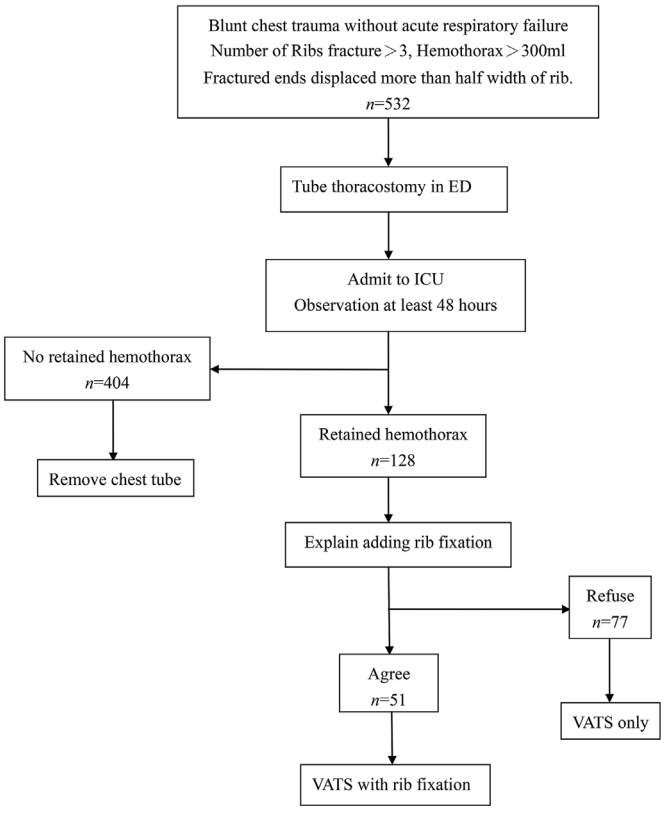


Fig. 1. A: Right side 3rd to 7th rib fractures with end displacements (white arrow), alone with retained hemothroax. B: VATS evacuation of retained hemothroax combined with rib fixation by titanium plates with locking screws.



ED: emergency department; VATS: video-assisted throacoscopic surgery; ICU: Intensive care unit.

Fig. 2. Treatment algorithm for serious-to-severe blunt chest trauma. Blunt chest trauma without acute respiratory failure, ED: emergency department; VATS: video-assisted throacoscopic surgery; ICU: Intensive care unit.

Subsequently, all independent variables were entered into the multivariate logistic regression analysis to detect the independent variables of rib fixation. The Hosmer–Lemeshow test was used to test the goodness of fit. Significant associations of the independent variables with the dependent variables were assessed using a 95% confidence interval (CI) and the respective adjusted odds ratio.

3. Result

During the study period, 1642 patients were admitted to the ED with blunt chest trauma, and 958 patients had three or more fractured ribs. All these patients had a fracture-end displacement that was half the width of the ribs. In total, 532 patients without acute respiratory failure who had hemothorax or pneumothorax (volume > 300 mL) that required tube thoracostomy in the ED. A total of 128 patients developed retained hemothorax, for which VATS was indicated. All these patients were included in this study. Among these patients, 51 patients received rib fixation combined with VATS and were enrolled as Group 1. The remaining 77 patients received VATS only and were assigned to Group 2. The basic demographic characteristics of the two groups are presented in Table 1. Although the mean age was higher in the rib fixation group (56.69 ± 10.20 vs. 50.73 ± 16.01, $P = 0.011$), most patients in the study did not exceed the age of 65 years. The sex distributions of the two groups were similar. In addition, the mean of fractured ribs and percentage of flail chest and lung contusion scores were all similar in the two groups. Chest AIS and ISS did not differ significantly between the two groups. Thus, the two groups were satisfactorily matched and could be compared on the basis of their similar characteristics.

All patients in this study received tube thoracostomy at the ED. The retained hemothorax diagnosis was observed at least 48 h after trauma. The mean time from trauma to operation was 4 days in this study, and no significant differences were observed between the two groups. Because rib fixation was included, Group 1 required operations of longer duration (104.80 ± 17.06 vs. 54.48 ± 11.50, $P = 0.001$). The retained blood clots and effusions evacuated during operations were similar for both groups, without statistical significance.

The clinical outcomes are outlined in Table 2. Nineteen patients required 1–2 days of ventilator support after VATS, and all belonged to Group 2 (0 vs. 24.7%, $P = 0.001$). Due to the short-term nature of ventilator dependence, ICU stays are slightly longer in Group 2 (3.14 ± 1.61 days vs. 3.79 ± 1.74 days, $P = 0.031$). The rate of continued air leakage more than 5 days after the operation was much higher in the group without rib fixation (0% vs. 10.4%, $P = 0.017$). This result contributes to the shorter duration of chest tube usage after operations for Group 1 (4.63 ± 1.67 days vs. 5.82 ± 2.86, $P = 0.004$). Hospital stay lengths were significantly decreased in Group 1 (9.29 ± 2.51days vs. 12.39 ± 4.65, $P = 0.001$). Compared with

Table 1
Comparison of basic demographics between groups.

	All patients (n = 128)	VATS with rib fixation (Group 1; n = 51)	VATS only (Group 2; n = 77)	P
Age (mean ± SD)	53.10 ± 14.25	56.69 ± 10.20	50.73 ± 16.01	0.011
Sex (Male)	102(79.7%)	41(80.4%)	61(79.2%)	0.872
Number of fractured ribs	5.24 ± 1.48	5.27 ± 1.59	5.22 ± 1.42	0.846
Flail chest	32(25.0%)	10(19.6%)	22(28.6%)	0.252
Pulmonary contusion scores	3.80 ± 1.46	3.53 ± 1.59	3.99 ± 1.35	0.095
Combined with pneumothorax	78(60.9%)	27(52.9%)	51(66.2%)	0.131
Thoracic AIS	3.18 ± 0.49	3.08 ± 0.52	3.25 ± 0.46	0.065
Head AIS	0.55 ± 0.93	0.73 ± 0.96	0.44 ± 0.90	0.096
Abdomen AIS	0.40 ± 0.92	0.31 ± 0.81	0.45 ± 0.98	0.379
Limb AIS	1.46 ± 0.85	1.49 ± 0.76	1.44 ± 0.91	0.744
ISS	15.33 ± 5.17	14.71 ± 5.22	15.74 ± 5.13	0.272
Time from trauma to VATS	3.91 ± 1.51	3.69 ± 1.42	4.06 ± 1.55	0.157
Evacuated volume(mL)	353.48 ± 43.52	351.18 ± 46.12	355.00 ± 41.99	0.635
Operation requiring time (minutes)	74.53 ± 28.27	104.80 ± 17.06	54.48 ± 11.50	0.001
Pain score at admit	8.96 ± 1.21	9.42 ± 0.64	8.60 ± 1.42	0.001
Pain score at discharge	4.45 ± 1.43	3.41 ± 0.70	5.24 ± 1.33	0.001

AIS: Abbreviate injury score; ED: emergency department; ISS: injury Severity Score; SD = standard deviation; VATS: video-assisted throacoscopic surgery.

Table 2
Comparison of clinical outcomes between groups.

	VATS with rib fixation (Group 1; n = 51)	VATS only (Group 2; n = 77)	P
Ventilator use after VATS	0	19 (24.7%)	0.001
Continued air-leakage	0	8 (10.4%)	0.017
Postoperative chest tube use (days)	4.63 ± 1.67	5.82 ± 2.86	0.004
ICU LOS (days)	3.14 ± 1.61	3.79 ± 1.74	0.031
Hospital LOS (days)	9.29 ± 2.51	12.39 ± 4.65	0.001
Morphine dose (mg)	52.45 ± 15.66	77.24 ± 50.47	0.001

ICU: Intensive care unit; LOS: length of stay.

Table 3
Binary logistic regression analysis of the associations in patients with groups.

Explanatory variables	Odds ratio	95% Confident Interval	P value
Sex	1.194	0.388–3.679	0.757
Age	0.962	0.926–1.000	0.053
Numbers of rib fracture	0.932	0.635–1.367	0.718
Lung contusion score	1.113	0.773–1.602	0.565
Pneumonia	0.000	0.000-	0.999
Empyema	0.505	0.039–6.496	0.600
Air leakage more than 5 days after VATS	0.000	0.000-	0.999
Ventilator used	0.000	0.000-	0.998
ISS	0.961	0.848–1.088	0.527
LOS in ICU	0.764	0.520–1.121	0.168
LOS inhospital	1.383	1.116–1.715	0.003

*P value is significant at the level < 0.05; ICU: Intensive care unit; LOS: length of stay; VATS: video-assisted throacoscopic surgery; ISS: injury Severity Score.

those in Group 2, pain scores were significantly higher in Group 1 at admission (9.42 ± 0.64vs. 8.60 ± 1.42, P = 0.001) but significantly lower at discharge (3.41 ± 0.70vs. 5.24 ± 1.33, P = 0.001). Moreover, the doses of analgesic agents for pain management in Group 1 were significantly lower (52.45 ± 15.66 mg vs. 77.24 ± 50.42, P = 0.001). Binary logistic regression was applied to test the parameters; the results are displayed in Table 3. According to the multivariate logistic regression, the only independent determinant of the two groups was length of hospital stay (AOR: 1.125; 95% CI: 1.014–1.249, P = 0.003). These results indicated a strong association between rib fixation and length of hospital stay. Calibration of the final model was assessed using the Hosmer–Lemeshow goodness of fit test. A P-value of 0.792 (χ^2 = 4.668) suggested that the model is accurate.

Some patients experienced postoperative complications Five patients had retained pleural effusion after VATS: two patients from Group 1 and three from Group 2. No significant difference was observed between the groups with regard to this complication. All five patients received successful secondary VATS without further complications. No mortality occurred in this study.

4. Discussion

Previous studies have demonstrated that VATS provides adequate evacuation of pleural effusion to expand lung volume and prevent pleural infection [17,18]. Recent studies revealed that rib fixation stabilizes the damaged chest wall structure, decreasing pain and enabling consistently full lung expansion [3,4,9]. In this study, we designed a new protocol to manage serious chest injury, including pleural effusion and chest wall injury, simultaneously. This combined VATS and rib fixation procedure can be applied to improve clinical outcomes considerably. The dose of pain control medication was reduced. Furthermore, the period of chest tube use after operation, lengths of ICU and hospital stays were all reduced.

Multiple rib fractures usually induce severe pain. This grave complication can limit movement of the chest wall and further lung atelectasis. Acute respiratory failure and post-trauma pneumonia may occur, potentially prolonging hospitalization. This pain derives mainly from friction between the fractured rib ends during respiratory movement and human body mobilization. Rib fixation can not only maintain the structure of the chest wall but also reduce most painful sensations. In previous studies, rib fixation has been proven to have high efficiency in managing this complication [11,13,14]. In the present study, patients in Group 1 had higher average pain scores than Group 2 just after trauma. Patients chose to add rib fixation primarily because they were subjectively afraid of pain. We found that adding rib fixation during VATS resulted in lower patient pain scores and doses of intravenous narcotic agents. Although a surgical wound for rib fixation may be another source of skin pain, the pain generated from fractured ribs is more persistent and severe than surgical wounds [5]. Thus, rib fixation prevents continual friction of fractured ribs, enabling patients to move and breathe deeply more easily.

Without concomitant great vessel injury, bleeding from disrupted intercostal vessels, pulmonary parenchymal lacerations, and fractured ends of ribs cause hemothorax after blunt trauma. Tube thoracostomy and VATS could provide adequate drainage, enabling full lung expansion, potentially resolving partial bleeding. Adding rib fixation can provide not only chest wall structure stability but also chest wall hemostasis. In addition to this benefit, rib fixation can decrease the proportion of patients exhibiting prolonged air leakage. In Group 2

patients, the fractured ends could penetrate and scrape lung parenchyma intermittently during respiration. These untreated fractured ribs could induce shallow lung lacerations with continual air leakage. Although these small lung lacerations could heal spontaneously with no further management required, the periods of chest tube usage were prolonged after VATS only without rib fixation. Because the time periods from trauma to VATS were equal in two groups, these two benefits from rib fixations shortened the duration of chest tube usage after operations in Group 1. The hospital stay duration could also be decreased substantially.

In this study, no patient had acute respiratory failure before VATS. After operations, all patients in Group 1 had their endotracheal tubes removed immediately. In Group 2, 19 patients had insufficient oxygen saturation when their operations were completed. These patients required 1–2 days of ventilator support. The percentage of this short term ventilator dependence after operations was much higher in the VATS-only group. This may derive from unstable structures of the thoracic cage without rib fixation. When VATS is performed, patients should be turned to a lateral position that can worsen the displacement of fractured ends. Even when the retained pleural collections were removed, the unstable chest wall could not maintain full lung expansion. The other reason is the persistent pain after VATS without rib fixation. Both reasons may cause temporary short-term ventilator dependence after operation in the VATS only group. Fortunately, no patients required long-term mechanical ventilation after operation in this study.

Although VATS combined with rib fixation has many advantages, this study has several limitations. Even though the study protocol was designed prospectively, patient selection was not randomized. We did not initially match the 2 compared groups, which may have caused selection bias. However, the demographic characteristics of the two groups did not exhibit statistical differences according to the binary logistic regression examination; therefore, potential confounding bias was low. Another limitation in the observation-based data were not recorded by a single staff member that were collected retrospectively from the Trauma Registry Data Bank of our hospital. A senior trauma surgeon reviewed all data for accuracy and consistency during the data collection phase of the study. Nursing staff rather than trauma surgeons recorded pain scores to prevent subjective bias. The variation in chest trauma of all patients represents a confounding bias in this study. However, all surgical procedures were performed by the same team, and the same surgeons were responsible for all decisions to perform rib fixation to avoid surgical confounding bias. Differences in socioeconomic status among patients constitute another limitation of this study. Patients were responsible for the costs of rib fixation materials. However, all patients in Taiwan are insured under the National Health Insurance system. Thus, for patients in this study, all other costs of in-hospital treatments, including surgical procedures, were paid for by National Health Insurance, which may have lessened potential economic bias. In fact, most patients receive rib fixation because they wish to resolve intolerable pain caused by fractured ribs. Randomized studies involving study cohorts from multiple hospitals are recommended to validate the finding that rib fixation with VATS may improve clinical outcomes.

5. Conclusion

Early VATS evacuation with rib fixation could be used to completely treat both pleural and chest wall injuries. This method could yield optimal clinical outcomes in patients with serious-to-severe blunt chest trauma.

Ethical approval

The protocol for this study was established in October 2012 with the approval of the Kaohsiung Veterans General Hospital's ethics committee.

Sources of funding

Nil.

Author contribution

Study conception and design: Tung-Ho Wu, Yih-Wen Tarng, Yi-Pin Chou.
Acquisition of data: Fong-Dee Huang.
Analysis and interpretation of data: Wen-Yen Huang.
Drafting of manuscript: Tung-Ho Wu, Yi-Pin Chou, Hsing-Lin Lin.
Critical revision: Yi-Pin Chou, Hsing-Lin Lin.

Conflict of interest statement

Nil.

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Guarantor

Yi-Pin Chou.
Hsing-Lin Lin.

Data statement

Due to the IRB of the hospital asked in this study, all raw data of patients should remain confidential and would not be shared.

CRediT authorship contribution statement

Hsing-Lin Lin: Conceptualization, Formal analysis, Methodology, Project administration, Resources, Supervision, Validation, Writing - review & editing. **Yih-Wen Tarng:** Conceptualization, Data curation, Methodology, Supervision, Validation, Visualization, Writing - original draft. **Tung-Ho Wu:** Conceptualization, Data curation, Formal analysis. **Fong-Dee Huang:** Conceptualization, Data curation, Formal analysis, Supervision, Validation. **Wen-Yen Huang:** Methodology, Project administration, Validation, Visualization. **Yi-Pin Chou:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Supervision, Validation, Visualization, Writing - original draft, Writing - review & editing.

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Appendix A. Supplementary data

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