Limited Influence of Flail Chest in Patients With Blunt Thoracic Trauma – A Matched-pair Analysis

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Abstract. *Background: Flail chest is considered as one of the most severe forms of blunt thoracic trauma. However, its actual influence on post-traumatic morbidity and mortality is debatable. Materials and Methods: A retrospective cohort analysis was performed of multiply injured patients (injury severity score ≥16) at a level I trauma center. Flail chest was defined as segment fracture of at least three consecutive ribs on at least one side. Propensity score matching was performed. Results: A total of 600 patients were included, with a mean age of 44.1±19.1 years and a mean injury severity score of 31.6±10.4. Overall, 367 patients (61.2%) had a serial rib fracture. Forty-five patients (7.5%) presented with flail chest. Patients with flail chest more often had lung contusions (70 vs. 50%, p=0.04) and pneumo-/hematothorax (93 vs. 71%, p=0.005). There were no differences in post-traumatic morbidity and mortality. Conclusion: Flail chest had no independent influence in addition to injury severity on post-traumatic morbidity and mortality in multiply injured patients with blunt thoracic trauma.*

Blunt trauma is the leading cause of thoracic injuries. About 50% of all multiply injured patients suffer from blunt chest trauma (1). It is the second most common severely injured body region [abbreviated injury scale (AIS) >3] in Germany after the head (2). According to recent research, chest trauma is responsible for about 25% of all deaths in multiply injured patients (1, 3, 4). Blunt thoracic trauma thereby causes higher morbidity and mortality compared to multiply injured patients without chest trauma (5-8). Therefore, early and

This article is freely accessible online.

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Key Words: Multiple injuries, thoracic trauma, serial rib fracture, flail chest, acute respiratory distress syndrome.

precise diagnose of specific chest injuries is useful for further clinical treatment in order to avoid posttraumatic complications and finally to reduce mortality.

In particular, flail chest as a severe form of a serial rib fracture should be deemed to be a predictor of morbidity and mortality (9). Its incidence in multiply injured patients varies from 1 to 16% among different studies, with reported mortality rates up to 25% (10-13). Flail chest can lead to chest wall instability and results in respiratory insufficiency with major difficulties in clinical treatment. The need for intubation and mechanical ventilation can cause ventilator-associated pneumonia and contribute to high rates of mortality in patients with flail chest (14). Serial rib fractures and flail chest are frequently accompanied by lung contusions, averaging 46-54% (11, 12, 15). Contusions of the lung, as well as chest wall instabilities are known to be a trigger for significantly high rates of complications and mortality. Experimental studies by Capello *et al*. demonstrated that lung contusions have a more negative effect on respiratory insufficiency than chest wall instability itself (16). In particular, the combination of flail chest and lung contusions lead to notably higher rates of mortality, reported to be as high as 40% (11, 17). While isolated unilateral flail chest has a mortality rate less than 6%, accompanying injuries substantially increase mortality (9).

This raises the question whether flail chest has an independent impact on outcome or is just an indicator of increased severity of chest injury (4, 7, 14, 18). Moreover, several studies have focused on the effect of single rib fractures on morbidity and mortality and thereby neglected specific defined fracture patterns like flail chest or compared mortality and morbidity between younger and older patients (wide range of patients) (10, 19-21). In addition, the definition of flail chest is largely inconsistent. The most accepted definition, which is applied in this study, is a segmental fracture of three or more consecutive ribs (22). However, different studies use the terms flail chest and unstable chest with inverted breathing interchangeably. Thus, the impact and prognostic value of flail chest are still a topic of controversial discussion (7, 15, 21-25).

Therefore, this study aimed to analyze the independent influence of precisely defined flail chest on post-traumatic morbidity [acute respiratory distress syndrome (ARDS), ventilator-associated pneumonia (VAP), prolonged mechanical ventilation etc.] and mortality in multiply injured patients with relevant blunt chest trauma.

Materials and Methods

A retrospective cohort analysis was performed. Between January 2005 and December 2014, all multiply injured patients [injury severity score (ISS) ≥16] with a minimum age of 15 years primarily admitted to a single level I trauma center in a mid-European metropolitan area were included (26). The study was approved by the Institutional Review Board (No. 3392-2016). All patients underwent precisely defined trauma management according to current guidelines. Demographic and baseline data including age, sex, mortality, duration of mechanical ventilation, duration of intensive care as well as overall in-patient care, and transfusion requirements [packed red blood cells (PRBC), fresh frozen plasma (FFP) and platelet concentrate (PC)] were collected from the hospital information system. Injury pattern and organ-related severity were classified using the 2008 update of the abbreviated injury scale (AIS) (22). Overall severity of injury was calculated using the ISS. Systolic blood pressure (SBP; in mmHg) was measured by either oscillometric method or, if applicable, invasive arterial measurement. SBP and heart rate (HR) were used to calculate the shock index (SI=HR/SBP). A shock index between 0.5 and 0.7 is considered physiological (27). Shock at admission was defined as SBP ≤90 mmHg with/without shock index ≥0.9. Multiple organ dysfunction syndrome (MODS) was diagnosed on the basis of MODS score by Marshall *et al*. MODS was deemed present if the sum of single organ dysfunctions was >8 on at least one day (28).

All patients underwent whole-body computed tomography (CT) with contrast agent administration at the time of admission. Appraisal of CT scans were performed by a consultant with specialization in skeletal radiology. All CT scans were checked for rib fractures and lung contusions, as well as pneumo-and hematothorax. A serial rib fracture was present if three consecutive ribs were fractured on at least one side. A flail chest was defined as segment fractures of at least three consecutive ribs on at least one side (22).

Statistical analyses were performed with IBM SPSS (Version 23; IBM, Armonk, NY, USA). Gaussian distributed variables were analyzed using parametric tests (Student's *t*-test) and other variables were analyzed using non-parametric tests (Mann–Whitney test for independent data; Wilcoxon test for dependent data). Fisher's exact test (exact chi-squared test) was used in the analysis of contingency tables. Binomial logistic regression analyses were performed and odds ratios (OR) and 95% confidence intervals (95% CI) were calculated. In order to avoid a potential bias due to different overall injury severity or injury pattern in patients with and without flail chest, a matched-pair analysis was performed using propensity score matching with nearest-neighbor matching and a 1:3 match ratio. The following covariates and flail chest as binary treatment indicator were used: age, sex, ISS, AIS_{Head}, AIS_{Face}, $AIS_{Abdomen}$, $AIS_{Extremities}$, $AIS_{External}$. The significance level was set at *p*=0.05.

Results

A total of 972 patients were evaluated for eligibility: 600 patients fulfilled the inclusion criteria and were enrolled for further statistical analysis (see also Figure 1). The mean follow-up was 23.9±20.1 days. Mean age was 44.1±19.1 years and mean ISS was 31.6±10.4; 439 patients (73.2%) were male. Table I summarizes the demographic, baseline and outcome data.

Serial rib fractures were diagnosed in 367 patients (61.2%), of which 45 (7.5%) presented with flail chest. There was no difference between patients with and without serial rib fractures regarding ISS. Although mortality was increased in the group with serial rib fracture (16.6 *vs*. 10.3%, *p*=0.03), the presence of a serial rib fracture was not identified as an independent predictor of mortality in a multivariate regression analysis (OR=1.2, 95% CI=0.7-2.2; *p*=0.5). Pneumo-and hematothorax were significantly more frequent in patients with serial rib fractures (74.1 *vs*. 58.8%, *p*<0.001). However, there were no differences in occurrence of lung contusions (58.0 *vs*. 59.7%, *p*=0.7). There were no differences in frequency of ARDS (34.3 *vs*. 34.3%, *p*=1.0) or VAP (16.3 *vs*. 11.2%, *p*=0.09). Thus, the duration of mechanical ventilation (298±351 *vs*. 229±278 h, *p*=0.3) and intensive care (16.0±15.8 *vs*. 13.3±12.7 days, *p*=0.2) did not differ significantly between the two groups.

One hundred and fifty patients (40 flail chest *vs*. 110 serial rib fracture but no flail chest) were matched using a propensity score matching with nearest-neighbor matching and a 1:3 match ratio to reduce confounding effects. Table II gives an overview of their demographic, baseline, and clinical data. Regarding matching quality, there were no significant differences in age (52.7±19.1 *vs*. 53.4±18.3 years, *p*=0.9), gender distribution, injury severity (ISS 30.7±9.5 *vs*. 28.8±8.4, *p*=0.3) or injury pattern (see also Table II). Patients with flail chest more often suffered from lung contusion (70 *vs*. 50%, *p*=0.04) and pneumo-/hematothorax (93 *vs*. 71%, *p*=0.005). Mortality was also increased (18 *vs*. 7%, *p*=0.1). However, this did not reach significance. Focusing on post-traumatic complications, patients with flail chest did not suffer from ARDS (38 *vs*. 33%, *p*=0.7) or VAP (23 *vs*. 16%, *p*=0.5) more often. The same applied to duration of mechanical ventilation (371±403 *vs*. 288±358 h, *p*=0.2) and duration of intensive care (19.8±17.6 *vs*. 15.5±15.2 days, *p*=0.2).

Discussion

The purpose of this study was to analyze the independent influence of flail chest on morbidity and mortality in multiply injured patients with relevant blunt thoracic trauma. Although flail chest was associated with a more frequent presence of lung contusion and pneumo-/hematothorax, no
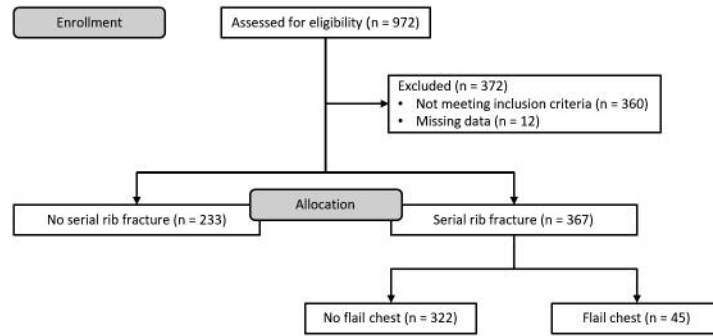
Figure 1. *Flow diagram of study patients.*

Table I. *Demographic, baseline and clinical data of the population, as well as patients with and without serial rib fracture.*

Characteristic	Total (n=600)	Serial rib fracture (n=367)	No serial rib fracture (n=233)	*p*-Value
Age (years), mean±SD	44.1±19.1	49.5±18.6	35.6±16.7	<0.001[a]
Male gender, n (%)	439 (73.2)	261 (71.1)	178 (76.4)	0.2[b]
Injury severity score, mean±SD	31.6±10.4	31.6±10.8	31.7±9.8	0.7[a]
Abbreviated injury scale, mean±SD				
Head	2.0±1.7	1.8±1.7	2.1±1.7	0.054[a]
Face	0.8±1.1	0.8±1.1	0.8±1.2	0.7[a]
Thorax	3.6±0.7	3.7±0.7	3.5±0.7	0.001[a]
Abdomen	1.4±1.5	1.5±1.5	1.2±1.5	0.02[a]
Extremities	2.3±1.3	2.2±1.3	2.3±1.3	0.1[a]
External	0.8±0.9	0.8±0.9	0.9±1.0	0.3[a]
Lung contusion, n (%)	352 (58.7)	213 (58.0)	139 (59.7)	0.7[b]
Pneumo-/hematothorax, n (%)	409 (68.2)	272 (74.1)	137 (58.8)	<0.001[b]
ARDS, n (%)	206 (34.3)	126 (34.3)	80 (34.3)	1.0[b]
VAP, n (%)	86 (14.3)	60 (16.3)	26 (11.2)	0.09[b]
Duration of mechanical ventilation (h), mean±SD	271±326	298±351	229±278	0.3[a]
Duration of intensive care (days), mean±SD	15.0±14.7	16.0±15.8	13.3±12.7	0.2[a]
Duration of in-patient care (days), mean±SD	23.9±20.1	24.0±19.7	23.7±20.8	0.8[a]
Transfusion requirement				
PRBC 48-h (units), mean±SD	7.7±10.9	8.3±11.5	6.9±10.0	0.2[a]
FFP 48-h (units), mean±SD	6.0±8.8	6.3±8.7	5.5±8.9	0.1[a]
PC 48-h (units), mean±SD	1.0±2.0	1.1±2.1	0.8±1.9	0.08[a]
PRBC (units), mean±SD	13.5±17.1	14.2±17.2	12.3±16.8	0.1[a]
FFP (units), mean±SD	8.7±13.4	9.1±12.7	8.0±14.4	0.1[a]
PC (units), mean±SD	1.4±3.6	1.6±3.7	1.2±3.4	0.049[a]
Mortality, n (%)	85 (14.2)	61 (16.6)	24 (10.3)	0.03[b]
Shock, n (%)	218 (36.3)	135 (36.8)	83 (35.6)	0.8[b]

ARDS: Acute respiratory distress syndrome, FFP: fresh-frozen plasma, PC: platelet cells, PRBC: packed red blood cells, SD: standard deviation, VAP: ventilator-assisted pneumonia, 48-h: within first 48 hours, [a]Mann–Whitney *U*-test, [b]Fisher's exact test.

independent influence on post-traumatic course of treatment, including occurrence of ARDS as well as mortality, was found.

This might, to some extent, be in contrast to the clinical reality. From daily experience, patients with a flail chest injury do have a more complicated clinical course. However, there are two major concerns. For one thing, there are several different definitions of flail chest and for another, flail chest could be a surrogate parameter of the severity of organ-related injury.

Addressing the first concern in depth, flail chest is more a collective term rather than a firm definition. The most accepted definition is most probably a segmental fracture of three or more consecutive ribs. This is consistent with the AIS. The Association for the Advancement of Automotive Medicine defines flail chest as three or more adjacent ribs,

Table II. *Demographic, baseline and clinical data of patients with and without flail chest after propensity score matching.*

Characteristic	Flail chest (n=40)	No flail chest (n=110)	p-Value
Age (years), mean±SD	52.7±19.1	53.4±18.3	0.9[a]
Male gender, n (%)	27 (68)	78 (71)	0.7[b]
Injury Severity Score (ISS), mean±SD	30.7±9.5	28.8±8.4	0.3[a]
Abbreviated injury scale, mean±SD			
Head	1.7±1.6	1.7±1.6	0.9[a]
Face	0.7±1.0	0.7±1.0	0.9[a]
Thorax	3.9±0.8	3.7±0.7	0.3[a]
Abdomen	1.2±1.4	1.1±1.3	1.0[a]
Extremities	2.4±1.0	2.2±1.0	0.5[a]
External	0.7±0.8	0.7±0.8	0.8a
Lung contusion, n (%)	28 (70)	55 (50)	0.04[b]
Pneumo-/hematothorax, n (%)	37 (93)	78 (71)	0.005[b]
ARDS, n (%)	15 (38)	36 (33)	0.7[b]
VAP, n (%)	9 (23)	18 (16)	0.5[b]
Duration of mechanical ventilation (h), mean±SD	371±403	288±358	0.2[a]
Duration of intensive care (days), mean±SD	19.8±17.6	15.5±15.2	0.2[a]
Duration of in-patient care (days), mean±SD	29.2±24.2	23.1±16.4	0.3[a]
Transfusion requirement			
PRBC 48-h (units), mean±SD	7.8±9.4	6.4±11.7	0.08[a]
FFP 48-h (units), mean±SD	5.3±6.7	4.7±7.7	0.3[a]
PC 48-h (units), mean±SD	0.9±1.8	0.8±1.9	0.7[a]
PRBC (units), mean±SD	13.6±19.7	11.3±16.7	0.4[a]
FFP (units), mean±SD	7.7±13.5	7.7±12.6	0.6[a]
PC (units), mean±SD	2.0±6.1	1.4±4.4	0.7[a]
Mortality, n (%)	7 (18)	8 (7)	0.1[b]
Shock, n (%)	10 (25)	32 (29)	0.7[b]

ARDS: Acute respiratory distress syndrome, FFP: fresh-frozen plasma, PC: platelet cells, PRBC: packed red blood cells, SD: standard deviation, VAP: ventilator-assisted pneumonia, 48-h: within first 48 h, [a]Mann–Whitney *U*-test, [b]Fisher's exact test.

each fractured in more than one location (*e.g.* posterolateral and anterolateral) to create a free-floating segment, which may or may not result in paradoxical chest movement (22). Two major studies carried out by Dehghan *et al.* (11) and Schulz-Drost *et al.* (12) used the AIS coding to identify patients with flail chest. Other studies regarding flail chest either did not specify the definition applied (10) or used an umbrella term which left a wide margin of interpretation (9, 18). Borman *et al.* (9), as well as Kilic *et al.* (18) state that "flail occurs when the integrity of the thoracic rigid cage is compromised and a segment, its size depending on the number of fractured ribs or costal cartilages, loses its continuity with the rest of the thoracic cage and moves paradoxically during spontaneous respiration". This represents a clinically driven definition and is partially in contrast to the anatomic AIS definition. Paradoxical chest movement is a *sine qua non* in the one definition and optional in the other. Thus, comparability of patients is severely limited. It seems conclusive to clinically identify patients at particular risk. The use of the clinical definition therefore results in a more seriously ill patient group. Not surprisingly, these patients have a poorer outcome compared

to clinically more stable ones. As yet there are no data about inter-and intra-rater reliability. Thus, comparability and generalizability of the findings are very limited. To exaggerate, the gain of knowledge is that seriously ill patients are more ill than healthier patients. Therefore, if the clinical definition of flail chest is unreliable, it might be better to use the anatomic definition. Major advantages are its objectivity and reproducibility. These advantages, however, are counteracted by the inherent problems of multicentric registry data. Hundreds and even thousands of different users enter data. In theory, all users have to apply the same definition of flail chest. In practice, there is no validation of the data. In the German Trauma Registry, there is only a consistency check. Entries are only spot-checked if documentation of diagnoses in the clinical information system is consistent with the documentation in the registry. The extent to which documented diagnoses are actually appropriate according to the AIS definition is simply not checked. Therefore, data validity of multicentric registries is questionable to some extent. Dehghan *et al.* identified 3,467 patients (1%) with flail chest during a 3-year period using the US/Canadian National Trauma Data Bank (11). Schulz-

Drost *et al*. identified 3,492 patients (16.1%) with flail chest during a 5-year period using the German Trauma Registry (12). Both authors used the same AIS-based definition. The substantial difference in the incidence might be explained, to some extent, by different inclusion criteria. The US/Canadian National Trauma Data Bank includes every hospitalized patient with a relevant injury, whereas the German Trauma Registry includes patients admitted to the operating theatre as well as Intensive Care Unit following Emergency Room treatment. Dehghan *et al*. (11) included patients with an ISS of 9 or higher and Schulz-Drost *et al*. (12) with an ISS of 16 or higher. Against this background, incidence of flail chest in the study performed by Schulz-Drost *et al*. (16.1%) (12) seems reasonable but is rather high compared to our own data (7.5%). This is even more surprisingly since our own data are part of the German Trauma Registry, and demographic as well as baseline parameters are comparable for both patient populations. Therefore, the question arises again whether data validity exists. A major advantage of our study is its data validity. A CT scan was performed in all the patients. The diagnoses were verified by a consultant with special qualification in diagnostic radiography. In summary, the lack of a standardized definition and the uncertain data validity compromise the significance and generalizability of many studies.

However, despite definitional uncertainties, the more interesting question seems to be whether flail chest has an independent influence on morbidity and mortality or is just a surrogate parameter of the severity of organ-related injury. Velmahos *et al*. identified flail chest and extrathoracic injuries as independent risk factors for significant respiratory complications (14). Kilic *et al*. reported that injury severity was a major risk factor for mortality from flail chest trauma. However, this study seems to have serious shortcomings. The reported mean ISS of patients with traumatic brain injury and flail chest was 75, which is equivalent to a non-survivable injury. Nevertheless, mortality was 19%. Patients with flail chest without traumatic brain injury had a mean ISS of 55.7; the corresponding mortality was 0% (18). Based on our professional experience and with regard to the structure and validity of the ISS, these findings are inexplicable. Borman *et al*. reported that accompanying extra-thoracic injuries, especially traumatic brain injury, increased mortality. Since there was no control group, it is not clear whether this finding is only due to the increased ISS. The authors did not make a statement on the independent role of flail chest compared with other thoracic injuries (9). Huber *et al*. demonstrated that extra-thoracic factors (age over 65 years, blood transfusion, shock, severe extra-thoracic injury) prolong ventilation. This also applies to intrathoracic injuries. Nearly every type of injury to the lung parenchyma, hemo- and severe pneumothorax, and major thoracic vessel and cardiac injuries prolonged ventilation with a correlation of injury severity to

the expected prolongation (29). Dehghan *et al*. also identified traumatic brain injury as a major risk factor of adverse outcome in patients with flail chest (11). In line with our own results, Huber *et al*. demonstrated unilateral flail chest not to be a predictor of increased mortality; only bilateral flail chest was significantly associated with elevated mortality (29). Since there were no patients with bilateral flail chest in our own study population, we are not able to make an objective statement concerning this matter. Schulz-Drost *et al*. reported a more frequent occurrence of multiple organ dysfunction syndrome and septic complications in patients with flail chest. Mortality was increased accordingly. Bilateral flail chest, as expected, had the highest mortality (12). However, injury severity was increased in the flail chest group (35.1±14.2 *vs*. 28.3±11.3) and the authors omitted analysis of the impact of flail chest injuries independent of increased injury severity (12). In summary, our own results support the assumption that flail chest is a surrogate parameter of increased severity of thoracic injury rather than an independent predictor of adverse outcome.

However, there are certain issues that are poorly analyzed or discussed. The impact of lung contusion and laceration is hardly understood yet. Huber *et al*. demonstrated a linear correlation of injury severity to the expected prolongation of ventilation for lung contusion as well as lung laceration (29). But these findings are inconsistent. Dehghan *et al*. reported a significant increase in the rate of pulmonary complications, even though the magnitude of the differences was low and clinical relevance was not existent (11). From a clinical point of view, it seems obvious that parenchymatous injuries to the lung affect ventilation and the risk of ARDS. But it is difficult to prove. What matters is the extent of lung contusion. However, this depends on the period from the accident to the first CT. The shorter the period, the greater the risk that the real extent of contusion is masked. To our knowledge, no study has yet focused on the correlation between volumetric extent of lung contusion and pulmonary complications. Another relevant issue is the possible bias caused by patients who died before reaching the hospital or in the Emergency Room. Kleber *et al*. reported that tension pneumothorax was one of the leading causes of trauma-related preventable deaths in the pre-hospital setting (30). Various studies and our own results show that pneumothorax is more common in patients with flail chest (11, 12, 29). Since every study excluded patients who died pre-hospital or in the Emergency Room, it is unclear, to what extent this biases the result. It is conceivable that patients with especially severe thoracic injuries die before reaching hospital and only patients with a rather benign form of flail chest arrive still alive at the hospital. Due to this selection bias, the outcome differences may be levelled.

This limitation also applies to our retrospective study. However, data quality is high and definition of flail chest in

comparison to serial rib fractures is well-defined. Nevertheless, there are some limitations one should take into consideration when interpreting the data. Therapy of blunt thoracic trauma has continuously changed during the study period. Alternating position and prone position replaced kinetic therapy. Respiratory therapy also changed. However, there are no convincing data that demonstrate advantages of one approach yet. There are other limitations that might bias our results. Eligibility criteria were well-defined; therefore, numerous patients were excluded. Furthermore, this study analyzed patients with blunt thoracic trauma only. Due to totally different dynamics of blunt and penetrating trauma, a transfer of results is not possible. Therefore, we cannot give any objective recommendations regarding penetrating trauma. However, our results can be generalized to high income countries with comparable therapy according to actual guidelines.

In conclusion, we demonstrated that there was no independent impact of flail chest on post-traumatic mortality and morbidity in multiply injured patients with blunt thoracic trauma. Therefore, it seems inappropriate to give recommendations on operative therapy based on the anatomic diagnosis of flail chest alone, although this is of particular interest. Future studies should analyze which particular injuries in blunt thoracic trauma independently worsen the outcome and necessitate an operative therapy. Special attention needs to be paid to the extent of lung contusion and in particular fracture patterns that hamper ventilation. A set definition of flail chest and scientifically sound knowledge about its impact on multiply injured patients provides the basis for this and helps to draw conclusions about the potential benefits of an operative therapy.

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