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Clinical outcomes of critically ill multiple trauma patients with rib fractures. A prospective study with retrospective control

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Abstract

Background: Rib fracture fixation is becoming more popular and widely accepted among trauma surgeons worldwide as the recommended treatment method for flail chest injury. Recent data demonstrate improved results when compared with non-operative treatment. Improved outcomes were reported regarding ICU stay, need for tracheostomy, length of hospital stay, ventilator-associated pneumonia (VAP), and even death. The objective of this study was to ascertain whether clinical respiratory parameters are improved after rib fracture fixation procedure.

Methods: This is a prospective study using a retrospective cohort for control, which took place at the Soroka University Medical Centre, Israel. Inclusion criteria included all patients over 18 years of age with flail chest injury or multiple ribs fractures, who were admitted to the General Intensive Care Unit (GICU). Between October 2015 and December 2018, we identified 24 patients who had their rib fractures operatively fixed and compared them to 61 patients with flail chest and multiple rib fractures, who were admitted to our GICU between the years 2010 and 2015 and were treated non-operatively. In all the surgical cases operations were performed within 72 hours of arrival in accordance with our treatment algorithm. All fractures were fixed using specialised anatomic locking plates/nails. Demographic data were collected, and respiratory parameters before and after the surgery were recorded and analysed.

Results: We compared patients who had had their rib fractures fixed with a cohort group of patients who had been treated non-operatively in the past. No demographic differences were found between the 2 groups, nor were there any differences in their clinical trauma scoring, mechanical ventilation days, length of ICU stay, VAP, and death rates. The respiratory parameters (paO_2/FiO_2 ratio and chest wall compliance) were significantly higher during the 3 ensuing days after surgery and continued to improve in Group 1 (rib fixation group), in comparison to group 2 (non-operative) patients ($P = 0.007$ and $P < 0.0001$, respectively). The peak inspiratory pressure and PEEP parameters were significantly lower in group 1 in comparison to group 2 during the 3 days, in favour of the operated group, with significant improvement noted over the 3 days post-surgery ($P = 0.007$ and $P = 0.02$, respectively).

Conclusions: We suggest that surgical treatment of flail chest and multiple rib fractures has clinical benefit and improves respiratory parameters even in the presence of multiple trauma injuries.

Key words: flail chest, multiple ribs fractures, fixation, respiratory parameters, intensive care unit.

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The surgical fixation of rib fractures is currently regaining popularity worldwide [1]. The concept was first introduced about 60 years ago, but with the development of modern positive pressure ventilation technology was gradually abandoned [2]. The recent rise in interest in the surgical treatment can be attributed to the increased amount of ventilation-associated complications (such as ventilator-associated pneumonia, prolonged intubation, tracheostomies, and lengthy hospitalisations in the intensive care unit [ICU]) and to the development of new fracture fixation technology, e.g. locked plates and specific rib fixation prostheses [3, 4].

Recent published data from randomized controlled trials and meta-analysis of multiple trials has demonstrated excellent results with the new surgical fixation techniques, showing decreased numbers of ventilation days, pneumonia rates, days in ICU, tracheostomies, and mortality rates [5–9]. Although the quantity of the data is limited, the overall evidence supports surgical fixation of flail chest injuries [10].

Early reports of rib fracture fixation using plates and screws raised concerns regarding the possibility of chest wall tightness and a restrictive breathing pattern due to the plates [11]. In these early surgeries, the plates were laid vertically, fixing several ribs together. Postoperative lung function tests of these patients demonstrated that contrary to this expectation there were good functional results, without any restrictive pattern. Similar results are evident in recent studies as well, emphasising the importance of post-trauma chest wall stabilisation to the breathing process [11, 12].

In this study, we analysed the effect of post-traumatic chest wall stabilisation on the clinical outcome of critically ill multiple trauma patients hospitalised in our General Intensive Care Unit (GICU).

METHODS

Soroka University Medical Centre is a 1000-bed university teaching hospital, tertiary-care, Level I Trauma (major trauma centre), located in Beer Sheva in southern Israel. This is a nonrandomised (quasi-experimental design), single-centre study. The study was approved by the local Human Research and Ethics Committee at Soroka University Medical Centre (approval number 0024-16-SOR). The patient data were anonymised. We collected clinical and laboratory data from multiple trauma patients with predominant thoracic trauma, who were admitted to our GICU at the Soroka University Medical Centre between January 2010 and June 2018. Between October 2015 and December 2018, we identified 24 patients who had their rib fractures surgically fixed and compared them to 61 patients with flail chest and multiple rib fractures, who were admitted to our GICU between the years 2010 and 2015 and treated non-operatively

Inclusion criteria

All multiple trauma patients, aged ≥ 18 years, who had predominant chest injury with multiple rib fractures (more than 4 ribs) and/or flail chest segment on admission to the Emergency Department (ED), and were admitted to the GICU between January 2010 and June 2018 were included in the study.

Exclusion criteria

Multiple trauma patients with severe injuries to other body parts (head, abdomen, extremities) and no documented blunt or penetrating chest injury on admission to the ED were excluded from the study. Patients who were hospitalised in the GICU for less than 48 hours or whose medical records contained insufficient data were also excluded.

Variables and measures

Data were collected from the patient electronic records and laboratory database. We documented their demographic data (age, gender, weight, and length of ICU and hospital stay) and their vital signs from the first 96 hours after admission to ICU (respiratory parameters, heart rate, and arterial blood pressure). We also recorded the patients' trauma diagnoses on admission to the GICU; their TISS (Trauma Injury Severity Score), their APACHE II (Acute Physiology and Chronic Health Evaluation II) scores on ICU admission, success of weaning from mechanical ventilation, percentage of new episodes of ventilator-associated pneumonia (VAP), and the therapeutic measures that were undertaken during the 4 days following the patients' admission to the GICU including intraoperative complications (for the surgical group).

Treatment protocol

Before 2015 multiple trauma critically ill patients with multiple rib fractures and/or a flail chest segment underwent supportive treatment (mechanical ventilation, fluid resuscitation, analgesia, etc.) during their GICU stay. In October 2015, the orthopaedic and thoracic surgeons' teams of Soroka University Medical Centre began operating on flail chest and multiple rib fractures patients, implementing a protocol presented by Bemelman *et al*. [13] (Figure 1).

All patients with a suspected multi-trauma and/or chest injury go through the computed tomography (CT) scanner on arrival as part of their initial trauma assessment. This scan allows us to judge which patients will require surgical treatment according to the protocol algorithm. Most of these patients are intubated due to the severity of their injury and are admitted to the GICU. We strive to operate on these patients as soon as possible, usually within 72 hours of arrival.

A 3D reconstruction of the CT scan is used to delineate the chest wall injury and to define the fractures, thus facilitating a plan for surgery accordingly. The surgical approach to the chest wall is dictated by the location of the fractures; occasionally more than one approach is utilised. The rib fractures are ex-

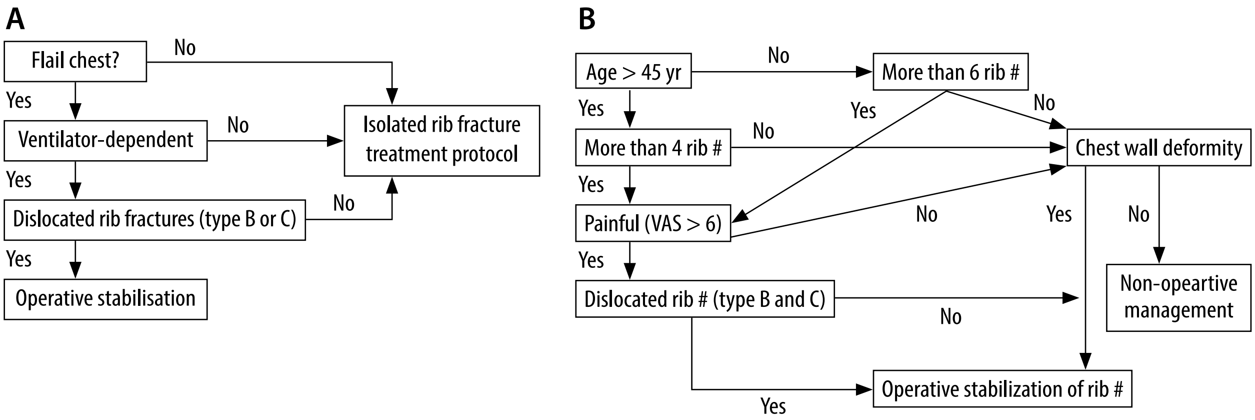

FIGURE 1. Surgical protocol for multiple-trauma, critically ill patients with flail chest **(A)** and multiple rib fractures **(B)** [13]. Algorithm (both figures) published courtesy of Dr. Bemelman (from Bemelman *et al*. [13])

posed, debrided, and reduced anatomically. For fixation of the fractures, we use the Matrix Rib fixation system (DePuy Synthes™, USA) with its anatomically designed low-profile locking plates and screws, and intramedullary nails. At the end of surgery, a chest drain was inserted (28F) on the operated side.

Statistical analysis

For categorical variables, proportions were compared using Fisher's exact test or χ^2 test as appropriate. Continuous variables were analysed with Student's *t*-test or the Wilcoxon rank sum test, depending on the validity of the normality assumption. For comparison of parametric data variability, the coefficient of variation was calculated and analysed with Student's *t*-test. A two-tailed *P*-value of < 0.05 was considered significant. All analyses were performed using SPSS version 22.

RESULTS

Between October 2015 and December 2018, we identified 24 patients who had had their rib fractures operatively fixed (Group 1 – rib fixation group, "Intervention"). The demographic, clinical, and laboratory data of group 1 patients was compared to 61 multiple-trauma patients with flail chest or multiple rib fractures, who were admitted to our GICU between the years 2010 and 2015 and were treated non-operatively (Group 2 – non-operative, "Control"). All patients included in present study were haemodynamically stable during 96 hours of ICU stay and intraoperatively.

No demographic data differences were found between these two groups regarding patients' age ($P = 0.40$), gender ($P = 0.43$), and weight at admission ($P = 0.60$). No differences were noted with regards their clinical scores – APACHE II and TISS ($P = 0.70$ and $P = 0.80$, respectively), and their length of GICU and hospital stay ($P = 0.13$ and $P = 0.64$) (Table 1).

TABLE 1. Patients' demographic data and clinical outcome. Data given as mean ± SD or %

Parameter	Group 1** (*n* = 24)	Group 2** (*n* = 61)	*P*-value *
Age, years	45.1 ± 18.6	41.57 ± 17.09	0.40
Gender, male	29.2%	24.6%	0.43
Body mass, kg	89.5 ± 23.2	94.3 ± 21.9	0.60
APACHE II	25.4 ± 3.2	28.4 ± 4.2	0.70
TISS score	24.1 ± 5.5	24.07 ± 4.3	0.80
ICU stay, days	21.25 ± 1.4	15.43 ± 1.6	0.13
Hospital stay, days	30.67 ± 1.4	35.3 ± 4.9	0.64

**P*-value considered statistically significant at less than 0.05. **Group 1 – "Intervention", Group 2 – "Control" group patients. TISS – Trauma Injury Severity Score, ICU – intensive care unit

All multiple-trauma patients were mechanically ventilated during their first 96 hours of GICU stay. Analysis of the respiratory-related variables (Table 2) demonstrated no differences between the two groups with regards to mechanical ventilation (MV) days, the percentage of VAP, and the percentage of patients weaning from MV ($P = 0.18$, $P = 0.19$, and $P = 0.20$, respectively). PEEP parameters were similar before surgery for both study groups (5.1 ± 1.1 – Group 1 vs. 5.8 ± 2.1 – Group 2, $P < 0.40$); however, they were significantly lower in group 1 four days after the procedure (6.1 ± 2.1 – Group 1 vs. 10.8 ± 2.5 – Group 2, $P < 0.02$).

The results of all respiratory parameters (FiO_2, PaO_2/FiO_2 ratio, peak inspiratory pressure [PIP], and chest wall compliance) were not significantly different between the groups before surgery but demonstrated significant improvement after surgery in favour of Group 1 ("Intervention") (Table 2). Moreover, the PaO_2/FiO_2 ratio and chest wall compliance were significantly higher during the next three days and continued to improve in Group 1 in comparison to Group 2 patients (Table 2). The PIP parameters were significantly lower in Group 1 in comparison

TABLE 2. Respiratory parameters and clinical outcome of multiple trauma critically ill patients with flail chest or multiple rib fractures

Parameter	Chest trauma patients		*P*-value*
	Group 1**	Group 2**	
FiO_2 day 1[a] (%, mean ± SD)	61.4 ± 23.1	68.3 ± 23.7	0.23
FiO_2 day 2 (%, mean ± SD)	48.9 ± 13.3	57.6 ± 21.3	0.03
FiO_2 day 3 (%, mean ± SD)	44.0 ± 11.2	53.5 ± 14.2	0.004
FiO_2 day 4 (%, mean ± SD)	40.7 ± 11.3	53.7 ± 14.1	< 0.0001
PO_2/FiO_2 ratio day 1 (mean ± SD)	219.6 ± 11.6	210.9 ± 8.7	0.70
PO_2/FiO_2 ratio day 2	236.1 ± 79.2	189.1 ± 51.3	0.007
PO_2/FiO_2 ratio day 3	266.1 ± 10.1	184.6 ± 55.1	0.002
PO_2/FiO_2 ratio day 4	265.7 ± 8.1	184.8 ± 79.7	<0.0001
PIP day 1[b] (cm H_2O, mean ± SD)	29.1 ± 5.3	28.1 ± 5.7	0.41
PIP day 2 (cm H_2O, mean ± SD)	25.6 ± 6.1	30.1 ± 6.9	0.007
PIP day 3 (cm H_2O, mean ± SD)	24.9 ± 6.2	29.7 ± 5.4	0.001
PIP day 4 (cm H_2O, mean ± SD)	24.2 ± 6.1	31.8 ± 7.5	< 0.0001
Compliance day 1[c]	36.2 ± 13.0	36.7 ± 12.8	0.87
Compliance day 2	44.7 ± 15.3	32.7 ± 12.6	< 0.0001
Compliance day 3	54.5 ± 2.9	34.0 ± 9.4	< 0.0001
Compliance day 4	51.8 ± 1.9	29.6 ± 9.3	< 0.0001
Mechanically ventilated days (days, mean ± SD)	22.2 ± 2.3	25.2 ± 4.2	0.18
VAPd (%)	47.7%	41.3%	0.19
Percent of weaning (%)	46.4%	41.6%	0.20

**P*-value considered statistically significant at less than 0.05. **Group 1 – "Intervention", Group 2 – "Control" group patients. [a]FiO_2 – fraction of inspired oxygen, [b]PIP – peak inspiratory pressure, [c] – Lung compliance, dVAP – ventilatory associated pneumonia.

Note: Group 1 patients (rib fixation group) underwent rib fixation procedure within 72 hours of their admission to ICU.

to Group 2 during the three days after the intervention. Moreover, all multiple trauma patients were haemodynamically stable in both study groups during the first 96 hours of ICU stay and intraoperatively (Group 1). There were no GICU or hospital mortalities in either study group.

DISCUSSION

The treatment of flail chest and multiple rib fractures is still controversial. While increasing amounts of scientific data and research demonstrating improved results with surgical treatment of these injuries has accumulated over the past 15 years, there are still many who claim that these injuries should be treated non-operatively [14].

We started our rib fixation initiative at the Soroka University Medical Centre in October 2015. We decided on a multi-disciplinary team approach including orthopaedic trauma surgeons, thoracic surgeons, and intensive care specialists. We chose to adopt the treatment protocol published by Bemelaman *et al*. [13], due to its simplicity and ease of use (Figure 1).

Our clinical impression, soon after the initiation of the rib fracture fixation project, was that this innovative surgical treatment revolutionised the way we treat and care for these patients. The current study was set up to find out whether this clinical impression was indeed true; hence, we compared patients who had had their rib fractures fixed with those who had been treated without an operation, in the pre-operation era.

In the comparison of Group 1 to Group 2 we found no differences between the two groups demographically, nor with their clinical scoring, or hospital and GICU length of stay. We found no differences between the groups with regards to development of VAP, and no related deaths were documented.

These findings contradict the findings of several other studies [6–9] that demonstrated significant decreases in ICU and hospitalisation days for the surgical patients as well as decreased rates of VAP and death rates. On the other hand, our findings are supported by the study of Farquhar *et al*. [14], which found no differences in these parameters when compared with non-operative management for their rib fracture patients. One possible explanation for this difference is the fact that most of our patients did not suffer an isolated chest injury, but rather had multiple trauma injuries, with high TISS and APACHE II scores of more than 25. These patients may have had to remain in the GICU due to injuries other than the chest injury itself. Findings that support this assumption are the significant improvement we found in our surgical patient group's respiratory parameters after the surgery, with continuing improvement in the following days after surgery for some of these parameters as well. We were able to improve their respiratory status with the surgery, but the GICU length of stay, the percentage of VAP, and their need for mechanical ventilation did not change – probably due to their other injuries.

In the normal respiratory physiology of humans, the mechanics of respiration involves complex interactions between the lungs, chest wall, and changing intra-thoracic pressure [15, 16]. A key property of pulmonary mechanics is the outward elastic recoil of the chest wall, which helps to keep the lungs expanded and facilitates the diaphragm in generating the negative intra-thoracic pressure gradient responsible for inspiration [15–17]. Pathophysiological changes in the properties of the ribs and chest wall are likely to directly affect lung volumes and respiratory function [17]. Multiple rib fractures and flail chest injuries represent significant chest wall trauma. With multiple segmental rib fractures, the chest wall becomes grossly unstable, the thoracic volume decreases, and paradoxical inward motion of the flail segment is seen during inspiration. This in turn may cause a significant decrease of lung compliance followed by increased inspiratory pressure, decreased oxygenation, and increased usage of high-percentage oxygen during the mechanical ventilation period. As a result, flail chest injuries and multiple rib fractures are associated with prolonged ICU stays, ventilator-associated complications, and long-term respiratory dysfunction [17–19]. In this study, we demonstrated significant clinical improvement in ventilation and benefit for patients with flail chest and multiple rib fractures after surgical fixation of their rib fractures. Even though our patients were multiple trauma patients and not isolated chest injury patients, the surgical intervention improved their respiratory status as demonstrated by their decreased need for oxygen after surgery, decreased need for PIP ventilation, and the improvement in their PO_2/FiO_2 ratio after the surgery. These findings are unique and to the best of our knowledge have not been previously published regarding rib fracture fixation.

Complications following rib fracture fixation are rare and can be divided into early- and late-onset complications [20]. Early postoperative complications include wound infection (0–10%), empyema (5%), haematoma, and persistent effusion [21]. Late complications include chest tightness and dyspnoea (19–33%) and chronic pain (11%) – both could be related to the operation or appear as a result of the original chest wall trauma [15], hardware failure (0–3%), hardware infection (0–3%), and periprosthetic fractures. Our surgical patients (Group 1) did not develop any of the abovementioned complications.

Our study has several limitations. The main limitation was the small sample sizes in both the operated and non-operated groups. Another limitation is the nonrandomised, quasi-experimental design of our study. We also did not analyse the patients' long-term outcome after GICU discharge.

CONCLUSIONS

Our study demonstrated that operative fixation of flail chest and multiple rib fractures in multi-trauma patients can improve their respiratory condition. These are novel results that have not been published previously to the best of our knowledge, and they could be used to aid in the decision-making process for treating these complicated injuries.

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