

# 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 However, the current literature on the epidemiology and outcomes of rib fractures is outdated and inconsistent.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.<sup>1</sup> 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.<sup>2,3</sup>

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.<sup>4,5</sup> Prompt evaluation with pre-emptive pain control, pulmonary hygiene and timely respiratory support is essential in the management of rib fractures.<sup>6,7</sup>

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.<sup>1,8</sup>

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.<sup>9–13</sup> Furthermore, other studies have reported that age, associated injuries and polytrauma might be better predictors for morbidity and mortality.<sup>14,15</sup>

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.<sup>14</sup> 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. Secondly, 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.

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## 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.<sup>16</sup> 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=51 611, 1.7%). After penetrating chest injury, the majority of patients sustained 1 (n=94 011, 58.4%) or 2 (n=36 171, 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            | 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)   | 4 777 (2.3)    | 7 178 (2.8)           | 2 078 (1.6)    | 9 877 (3.0)         | 8 215 (2.9)    | 3 740 (2.1)              | 518 (2.7)     | 11 437 (2.6)   | 11 955 (2.7)   | 0 (0)          |             |
| Assault                  | 16 173 (3.5)   | 8 611 (4.1)    | 7 562 (3.0)           | 4 999 (0.4)    | 15 674 (4.7)        | 10 213 (3.6)   | 5 960 (3.4)              | 78 (0.4)      | 16 095 (3.6)   | 0 (0)          | 16 173 (100)   |             |
| Struck-by                | 16 819 (3.6)   | 5 593 (2.7)    | 11 226 (4.4)          | 2 045 (1.6)    | 14 774 (4.5)        | 12 166 (4.3)   | 4 653 (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)         | 8 399 (6.4)    | 40 650 (12.3)       | 33 224 (11.6)  | 15 825 (9.0)             | 2 457 (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)   | 8 615 (3.4)    | 7 564 (2.4)           | 500 (0.3)      | 15 679 (3.9)        | 10 261 (2.9)   | 5 963 (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)        | 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 (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 (0–1)        | 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 (0–2)        | 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)   | 4 657 (1.8)    | 10 035 (3.2)          | 11 115 (6.9)   | 3 577 (0.9)         | 10 319 (2.9)   | 4 373 (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)            | 72 98 (31.2)  | 162 747 (30.1) | 166 539 (30.8) | 1 259 (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)             | 1 811 (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)          | 7 992 (4.9)    | 22 629 (5.6)        | 18 573 (5.3)   | 12 048 (5.6)             | 1 765 (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)            | 3 678 (15.7)  | 92 901 (17.2)  | 91 716 (17.0)  | 3 123 (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) | 9 401 (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)  | 3 617 (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)  | 1 115 (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) | 1 209 (7.5)    |             |
| Flail chest              | 23 388 (4.1)   | 18 227 (7.2)   | 5 161 (1.7)           | 6 723 (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)   | 6 776 (2.7)    | 4 657 (1.5)           | 444 (0.3)      | 10 969 (2.7)        | 6 879 (2.0)    | 4 554 (2.1)              | 31 (0.1)      | 11 402 (2.1)   | 2 643 (0.5)    | 8 680 (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 |
| <b>Concomitant injuries</b> |                |                       |               |                     |                |                          |               |               |                |                |             |
| 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)   |
| <b>Interventions</b>        |                |                       |               |                     |                |                          |               |               |                |                |             |
| 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

| Outcome       | Polytrauma (ISS > 16) |                | Elderly (>65 years) |               | Isolated thoracic trauma |                | Flail chest    |               | Type of injury |                |              |
|---------------|-----------------------|----------------|---------------------|---------------|--------------------------|----------------|----------------|---------------|----------------|----------------|--------------|
|               | Total patients        | Yes            | No                  | Yes           | No                       | Yes            | No             | Yes           | No             | Blunt          | Penetrating  |
|               | 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)  | 4 626 (1.5)         | 12 239 (7.6)  | 19 285 (4.8)             | 7 347 (2.1)    | 24 177 (11.3)  | 3039 (13.0)   | 28 485 (5.3)   | 29 014 (5.3)   | 1 964 (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

| Outcome                 | Polytrauma (ISS > 16) |              | Elderly (>65 years) |             | Isolated thoracic trauma |             | Flail chest  |              | Type of injury |              |             |
|-------------------------|-----------------------|--------------|---------------------|-------------|--------------------------|-------------|--------------|--------------|----------------|--------------|-------------|
|                         | Total patients        | Yes          | No                  | Yes         | No                       | Yes         | No           | Yes          | No             | Blunt        | Penetrating |
|                         | 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) | 6 263 (2.0)         | 7 917 (4.9) | 20 924 (5.2)             | 9 178 (2.6) | 19 663 (9.2) | 3 203 (13.7) | 25 638 (4.7)   | 27 594 (5.1) | 779 (4.8)   |
| ARDS                    | 11 488 (2.0)          | 9 190 (3.6)  | 2 314 (0.7)         | 3 127 (1.9) | 8 361 (2.1)              | 3 590 (1.0) | 7 898 (3.7)  | 1 360 (5.8)  | 10 128 (1.9)   | 10 917 (2.0) | 391 (2.4)   |
| DVT                     | 9 895 (1.8)           | 8 022 (3.2)  | 1 873 (0.6)         | 2 649 (1.6) | 7 246 (1.8)              | 2 647 (0.8) | 7 248 (3.4)  | 1 043 (4.5)  | 8 852 (1.6)    | 9 435 (1.7)  | 337 (2.1)   |
| Pulmonary embolism      | 4 341 (0.7)           | 3 200 (1.3)  | 1 141 (0.4)         | 1 040 (0.6) | 3 301 (0.8)              | 1 459 (0.4) | 2 882 (1.3)  | 376 (1.6)    | 3 965 (0.7)    | 4 130 (0.8)  | 158 (1.0)   |
| Myocardial infarction   | 1 993 (0.4)           | 1 264 (0.5)  | 729 (0.2)           | 1 288 (0.8) | 705 (0.2)                | 841 (0.2)   | 1 152 (0.5)  | 160 (0.7)    | 1 833 (0.3)    | 1 993 (0.4)  | 30 (0.2)    |
| Cardiac arrest with CPR | 8 380 (1.5)           | 7 007 (2.8)  | 1 373 (0.4)         | 2 871 (1.8) | 5 509 (1.4)              | 2 311 (0.7) | 6 069 (2.8)  | 944 (4.0)    | 7 436 (1.4)    | 7 787 (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 |
|-----------------------------|------|-------------|---------|
| <b>Age (years)</b>          |      |             |         |
| 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  |
| <b>Comorbidity</b>          |      |             |         |
| 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  |
| <b>Concomitant injuries</b> |      |             |         |
| 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.<sup>1</sup> 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.<sup>7</sup> 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.<sup>15</sup> 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.<sup>17</sup>

The estimated mortality among patients with traumatic rib fractures varies within the current literature, ranging from 10% to 25%.<sup>1 18</sup> 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%).<sup>1 18</sup> 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.<sup>14</sup> 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’.<sup>19</sup> Similar outcomes have been described among patients with cardiovascular disease.<sup>20</sup> 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.<sup>11 13 21</sup> 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.<sup>5 9–13</sup> One of the first NTDB studies conducted by Fligel *et al* reported that the number of rib fractures was directly correlated with higher pulmonary complications and mortality.<sup>13</sup> 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.<sup>11</sup> 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.<sup>14 21 22</sup> 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.<sup>21</sup> 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.<sup>23 24</sup> 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.<sup>23</sup> 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.<sup>25</sup>

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.<sup>26</sup> 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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#### REFERENCES

- Ziegler DW, Agarwal NN. The morbidity and mortality of rib fractures. *J Trauma* 1994;37:975–9.
- Meredith JW, Hoth JJ. Thoracic trauma: when and how to intervene. *Surg Clin North Am* 2007;87:95–118.
- Vana PG, Neubauer DC, Luchette FA. Contemporary management of flail chest. *Am Surg* 2014;80:527–35.
- Marasco S, Lee G, Summerhayes R, Fitzgerald M, Bailey M. Quality of life after major trauma with multiple rib fractures. *Injury* 2015;46:61–5.
- Bulger EM, Arneson MA, Mock CN, Jurkovich GJ. Rib fractures in the elderly. *J Trauma* 2000;48:1040–7.
- Kasotakis G, Hasenboehler EA, Streib EW, Patel N, Patel MB, Alarcon L, Bosarge PL, Love J, Haut ER, Como JJ, *et al*. Operative fixation of rib fractures after blunt trauma: a practice management guideline from the eastern association for the surgery of trauma. *J Trauma Acute Care Surg* 2017;82:618–26.
- Chrysou K, Halat G, Hokschi B, Schmid RA, Kocher GJ. Lessons from a large trauma center: impact of blunt chest trauma in polytrauma patients—still a relevant problem? *Scand J Trauma Resusc Emerg Med* 2017;25:42.
- Shorr RM, Rodriguez A, Indeck MC, Crittenden MD, Hartunian S, Cowley RA. Blunt chest trauma in the elderly. *J Trauma* 1989;29:234–7.
- Kent R, Woods W, Bostrom O. Fatality risk and the presence of rib fractures. *Ann Adv Automot Med* 2008;52:73–82.
- Stawicki SP, Grossman MD, Hoey BA, Miller DL, Reed JF. Rib fractures in the elderly: a marker of injury severity. *J Am Geriatr Soc* 2004;52:805–8.
- Shulzhenko NO, Zens TJ, Beems MV, Jung HS, O'Rourke AP, Liepert AE, Scarborough JE, Agarwal SK. Number of rib fractures thresholds independently predict worse outcomes in older patients with blunt trauma. *Surgery* 2017;161:1083–9.
- Holcomb JB, McMullin NR, Kozar RA, Lygas MH, Moore FA. Morbidity from rib fractures increases after age 45. *J Am Coll Surg* 2003;196:549–55.
- Flagel BT, Luchette FA, Reed RL, Esposito TJ, Davis KA, Santaniello JM, Gamelli RL. Half-a-dozen ribs: the breakpoint for mortality. *Surgery* 2005;138:717–25.
- Battle CE, Hutchings H, Evans PA. Risk factors that predict mortality in patients with blunt chest wall trauma: a systematic review and meta-analysis. *Injury* 2012;43:8–17.
- Lin FC-F, Tsai SC-S, Li R-Y, Chen H-C, Tung Y-W, Chou M-C. Factors associated with intensive care unit admission in patients with traumatic thoracic injury. *J Int Med Res* 2013;41:1310–7.
- American College of Surgeons. National Trauma Databank. Copyright 1996–2018. Chicago, IL: American College of Surgeons. <https://www.facs.org/quality-programs/trauma/ntdb> (15 Jun 2018).

- 17 Sirmali M, Türüt H, Topçu S, Gülhan E, Yazici U, Kaya S, Taştepe I. A comprehensive analysis of traumatic rib fractures: morbidity, mortality and management. *Eur J Cardiothorac Surg* 2003;24:133–8.
- 18 Pressley CM, Fry WR, Philp AS, Berry SD, Smith RS. Predicting outcome of patients with chest wall injury. *Am J Surg* 2012;204:910–4.
- 19 Bell TM, Bayt DR, Zarzaur BL. "Smoker's Paradox" in Patients Treated for Severe Injuries: Lower Risk of Mortality After Trauma Observed in Current Smokers. *Nicotine Tob Res* 2015;17:1499–504.
- 20 Andrikopoulos GK, Richter DJ, Dilaveris PE, Pipilis A, Zaharoulis A, Gialafos JE, Toutouzias PK, Chimonas ET. In-hospital mortality of habitual cigarette smokers after acute myocardial infarction; the "smoker's paradox" in a countrywide study. *Eur Heart J* 2001;22:776–84.
- 21 Whitson BA, McGonigal MD, Anderson CP, Dries DJ. Increasing numbers of rib fractures do not worsen outcome: an analysis of the National trauma data bank. *Am Surg* 2013;79:140–50.
- 22 Harrington DT, Phillips B, Machan J, Zacharias N, Velmahos GC, Rosenblatt MS, Winston E, Patterson L, Desjardins S, Winchell R, *et al.* Factors associated with survival following blunt chest trauma in older patients: results from a large regional trauma cooperative. *Arch Surg* 2010;145:432–7.
- 23 Dehghan N, Mah JM, Schemitsch EH, Nauth A, Vicente M, McKee MD. Operative stabilization of flail chest injuries reduces mortality to that of stable chest wall injuries. *J Orthop Trauma* 2018;32:15–21.
- 24 Cannon RM, Smith JW, Franklin GA, Harbrecht BG, Miller FB, Richardson JD. Flail chest injury: are we making any progress? *Am Surg* 2012;78:398–402.
- 25 Beks RB, Peek J, de Jong MB, Wessem KJP, Öner CF, Hietbrink F, Leenen LPH, Groenwold RHH, Houwert RM. Fixation of flail chest or multiple rib fractures: current evidence and how to proceed. A systematic review and meta-analysis. *Eur J Trauma Emerg Surg* 2019;45:631–44.
- 26 Kardooni S, Haut ER, Chang DC, Pierce CA, Efron DT, Haider AH, Pronovost PJ, Cornwell EE. Hazards of benchmarking complications with the National trauma data bank: numerators in search of denominators. *J Trauma* 2008;64:273–9.