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Original Article

Trauma patient adverse outcomes are independently associated with rib cage fracture burden and severity of lung, head, and abdominal injuries

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Abstract: *Objective:* We hypothesized that lung injury and rib cage fracture quantification would be associated with adverse outcomes. *Subjects and methods:* Consecutive admissions to a trauma center with Injury Severity Score ≥ 9, age 18-75, and blunt trauma. CT scans were reviewed to score rib and sternal fractures and lung infiltrates. Sternum and each anterior, lateral, and posterior rib fracture was scored 1 = non-displaced and 2 = displaced. Rib cage fracture score (RCFS) = total rib fracture score + sternal fracture score + thoracic spine Abbreviated Injury Score (AIS). Four lung regions (right upper/middle, right lower, left upper, and left lower lobes) were each scored for % of infiltrate: 0% = 0; ≤ 20% = 1, ≤ 50% = 2, > 50% = 3; total of 4 scores = lung infiltrate score (LIS). *Results:* Of 599 patients, 193 (32%) had 854 rib fractures. Rib fracture patients had more abdominal injuries ($p < 0.001$), hemo/pneumothorax ($p < 0.001$), lung infiltrates ($p < 0.001$), thoracic spine injuries ($p = 0.001$), sternal fractures ($p = 0.0028$) and death or need for mechanical ventilation ≥ 3 days (Death/Vdays ≥ 3) ($p < 0.001$). Death/Vdays ≥ 3 was independently associated with RCFS ($p < 0.001$), LIS ($p < 0.001$), head AIS ($p < 0.001$) and abdominal AIS ($p < 0.001$). Of the 193 rib fracture patients, Glasgow Coma Score 3-12 or head AIS ≥ 2 occurred in 43%. A lung infiltrate or hemo/pneumothorax occurred in 55%. Thoracic spine injury occurred in 23%. RCFS was 6.3 ± 4.4 and Death/Vdays ≥ 3 occurred in 31%. Death/Vdays ≥ 3 rates correlated with RCFS values: 19% for 1-3; 24% for 4-6; 42% for 7-12 and 65% for ≥ 13 ($p < 0.001$). Death/Vdays ≥ 3 was independently associated with RCFS ($p = 0.02$), LIS ($p = 0.001$), head AIS ($p < 0.001$) and abdominal AIS ($p < 0.001$). Death/Vdays ≥ 3 association was better for RCFS ($p = 0.005$) than rib fracture score ($p = 0.08$) or number of fractured ribs ($p = 0.80$). *Conclusion:* Rib fracture patients have increased risk for truncal injuries and adverse outcomes. Adverse outcomes are independently associated with rib cage fracture burden. Severity of head, abdominal, and lung injuries also influence rib fracture outcomes.

Keywords: Rib fractures, CT imaging, hospital mortality, mechanical ventilation, pneumonia, intensive care, lung injury, head injuries, abdominal injuries

Introduction

Approximately 10% of patients admitted to a trauma center in the USA have one or more rib fractures [1, 2]. Substantial controversy exists regarding the impact of multiple rib fractures on patient outcomes such as mortality, need for mechanical ventilation, development of pulmonary complications, and hospital length of stay. While some investigations have demonstrated that the number of ribs fractured is associated with increased mortality [2-6], a lack of correlation with mortality has been shown by others [7-10]. As well, certain studies have presented evidence that the number of ribs fractured correlates with the need for mechanical ventilation [3, 4, 8], others provide evidence that an association does not exist [7, 8, 10]. Similarly, some investigators have found an association between the number of fractured ribs and hospital length of stay [3, 7, 8, 11-13], whereas other investigators failed to find an association [7, 8, 10]. Of interest are 3 studies that have shown mortality to have a univariate correlation with the number of ribs fractured, yet the number of ribs fractured failed to be an independent risk for death [2, 3, 5]. All 3 studies included the Injury Severity Score (ISS) in the mortality model and showed that ISS was an independent correlate. Readers may be left with the impression that the number of ribs fractured is not clinically important as a risk condition. Further, practitioners primarily manage patients in concordance with conditions that are practically complex, as opposed to an ordinal rank estimate of overall "injury severity".

The current study is a retrospective investigation of patients admitted to a Level I trauma center without and with rib fractures. We hypothesized that a rib cage fracture score (RCFS) would better correlate with clinical outcomes, when compared to a rib fracture score (rib fx score), that quantifies each individual rib fracture, or the number of ribs fractured. We also conjectured that associated injuries (head, lung, and abdomen) would be independently associated with outcomes. Because the literature is sparse and clinical perspective is often informative, we compared rib fracture patient outcomes to those without a rib fracture.

Materials and methods

Ethics statement

This study was approved by the Humility of Mary Health Partners Institutional Review Board for Human Investigations. The Institutional Review Board waived the need for written informed consent from the patients, due to the retrospective nature of the investigation. Patients included were those with age ≥ 18 years, blunt trauma mechanism, and ISS ≥ 9. Patients were excluded from analysis if they died in the trauma resuscitation room, had a preinjury hospice-status, were transferred to another hospital or left against medical advice within 24 hours, or had unhealed preinjury rib fractures. Data obtained from the trauma registry included ISS, admission Glasgow Coma Score (GCS), head Abbreviated Injury Scale Score (AIS), abdominal AIS, chest AIS, thoracic spine AIS, days of mechanical ventilation, ICU stay, and hospital stay, and pneumothorax-hemothorax, thoracic spine fracture or dislocation, mortality, and pneumonia status.

When a chest CT scan had been performed at admission, the scan was reviewed to determine whether a rib fracture, a sternal fracture, or lung infiltrate was present. Rib fractures were categorized as to the total number of fractured ribs, whether they were unilateral or bilateral, and according to anatomic location (anterior, lateral, or posterior). When reviewing the CT scan, the anterior, lateral, and posterior segments of each rib were assessed for the presence of a rib fracture. The absence of a rib fracture was scored as 0, the presence of a fracture without displacement or comminution was scored as 1, and the presence of a fracture with displacement or comminution was scored as 2. The rib fx score was the sum of all the individual rib segmental scores. Sternal fractures were scored as a 0 when absent, a 1 when a fracture was present and without displacement or comminution, and 2 when a fracture was present and had either displacement or comminution. The RCFS was the sum of the rib fx score, the sternal fracture score, and the thoracic spine AIS. The lung windows of each CT scan were assessed for the presence of a lung infiltrate and scored according to the magnitude of infiltrate. The following 4 lung regions were assessed: right upper/middle lobe, right lower lobe, left upper lobe, and left lower lobe. Each lung region was scored according to the magnitude of the infiltrate: 0 was 0% infiltrate, 1 was ≤ 20% infiltrate, 2 was ≤ 50% infiltrate, and 3 was > 50% infiltrate. The lung infiltrate score (LIS) was the sum of the 4 lung region infiltrate scores.

Primary outcome variables were death or mechanical ventilator days ≥ 3 (Death/Ventilator Days ≥ 3), death or ICU days ≥ 7 (Death/ICU Days ≥ 7), death or hospital days ≥ 10 (Death/Hospital Days ≥ 10), and pneumonia. Associations between potential risk conditions and the primary outcome variables were evaluated for all of the patients included in the investigation and then for the subset with rib fractures.

Statistical analysis

Data were entered into a Microsoft Excel® 2010 spreadsheet and imported into a SAS System for Windows, release 9.2 (SAS Institute Inc., Cary, NC, USA), for statistical analyses. For continuous variable cohort data, standard deviation was used to complement the mean. Nonparametric analysis was used to compare continuous data results between two groups. Fischer's exact testing was used to assess the relationship of two dichotomous variables. Multivariate logistic regression analysis was performed to assess independent variable relationships with a dependent variable that was dichotomous.

Results

All injury severity score ≥ 9 patients

Eleven patients were excluded from the analysis due to death in the trauma resuscitation

Table 1. Comparison of Patients without and with Rib Fractures

	No Rib Fracture	Rib Fracture	*P*-value
Number	406 (67.8%)	193 (32.2%)	
Injury Severity Score ≥ 15	129 (31.8%)	106 (54.9%)	< 0.0001
Admission GCS 3-12	54 (13.9%)	31 (16.9%)	0.3519
Head AIS ≥ 2	216 (53.2%)	76 (39.4%)	0.0016
Abdominal AIS ≥ 2	24 (5.9%)	40 (20.7%)	< 0.0001
Chest CT scan	242 (59.6%)	193 (100%)	< 0.0001
Pneumothorax-Hemothorax	13 (3.2%)	88 (45.6%)	< 0.0001
Lung infiltrate	31 (7.6%)	64 (33.2%)	< 0.0001
Thoracic spine injury	51 (12.6%)	44 (22.8%)	0.0013
Sternal fracture	9 (2.2%)	15 (7.8%)	0.0028
Ventilator Days ≥ 3	43 (10.6%)	55 (28.5%)	< 0.0001
Mortality	12 (3.0%)	9 (4.7%)	0.2883
Death/Ventilator Days ≥ 3	51 (12.6%)	60 (31.1%)	< 0.0001
Death/ICU Days ≥ 7	56 (13.8%)	63 (32.6%)	< 0.0001
Death/Hospital Days ≥ 10	80 (19.7%)	82 (42.5%)	< 0.0001
Pneumonia	32 (7.9%)	29 (15.0%)	0.0069

GCS, Glasgow Coma Score; AIS, Abbreviated Injury Scale score; ICU, intensive care unit.

Table 2. Fracture Correlations with Death or Need for Mechanical Ventilation-All ISS ≥ 9 Patients

	Lived/Vent Days < 3	Death/Vent Days ≥ 3	*P*-value
Number	488	111	
Total ribs fractured	1.1 ± 2.2	2.9 ± 3.8	< 0.0001
Rib Fracture Score	1.3 ± 2.8	3.9 ± 5.3	< 0.0001
Rib Cage Fracture Score	1.7 ± 3.0	4.7 ± 5.6	< 0.0001
Sternal fracture	13 (2.7%)	11 (9.9%)	0.0003
Thoracic spine AIS	0.3 ± 0.9	0.6 ± 1.2	0.0263
Chest AIS	1.0 ± 1.4	2.2 ± 1.8	< 0.0001

ISS, Injury Severity Score; Vent, ventilator; AIS, Abbreviated Injury Scale score.

Table 3. Risk Condition Correlations with Death or Need for Mechanical Ventilation-All ISS ≥ 9 Patients

	Lived/Vent Days < 3	Death/Vent Days ≥ 3	*P*-value
Number	488	111	
Rib Cage Fracture Score	1.7 ± 3.0	4.7 ± 5.6	< 0.0001
Lung Infiltrate Score	0.2 ± 0.6	1.6 ± 2.4	< 0.0001
Head AIS	1.3 ± 1.5	2.7 ± 1.9	< 0.0001
Abdominal AIS	0.2 ± 0.6	0.9 ± 1.5	< 0.0001

ISS, Injury Severity Score; Vent, ventilator; AIS, Abbreviated Injury Scale score.

room, preinjury hospice-status, transferred to another hospital or left against medical advice within 24 hours, or had unhealed preinjury rib fractures. A comparison of the 599 patients, according to their rib fracture status, is delineated in **Table 1**. Rib fracture patients had more truncal injuries (lung, abdomen, and thoracic spine injuries, sternal fractures, pneumothorax-hemothorax), higher Injury Severity Scores, and a greater percent of chest CT scanning. Rib fracture patients were just as likely to have altered cognition (GCS 3-12), but had slightly fewer anatomic head injuries (head AIS ≥ 2). An increased rate of Death/Ventilator Days ≥ 3, Death/ICU Days ≥ 7, Death/Hospital Days ≥ 10, and pneumonia were also seen in rib fracture patients. Among the 599 patients, age had no correlation with mortality ($p = 0.7917$), ventilator days ($p = 0.4628$), or pneumonia ($p = 0.9982$) and a marginally significant inverse relationship with Death/Ventilator Days ≥ 3 ($p = 0.0478$). The presence of a lung infiltrate was independently associated with admission GCS 3-8 ($p < 0.0001$), RCFS ($p < 0.0001$), and pneumothorax-hemothorax ($p < 0.0001$).

Death/Ventilator Days ≥ 3 had univariate associations with total ribs fractured, rib fx score, RCFS, sternal fracture, thoracic spine AIS, and chest AIS (**Table 2**). Death/Ventilator Days ≥ 3 was independently associated with RCFS ($p = 0.0270$), but not with the number of ribs with a fracture, rib fx score, sternal fracture, or thoracic spine AIS ($p > 0.05$). The stepwise logistic regression procedure selected only RCFS ($p < 0.0001$), when considering these 5 variables. Relative to Death/Ventilator Days ≥ 3, the stepwise logistic regression procedure selected rib fx score ($p < 0.0001$) over the number of ribs fractured ($p = 0.5649$). Death/Ventilator Days ≥ 3 was independently associated with RCFS ($p = 0.0097$) and chest AIS ($p < 0.0001$). Univariate analysis demonstrated that Death/Ventilator Days ≥ 3 had associations with RCFS, LIS, head AIS, and abdominal

Table 4. Unilateral and Bilateral Rib Fracture Patient Outcomes

Rib Fracture	Unilateral	Bilateral	*P*-value
Patients	164 (85.0%)	29 (15.0%)	
Ventilator Days	3.3 ± 6.5	8.6 ± 13.7	0.0506
Pneumonia	21 (12.8%)	8 (27.6%)	0.0502
Death/Ventilator Days ≥ 3	48 (29.3%)	12 (41.4%)	0.1940

Table 5. Isolated Anterior-Lateral and Isolated Posterior Rib Fracture Comparisons

Rib Fracture	Anterior-Lateral	Posterior	*P*-value
Patients	88	48	
Fractured ribs	3.6 ± 2.2	3.5 ± 2.2	0.7932
Rib Fracture Score	4.1 ± 2.5	4.0 ± 2.7	0.9377
Rib Cage Fracture Score	4.5 ± 2.7	5.1 ± 3.1	0.2540
Lung Infiltrate Score	0.6 ± 1.5	1.1 ± 2.3	0.1453
Pneumothorax-Hemothorax	39 (44.3%)	15 (31.3%)	0.1366
Thoracic spine fracture	14 (15.9%)	19 (39.6%)	0.0021
Injury Severity Score	17.9 ± 10.6	20.2 ± 10.3	0.2343
Pneumonia	9 (10.2%)	9 (18.8%)	0.1610
Death/Ventilator Days ≥ 3	19 (21.6%)	17 (35.4%)	0.0807

Table 6. Fracture Correlations with Death or Need for Mechanical Ventilation-Rib Fracture Patients

	Lived/Vent Days < 3	Death/Vent Days ≥ 3	*P*-value
Number	133	60	
Total ribs fractured	4.0 ± 2.4	5.4 ± 3.6	0.0077
Rib Fracture Score	4.9 ± 3.4	7.2 ± 5.3	0.0024
Rib Cage Fracture Score	5.4 ± 3.5	8.2 ± 5.5	0.0004
Sternal fracture	7 (5.3%)	8 (13.3%)	0.0534
Thoracic spine AIS	0.4 ± 1.0	0.8 ± 1.4	0.0463
Chest AIS	2.8 ± 0.9	3.4 ± 1.1	< 0.0001

Vent, ventilator; AIS, Abbreviated Injury Scale score.

AIS (**Table 3**). Death/Ventilator Days ≥ 3 was independently associated with RCFS ($p < 0.0001$), LIS ($p < 0.0001$), head AIS ($p < 0.0001$), and abdominal AIS ($p < 0.0001$) ($r^2 = 0.3608$).

The number of ribs fractured correlated with Death/ICU Days ≥ 7 ($p < 0.0001$). The stepwise logistic regression procedure selected the rib fx score ($p < 0.0001$) over the number of ribs fractured ($p = 0.2713$) and RCFS ($p < 0.0001$) over the rib fx score ($p = 0.0936$). Death/ICU Days ≥ 7 was independently associated with RCFS ($p < 0.0001$), LIS ($p < 0.0001$), head AIS ($p < 0.0001$), and abdominal AIS ($p < 0.0001$).

The number of fractured ribs correlated with Death/Hospital Days ≥ 10 ($p < 0.0001$). The stepwise logistic regression procedure selected rib fx score ($p < 0.0001$) over the number of ribs fractured ($p = 0.1755$) and RCFS ($p < 0.0001$) over the rib fx score ($p = 0.1712$). Death/Hospital Days ≥ 10 was independently associated with RCFS ($p < 0.0001$), LIS ($p = 0.0002$), head AIS ($p < 0.0001$), and abdominal AIS ($p < 0.0001$).

Of the 599 total patients, 61 (10.2%) developed pneumonia with a mean mechanical ventilation duration of 13.8 days. Pneumonia had univariate associations with total ribs fractured ($p = 0.0226$), rib fx score ($p = 0.0159$), RCFS ($p = 0.0047$), LIS ($p < 0.0001$), head AIS ($p < 0.0001$), and abdominal AIS ($p < 0.0001$). The stepwise logistic regression procedure selected the rib fx score ($p < 0.0001$) over the number of ribs fractured ($p = 0.9305$) as a correlate with pneumonia. RCFS was a better predictor of pneumonia ($p = 0.0040$), when compared to the rib fx score ($p = 0.0983$). Pneumonia was independently associated with RCFS ($p = 0.0197$), LIS ($p = 0.0498$), head AIS ≥ 2 ($p < 0.0001$), and abdominal AIS ≥ 2 ($p = 0.0137$).

Rib fracture patients

Of the 193 rib fracture patients, sternal fractures were present in 15 patients, the total rib with one or more fractures was 854, the sum of the rib fx score was 1,077, mean ribs fractured was 4.4 ± 2.9 (1-20), mean rib fx score was 5.6 ± 4.2 (1-22), and mean RCFS was 6.3 ± 4.4 (1-23). Rib fracture patient initial clinical condition rates were admission GCS 3-12 or head AIS ≥ 2 in 83 (43.0%); abdominal AIS ≥ 2 in 40 (20.7%), hemothorax, pneumothorax, or lung injury in 107 (55.4%); and thoracic spine fracture/dislocation or spinal cord deficit in 45 (23.3%). Of the 29 (15.0%) patients who developed pneumonia, the mean mechanical ventilation duration was 16.3 days. Age had no correlation with mortality (p = 0.4009), ventilator days (p = 0.8666), pneumonia (p = 0.4445), or Death/Ventilator Days ≥ 3 (p = 0.1185).

A comparison of unilateral and bilateral rib fracture outcomes are in **Table 4**. The overwhelming majority of rib fractures were unilateral. Bilateral rib fracture patients showed a trend toward greater ventilator days and more pneumonia, when compared to unilateral fractures. However, the Death/Ventilator Days ≥ 3 rates were similar.

A comparison of patients with isolated anterior-lateral rib fractures (no posterior fracture) and isolated posterior rib fractures (no anterior-lateral fracture) is in **Table 5**. Rib fracture quantifications, LIS, pneumothorax-hemothorax, and ISS were similar; however, patients with posterior rib fractures had more thoracic spine fractures. Pneumonia rates were similar for the posterior rib fractures and anterior-lateral rib fracture groups. However, patients with a posterior rib fracture had a trend toward a higher rate of Death/Ventilator Days ≥ 3.

In patients with rib fractures, Death/Ventilator Days ≥ 3 had univariate associations with RCFS, rib fx score, total ribs fractured, thoracic spine AIS, and chest AIS and a trend for significance with sternal fracture (**Table 6**). The Death/Ventilator Days ≥ 3 rate was higher when the number of fractured ribs was ≥ 6 (50.0%), compared to less than 6 fractured ribs (24.1%; p = 0.0006). When the rib fx score was ≥ 8 (52.2%), the Death/Ventilator Days ≥ 3 rate was higher compared to a score less than 8 (24.5%; p = 0.0004). Relative to Death/Ventilator Days ≥ 3, RCFS was an independent predictor (p = 0.0048), but the rib fx score was not (p = 0.0734). When correlating Death/Ventilator Days ≥ 3, stepwise logistic regression selected the rib fx score (0.0008) over the number of ribs fractured (0.7846). Death/Ventilator Days ≥ 3 had an independent association with RCFS (p = 0.0075) and chest AIS (p = 0.0071). RCFS categorical values correlated with rates of Death/Ventilator Days ≥ 3: RCFS 1-3 had a rate of 18.9%, RCFS 4-6 had a rate of 24.3%, RCFS 7-12 had a rate of 41.5%, and RCFS 13-23 had a rate of 64.7% (p < 0.0001). The RCFS ≥ 5 group had a higher Death/Ventilator Days ≥ 3 rate (40.5% [45/111]), when compared to RCFS 1-4 (18.3% [15/82]; RR 2.0; p = 0.0009). LIS ≥ 2 had a higher Death/Ventilator Days ≥ 3 rate (68.4% [26/38]), when compared to LIS 0-1 (21.9% [34/155]; RR 1.6; p < 0.0001). Head AIS ≥ 2 had a higher Death/Ventilator Days ≥ 3 rate (46.1% [35/76]), when compared to Head AIS 0-1 (21.4% [25/117]; RR 1.7; p = 0.0003). Abdominal AIS ≥ 2 had a higher Death/Ventilator Days ≥ 3 rate (62.5% [25/40]), when compared to abdominal AIS 0-1 (22.9% [35/153]; RR 1.5; p < 0.0001). Death/Ventilator Days ≥ 3 had an independent association with RCFS (p = 0.0213), LIS (p = 0.0014), head AIS (p < 0.0001), and abdominal AIS (p = 0.0004) (r^2 = 0.3840). A risk condition assessment for Death/Ventilator Days ≥ 3 was performed and included the following conditions: RCFS ≥ 5, LIS ≥ 2, head AIS ≥ 2, and abdominal AIS ≥ 2. Each risk condition was scored 0 for no and 1 for yes with a range of 0-4. As the number of risk conditions increased, so did the Death/Ventilator Days ≥ 3 rate: 0 conditions had a rate of 2.4%, 1 condition 18.1%, 2 conditions 50.0%, and 3 conditions 69.6%, and 4 conditions 83.3% (p < 0.0001). Risk conditions with a value of ≥ 2 had a higher Death/Ventilator Days ≥ 3 rate (58.2%), when compared to risk conditions with a value of 0 or 1 (12.3%; RR 3.2; p < 0.0001).

Death/ICU Days ≥ 7 had univariate correlations with total ribs fractured (p < 0.0001), rib fx score (p < 0.0001), RCFS (p < 0.0001), LIS (p < 0.0001), head AIS (p < 0.0001), and abdominal AIS (p < 0.0001). Relative to Death/ICU Days ≥ 7, the rib fx score had an independent correlation (p = 0.0002), when compared with the number of ribs fractured (p = 0.3915). In turn, the RCFS had an independent correlation (p = 0.0023), when compared with the rib fx score (p = 0.3915), relative to Death/ICU Days ≥ 7. Death/ICU Days ≥ 7 had an independent association with RCFS (p = 0.0038), LIS (p = 0.0016), head AIS (p < 0.0001), and abdominal AIS (p < 0.0001) (r^2 = 0.4183).

Death/Hospital Days ≥ 10 had univariate correlations with total ribs fractured (p < 0.0001), rib fx score (p < 0.0001), RCFS (p < 0.0001), LIS (p < 0.0001), head AIS (p < 0.0001), and abdominal AIS (p < 0.0001). Relative to Death/Hospital Days ≥ 10, the rib fx score had an independent correlation (p < 0.0001), when compared with the number of ribs fractured (p = 0.1956) and the RCFS had an independent correlation (p < 0.0001), when compared with the rib fx score (p = 0.2818). Death/Hospital Days

≥ 10 had an independent association with RCFS (p = 0.0002), LIS (p = 0.0403), head AIS ≥ 3 (p = 0.0010), and abdominal AIS ≥ 2 (p = 0.0004) (r^2 = 0.2822).

Pneumonia had univariate correlations with RCFS (p = 0.0247), LIS (p = 0.0004), head AIS (p = 0.0008), and abdominal AIS (p = 0.0027). Pneumonia did not correlate with the total ribs fractured (p = 0.2190); however, the rib fx score approached significance (p = 0.0952). Pneumonia had an independent association with the LIS (p = 0.0092) and head AIS (p = 0.0070).

Discussion

Rib fracture patients

Impaired cognition or anatomic head injury, abdominal injury, pneumothorax-hemothorax, lung injury, and thoracic spine injury were found to be common clinical conditions in the patients with one or more fractured ribs. Numerous other investigators have also found rib fracture patients to frequently have head injuries [1, 2, 14-16], pneumothorax-hemothorax [1, 4, 5, 7, 9, 12, 16-19], lung injury [1, 4-7, 9, 16-19], abdominal injury [1, 12, 15, 16, 18], and thoracic spine injury [4, 8, 10]. The sternal fracture rate of 7.7% is comparable to that found by other investigators studying rib fracture patients [1, 7, 19].

Major adverse outcomes (Death/Ventilator Days ≥ 3, Death/ICU Days ≥ 7, Death/Hospital Days ≥ 10 days) occurred in ≥ 30% of rib fracture patients. Further, pneumonia occurred in 15% and was associated with substantial ventilator dependency. Several other investigators have also noted that rib fracture patients commonly require mechanical ventilation and have lengthy ICU and hospital lengths of stay [3, 4, 7, 8, 10]. The literature indicates that rib fracture associated pneumonia rates have ranged from 2.8% to 11.3% [3, 5, 9, 19].

Bilateral rib fractures were relatively uncommon and did not lead to significantly worse outcomes, when compared to unilateral fractures. Patient outcomes were insignificantly worse with posterior rib fractures, compared to anterolateral rib fractures. This may be related to the higher thoracic spine fracture rate found in patients with posterior rib fractures.

Rib fracture patient correlations

The number of ribs fractured was found to correlate with major adverse outcomes (Death/Ventilator Days ≥ 3, Death/ICU Days ≥ 7, and Death/Hospital Days ≥ 10 days). However, multivariate analyses indicated that the rib fx score was a better predictor of adverse outcomes, compared to the number of ribs fractured. Further, the RCFS was found to be a better adverse outcome predictor, when compared to the rib fx score. Pneumonia correlated with the RCFS, but had no association with either the number of fractured ribs or the rib fx score. Although adverse outcomes are related to the number of fractured ribs, grading the total rib fracture burden was found to provide a better predictor. This indicates that rib fracture grading is a more valid indicator of adverse outcomes than just counting the number of ribs fractured. Other investigators have also studied rib fracture grading and found correlations with mortality and pneumonia rates [5] and ICU and hospital lengths of stay [15]. Of greater importance is the finding that the RCFS better predicts adverse outcomes, when compared to the other methods of rib fracture quantification. These findings indicate that the rib fracture burden should be quantified according to the pattern of each individual rib fracture and contextualized according to the presence and severity of associated sternal and thoracic spine fractures. That is, an overall rib cage fracture burden is a better indicator of adverse outcomes, as opposed to only considering rib fractures to be an isolated thoracic fracture entity. This notion is corroborated by the finding that Death/Ventilator Days ≥ 3 had an independent association with RCFS and chest AIS.

Major adverse outcomes (Death/Ventilator Days ≥ 3, Death/ICU Days ≥ 7, and Death/Hospital Days ≥ 10 days) were shown to have independent associations with RCFS, LIS, head AIS, and abdominal AIS. These findings further indicate that the rib-cage fracture burden is a significant and independent predictor of adverse outcomes. The data also imply that concomitant lung injury/infiltrate, head injury, and abdominal injury also influence the development of adverse outcomes. Rib fracture patients with lung contusion have been documented to have increased pneumonia [5, 6]. Other studies have shown that pulmonary contusion size is associated with pneumonia [20], ARDS [20-22], duration of mechanical ventilation [20, 21], and hospital length of stay [23]. Of relevance, Maxwell et al. have shown that head AIS, in rib fracture patients, correlates with ICU and hospital lengths of stay [15]. The same group also demonstrated that abdominal injury showed an association with increased ICU and hospital lengths of stay.

As the number of discriminate risk conditions increased, RCFS ≥ 5, LIS ≥ 2, head AIS ≥ 2, and abdominal AIS ≥ 2, the rate of Death/Ventilator Days ≥ 3 substantially rose. Death or the need for ≥ 3 days of mechanical ventilation was substantially less than 10%, when no such risk condition was present. The risk for death or the need for ≥ 3 days of mechanical ventilation was 18% when any one of the risk conditions was present. Further, the risk for death or the need for ≥ 3 days of mechanical ventilation markedly increased when ≥ 2 risk conditions were present. These results indicate that rib fracture patient outcomes vary according to the severity of rib cage fractures, as well as the presence of associated injuries (lung, head, and abdominal). In general, the need for mechanical ventilation is dependent on airway compromise (obstructed or unprotected), inadequate oxygenation, and/or inadequate spontaneous ventilator function [24]. Apropos, head injury may lead to airway obstruction and loss of airway protection; chest wall fractures can cause an impairment of spontaneous chest wall excursion; and lung trauma may impair oxygenation via contusion or impede ventilation from hemothorax or pneumothorax. Further, abdominal injury may create pulmonary complexity, because hemorrhage can decrease oxygen carrying capacity; abdominal hypertension may cause lung compression, impairing oxygenation and ventilation; and abdominal pain can mitigate diaphragmatic excursion. Thus the 4 independent factors independently statistically associated with death or need for ≥ 3 days of mechanical ventilation have a rational clinical foundation.

The development of pneumonia had univariate associations with the same 4 clinical risk conditions, RCFS, LIS, head AIS, and abdominal AIS. Pneumonia was independently associated with the LIS and head AIS. This indicates that head injuries, likely due to a risk for pulmonary aspiration, and direct lung trauma create lung injury that forecasts a risk for pneumonia.

Rib fracture and non-rib fracture patient comparisons

Blunt trauma injuries with ISS ≥ 9 were used as study selection criteria to exclude patients with minor injuries. This also helped to standardize injury severity, with intent to infer the relative impact of rib fractures on patient outcomes. A chest CT was performed in 60% of the non-rib fracture patients and all of those with one or more rib fractures. Rib fracture patients had more lung, abdominal, and thoracic spine injuries, sternal fractures, and pneumothorax-hemothorax, compared to non-rib fracture patients. In addition to more truncal injuries, Injury Severity Scores were higher in the patients with rib fractures. Of interest, rib fracture patients are just as likely to have altered cognition as patients without rib fractures; however, anatomic head injury was less common. Rib fracture patients had increased rates of Death/Ventilator Days ≥ 3, Death/ICU Days ≥ 7, Death/Hospital Days ≥ 10 days, and pneumonia. Lung infiltrate was independently associated with admission GCS 3-8, RCFS, and pneumothorax-hemothorax, indicating that lung infiltrate was likely related to pulmonary aspiration and or direct lung trauma.

Combined rib fracture and non-rib fracture patient correlations

Many of the correlations with outcomes in the combined cohorts of rib fracture and non-rib fracture patients are comparable to the findings with only the rib fracture patients. That is, the number of ribs fractured was found to correlate with major adverse outcomes (Death/Ventilator Days ≥ 3, Death/ICU Days ≥ 7, and Death/Hospital Days ≥ 10 days). However, the rib fx score was a better predictor, compared to the number of ribs fractured.

This indicates that rib fracture scoring is a more valid predictor of adverse outcomes, than simply counting the number of ribs fractured. Further, the RCFS was found to be a better adverse outcome predictor, when compared to the rib fx score. Again, this implies that rib cage fracture burden correlates better with outcomes, when compared to the number of ribs fractured or the rib fracture burden resulting from grading individual fractures.

Analyses in the combined patient cohorts also showed that adverse outcomes were independently associated with RCFS, LIS, head AIS, and abdominal AIS. This indicates that rib fracture patient outcomes are related to rib-cage fracture burden, but are also influenced by associated lung, head, and abdominal injuries. Death/Ventilator Days ≥ 3 was independently associated with RCFS and chest AIS, implying the clinical validity of this paradigm for modeling thoracic boney injury. Of interest, the development of pneumonia was also better predicted by RCFS when compared to the other two methods for quantifying rib fractures. Further, pneumonia was independently associated with RCFS and lung, head, and abdominal injuries, providing additional evidence to validate the RCFS.

Recent, large chest injury analysis

Of relevance is a large investigation of major chest trauma by Huber et al., published 2014, which states that "chest wall injuries such as rib fractures or flail chest, existing data remain controversial as to their prognostic impact" [25]. Inclusion criteria were chest AIS ≥ 2 and ISS ≥ 16 with an incidence of rib fractures in 34.5%, lung contusion in 48.0%, and sternal fracture in 8.6%. Using univariate analyses, mortality and duration of mechanical ventilation were each shown to increase with the magnitude of lung contusion, head injury, and abdominal injury, based on AIS scores. Additionally, mortality was found to be increased according to the number of rib fractures. Head injury and abdominal injury were demonstrated to be independent predictors of mortality. For clinical and statistical reasons, mortality analyses included death at any time; however, the duration of mechanical ventilation examinations excluded patients dying during the first-two weeks of hospitalization. Similar motivations prompted us to create a combined variable, Death/Ventilator Days ≥ 3, as the primary measure of outcome.

Limitations

Although the study is retrospective, the following evidence indicates that common study weaknesses have been mitigated. Much of the data results emanated from the trauma registry, where information was obtained from the Trauma History and Physical form, the Trauma Tertiary Survey form, the trauma service Advanced Practice Nurses' daily work-sheet documentation, operative records, radiography reports, and discharge summaries. The Trauma History and Physical form is a comprehensive database completed at the time of patient admission by the trauma resident and verified by the attending trauma surgeon. At 24 hours following admission, a comprehensive Trauma Tertiary Survey form was completed by a trauma service resident and confirmed by the attending trauma surgeon. Each day, an Advanced Practice Nurse updated a work-sheet that captured initial injuries, injuries with a delay in diagnosis, and complications. Further, the Advanced Practice Nurses met weekly with the surgical attending staff to discuss patient deaths and all complications. This provided an opportunity to clarify ongoing patient conditions and outcomes in the nurses' daily work-sheet. Accordingly, mechanism of injury, admission and discharge GCS, preinjury antithrombotic agent use, preinjury medical conditions, patient injuries, and complications were prospectively documented and subsequently stored in the trauma registry. From injury data, trauma registry personnel compute Abbreviated Injury Scale and Injury Severity Score values. On multiple occasions, American College of Surgeons' Trauma Quality Improvement Program® personnel have assessed trauma registry data and found it to be accurate and reliable, with compliance at all levels. Further, the State of Ohio Department of Public Safety has also appraised the trauma registry data and found it to be reliable. As an attending trauma surgeon with board certification in surgical critical care and an extensive history of collaboration with radiologists, the first-author has interpreted chest CT images for 30 years. Several patients without rib fractures did not undergo chest CT scanning. Typically, the absence of rib fractures was based on multiple chest x-rays obtained throughout the hospital course and a lack of chest wall pain or tenderness. Although it is possible some of these patients might have had an occult rib fracture, this is improbable.

We believe that information bias, improper classification of rib fracture quantification or outcomes, is minimal, because the data quality is creditable. We think that selection bias has been minimized by using the trauma registry to identify all patients who were age 18-75 and with an Injury Severity Score ≥ 9.

Conclusions

Patients with rib fractures have increased torso injury rates (abdomen, lung infiltrate, hemothorax-pneumothorax, sternal fracture, and thoracic spine injuries) and adverse outcomes (pneumonia, death or ventilator dependence, and death or lengthy hospital stay), compared to those without rib fractures. This study investigated 3 methods for quantifying rib fractures: 1) summing the number of ribs with one or more fractures, 2) grading each individual fracture and summing their values (rib fx score); 3) interacting the rib fracture graded sums with sternal fracture and thoracic spine injury severity (RCFS). The analyses demonstrate that adverse outcome rates increase the larger the number of fractured ribs, rib fx score, and RCFS. Statistical interrogation also showed that adverse outcomes best correlated with the RCFS, and that the rib fx score had superior associations, compared to the total number of fractured ribs. Further, adverse outcomes were independently associated with the RCFS and the degree of lung infiltrate, head injury, and abdominal injury. These observations not only enhance the validity of the RCFS, but also indicate that these injuries are influential in affecting adverse patient outcomes. Apropos, clinicians assessing rib fracture patient risk and potential for rib fracture stabilization should consider multiple factors: magnitude of the total rib fracture burden (rib fx score), grade of sternal fracture and thoracic spine injury, and associated lung infiltrate, head injury, and abdominal injury. Based on the aforementioned, we recommend the RCFS as a quantification methodology for risk stratification, because it provides a comprehensive assessment of the rib cage fracture burden (ribs, sternum, and thoracic spine).

Disclosure of conflict of interest

None to declare.

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References

[1] Ziegler DW and Agarwal NN. The morbidity and mortality of rib fractures. J Trauma 1994; 37: 975-979.

[2] Flagel BT, Luchette FA, Reed RL, Esposito TJ, Davis KA, Santaniello JM and Gamelli RL. Half-a-dozen ribs: the breakpoint for mortality. Surgery 2005; 138: 717-723; discussion 723-715.

[3] Whitson BA, McGonigal MD, Anderson CP and Dries DJ. Increasing numbers of rib fractures do not worsen outcome: an analysis of the national trauma data bank. Am Surg 2013; 79: 140-150.

[4] Livingston DH, Shogan B, John P and Lavery RF. CT diagnosis of Rib fractures and the prediction of acute respiratory failure. J Trauma 2008; 64: 905-911.

[5] Byun JH and Kim HY. Factors affecting pneumonia occurring to patients with multiple rib fractures. Korean J Thorac Cardiovasc Surg 2013; 46: 130-134.

[6] Bergeron E, Lavoie A, Clas D, Moore L, Ratte S, Tetreault S, Lemaire J and Martin M. Elderly trauma patients with rib fractures are at greater risk of death and pneumonia. J Trauma 2003; 54: 478-485.

[7] Bulger EM, Arneson MA, Mock CN and Jurkovich GJ. Rib fractures in the elderly. J Trauma 2000; 48: 1040-1046; discussion 1046-1047.

[8] Holcomb JB, McMullin NR, Kozar RA, Lygas MH and Moore FA. Morbidity from rib fractures increases after age 45. J Am Coll Surg 2003; 196: 549-555.

[9] Karadayi S, Nadir A, Sahin E, Celik B, Arslan S and Kaptanoglu M. An analysis of 214 cases of rib fractures. Clinics (Sao Paulo) 2011; 66: 449-451.

[10] Testerman GM. Adverse outcomes in younger rib fracture patients. South Med J 2006; 99: 335-339.

[11] Bakhos C, O'Connor J, Kyriakides T, Abou-Nukta F and Bonadies J. Vital capacity as a predictor of outcome in elderly patients with rib fractures. J Trauma 2006; 61: 131-134.

[12] Lee RB, Bass SM, Morris JA Jr and MacKenzie EJ. Three or more rib fractures as an indicator for transfer to a Level I trauma center: a population-based study. J Trauma 1990; 30: 689-694.

[13] Stawicki SP, Grossman MD, Hoey BA, Miller DL and Reed JF 3rd. Rib fractures in the elderly: a marker of injury severity. J Am Geriatr Soc 2004; 52: 805-808.

[14] Dittmann M, Steenblock U, Kranzlin M and Wolff G. Epidural analgesia or mechanical ventilation for multiple Rib fractures? Intensive Care Med 1982; 8: 89-92.

[15] Maxwell CA, Mion LC and Dietrich MS. Hospitalized injured older adults: clinical utility of a rib fracture scoring system. J Trauma Nurs 2012; 19: 168-174; quiz 175-166.

[16] Sirmali M, Turut H, Topcu S, Gulhan E, Yazici U, Kaya S and Tastepe I. A comprehensive analy-

sis of traumatic rib fractures: morbidity, mortality and management. Eur J Cardiothorac Surg 2003; 24: 133-138.
[17] Barnea Y, Kashtan H, Skornick Y and Werbin N. Isolated rib fractures in elderly patients: mortality and morbidity. Can J Surg 2002; 45: 43-46.
[18] Sharma OP, Oswanski MF, Jolly S, Lauer SK, Dressel R and Stombaugh HA. Perils of rib fractures. Am Surg 2008; 74: 310-314.
[19] Todd SR, McNally MM, Holcomb JB, Kozar RA, Kao LS, Gonzalez EA, Cocanour CS, Vercruysse GA, Lygas MH, Brasseaux BK and Moore FA. A multidisciplinary clinical pathway decreases rib fracture-associated infectious morbidity and mortality in high-risk trauma patients. Am J Surg 2006; 192: 806-811.
[20] Becher RD, Colonna AL, Enniss TM, Weaver AA, Crane DK, Martin RS, Mowery NT, Miller PR, Stitzel JD and Hoth JJ. An innovative approach to predict the development of adult respiratory distress syndrome in patients with blunt trauma. J Trauma Acute Care Surg 2012; 73: 1229-1235.
[21] Miller PR, Croce MA, Bee TK, Qaisi WG, Smith CP, Collins GL and Fabian TC. ARDS after pulmonary contusion: accurate measurement of contusion volume identifies high-risk patients. J Trauma 2001; 51: 223-228; discussion 229-230.
[22] Wang S, Ruan Z, Zhang J and Jin W. The value of pulmonary contusion volume measurement with three-dimensional computed tomography in predicting acute respiratory distress syndrome development. Ann Thorac Surg 2011; 92: 1977-1983.
[23] Tyburski JG, Collinge JD, Wilson RF and Eachempati SR. Pulmonary contusions: quantifying the lesions on chest X-ray films and the factors affecting prognosis. J Trauma 1999; 46: 833-838.
[24] Dunham CM, Barraco RD, Clark DE, Daley BJ, Davis FE 3rd, Gibbs MA, Knuth T, Letarte PB, Luchette FA, Omert L, Weireter LJ and Wiles CE 3rd. Guidelines for emergency tracheal intubation immediately after traumatic injury. J Trauma 2003; 55: 162-179.
[25] Huber S, Biberthaler P, Delhey P, Trentzsch H, Winter H, van Griensven M, Lefering R and Huber-Wagner S. Predictors of poor outcomes after significant chest trauma in multiply injured patients: a retrospective analysis from the German Trauma Registry (Trauma Register DGU(R)). Scand J Trauma Resusc Emerg Med 2014; 22: 52.