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Traumatic rib fractures: a marker of severe injury. A nationwide study using the National Trauma Data Bank

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ABSTRACT

Background In recent years, there has been increasing interest in the treatment of patients with rib fractures. However, the current literature on the epidemiology and outcomes of rib fractures is outdated and inconsistent. Furthermore, although it has been suggested that there is a large heterogeneity among patients with traumatic rib fractures, there is insufficient literature reporting on the outcomes of different subgroups.

Methods A retrospective cohort study using the National Trauma Data Bank was performed. All adult patients with one or more traumatic rib fractures or flail chest who were admitted to a hospital between January 2010 and December 2016 were identified by the International Classification of Diseases Ninth Revision diagnostic codes.

Results Of the 564 798 included patients with one or more rib fractures, 44.9% (n=2 53 564) were patients with polytrauma. Two per cent had open rib fractures (n=11 433, 2.0%) and flail chest was found in 4% (n=23 388, 4.1%) of all cases. Motor vehicle accidents (n=237 995, 51.6%) were the most common cause of rib fractures in patients with polytrauma and flail chest. Blunt chest injury accounted for 95.5% (n=5 39 422) of rib fractures. Rib fractures in elderly patients were predominantly caused by high and low energy falls (n=67 675, 51.9%). Ultimately, 49.5% (n=2 79 615) of all patients were admitted to an intensive care unit, of whom a quarter (n=146 191, 25.9%) required invasive mechanical ventilatory support. The overall mortality rate was 5.6% (n=31 524).

Discussion Traumatic rib fractures are a marker of severe injury as approximately half of patients were patients with polytrauma. Furthermore, patients with rib fractures are a very heterogeneous group with a considerable difference in epidemiology, injury characteristics and in-hospital outcomes. Worse outcomes were predominantly observed among patients with polytrauma and flail chest. Future studies should recognize these differences and treatment should be evaluated accordingly.

Level of evidence II/III.

INTRODUCTION

Thoracic trauma is a frequently encountered injury, comprising 10%–15% of all trauma-related hospital admissions.[1] Currently, it is responsible for approximately 35% of all trauma-related deaths in the USA, making it one of the leading causes of death among the trauma population after cardiovascular injury and traumatic brain injury.[2 3]

Traumatic rib fractures represent the most common injury sustained following thoracic trauma and are often caused by a high impact force to the chest wall. Rib fractures are clinically relevant injuries as they are associated with significant pulmonary morbidity, mortality and decreased long-term quality of life.[4 5] Prompt evaluation with pre-emptive pain control, pulmonary hygiene and timely respiratory support is essential in the management of rib fractures.[6 7]

Fractured ribs can occur as simple isolated injury or as part of more extensive thoracic and extrathoracic injuries. Previous studies implied that rib fractures should be considered as a marker of severe injury, as >90% of patients have severe concomitant injuries mostly involving head, abdomen and extremities.[1 8]

The clinical significance of the number of fractured ribs has been debated in the literature. Several studies have suggested that there is a direct correlation between an increased number of rib fractures and pulmonary morbidity and mortality.[5 9–13] Furthermore, other studies have reported that age, associated injuries and polytrauma might be better predictors for morbidity and mortality.[14 15]

A systematic review and meta-analyses reported an age of 65 years or more, three or more rib fractures and the presence of pre-existing disease, especially cardiopulmonary disease, to be risk factors for mortality following blunt chest wall trauma. In addition, the development of pneumonia post-injury was a significant risk factor for mortality. However, the results of the review were limited by the small number and variable quality of studies included.[14] Different subgroups of patients with traumatic rib fractures are at risk of developing complications, however, currently no guidelines exist to assist in the recognition of these high-risk patient populations.

The primary aim of this nationwide database study was to determine the epidemiology, injury characteristics and in-hospital outcomes of patients with traumatic rib fractures. Secondarily, all data were presented for patients with polytrauma, elderly, isolated thoracic trauma, flail chest and type of injury to describe the differences among these subgroups. Finally, we sought to determine factors associated with mortality.

METHODS

Study design and participants

A study using the National Trauma Data Bank (NTDB) was performed. The NTDB, maintained by the American College of Surgeons, is the largest trauma registry of the USA and contains prospectively gathered data regarding trauma admissions at level I–V trauma centers from over 900 registered US trauma centers.[16] Patients were identified using the *International Classification of Diseases Ninth Revision (ICD-9)* diagnosis codes 807.00–807.09 for closed rib fractures, 807.10–807.19 for open rib fractures and 807.4 for flail chest. In addition, patients were screened for the presence of concomitant sternum fractures using ICD-9 diagnosis codes 807.3 and 807.4. To identify key interventions, the following ICD-9 procedure codes were used: 03.91 and 03.92 for epidural analgesia, 34.02 for exploratory thoracotomy and 34.79 and 79.39 for rib fixation. All patients aged 18 years or older, with one or more traumatic rib fractures or flail chest who were admitted to hospital between January 2010 and December 2016 were eligible for inclusion.

Patient characteristics and outcome measures

Patient demographics and injury-related characteristics that were obtained from the database included age, sex, mechanism of injury (motor vehicle accident, fall from heights/stairs, pedestrian, assault, struck-by and other), type of injury (blunt or penetrating), Abbreviated Injury Scale (AIS), Injury Severity Score (ISS), Glasgow Coma Scale (GCS), pre-existent comorbidities (congestive heart failure, hypertension, diabetes mellitus and respiratory disease), current smoking status, obesity, number of rib fractures, presence of a flail segment and presence of sternum fracture. The key interventions included epidural analgesia, thoracotomy and rib fixation.

The in-hospital outcomes included mortality, length of stay (LOS), admission to the intensive care unit (ICU), ICU length of stay (ILOS), need and duration of invasive mechanical ventilation (IMV) and complications. Complications that were retrieved included pneumonia, pneumothorax, acute respiratory distress syndrome, venous embolism and thrombosis of deep vessels of lower extremity, pulmonary embolism, and acute myocardial infarction. All pre-existent comorbidities and complications were also identified with the corresponding ICD-9 codes.

Statistical analysis

The in-hospital outcomes LOS, admission to ICU, ILOS, need and duration of IMV and the incidence of complications are presented as descriptive data. Stratification into patient groups was performed to describe the difference in demographics, injury-related characteristics and in-hospital outcomes for: (1) patients with polytrauma, (2) elderly patients, (3) patients with isolated thoracic trauma and (4) patients with a flail chest. In addition, subgroup analysis was performed according to the type of injury (blunt vs penetrating chest injury). Elderly patients were defined as all patients aged 65 years or older. Patients with polytrauma were defined as all patients with an ISS score of 16 or higher. Patients with isolated thoracic trauma were defined as those patients in which the AIS was the highest for the thoracic domain. In addition, patients were excluded if they had an AIS higher than two in one or more of the other AIS domains.

Categorical and dichotomous variables were presented as numbers with percentages (%). Continuous variables were expressed as means with SD for normally distributed data, or as median with IQR for non-normally distributed data. The Shapiro-Wilk test and Q-Q plots were performed to determine the distribution of the continuous variables. Categorical variables were compared using the $\chi 2$ test, as appropriate. For the comparison of dichotomous and continuous variables, the Mann-Whitney U was used. Multivariable binary logistic regression analyses were performed to identify factors that were associated with the in-hospital mortality and presented as OR with 95% CI. The covariates to adjust for in the multivariable binary logistic regression analyses were selected a priori based on clinical relevance and directed acyclic graphs.

All statistical analyses were performed using Stata V.13.0 (StataCorp, College Station, Texas, USA). A two-sided p value of <0.05 was considered as statistically significant.

RESULTS

Demographics

A total of 564 798 patients with one or more traumatic rib fractures or flail chest were included from the NTDB. The overall median age was 53 (IQR 39–67) years and the majority (n=390 101, 69.1%) were male. Subgroup analyses identified 253 564 (44.9%) patients with polytrauma, 161 579 (28.6%) elderly patients, 350 898 (62.1%) patients with isolated thoracic trauma and 23 388 (4.1%) with flail chest. Blunt chest injury accounted for 95.5% (n=539 422) of rib fractures, penetrating chest injury accounted for 2.9% (n=16 179). The demographic characteristics for the entire group and subgroups are enumerated in table 1.

Injury-related characteristics

Motor vehicle accidents were the most common mechanism of injury for rib fractures (n=237 995, 51.6%). Even higher rates of motor vehicle accidents were observed in the subgroups of patients with polytrauma (n=130 039, 62.4%) and flail chest (n=11 458, 60.3%). The most common mechanism of injury in elderly patients were falls from heights or stairs (n=67 675, 51.9%), assault accounted for all penetrating chest injury.

Among all patients, the most common concomitant pulmonary injury was pneumothorax (n=148 216, 26.2%) followed by pulmonary contusion (n=143 096, 25.3%) and then hemothorax (n=35 898, 6.4%). Concomitant pulmonary injuries were also more prevalent in patients with polytrauma, flail chest and after blunt chest trauma.

Of the entire cohort, the median number of rib fractures was 3 (IQR 2–6). Two per cent (n=11 433) had open rib fractures and in 4.1% a manifest flail chest was present. The number of patients with a flail chest was higher in the polytrauma group (n=18 227, 7.2%), compared with the non-polytrauma group (n=5161, 1.7%). After penetrating chest injury, the majority of patients sustained 1 (n=9401, 58.4%) or 2 (n=3617, 22.5%) fractured ribs. The injury characteristics and the distribution of the number of rib fractures are shown in table 1.

Interventions

Epidural analgesia was administered in 0.4% (n=2505) of all patients and a thoracotomy was performed in 0.8% (n=4397). Rib fixation was performed in 4.5% (n=25 388) of the entire cohort, with a higher incidence observed among patients with polytrauma (n=17 102, 6.8%), and those who sustained a flail chest (n=2939, 12.6%) (table 1).

In-hospital outcomes and complications

Overall, the median LOS was 5 (IQR 3–9) days and 279 615 patients (49.5%) were admitted to the ICU, with a median ILOS of 4 (IQR 2–8) days. Among these patients, 146 191 (25.9%)

Table 1 Demographics, injury-related characteristics and interventions of patients with traumatic rib fractures

Variable	Total cohort	Polytrauma (ISS >16)		Elderly (>65 years)		Isolated thoracic trauma		Flail chest		Type of injury	
		Yes	No	Yes	No	Yes	No	Yes	No	Blunt	Penetrating
All, no. (%)	564 798	253 564 (44.9)	311 234 (55.1)	161 579 (28.6)	403 219 (71.4)	350 898 (62.1)	213 900 (37.8)	23 388 (4.1)	541 410 (95.9)	539 422 (95.5)	16 179 (2.9)
Age at trauma	53 (39–67)	50 (34–63)	56 (43–70)	76 (70–82)	46 (33–55)	350 898	50 (34–64)	55 (45–66)	53 (39–67)	54 (40–67)	29 (23–41)
Male sex	390 101 (69.1)	180 082 (71.0)	210 019 (67.5)	90 521 (56.0)	299 580 (74.3)	241 872 (68.9)	148 033 (69.3)	17 528 (74.9)	372 573 (68.8)	368 796 (63.4)	14 481 (89.5)
Mechanism of injury											
Motor vehicle accident	237 995 (51.6)	130 039 (62.4)	107 956 (42.6)	49 591 (38.1)	188 404 (56.9)	128 905 (45.1)	109 090 (62.0)	11 458 (60.3)	226 537 (51.2)	237 995 (54.6)	0 (0)
Fall from height/stairs	129 577 (28.1)	38 618 (18.5)	90 939 (35.9)	67 675 (51.9)	61 882 (18.7)	92 781 (32.5)	36 776 (20.9)	3974 (21.0)	125 583 (28.4)	129 577 (29.7)	0 (0)
Pedestrian	11 955 (2.6)	4777 (2.3)	7178 (2.8)	2078 (1.6)	9877 (3.0)	8215 (2.9)	3740 (2.1)	518 (2.7)	11 437 (2.6)	11 955 (2.7)	0 (0)
Assault	16 173 (3.5)	8611 (4.1)	7562 (3.0)	499 (0.4)	15 674 (4.7)	10 213 (3.6)	5960 (3.4)	78 (0.4)	16 095 (3.6)	0 (0)	16 173 (100)
Struck-by	16 819 (3.6)	5593 (2.7)	11 226 (4.4)	2045 (1.6)	14 774 (4.5)	12 166 (4.3)	4653 (2.6)	523 (2.8)	16 296 (3.7)	16 819 (3.9)	0 (0)
Other	49 049 (10.6)	20 738 (10.0)	28 311 (11.2)	8399 (6.4)	40 650 (12.3)	33 224 (11.6)	15 825 (9.0)	2457 (12.9)	46 592 (10.5)	39 846 (9.1)	0 (0)
Type of injury											
Blunt	539 422 (95.5)	241 344 (95.2)	298 078 (95.8)	159 344 (98.6)	380 078 (94.3)	334 500 (95.3)	204 922 (95.8)	22 904 (97.9)	516 518 (95.4)	539 422 (100)	0 (0)
Penetrating	16 179 (2.9)	8615 (3.4)	7564 (2.4)	500 (0.3)	15 679 (3.9)	10 261 (2.9)	5963 (2.8)	78 (0.01)	16 101 (3.0)	0 (0)	16 179 (100)
AIS											
Head	0 (0–1)	0 (0–3)	0 (0–0)	0 (0–1)	0 (0–2)	0 (0–0)	2 (0–4)	0 (0–0)	0 (0–1)	0 (0–2)	0 (0–0)
Thorax	3 (2–3)	3 (3–4)	3 (2–3)	3 (2–3)	3 (2–4)	3 (2–3)	2 (2–4)	3 (3–4)	3 (2–3)	3 (2–3)	3 (3–4)
Abdomen	0 (0–1)	0 (0–2)	0 (0–0)	0 (0–0)	0 (0–1)	0 (0–0)	0 (0–3)	0 (0–2)	0 (0–1)	0 (0–1)	0 (0–2)
Extremities	0 (0–2)	0 (0–2)	0 (0–0)	0 (0–2)	0 (0–2)	0 (0–0)	1 (0–3)	1 (0–2)	0 (0–2)	0 (0–2)	0 (0–1)
ISS	14 (9–22)	22 (18–29)	10 (8–13)	13 (9–18)	14 (10–22)	10 (9–14)	22 (17–29)	24 (17–33)	14 (9–21)	14 (9–22)	17 (10–26)
Polytrauma (ISS >16)	253 564 (44.9)	253 564 (100)	0 (0)	56 704 (35.1)	196 860 (48.8)	76 466 (21.8)	177 098 (82.8)	18 227 (77.9)	255 044 (43.5)	241 344 (95.3)	298 078 (95.8)
GCS	15 (15–15)	15 (13–15)	15 (15–15)	15 (15–15)	15 (15–15)	15 (15–15)	15 (14–15)	15 (10–15)	15 (15–15)	15 (15–15)	15 (12–15)
Comorbidity											
Congestive heart failure	14 692 (2.6)	4657 (1.8)	10 035 (3.2)	11 115 (6.9)	3577 (0.9)	10 319 (2.9)	4373 (2.0)	474 (2.0)	14 218 (2.6)	14 485 (2.7)	62 (0.4)
Hypertension	170 045 (30.1)	63 762 (25.1)	106 283 (34.1)	91 395 (56.6)	78 650 (19.5)	115 550 (32.9)	54 473 (25.5)	7298 (31.2)	162 747 (30.1)	166 539 (30.8)	1259 (7.8)
Diabetes mellitus	69 798 (12.4)	26 593 (10.5)	43 205 (13.9)	35 766 (22.1)	34 032 (8.4)	47 111 (13.4)	22 687 (10.6)	3123 (13.4)	66 675 (12.3)	68 482 (12.7)	443 (2.7)
Respiratory disease	42 764 (7.6)	15 221 (6.0)	27 543 (8.8)	20 250 (12.5)	22 514 (5.6)	29 956 (8.5)	12 808 (6.0)	1811 (7.7)	40 953 (7.6)	41 465 (7.7)	631 (3.9)
Obesity	30 621 (5.4)	14 734 (5.8)	15 887 (5.1)	7992 (4.9)	22 629 (5.6)	18 573 (5.3)	12 048 (5.6)	1765 (7.5)	28 856 (5.3)	29 946 (5.6)	395 (2.4)
Smoker	96 579 (17.1)	42 469 (16.7)	54 110 (17.4)	11 319 (7.0)	85 155 (21.1)	61 515 (17.5)	35 064 (16.4)	3678 (15.7)	92 901 (17.2)	91 716 (17.0)	3123 (0.0)
Number of rib fractures											
1	116 689 (21.6)	36 984 (15.7)	79 705 (26.0)	27 748 (17.9)	88 941 (23.0)	71 636 (21.2)	45 053 (22.2)	–	116 689 (21.6)	105 076 (20.3)	9401 (58.4)
2	88 243 (16.3)	29 200 (12.4)	59 043 (19.3)	24 835 (16.0)	63 408 (16.4)	56 649 (14.7)	31 594 (15.6)	–	88 243 (16,3)	83 072 (16.1)	3617 (22.5)
3	69 765 (12.9)	27 988 (11.9)	41 777 (13.4)	22 003 (14.2)	47 762 (12.4)	47 023 (12.2)	22 742 (11.2)	–	69 765 (12.9)	67 518 (13.1)	1115 (6.9)
4	75 373 (13.9)	35 792 (15.2)	39 581 (12.9)	23 077 (14.9)	52 296 (13.5)	50 054 (12.9)	25 319 (12.5)	–	75 373 (13.9)	73 678 (14.3)	561 (3.5)
5	41 466 (7.7)	19 928 (8.5)	21 538 (7.0)	12 807 (8.3)	28 659 (7.4)	27 354 (7.1)	14 112 (7.0)	–	41 466 (7.7)	40 681 (7.9)	198 (1.2)
>6	149 874 (27.7)	85 332 (36.3)	64 429 (21.1)	44 386 (28.7)	105 488 (27.3)	133 838 (34.6)	64 150 (31.6)	–	149 758 (26.5)	146 493 (28.4)	1209 (7.5)
Flail chest	23 388 (4.1)	18 227 (7.2)	5161 (1.7)	6723 (4.2)	16 665 (4.1)	12 458 (3.6)	10 861 (5.1)	23 388 (100)	0 (0)	22 904 (4.2)	78 (0.5)
Open rib fractures	11 433 (2.0)	6776 (2.7)	4657 (1.5)	444 (0.3)	10 969 (2.7)	6879 (2.0)	4554 (2.1)	31 (0.1)	11 402 (2.1)	2643 (0.5)	8680 (53.6)

Continued

Table 1 Continued

Variable	Total cohort	Polytrauma (ISS >16)		Elderly (>65 years)		Isolated thoracic trauma		Flail chest		Type of injury	
		Yes	No	Yes	No	Yes	No	Yes	No	Blunt	Penetrating
Concomitant injuries											
Pulmonary contusion	143 096 (25.3)	90 926 (35.9)	52 170 (16.8)	24 659 (15.3)	118 437 (29.4)	78 102 (22.3)	64 994 (30.4)	11 256 (48.1)	131 840 (24.4)	138 792 (25.7)	2364 (14.6)
Pneumothorax	148 216 (26.2)	78 287 (30.9)	69 929 (22.5)	30 679 (19.0)	117 537 (29.1)	91 874 (26.2)	56 342 (26.3)	8756 (37.4)	139 460 (25.8)	144 418 (26.8)	1270 (7.8)
Hemothorax	35 898 (6.4)	21 114 (8.3)	14 784 (4.8)	10 944 (6.8)	24 954 (6.2)	21 166 (6.0)	14 732 (6.9)	3513 (15.0)	32 385 (6.0)	34 298 (6.4)	1020 (6.3)
Sternum fracture	43 134 (7.6)	25 162 (9.9)	17 972 (5.8)	14 308 (8.9)	28 826 (7.1)	24 202 (6.9)	18 932 (8.9)	2680 (11.5)	40 454 (7.5)	42 368 (7.9)	342 (2.1)
Interventions											
Epidural analgesia	2505 (0.4)	1202 (0.4)	1303 (0.4)	890 (0.5)	1615 (0.4)	1834 (0.5)	671 (0.3)	332 (1.4)	2173 (0.4)	2456 (0.5)	7 (0.01)
Thoracotomy	4397 (0.8)	3427 (1.4)	970 (0.3)	698 (0.4)	3699 (0.9)	2060 (0.6)	2337 (1.1)	658 (2.8)	3739 (0.7)	3210 (0.6)	1130 (7.0)
Rib fixation	25 338 (4.5)	17 102 (6.8)	8236 (2.6)	3655 (2.3)	21 683 (5.4)	11 052 (3.5)	14 286 (6.7)	2939 (12.6)	22 399 (4.1)	24 966 (4.6)	147 (0.9)

All categorical and dichotomous variables are presented as number (%).
All continuous variables are presented as median (IQR).
*Numbers may not add up to total number of patients due to missing values.
AIS, Abbreviated Injury Scale; GCS, Glasgow Coma Scale; ISS, Injury Severity Score; No., Number.

required IMV, with a median duration of 4 (IQR 2–11) days. The in-hospital mortality rate was 5.6% (n=31 524) and the most common complication encountered in this cohort was pneumonia (n=28 841, 5.1%). The in-hospital outcomes and complications are presented in tables 2 and 3, respectively.

With respect to our subgroups, patients with polytrauma as well as patients with a flail chest were more likely to be transferred to the ICU. In the polytrauma group, 69.1% (n=175 120) of patients were ultimately admitted to the ICU, while this was 33.7% (n=104 772) in the non-polytrauma group. The incidence of ICU admission among patients with flail chest was 71.4% (n=16 695) and 48.6% (n=263 197) for those without. The incidence of ICU admission was higher after penetrating chest injury (n=9769, 60.4%), compared with blunt chest injury (n=265 716, 49.2%).

Additionally, the need for intubation with subsequent IMV was higher among the patients with polytrauma (41.3% vs 13.3%), and patients with flail chest (47.7% vs 24.9%). The total length of ICU stay and duration of IMV was prolonged in the flail chest group, while no differences were found between other subgroups. The highest mortality rate was found in patients with flail chest (n=3039, 13.0%), polytrauma (n=26 898, 10.6%) and elderly patients (n=12 239, 7.6%). The mortality rate after blunt chest injury was 5.3% (n=29 014), while this was 12.1% (n=1964) after penetrating chest injury. A lower mortality rate was observed in patients with isolated thoracic trauma (n=7347, 2.1%).

The overall incidence of complications was also higher in both patients with polytrauma and flail chest. The most frequent complication was pneumonia with 5.1% (n=28 841) in the total cohort. Higher rates were observed among patients with polytrauma (8.9% vs 2.0%) and patients with flail chest (13.7% vs 4.7%). A lower incidence of pneumonia was observed among patients with isolated thoracic trauma (2.6% vs 9.2%). There was no clear difference in the occurrence of complications in the elderly.

Multivariable analyses

The results of multivariable logistic regression on mortality are shown in table 4. Variables that were independently associated with a higher risk of mortality were: age, male sex, ISS score, GCS score, pre-existing comorbidity (congestive heart failure, diabetes mellitus, respiratory disease and obesity), number of rib fractures, open rib fractures, the presence of a concomitant hemothorax or sternum fracture and thoracotomy. Patients who underwent a thoracotomy had a 3.92 times higher mortality risk (OR 3.92, 95% CI 3.45 to 4.32, p<0.001). Patients with open rib fractures had a 1.84 times higher mortality risk compared with patients with closed rib fractures (OR 1.84, 95% CI 1.69 to 2.01, p<0.001). Patients with congestive heart failure had a 1.85 times higher mortality risk (OR 1.85, 95% CI 1.72 to 1.99, p<0.001), and the presence of a concomitant hemothorax was associated with a 1.41 times higher mortality risk (OR 1.41, 95% CI 1.34 to 1.48, p<0.001). A lower mortality risk was observed among patients who received rib fixation (OR 0.18, 95% CI 0.16 to 0.21, p<0.001) and epidural analgesia (OR 0.49, 95% CI 0.35 to 0.68, p<0.001).

DISCUSSION

The present study aimed to describe the epidemiology, injury characteristics and in-hospital outcomes of patients with traumatic rib fractures. Data were reported for polytrauma, elderly, isolated thoracic trauma, flail chest and type of injury (blunt vs

Table 2 In-hospital outcomes of patients with traumatic rib fractures

	Total patients	Polytrauma (ISS >16)		Elderly (>65 years)		Isolated thoracic trauma		Flail chest		Type of injury	
		Yes	No	Yes	No	Yes	No	Yes	No	Blunt	Penetrating
Outcome	n=564 798	n=253 564	n=311 234	n=161 579	n=403 219	n=350 898	n=213 900	n=23 388	n=541 410	n=539 422	n=16 179
HLOS	5 (3–9)	7 (4–14)	4 (2–6)	5 (3–9)	5 (2–9)	4 (2–7)	7 (4–15)	9 (4–17)	5 (3–9)	5 (3–9)	6 (2–12)
ICU admission	279 615 (49.5)	175 120 (69.1)	104 772 (33.7)	80 424 (49.8)	199 138 (49.5)	128 932 (36.7)	150 960 (70.6)	16 695 (71.4)	263 197 (48.6)	265 716 (49.2)	9769 (60.4)
ILOS	4 (2–8)	4 (2–10)	3 (2–5)	4 (2–7)	4 (2–8)	3 (2–5)	4 (2–10)	6 (3–15)	3 (2–7)	4 (2–8)	3 (2–7)
Need for IMV	146 191 (25.9)	104 712 (41.3)	41 479 (13.3)	35 975 (22.3)	110 216 (27.3)	55 010 (15.7)	91 181 (42.6)	11 151 (47.7)	135 040 (24.9)	136 811 (25.4)	6836 (42.3)
Duration IMV	4 (2–11)	5 (2–12)	3 (1–7)	5 (2–12)	4 (2–11)	3 (2–9)	5 (2–12)	8 (3–15)	4 (2–11)	5 (2–12)	2 (1–6)
Mortality	31 524 (5.6)	26 898 (10.6)	4626 (1.5)	12 239 (7.6)	19 285 (4.8)	7347 (2.1)	24 177 (11.3)	3039 (13.0)	28 485 (5.3)	29 014 (5.3)	1964 (12.1)

All categorical and dichotomous variables are presented as number (%).
All continuous variables are presented as median (IQR).
HLOS, hospital length of stay; ICU, intensive care unit; ILOS, ICU length of stay; IMV, invasive mechanical ventilation; ISS, Injury Severity Score.

Table 3 Complications of patients with traumatic rib fractures

	Total patients	Polytrauma (ISS >16)		Elderly (>65 years)		Isolated thoracic trauma		Flail chest		Type of injury	
		Yes	No	Yes	No	Yes	No	Yes	No	Blunt	Penetrating
Outcome	n=564 798	n=253 564	n=311 234	n=161 579	n=403 219	n=350 898	n=213 900	n=23 388	n=541 410	n=539 422	n=16 179
Pneumonia	28 841 (5.1)	22 578 (8.9)	6263 (2.0)	7917 (4.9)	20 924 (5.2)	9178 (2.6)	19 663 (9.2)	3203 (13.7)	25 638 (4.7)	27 594 (5.1)	779 (4.8)
ARDS	11 488 (2.0)	9190 (3.6)	2314 (0.7)	3127 (1.9)	8361 (2.1)	3590 (1.0)	7898 (3.7)	1360 (5.8)	10 128 (1.9)	10 917 (2.0)	391 (2.4)
DVT	9895 (1.8)	8022 (3.2)	1873 (0.6)	2649 (1.6)	7246 (1.8)	2647 (0.8)	7248 (3.4)	1043 (4.5)	8852 (1.6)	9435 (1.7)	337 (2.1)
Pulmonary embolism	4341 (0.7)	3200 (1.3)	1141 (0.4)	1040 (0.6)	3301 (0.8)	1459 (0.4)	2882 (1.3)	376 (1.6)	3965 (0.7)	4130 (0.8)	158 (1.0)
Myocardial infarction	1993 (0.4)	1264 (0.5)	729 (0.2)	1288 (0.8)	705 (0.2)	841 (0.2)	1152 (0.5)	160 (0.7)	1833 (0.3)	1993 (0.4)	30 (0.2)
Cardiac arrest with CPR	8380 (1.5)	7007 (2.8)	1373 (0.4)	2871 (1.8)	5509 (1.4)	2311 (0.7)	6069 (2.8)	944 (4.0)	7436 (1.4)	7787 (1.4)	482 (3.0)

All data are presented as mean (%).
ARDS, acute respiratory distress syndrome; CPR, cardiopulmonary resuscitation; DVT, deep vein thrombosis; ISS, Injury Severity Score.

Table 4 Multivariable analysis on mortality

Variable	OR	95% CI			P value
Age (years)					
18–29	Ref	–	–	–	–
30–39	1.09	1.03	–	1.16	0.005
40–49	1.35	1.28	–	1.43	<0.001
50–59	1.91	1.80	–	2.02	<0.001
60–69	2.98	2.81	–	3.17	<0.001
70–79	5.58	5.24	–	5.94	<0.001
80–89	10.7	10.1	–	11.4	<0.001
Male sex	1.19	1.16	–	1.24	<0.001
ISS	1.07	1.06	–	1.07	<0.001
GCS score	1.28	1.28	–	1.29	<0.001
Comorbidity					
Congestive heart failure	1.85	1.72	–	1.99	<0.001
Hypertension	0.88	0.85	–	0.92	<0.001
Diabetes mellitus	1.24	1.18	–	1.30	<0.001
Respiratory disease	1.35	1.28	–	1.43	<0.001
Obesity	1.17	1.09	–	1.25	<0.001
Smoker	0.66	0.62	–	0.69	<0.001
Number of rib fractures	1.05	1.04	–	1.06	<0.001
Open rib fractures	1.84	1.69	–	2.01	<0.001
Concomitant injuries			–		
Pulmonary contusion	0.94	0.91	–	0.97	<0.001
Pneumothorax	0.85	0.82	–	0.88	<0.001
Hemothorax	1.41	1.34	–	1.48	<0.001
Sternum fracture	1.15	1,20	–	1.21	<0.001
Rib fixation	0.18	0.16	–	0.21	<0.001
Thoracotomy	3.92	3.45	–	4.32	<0.001
Epidural analgesia	0.49	0.35	–	0.68	<0.001

CI, Confidence Interval; GCS, Glasgow Coma Scale; ISS, Injury Severity Score.

penetrating) as it was hypothesized that these subgroups should be considered as different entities. To our knowledge, with the inclusion of 564 798 patients using the NTDB, this study consists of one of the largest cohorts to establish normative data and in-hospital outcomes of patients with traumatic rib fractures.

In this study, we demonstrated that traumatic rib fractures must be considered as a surrogate marker of severe injury, as about half of our cohort consisted of patients with polytrauma. Among these patients, significant worse outcomes were observed with respect to mortality, number of complications and other in-hospital outcomes, such as admission to the ICU and need for mechanical ventilation. These results are in accordance with previous studies. As stated in a study by Ziegler and Agarwal, rib fractures are a reflection of severe chest trauma, and of associated injuries.[1] In their study, they reported that 96% of the 7147 patients had associated extrathoracic injuries. Additionally, a large multicenter study by Chrysou *et al* reported that the mortality in patients with polytrauma with blunt chest trauma was predominantly determined by the severity of associated head injuries.[7] No correlation was found between severity of chest injury and mortality. In line with these findings, our results showed that about 20% of the patients with polytrauma had a GCS score lower than 8, corresponding to severe head injury. Therefore, the mortality in patients with thoracic trauma appears to be highly dependent on the severity of the extrathoracic injuries. Furthermore, a large prospective cohort study by Lin *et al*, including 1333 patients, described that the associated injuries in patients with polytrauma with flail chest were of a greater importance than the thoracic factors, with respect to ICU admission and prolonged duration of ICU care.[15] As shown in our study, patients with isolated thoracic trauma had significantly better outcomes regarding mortality and complications, compared with our polytrauma group. Consequently, as previously emphasized by Sirmali *et al*, the ISS seem to be of great importance for the evaluation of trauma severity as well as for the accurate decision making in the subsequent treatment.[17]

The estimated mortality among patients with traumatic rib fractures varies within the current literature, ranging from 10% to 25%.[1 18] In our study, we described an overall unadjusted mortality rate of 5%. As we pointed out, there was a vast difference in mortality rates between the different subgroups that we studied. The highest mortality rate was observed among patients with flail chest (13.0%), followed by patients with polytrauma (10.6%) and elderly patients (7.6%). Furthermore, with this study we emphasized the increased lethality of penetrating chest injury. The difference in mortality between these subgroups might explain the varying mortality rates reported within the current literature (10%–25%).[1 18] Future research could compare treatment outcomes and mortality rates according to different age groups, flail chest and severity of associated injuries, to determine the optimal treatment of patients with traumatic rib fractures.

Over the past years, several studies have reported risk factors that are associated with mortality in patients with rib fractures after blunt chest trauma.[14] However, the current literature is inconclusive, as contradictory outcomes have been reported. In the current study, age, male gender, ISS, GCS score, pre-existent comorbidities, number of rib fractures, open rib fractures, thoracotomy and the presence of a concomitant hemothorax or sternum fracture were independently associated with a higher risk of mortality in our multivariable regression model. With respect to these findings, it should be noted that several factors had relatively small ORs. So, although statistically significant in our analysis, the clinical relevance might be debatable and should be seen in a wider context.

An unexpected finding in our analysis was that the risk factors of smoking, pulmonary contusion and pneumothorax were inversely correlated with mortality. This could be due to potential confounding or collinearity between our included variables. Another explanation is that there might be an increased vigilance for patients with concomitant pulmonary injuries resulting in more intensive monitoring or care. Furthermore, it has been described that smoking might significantly reduce the number of complications and mortality in severely injured patients, which is known as the 'smoker's paradox'.[19] Similar outcomes have been described among patients with cardiovascular disease.[20] However, the potential protective mechanisms behind this phenomenon and its clinical implications are not well established.

The number of rib fractures, as a risk factor that is associated with mortality, remains an important topic of discussion.[11 13 21] In previous studies, it has been suggested that the number of rib fractures could be considered as an important predictor for overall trauma severity and mortality.[5 9–13] One of the first NTDB studies conducted by Flagel *et al* reported that the number of rib fractures was directly correlated with higher pulmonary complications and mortality.[13] Six or more rib fractures were considered as an important threshold for mortality, since the incidence increased from 1.8% to 6.8%. A recent study by Shulzhenko *et al* showed similar results and reported that in elderly patients the threshold of mortality was eight or more fractured ribs.[11] However, other studies have shown opposite results and reported that not the number of rib fractures was associated with worse outcomes, but that age, ISS or a flail chest were independent risk factors for mortality.[14 21 22] Whitson *et al* showed, in a large NTDB study, that the total number of rib fractures was not an independent predictor for either in-hospital morbidities or mortality.[21] Although, the number of rib fractures was independently associated with the mortality in our multivariable analysis, it did not seem to have a large effect on the overall mortality risk (OR 1.05, 95% CI 1.04 to 1.06, $p<0.001$).

In line with the current literature, our study showed that age is an important independent predictor for mortality in patients with traumatic rib fractures. However, an interesting and unexpected finding of this study was that the total length of hospital stay in the elderly patients did not appear to be longer than their younger counterparts. Moreover, the need for critical care support in the ICU was not higher among the elderly patients, and, in fact, it turned out that they were even less likely to be mechanically ventilated compared with patients younger than 65 years (22% vs 27%). This could be explained by the fact that the elderly patients less frequently sustained polytrauma and that the incidence of concomitant pulmonary injuries was also considerably lower.

Patients with flail chest tend to have significantly worse outcomes than those diagnosed with multiple rib fractures.[23 24] The stability of the chest wall appears to be an important prognostic factor for mortality, and flail chest is often associated with high impact trauma.[23] In accordance with previous results, our large-scale data demonstrated that there is a clear difference between patients with or without flail chest. The flail chest group was associated with a significant higher incidence of respiratory complications, an increased duration of hospital and ICU stay and they were more likely to be intubated and mechanically ventilated. Furthermore, the mortality rate was nearly 2.5 times higher in patients with flail chest than in those without. These results explain why studies on patients with flail chest showed promising results for rib fixation whereas rib fixation has not shown to be beneficial for patients with solely multiple rib fractures yet. Therefore, patients with flail chest should be considered as an independent entity and surgical treatment might play a pivotal role in improving outcome for these patients.[25]

This study should be interpreted in the light of several limitations. First, the NTDB is subject to missing data and under-reporting, as it is based on the voluntary supply of the contributing trauma centers.[26] Hence, complications may have been underestimated. Second, interesting information such as indication for ICU admission or cause of mortality cannot be extracted from the NTDB. Third, although it is well-known that adequate pain relief is the cornerstone in the treatment of rib fractures, the number of patients with epidural analgesia was low. However, we expect that this might be underestimated due to miscoding and missing data. Fourth, with this study we could only report on the in-hospital outcomes, as we did not have any information about the long-term outcomes.

In conclusion, traumatic rib fractures are a marker of severe injury as about half of patients were patients with polytrauma. Furthermore, half of all patients were admitted to an ICU, with a quarter requiring invasive mechanical ventilatory support. This study primarily shows that patients with rib fractures are a very heterogeneous group with a considerable difference in epidemiology, injury characteristics and in-hospital outcomes. Future studies should recognize these differences and treatment should be evaluated accordingly. Worse outcomes were predominantly seen in patients with polytrauma and flail chest.

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