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THORACIC

Chest wall stabilization in ventilator-dependent traumatic flail chest patients: who benefits?†

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Abstract

OBJECTIVES: Traumatic flail chest is a potentially life threatening injury, often associated with prolonged invasive mechanical ventilation and intensive care unit stay. This study evaluates the usefulness and cost-effectiveness of surgical rib stabilization in patients with flail chest resulting in ventilator dependent respiratory insufficiency.

METHODS: A retrospective study on a consecutive series of patients with flail chest with the need for mechanical ventilation was performed. Effectiveness of rib fixation was evaluated in terms of predictors for prolonged ventilation, cost-effectiveness and outcome.

RESULTS: A total of 61 patients underwent flail chest stabilization using a locked titanium plate fixation system between July 2010 and December 2015 at our institution. 62% ($n = 38$) of patients could be weaned from the ventilator within the first 72 h after surgery. Multiple linear regression analysis revealed that closed head injury, bilateral flail chest, number of stabilized ribs and severity of lung contusion were the main independent predictors for prolonged mechanical ventilation (Odds ratio (OR) 6.88; 3.25; 1.52 and 1.42) and tracheostomy (OR 9.17; 2.2; 1.76 and *0.84*), respectively. Furthermore cost analysis showed that already a two day reduction in ICU stay could outweigh the cost of surgical rib fixation.

CONCLUSIONS: Operative rib fixation has the potential to reduce ventilator days and ICU stay and subsequently hospital costs in selected patients with severe traumatic flail chest requiring mechanical ventilation. Especially associated closed head injury can adversely affect mechanical ventilation time. Furthermore the subgroups of patients sustaining a fall from a height and those with flail chest after cardiopulmonary re-animation seem to profit only marginally from surgical rib fixation.

Keywords: Blunt chest trauma • Flail chest • Rib fracture • Rib and sternal fixation

INTRODUCTION

Blunt chest trauma frequently results from motor vehicle crashes (MVC) and is associated with significant mortality. Flail chest is seen in around 6% of blunt chest trauma patients and results in an in-hospital mortality of up to 33% [1]. Furthermore morbidity rates are even higher, not only due to concomitant injuries but also due to the frequent need for intubation and mechanical ventilation with all its complications, particularly ventilator-associated pneumonia. Traditional flail chest management consists of pain control (including epidural anaesthesia), aggressive pulmonary toilet and non-invasive ventilation or even intubation and mechanical ventilation if necessary. Once a flail chest patient is on the respirator, a total number of 12–18 ventilator days are often necessary before a permanent liberation from the respirator can be achieved [2, 3]. This is reflected by relatively long and cost-intensive stays in the intensive care unit (ICU). Furthermore flail chest patients may not only suffer from acute life-threatening respiratory problems, but also from persisting chest pain and restricted lung function which both interfere with the ability to return to work and normal daily activities. Only a few randomized controlled studies have been performed so far [2–4] with most of them indicating a beneficial effect of surgical rib fixation in terms of reduction of ventilator days. Other studies furthermore showed a beneficial effect of rib stabilization in flail chest on preservation of lung function and possible prevention of persisting chest wall deformity and the formation of painful pseudarthrosis [5–7].

The present retrospective study focuses exclusively on the treatment of mechanically ventilated patients with traumatic flail chest and investigates the usefulness and cost-effectiveness of surgical rib fixation. Furthermore multiple influencing factors on patient outcome are analysed in order to identify optimal indications and ideal candidates for chest wall stabilization.

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MATERIAL AND METHODS

Only patients that underwent rib stabilization for traumatic flail chest with the inability to be weaned from the respirator were included in this retrospective study. Furthermore these patients were only evaluated for rib fixation in the first place when chest wall instability was thought to be the main limiting factor precluding a timely weaning from the respirator. Flail chest was defined as the presence of a paradoxically moving chest wall segment due to three or more consecutive and multiply fractured ribs. Diagnosis was made clinically and confirmed by CT imaging. Informed consent was obtained from all patients or their next of kin and patients' charts were reviewed including demographics, mechanism of trauma and perioperative course from admission until hospital discharge and follow-up. This study was performed in accordance with the Helsinki Declaration as revised in 2013.

For surgical rib fixation the MatrixRIB^{TM} fixation system (De Puy Synthes, Johnson & Johnson AG, Zuchwil, Switzerland) was used. The set contains pre-contoured locking plates made from titanium alloy with various lengths as well as intramedullary splints (Fig. 1).

Surgical procedure

Depending on the fracture sites, the patient was either put in a supine, semi-lateral or lateral decubitus position. As a general rule, only ventral or lateral rib fractures were fixated, whereas posterior paravertebral fractures were newer approached. A left-sided double-lumen tube was only used in patients with suspected active intrathoracic bleeding and/or severe lung laceration. One incision was mostly sufficient, only rarely a second incision was necessary for stabilization of an unstable sternum or anterior fractures of the second and third rib. Chest wall muscles were spared whenever possible by splitting them within the direction of their fibres (Fig. 2). In multiply fractured ribs, first stabilization of the best accessible fracture was attempted and if stability was achieved, the next rib was approached. For fixation of the sternum, two parallel 8-hole locking plates were used (Fig. 3).

Primary endpoint of the study was duration of mechanical ventilation. Secondary end-points were ICU stay, tracheostomy rate and complications. Severity of lung contusion was defined as either mild (less than 10% of total lung volume), moderate (10–20% of total lung volume) and severe (>20% of total lung volume). Concerning complications, respiratory complications (i.e. pneumonia) and surgical complications (i.e. wound infection, implant breakage) were of main interest. Routine follow-up visits were scheduled 2 weeks and 3 months after discharge from the hospital and repeated if deemed necessary.

Statistical analysis

Quantitative data are expressed as mean ± SD and range. Statistical analysis included independent-samples *t*-test for analysis of the different trauma subgroups and outcome (Table 2). Linear regression analysis was performed using univariable ANOVA analysis implemented in the SPSS v21.0 statistical software package (SPSS, Chicago, IL) for identification and quantification of predictors for prolonged mechanical ventilation

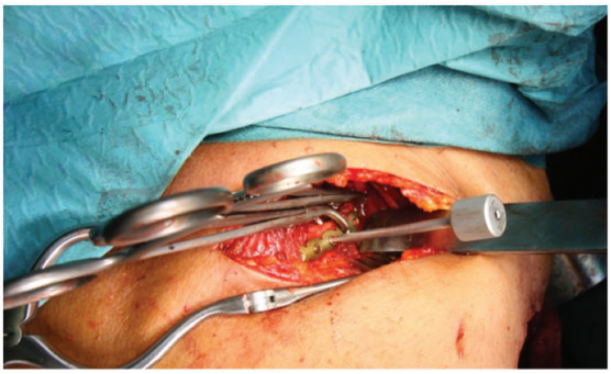

Figure 2: Intraoperative view of rib fixation with 8-hole locking plate.

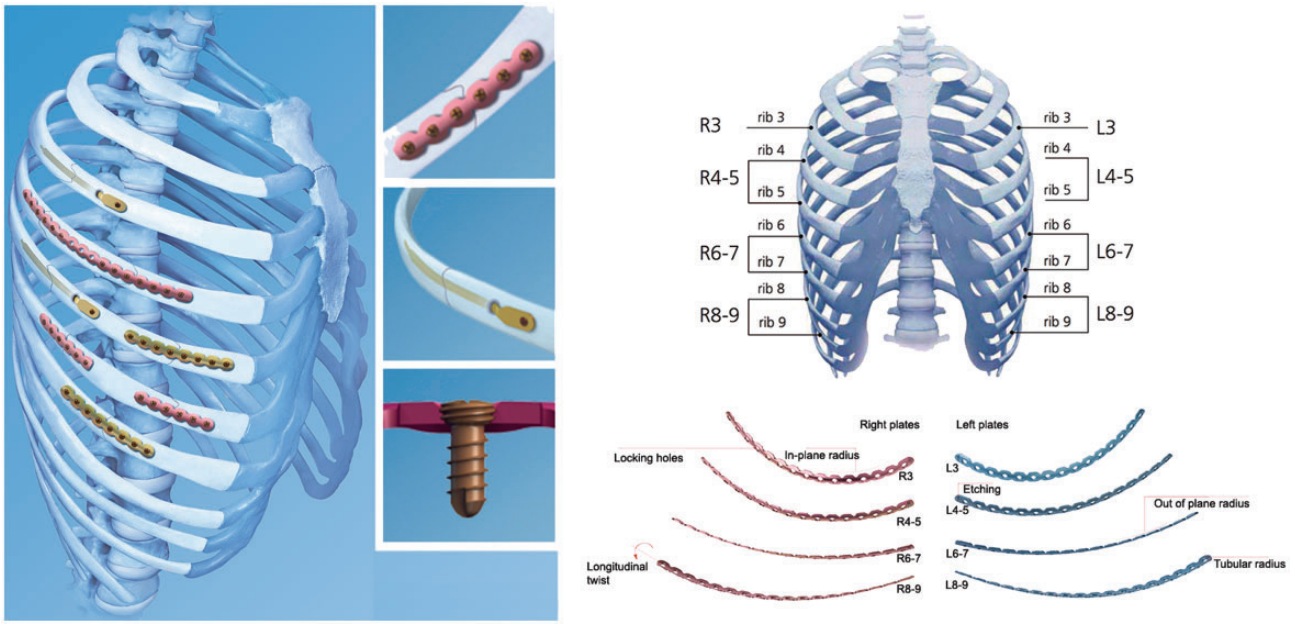

Figure 1: MatrixRIB fixation system with pre-contoured locking plates and splints.

Figure 3: Sternal fracture fixation with two parallel locking plates. Preoperative CT-scan on the left and operative result (x-ray) on the right.

(defined as > 48 h) and tracheostomy, respectively (Table 3). Odds ratios and 95% confidence intervals were calculated using a binary logistic regression model. All *P*-values less than 0.05 were considered statistically significant and those < 0.01 were considered to be highly significant.

RESULTS

Since the introduction of the MatrixRIB fixation system at our institution in July 2010, a total of 105 patients underwent surgical rib fixation. During the 4½ year study period 44 patients underwent rib fixation for either acute trauma without respiratory compromise (i.e. rib fixation was performed during thoracotomy for other indications) or for late sequelae after chest trauma such as pseudarthrosis with painful chest wall instability. Those 44 abovementioned patients were not included in our study. A total of 61 patients fulfilled the criteria of surgical rib stabilization in flail chest with ventilator dependency, which was mainly attributable to chest wall instability. The main characteristics of this study population are summarized in Table 1.

Mean patient age was 67.9 years (range 36–87) with a male to female ratio of 44:17. Mean number of fractured ribs was 10.3 ± 3.9 (range 4–21) resulting in bilateral flail chest in 41% (*n* = 25) of patients. Operative rib stabilization was performed within 48 h after arrival at our trauma centre in more than half of patients (60.7%, *n* = 37). Mean interval between diagnosis and surgical intervention was 3.7 ± 3.5 days (range 12 h–35 days). Mean duration of surgical stabilization was 126.7 ± 33.4 min with a mean number of 4.5 ± 1.8 stabilized ribs (Fig. 4). Concomitant stabilization of the sternum was performed in eight patients, whereas in one patient with bilateral rib fractures only the fractured sternum was fixated with two parallel titanium plates.

Associated injuries were common (*n* = 46, 75.4%) and included closed head injury (*n* = 16, 26.2%), pelvic and/or spine fracture(s) (*n* = 31, 50.8%), abdominal injury (*n* = 16, 26.2%) as well as long bone fractures (*n* = 16, 26.2%).

Table 1: Patients' characteristics

Characteristics	*n* (%); total *n* = 61
Age	67.9 (range 36–87)
Sex	44 male (72%)
Trauma	
Road traffic accident	28 (45.9%)
Fall	16 (26.2%)
Fall from height	7 (11.5%)
Suicidal attempt	4
CPR	7 (11.5%)
Crush injury	3 (4.9%)
Pattern of injury	
Number of fractured ribs	10.3 ±3.9 (range 4–21)
Bilateral flail chest	25 (41%)
Mean Chest AIS	4.02
Closed head injury	16 (26.2%)
Mean Head AIS	0.97
Fracture of pelvis and spine	11 (18%)
Spine fracture only	14 (23%)
Pelvic fracture only	6 (9.8%)
Abdominal injury	16 (26.2%)
Mean Abdominal AIS	2.13
Long bone injury	16 (26.2%)
Mean Extremity AIS	1.82
Mean ISS Score	32.66

CPR: cardiopulmonary resuscitation; AIS: abbreviated injury scale: ISS, Injury Severity Score.

Mean number of postoperative ventilator days was 4.08 (SD ±3.93) with a total of 13 patients (21.3%) undergoing tracheostomy between POD 2-11. Another three patients had already undergone tracheostomy before rib fixation due to concomitant severe maxillofacial trauma (*n* = 1), severe polytrauma (including closed head injury, abdominal, pelvic, spine and longbone injuries) (*n* = 1), and intraoperative cardiac arrest during pancreaticoduodenectomy with hypoxic cerebral injury despite timely cardiopulmonary resuscitation (CPR) (*n* = 1). Both of the latter patients recovered from brain injury within several days, thus persisting chest wall instability was considered the main reason for mechanical ventilation and so the decision for rib fixation was made 19 days (polytrauma) and 30 days (CPR) after trauma, respectively.

The mean duration of ICU stay was 4.5 days (SD ± 5.02) with a total hospital stay of 9.54 ± 7.12days. 37 patients (60.66%) were discharged to a rehabilitation centre, 13 (21.3%) patients were transferred to other hospitals for further treatment and 8 (13.1%) patients were directly discharged home.

Thirty-day mortality was 4.9% (*n* = 3): Two patients died from the complications of their concomitant severe abdominal trauma. Patient 3 was an 85-year-old female patient that died from severe pneumonia with sepsis and multiorgan failure despite surgical rib fixation with improved respiratory mechanics.

Pulmonary complications were rare and included pneumonia in 8.2% (*n* = 5) and ARDS in one patient (1.6%), respectively.

Surgical complications were very rare, with only one patient suffering from a subcutaneous surgical site infection which healed after 10 days of vacuum-assisted closure (VAC) treatment. Another patient was bothered by the sternal osteosynthesis plates, which were then removed 2 years after surgery. No infection, breakage or loosening of any of the implanted

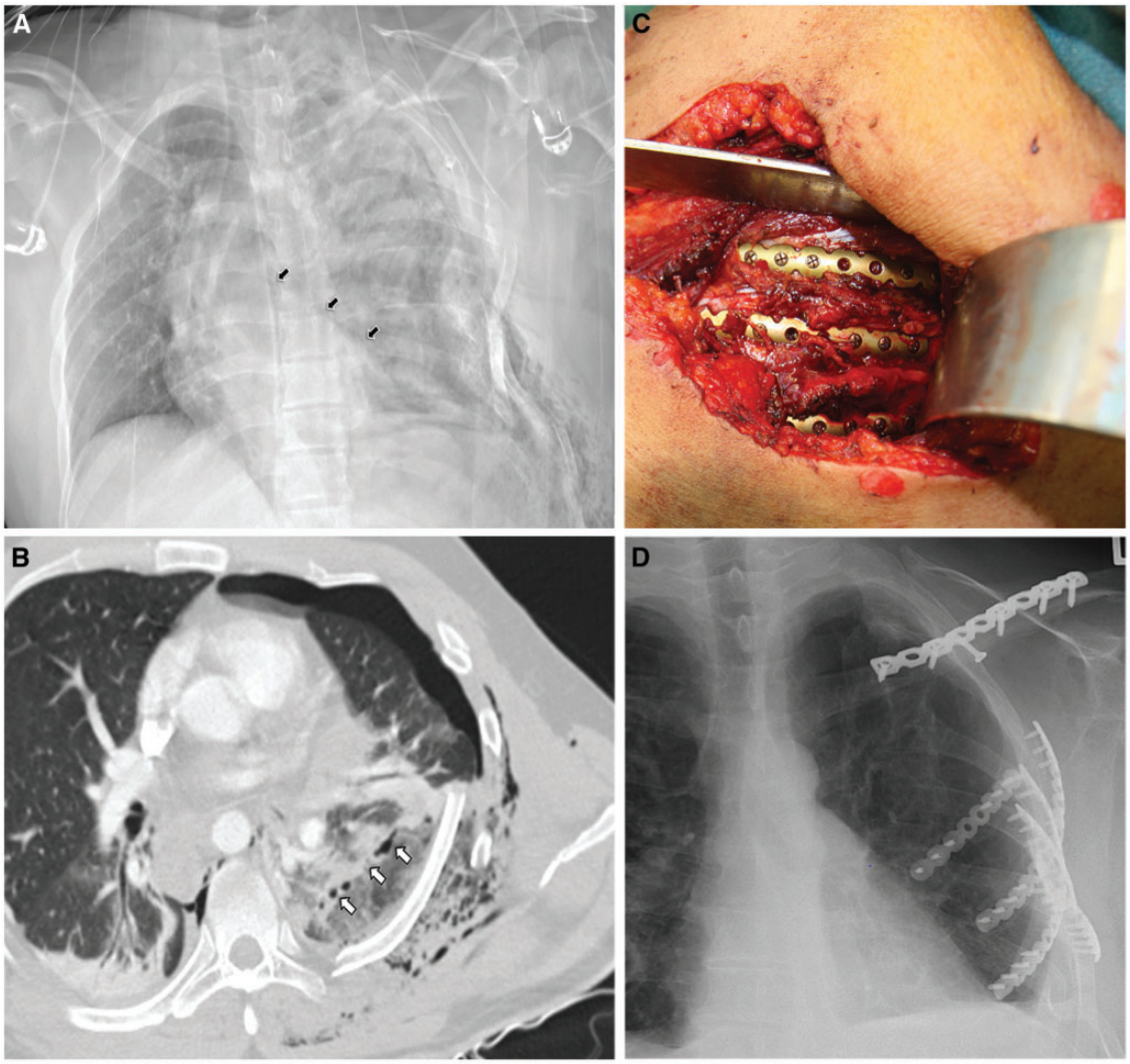

Figure 4: Severe chest trauma following motor cycle accident with traumatic left sided flail chest and tension pneumothorax (**A**). CT-scan following emergency tube thoracostomy shows concomitant lung laceration and lung contusion on the left side (**B**). Anterolateral rib fractures were fixated with MatrixRIB^{TM} locking plates (**C**). Postoperative result two weeks after stabilization (**D**) – note that posterior rib fractures were not fixated.

osteosynthesis plates was recorded during the follow-up of 25.7 ± 13.42 months (range 3–61 months).

Linear regression analysis showed that bilateral flail chest, closed head injury, number of stabilized ribs and severity of lung contusion were the main independent predictors for prolonged mechanical ventilation (Table 2). The same factors influenced the rate of tracheostomy as well except for lung contusion.

When comparing the different trauma mechanisms, fall from height and CPR both showed prolonged respirator periods as well as a higher rate of tracheostomies when compared to other trauma causes (Table 3). Whereas, CPR often lead to bilateral flail chest with a higher number of fractured ribs, fall from height (free fall from > 4 m height) additionally was associated with a high rate of closed head injury, which both resulted in prolonged ventilation and tracheostomy in these two subgroups of patients. Furthermore all patients who fell from height had without exception one or more associated injuries (i.e. closed head injury ($n = 5$), pelvic fracture ($n = 4$), spine fracture ($n = 5$), abdominal injury ($n = 5$) and/or longbone fracture ($n = 4$)), which needed further surgical treatment and thus contributed to longer ventilator times in these patients.

An estimation of the cost of ICU treatment and the cost of operative rib fixation itself was performed to evaluate the cost-effectiveness of surgical rib fixation. We based our calculations on the mean numbers of our study cohort. In our hospital the cost of running an ICU bed with a patient on the ventilator is around €4000 per patient and day (24 h). For operative rib fixation on the other hand, an operating room for ±130 min (€2360) and the appropriate materials for osteosynthesis of ± 4.5 ribs (€4580) is required. According to these numbers rib fixation will already be cost-effective starting from 2 days of ICU treatment that can be saved due to earlier extubation.

DISCUSSION

Blunt chest trauma often results in rib fractures and occasionally in flail chest depending on the mechanism of trauma. While simple rib fractures may result in pain, sometimes leading to pneumonia in the short-term or painful pseudarthrosis in the long term, flail chest on the other hand is associated with much higher morbidity and mortality rates. With the aim of reducing invasive

Table 2: Predictors for prolonged ventilation and tracheostomy

Patients $n = 61$	Closed head injury	Bilateral flail chest	Number of stabilized ribs	Severity of lung contusion
Delayed extubation	$P < 0.001$ OR 6.88 (95%CI 1.48–32.03)	$P < 0.001$ OR 3.25 (95%CI 0.82–12.95)	P 0.001 OR 1.52 (95%CI 0.96–2.41)	P 0.045 OR 1.42 (95%CI 0.53–3.81)
Tracheostomy rate	$P < 0.001$ OR 9.17 (95%CI 1.88–44.73)	P 0.003 OR 2.2 (95%CI 0.42–11.64)	P 0.002 OR 1.76 (95%CI 1.04–2.986)	P 0.13 OR 0.84 (95% CI 0.28–2.53)

Table 3: Different trauma mechanisms and outcome

Patients $n = 61$	Closed head injury	Number of stabilized ribs	Bilateral flail chest	Time to extubation	Tracheostomy	ICU stay (days)
Others (MVC, etc.) (n=47)	19.1% (n=9)	4.26 ± 1.72	27.6% (n=13)	1.54 ± 1.29 days	15% (n=7)	3.26 ± 3.55
Fall from height (n=7)	71.4% (n=5)	4.57 ± 1.05	85.7% (n=6)	8.0 ± 2.77 days *P < 0.001**	57% (n=4) *P 0.025**	10.43 ± 8.85 *P 0.0002**
CPR (n=7)	28.6% (n=2)	6.0 ±1.69	85.7% (n=6)	7.57 ± 1.57 days *P < 0.001**	71% (n=5) *P 0.0041**	7.00 ± 4.55 *P 0.0152**

*Other injury mechanisms (mainly traffic accidents) compared to fall from height and cardiopumonary resuscitation (CPR), respectively.

ventilation and associated complications as well as cost-intensive ICU care, studies have been designed to investigate the impact of surgical rib fixation in these patients. Only three randomized trials have been reported so far in the international literature [2–4] and only two of them were able to demonstrate a reduction in mechanical ventilator days following surgical rib fixation for flail chest: Tanaka *et al.* [2] demonstrated a reduction of ventilator support of 8 days (18 versus 10 days) and Granetzny *et al.* [3] reported a 10 day reduction (12 versus 2 days) for the surgically treated group. Also spirometry findings were compared with contradictory results: While Granetzny and colleagues [3] found a less restrictive pattern 2 months after surgery, Marasco *et al.* [4] found no differences in spirometry 3 months after rib fixation in flail chest patients compared to conservative management. In the meantime several, mostly retrospective studies have investigated the usefulness of surgical rib fixation for traumatic flail chest and most of them were able to show a trend versus shorter duration of mechanical ventilation and ICU stay as well as decreased rates of pneumonia and decreased mortality in surgically treated patients compared to conservative management [5–12]. The main problem of all studies is that they deal with a rather heterogeneous group of patients. Not only do the patients' characteristics including age and comorbidities differ dramatically, but also the mechanism of trauma and the resulting pattern of injuries show great variety in patients with flail chest. Furthermore most studies, except the three aforementioned RCT's, compare their operated patients with historic controls that did not undergo surgery, which inevitably results in selection bias. Another important issue is that most studies include a mix of patients ranging from painful chest deformity without major respiratory problems to patients who are on the respirator due to severe chest wall instability.

In the present series, we therefore only included patients who needed invasive mechanical ventilation due to severe chest wall instability, because we mainly wanted to evaluate the usefulness of surgical rib fixation in terms of a timely weaning from the respirator as well as search for predictors that may help to identify patients who do not benefit from surgery. Overall weaning from the respirator was possible within more or less 4 days after operative rib fixation. When excluding the patients with a fall from height > 4 meters and those with flail chest resulting from cardiopulmonary resuscitation, weaning was even possible 1.54 ± 1.29 days after surgery. When taking into account the average reported weaning period for conservative flail chest management of 12–18 days, [2, 3] this finding indicates that patients who sustain blunt chest trauma due to traffic and other accidents (except direct fall from height) are excellent candidates for surgical rib fixation. The explanation for this finding lies in a high rate of associated injuries, including closed head injury (71.5% in our series) in patients that sustain a fall from height. Even if an occasional neurologic deficit due to concomitant head injury improved after several days, associated injuries were often the cause for other surgical procedures under general anaesthesia which again delayed permanent extubation and furthermore resulted in limited patient mobility. Also some patients following CPR were included in our study, but in most cases concomitant comorbidities prolonged the weaning process more than expected.

We identified closed head injury, bilateral flail chest, number of stabilized ribs and severity of lung contusion as independent risk factors for prolonged mechanical ventilation. Since especially head injury was found to be associated with significantly longer ventilator periods despite surgical rib stabilization, the benefit of the procedure is rather unclear in these patients. Maybe rib

fixation might in the end also result in a reduction of ventilator days, but just after a longer period of time, but this remains pure speculation and has to be the subject of future studies.

On the other hand bilateral flail chest and number of stabilized ribs are given factors, which are rather an indicator of the severity of trauma than influenceable variables. Whether the presence of lung contusion should influence the decision for surgery is controversial [8, 9]. In our study, the association between the severity of lung contusions and mechanical ventilation, respectively, was only barely significant. When considering the peak of respiratory distress due to lung contusion to occur around 72 h after injury and a dissolution of symptoms within 7 days after trauma, [13] rib stabilization might still be worthwhile in order to reduce ventilator days in selected patients [14].

One also has to consider the invasiveness of surgical rib fixation which sometimes requires extensive soft tissue mobilization, and which may thus be complicated by infection and haematoma. Furthermore, intraoperative deperiostation might interfere with bone healing and can be the cause for pseudarthrosis and implant failure. The MatrixRIB Fixation System which was used in our cohort offers the possibility of using precontoured plates and bicortical locking screws. Locking plates hold the 2-fold advantage of preservation of the periosteal blood supply as well as a firm hold even in osteoporotic bone. Furthermore with the use of these low-profile implants made from titanium alloy, implant infections are a rarity and implant removal is usually not necessary [15]. Of course the costs for operative rib fixation are not negligible, but according to our calculations surgical stabilization did cost less than two days of ICU treatment on the respirator, indicating that rib fixation is a cost-effective treatment method for selected flail chest patients [16].

Although our mean follow-up was only 2 years, only one patient was bothered by the implants and requested their removal, despite any sign of pseudarthrosis or infection. These findings are consistent with the literature, demonstrating that flail chest stabilization results in good quality of life also in the long-term [17–19].

Main limitation of our study is the missing of a control group. But when taking into account the present evidence which shows clear advantages of operative rib fixation in selected patients, [20] the realization of a randomized controlled trial for ventilator-dependent flail chest patients was considered difficult, if not even unethical.

In conclusion selected patients suffering from traumatic flail chest may profit from early rib fixation if chest wall instability is the main reason for ventilator-dependency. Furthermore a good neurologic status is one of the basic requirements for a successful and permanent liberation from the respirator, which makes patients with an associated closed head injury questionable candidates for surgery. In addition, rib fixation has not only the potential to save hospital costs, but may also prevent respiratory complications as well as long-term pain and respiratory restriction as demonstrated by previous studies [17–19, 21].

Conflict of interest: none declared.

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