Predictors of mortality in patients with rib fractures

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Abstract

Background The aim of this study was to identify risk factors for morbidity and mortality in patients with rib fractures with focus on identifying a more exact age-dependent cut-off for increased morbidity and mortality.

Methods Retrospective study of patients 16 years or older with rib fractures from blunt trauma. Exclusion criteria: patients undergoing rib plating. Initial chest X-ray and Computed Tomography (CT) scans were re-read for the number of rib fractures (NRF) and presence of pulmonary contusion (PC). Data included demographics, mechanism of injury (MOI), NRF, associated injuries, Injury Severity Score (ISS), Glasgow Coma Scale (GCS), Geriatric Trauma Outcome Score (GTOS), presence of pneumothorax, hemothorax, hemo-pneumothorax, PC, Adult Respiratory Distress Syndrome (ARDS), pulmonary complications (ventilator-associated pneumonia, nosocomial pneumonia), and mortality. PC was quantified from CT scans with Mimics. Continuous data were analyzed using Student's *t* test. Variables significantly different by univariate analysis were analyzed by logistic regression analysis.

Results The study group consisted of 1188 adult trauma patients admitted during a 2-year period; 800 males and 388 females, with a mean age of 54 ± 21 . MOI: MVC, 735 (61.8%); falls, 364 (30.6%); other: 89. Mean NRF, 4 ± 2 ; GCS, GTOS, and ISS, 15 (15–15), 101 (82–124), and 19 ± 9 , respectively. Incidence of PC was 329 (27.7%); PTX, HTX, and HTX/PTX, 264 (20.2%), 57 (4.8%), and 147 (12.4%). Flail chest, in 17 (1.4%); 321 required mechanical ventilation. Age, GCS, male gender, and ISS but not NRF and/or PC were predictive of mortality.

Conclusions Increased mortality in patients with rib fractures starts at 65 years of age without a further increase until age ≥ 80 . NRF does not predict increased mortality independent of age. Severe TBI is the most common cause of death in patients 16–75 years, as opposed to respiratory complications in patients 80 years-old or greater.

Keywords Chest trauma · Rib fractures · Pulmonary contusion · Mortality

Abbreviations

M/F	Male/female
MVC	Motor vehicle crash
MOI	Mechanism of injury
NRF	Number of rib fractures
GCS	Glasgow Coma Scale
ISS	Injury Severity Score
GTOS	Geriatric Trauma Outcome Score

PC	Pulmonary contusion
PTX	Pneumothorax
HTX	Hemothorax
ARDS	Acute Respiratory Distress Syndrome
ICU	Intensive care unit
SOI	Solid organ injury
sTBI	Severe traumatic brain injury
ARF	Acute respiratory failure

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Background

Rib fractures occur with a reported incidence ranging from 10 to 26%, most commonly in patients suffering blunt thoracic trauma from either motor vehicles crashes (MVC) or falls, and less frequently from penetrating trauma [1, 2]. Many patients with multiple rib fractures have associated

injuries, such as solid organ injuries (SOI), as well as traumatic brain injury (TBI) that contribute to their morbidity and mortality.

Previous studies have identified age of 65 years or more and the number of rib fractures as the most important risk factors for mortality [3–5]. In a 10-year retrospective study of younger (18–64) and older (> 64) cohorts of patients with comparable injury severity scores, Bulger and her associates [6] reported a mortality rate of 10% for younger adults, and 22% for the older patients ($p < 0.01$). More recently, the Western Trauma Association guidelines published in 2017 [7] have reported a mortality of 10% in young adults and of at least 20% in the elderly, defined by age 65 years or older, and continue to recommend that patients with more than two rib fractures older than 65 years be admitted to a monitored unit with intensive care unit (ICU) level.

However, the age-dependent cut-off of 65 years (old age) that is used for the current geriatric rib fracture guidelines, including whether to admit patients to an ICU may not be applicable to today patients, because as life expectancy has increased, so too have the years that people remain healthy, more fit, physically active, and productive. Therefore, the age-cut-off of 65 years may be an outdated and imprecise predictor of outcome because it is based on an old measure of population aging, namely, fixed chronological age rather than remaining life expectancy years. Probabilistic population aging data have clearly shown that the old age boundary of 65 based on chronological age may be an inaccurate old age threshold [8]. It is within this context that the present study was designed to identify risk factors for morbidity and mortality in patients with multiple rib fractures with and without associated injuries with focus on identifying a more reliable age-dependent cut-off for increased morbidity and mortality and the contributions of associated injuries to their outcome.

Methods

Institutional Review Board approval was obtained. The study cohort included review of medical records of patients 16 years or older with rib fractures and associated injuries from blunt trauma documented by chest X-ray (CXR) and Computed Tomography (CT) scan admitted to our American College of Surgeons verified Level 1 trauma center from January 1, 2013 to December 31, 2014. Patients undergoing rib plating were excluded. Both the initial CXR and the CT scans were re-read for the number of fractured ribs and presence of pulmonary contusion (PC).

Data acquired included demographics, mechanism of injury (MOI), the number of rib fractures, associated injuries, Injury Severity Score (ISS), Glasgow Coma Scale (GCS), calculated Geriatric Trauma Outcome Scores

(GTOS) [9], presence of pneumothorax (PTX), hemothorax (HTX), hemo-pneumothorax (HTX/PTX), PC, Adult Respiratory Distress Syndrome (ARDS), admission to the ICU, requirement for ventilatory support, ICU length of stay, ventilator days, pulmonary complications in the form of ventilator-associated pneumonia, nosocomial pneumonia, empyema, and mortality.

All patients were treated with a standardized pain management protocol that included patient-controlled analgesia for patients with vital capacity (VC) > 10 ml/kg and epidural analgesia for patients with VC < 10 ml, and three or more rib fractures. The mode of ventilation included assisted ventilation with tidal volume (TV) 5–7 ml/kg of ideal body weight or pressure support ventilation titrated to a rapid shallow breathing index 50 breaths/min/l or less. The percent volume of PC was quantified in 93 patients from CT scans with Materialise Mimics (Materialise Interactive Medical Image Control System) software (Materialise NV; Leuven, Belgium) using the method described by Weaver et al. [10].

Statistical analysis

Data are presented as means with standard deviations (SD) and medians with interquartile range (IQR). Statistical analysis was performed using SPSS (SPSS Version 25.0; IBM, Armonk, New York). Continuous data were analyzed using Student's *t* test or analysis of variance and categorical data with 2×2 and other contingency methods. Variables significantly different between survivors and non-survivors by univariate analysis were analyzed by logistic regression analysis to assess their influence on mortality. The development of pulmonary complications was also assessed with stepwise logistic regression. Age, ISS, GCS, and NRF were entered as continuous variables and the remaining variables as indicator categorical parameters.

Nonparametric correlation between the NRF and the presence of PC, MOI, and age was assessed by Spearman's and Pearson tests. Groups analysis included survivors versus non-survivors, survivorship by age and GCS, NRF, presence or absence of severe TBI (sTBI), and flail chest (FC).

Results

The study group consisted of 1188 of 3860 (30.8%) adult trauma patients admitted from 1/1/2013 to 12/31/2014 with rib fractures and additional injuries, including sTBI (GCS ≤ 8) in 139 (11.7%) and moderate (GCS 9–13) in 24 patients (2.0%), as well as SOI in 228 (19.4%) patients, comprised of 77 splenic, 64 hepatic, 24 kidney and a combination of SOI as shown in Table 1.

The mean age of the group was 54 ± 21 , with 800 males and 388 females. The MOI included MVC in 735 (61.8%) patients, falls in 364 (30.6%), and other MOI in 89 patients. The mean NRF was 4 ± 2 . The GCS, ISS, and GTOS were 15 (15–15), 19 ± 9 , and 101 (82–124), respectively. The incidence of PC was 27.7% (329/1188). The volume of pulmonary contusion, in the 93 patients in whom it was measured, ranged from 306 ± 255 mL corresponding to a percentage of PC ranging from 0.7% to 38.9%. Only 13 of the 93 (13.9%) patients had a percentage of pulmonary contusion $> 20\%$.

The incidence of PTX, HTX, and HTX/PTX was 264 (20.2%), 57 (4.8%), and 147 (12.4%) out of 1188 patients, respectively. Flail chest, defined by the presence of three or more consecutive ribs broken in two or more places, was identified in 17/1188 (1.4%) of the group. Twenty-seven percent (321/1188) of patients required mechanical ventilation.

There was no correlation between age and the NRF ($r^2 = 0.031$), the NRF and the incidence of PC ($r^2 = 0.026$), and between the presence of PC and the development of ARDS ($r^2 = 0.001$). While patients injured in MVC had a higher incidence of PC, the mechanism of injury had a poor association with patients having PC ($r^2 = 0.019$).

The incidence of pulmonary complications was 162/1188 (13.6%); 99 patients (8.3%) developed ARDS and 63 patients developed pneumonia. The overall mortality was 72/1188 (6.0%). While in the univariate analysis there was a statistically significant difference in age, gender, ISS, GCS, GTOS, the NRF, the incidence of PC, HTX, and falls between survivors and non-survivors, these differences became limited only to age, GCS, male gender, and ISS in the multivariate analysis (Table 2). The presence of either single or multiple SOI did not have an effect on mortality. Of note, the mortality in the 329 patients with PC was 27/329 (8.2%) as opposed to a mortality of 44/859 (5.1%) in patients without PC ($p = 0.05$).

Table 2 Odds ratio of variables predictive of mortality

Variable	Odds ratio	95% CI for OR	
Age	1.062	1.044	1.080
ISS	1.110	1.070	1.141
GCS	− 0.903	0.848	0.961
Male	3.019	1.492	6.110

Table 1 Comparison of survivors versus non-survivors

Variable	Overall group (n = 1188)	Survivors (n = 1116)	Non-survivors (n = 72)	P value
Age	54 ± 21	53 ± 20	67 ± 23	0.0001
Male/female	800/388	744/372	56/16	0.01
MVC	735	698 (62.5%)	37 (51.4%)	0.06
Falls	364	331 (29.6%)	32 (44.4%)	0.01
Other MOI	89	86	3	1
NRF	4 ± 2	4 ± 2	5 ± 3	0.001
GCS	15 (15–15)	15 (15–15)	13 (3–15)	0.001
ISS	19 ± 9	17 ± 9	27 ± 12	0.0001
GCS ≤ 8	139 (11.7%)	114 (10.2%)	25 (34.7%)	0.001
PC	329 (27.7%)	301 (26.9%)	28 (38.9%)	0.04
PTX	264 (22.2%)	248 (22.2%)	16 (22.2%)	1
HTX	57 (4.8%)	45 (4.0%)	12 (16.7%)	0.0001
HTX/PTX	147 (12.4%)	140 (12.5%)	7 (9.7%)	0.58
Flail chest	17 (1.4%)	15 (1.3%)	2 (2.8%)	0.02
Vented pts	321 (27.0%)	261 (23.4%)	60 (83.3%)	0.001
ARDS	99 (8.3%)	73 (6.5%)	26 (36.1%)	0.0001
Pneumonia	63 (5.3%)	57 (5.1%)	6 (8.3%)	0.26
Splenic injury	77 (6.5%)	71 (6.4%)	6 (8.3%)	0.69
Liver injury	64 (5.4%)	60 (5.3%)	4 (5.6%)	0.39
Kidney injury	24 (2.0%)	19 (1.7%)	5 (6.9%)	0.39
Spleen/liver	28 (2.4%)	28 (2.5%)	0	1
Spleen/kidney	19 (1.6%)	17 (1.5%)	2 (2.8%)	1
Liver/kidney	16 (1.4%)	15 (1.3%)	1 (1.4%)	1
ICU admission	870 (73.2%)	800 (71.7%)	70 (97.2%)	0.0001

MVC motor vehicle crush, MOI mechanism of injury, NRF number of rib fractures, GCS Glasgow Coma Scale, ISS Injury Severity Score, PC pulmonary contusion, PTX pneumothorax, HTX hemothorax, ARDS: Adult Respiratory Distress Syndrome, ICU intensive care unit

Additionally, there was no correlation between the NRF and the incidence of TBI as depicted by GCS ($r^2=0.002$). The mortality of patients with rib fractures was affected by the presence of severe and moderate TBI with an aggregate mortality of 33/163 (20.2%) compared to a mortality of 39/1025 (3.8%) in patients with mild and no TBI ($p=0.001$).

Patient analysis stratified by age

As shown in Table 3 increasing age was associated with a shift in the M/F ratio from a 3:1 ratio in the younger age group to 1:1.4 in the 86–103 age group, as well as a change in the MOI from MVC/Fall of 67.9% and 22.5% to 40.9% and 59.1%. Of note, despite the higher number of fractured ribs in the oldest age group, the incidence of PC and PTX was lower when compared to the younger age group. The incidence of PC decreased progressively with increasing age. Patients 75 years or older had a higher incidence of pulmonary complications (nosocomial and ventilator associated pneumonia and ARDS): 107/233 (45.9%) as opposed to 55/955 (16.2%) for the 16–74 age group, ($p<0.05$). The mortality data show the first inflection point for increased mortality at age 65 with no additional increase in mortality until the age of ≥ 86 years.

Analysis of non-survivors

Non-survivors, 56 males and 16 females, had mean age of 67 ± 23 , GCS of 13 (3–15), and an ISS 27 ± 12 . The 56 men were significantly younger, mean age 63 ± 23 as opposed to 87 ± 8 for women, had a lower GCS score 12 (3–15) versus 15 (13–15) a higher ISS score 32 ± 14 versus 29 ± 12 , and more importantly, there were more likely to have had sTBI than their female counterpart, namely 24/56 (42.8. %) as opposed to 1/16 (6.3%). Twenty-two of the 56 (39.3%) male

patients died from sTBI; in contrast, all 16 female patients died from the complications of the rib fractures. The mortality in the younger age group was determined by the severity of TBI and by the higher ISS in this group.

While there was a lower mortality rate in female compared to males 16/388 (4.1%) versus 56/800 (7.0%), respectively, the difference did not achieve statistical significance ($p=0.05$). Of note, only five of the 336 (1.5%) female patients aged 16 to 85 died, in contrast to 11/52 (21.1%) females older than 85. The change in the proportion of patients' gender from males to females in non-survivors corresponded to the increased proportion of females with increasing age in the overall group. While mortality increased from 4.3% (24/564) to 6.6% (24/364) and 9.2% (24/260) in patients with 1–3, 4–6, and seven or more fractured ribs, respectively, the number of rib fractures was not predictive of mortality.

Analysis of patients stratified by the presence or absence of severe TBI

A total of 845/1188 (71.1%) suffered some type of TBI. As shown in Table 4, the 139 patients with sTBI were younger than those without it and had a higher incidence of MVC as opposed to falls as the MOI that caused the rib fractures. The mortality was clearly affected by the presence of sTBI. In fact, 25/72 (34.7%) patients who died had sTBI. While the number of fractured ribs did not differ between patients with and without sTBI, 4 ± 3 versus 4 ± 2 , respectively, as well as the incidence of associated solid organ injury, patients with sTBI had higher ISS from the AIS Head 4 (4–5) and had a statistically higher incidence of PC, and pulmonary complications in the form of ARDS and pneumonia. However, their mortality was mostly attributable to their sTBI. The majority of sTBI occurred in patients in the 16–64 age group, namely 114/139

Table 3 Analysis of non-survivors stratified by age groups

Variable	Group 16–65 ($n=820$)	Group 66–75 ($n=145$)	Group 76–85 ($n=135$)	Group 86–103 ($n=88$)
Age	43 ± 15	71 ± 3	81 ± 3	90 ± 3
Male/female	610/210	87/58	67/68	36/52
MVC/fall/other	557/185/78	82/56/7	69/63/3	27/61
GCS	15 (15–15)	15 (15–15)	15 (15–15)	15 (15–15)
ISS	20 ± 10	18 ± 9	18 ± 9	19 ± 11
NRF	4 ± 3	4 ± 3	4 ± 3	5 ± 3
PC	255 (27.9%)	30 (20.7%)	29 (21.5%)	15 (17.0%)
PTX	198 (21.6%)	31 (21.4%)	19 (8.3%)	16 (18.2%)
HTX	31 (3.4%)	9 (6.2%)	12 (5.2%)	5 (5.7%)
HTX/PTX	102 (12.4%)	17 (11.7%)	11 (8.1%)	17 (19.3%)
Mortality	28 (3.5%)	12 (8.3%)	11 (8.1%)	21 (23.8%)

MVC motor vehicle crash, GCS Glasgow Coma Scale, ISS Injury Severity Score; NRF number of rib fractures, PC pulmonary contusion, PTX pneumothorax, HTX hemothorax

Table 4 Comparison of patients with and without severe TBI

Variable	sTBI (n = 139)	No sTBI (n = 1049)	P value
Age	44 ± 19	55 ± 21	0.001
Male/female	104/35 (74.8%/25.2%)	698/351 (66.5%/33.5%)	0.05
MVC	97 (69.8%)	638 (60.8%)	0.04
Fall	29 (20.8%)	335 (31.9%)	0.008
NRF	4 ± 3	4 ± 2	NS
Splenic injury	14 (10.0%)	110 (10.5%)	NS
Liver injury	16 (11.5%)	92 (8.8%)	NS
Kidney injury	5 (3.6%)	54 (5.1%)	NS
Number SOI	1 ± 2	1 ± 1	NS
GCS	3 (3–3)	15 (15–15)	0.001
ISS	31 ± 12	18 ± 9	0.001
PC	57 (41.0%)	272 (25.9%)	0.0004
Vented patients	139(100%)	187 (17.8%)	0.0001
ARDS	44 (31.7%)	55 (5.2%)	0.0001
Pneumonia	19 (13.7%)	44 (4.2%)	0.001
Mortality	25 (18.0%)	47 (4.5%)	0.0001

MVC motor vehicle crush, NRF number of rib fractures, SOI solid organ injury, GCS Glasgow Coma Scale, ISS Injury Severity Score, PC pulmonary contusion, ARDS Adult Respiratory Distress Syndrome

(82%); the remaining 25 cases were almost equally distributed in the other three age groups. Of note, MVC was the cause of the sTBI in 99/114 (86.8%) patients in the 16–64 age group.

Analysis of patients with flail chest

Seventeen of the 1188 patients (1.4%) suffered FC. There was no difference in age, gender, MOI, presence of sternal and scapular fracture when these patients were compared to those without FC (Table 5). Patients with FC had a significantly higher number of rib fractures, 7 ± 1 versus 4 ± 2 , were more likely to have pulmonary contusion, pneumothorax, hemo-pneumothorax, and ARDS than patients without it. Additionally, they had a statistically higher incidence of sTBI and requirement for ventilatory support compared to patients without FC, 35.2% versus 11.3% and 70.6% versus 23.6%, respectively ($p < 0.05$). Despite their higher ISS, there was no difference in the mortality rate of patients with FC as opposed to those without it, 70/1171 (5.9%) versus 2/17 (11.7%), $p = 0.27$.

Discussion

Previous studies, including a recent systematic review of 29 studies, have identified age of 65 years or more and the NRF as the most important risk factors for mortality in patients with blunt chest trauma [3–5, 11]. However, questions still remain regarding the exact age-dependent cutoff at which

Table 5 Comparison of patients with and without flail chest

	No flail chest (n = 1171)	Flail chest (n = 17)	P value
Age	54 ± 21	47 ± 23	0.17
Male/female	789/382	13/4	0.60
MVC/fall	789/382	14/3	0.29
NRF	4 ± 2	7 ± 1	0.001
PC	259 (22.0%)	7 (41.1%)	0.02
PTX	56 (4.8%)	5 (29.4%)	0.001
HTX	194 (16.5%)	1 (5.9%)	0.33
HTX/PTX	138 (11.8%)	9 (52.9%)	0.0001
PN	46 (3.9%)	4 (23.5%)	0.004
ARDS	76 (6.5%)	4 (23.5%)	0.02
ARF	408 (34.8%)	4 (23.5%)	0.44
GCS	15 (15–15)	15 (3–15)	0.002
GCS ≤ 8	133 (11.3%)	6 (35.2%)	0.009
ISS	19 ± 10	32 ± 8	0.0001
MV	309 (23.6%)	12 (70.6%)	0.0002
Sternal fx	188 (16.0%)	2 (11.7%)	1
Scapula fx	221 (18.8%)	6 (35.3%)	0.11
Vent. days	11 ± 15	13 ± 10	0.11
Mortality	70 (5.9%)	2 (11.7%)	0.27

MVC motor vehicle crush, NRF number of rib fractures, PC pulmonary contusion, PTX pneumothorax, HTX hemothorax, PN pneumonia, ARDS Adult Respiratory Distress Syndrome, ARF Acute Respiratory Failure, GCS Glasgow Coma Scale, ISS Injury Severity Score, MV mechanical ventilation

the risk of mortality increases significantly in view of the improved functional fitness documented in the old elderly (70–80) in the past decade suggesting that significant loss of physiologic reserve may not occur until a later age in life in the absence of pre-existing co-morbid conditions compromising physiologic reserve in people who continue to be physically active. Our study was designed to identify factors predictive of outcome in patients with rib fractures with and without two types of associated injuries, namely TBI and SOI, and to identify a more specific age inflection point associated with increased risk of morbidity and mortality.

Patients with rib fractures in our study had by design none or associated injuries that varied according to age and the MOI. A shift in the age from 16 to 64 to the older age groups was associated with a change in the incidence of associated TBI and SOI and the cause of attributable mortality. This shift was the result of the changes in the MOI responsible for the rib fractures. Younger patients suffered rib fractures and their associated injuries from MVC as opposed to older patients whose rib fractures were caused more frequently by falls. As a result of the impact of the MOI on the associated injuries, the attributable mortality of the groups stratified by age shifted from mortality due to sTBI in patients up to age 75 to pulmonary complications and ensuing multiple organ failure (MOF) in patients 76 years of age or older.

Older patients had more rib fractures from falls as opposed to MVC, 6 ± 2 versus 4 ± 2 , but despite the higher NRF they had a lower incidence of PC and PTX. One can hypothesize that falls are associated with less kinetic energy transmitted to the chest; therefore, while the brittle ribs of the elderly fracture easily, they are less likely to be associated with PC from the transmission of kinetic energy.

However, despite the lower incidence of PC and PTX, patients 75 years or older developed more pulmonary complications that ultimately contributed to their higher mortality. It is reasonable to deduct that older patients, and in particular the 86–103 age group, which contributed a higher number of deaths, have compromised pulmonary reserve from the aging process that is responsible for the development of respiratory complications, which in turn, lead to the development of MOF and death.

Clearly, sTBI was responsible for a significant number of non-survivors independent of the NRF in younger patients. Death due to sTBI became less frequent with increasing age. In fact, the most common cause of death in the very elderly was pulmonary failure with ensuing MOF. The time to death of patients with sTBI was shorter when compared to patients with multiple rib fractures but without sTBI. The time to death of patients with sTBI was 1 to 3 days compared to an average of 11 days after admission for patients without it. Our findings regarding the impact of sTBI on the mortality of patients with multiple rib fractures corroborate the findings of Clark [12] and Stellan [13], who both in separate reviews of 144 and 203 patients with chest trauma noted that TBI is the most common associated injury and that most deaths in patients with rib fractures are caused by brain injury and shock rather than by pulmonary failure.

The logistic regression analysis identified age, male gender, GCS, and ISS as predictors of mortality. A subsequent analysis of patients that excluded patients with sTBI continued to identify age, gender, ISS, and GCS as predictors of outcome. Therefore, it appears that the mortality in patients with rib fractures is affected by the presence of TBI. Of note, the MOI and the presence of PC were not significantly different between survivors and non-survivors.

There was an increasing mortality with an increasing number of fractured ribs from 4.4% in patients with one rib fracture to 9.8% in patients with eight or more rib fractures; however, the NRF was not predictive of mortality corroborating the findings reported by Whitson and his associates [14] in 2013 and by Shulzenko et al. in 2017 [15]. An additional finding is the relatively lower mortality of patients with seven or more rib fractures compared to previously published reports showing mortality rates in excess of 20% in elderly patients with multiple rib fractures [5]. While the first inflection point for increased mortality was seen at age 65, although with a significantly lower mortality than previously reported [6], a steep increase in mortality, attributable

to respiratory complications leading to MOF, did not occur until age 85. Of note, while the multivariate analysis did not identify the GTOS as an independent predictor of mortality, 48/72 (66.7%) of the patients who died had a GTOS greater than 150. The increasing age of patients correlated with a shift in the cause of death in patients with rib fractures from death due to sTBI in patients up to 75 years of age to complications directly attributable to multiple rib fractures in patients older than 75. Another important finding of our study is the contribution of the male gender to increased mortality. The male gender correlated with an increased likelihood of rib fractures occurring in younger patients from MVC, which in turn was associated with an increased incidence of sTBI, a major factor contributing to mortality. Additionally, our results do not corroborate the increased mortality for patients over age 45 years with rib fractures and no other AIS 3 or higher for head and abdomen reported by Holcomb et al. [16].

In contrast to work published by Miller et al. [17] in 2001 and Prunet [18] in 2019, we could not document a correlation between the volume of PC and the possibility of patients developing ARDS. We speculate that the absence of an association between pulmonary contusion and the development of ARDS in our study as opposed to the studies by Miller and Prunet may be in part explained by the small number of patients with a volume of contused lung > 20% based on the analysis of the 93 patients in whom the volume of PC was actually measured, and additionally, on the possibility that the cause of ARDS may not be necessarily the presence of pulmonary contusion per se, but the robust systemic inflammatory reaction from severe trauma that actually causes the deterioration in pulmonary function [19]. However, we were unable to demonstrate an association between the ISS, as a marker of an inflammatory response to severe trauma, and the development of ARDS in our study. Additionally, we could not correlate a higher incidence of FC in patients with multiple rib fractures in contrast to previously published work; we found that only 1.4% of the 1188 patients with multiple rib fractures presented with FC [17]. The mortality of patients with FC was 11.7% compared to a mortality of 5.9% in patients without it; this difference did not achieve statistical significance. The mortality of patients with FC in our group of 11.7% was lower compared with the mortality rates of 16% to 17% reported by other authors [19, 20]. Additionally, while our data corroborate a higher incidence of PC in patients with FC, we could not corroborate a mortality of 42% in patients with FC and PC reported by other authors [11, 19–21]. Furthermore, our results do not confirm that associated brain injury is the most common cause of death in patients with FC as reported by Rellihan et al. [22] in a review of 85 patients with FC.

Our results do not support the conclusions reached by other authors that five or more rib fractures in older patients

with trauma is a predictor of worse outcome independent of trauma burden and the conclusions reached by a 13-year study of 27,855 patients with multiple rib fractures that found that patients aged ≥ 65 have mortality of 20.1% when stratified by number of ribs fractured [5, 23].

Based on the results of our study, we conclude that the outcome of patients with rib fractures depends more on the associated injuries such as TBI than on age and the number of rib fractures and that patients younger than 65 years are more likely to die from the presence of sTBI than from the complications of the rib fractures. Additionally, while the age threshold of 65 years is associated with an increased mortality compared to younger patients, it is not different from the age of 66 to 80 from the standpoint of morbidity and mortality. The mortality directly attributable to the presence of rib fractures is observable in patients older than 80 years of age.

Our paper adds to the existing literature of patients with rib fractures the fact that the threshold age of 65 is probably not an accurate determinant to decide about the disposition of these patients from the standpoint of monitoring unless the patient has an associated TBI. Additionally, it clearly points out that the presence of sTBI is the most dominant cause of mortality in younger patients with multiple rib fractures. Obviously, it confirms the negative impact of increasing age on the outcome of patients with multiple rib fractures; however, it does not corroborate the finding that the number of the fractures is an independent risk factor for mortality.

Limitations

Our study has the following limitations: (1) it is a retrospective chart review; (2) it is a single center study; (3) it has not analyzed the impact of the anatomic fracture location (anterior, lateral or posterior) of the rib fractures on the morbidity and mortality; (4) the quantification of PC is limited to 93 patients; therefore, due to the small sample size no conclusions can be reached regarding the impact of the volume of PC on the development of ARDS and on the mortality of this subgroup of patients.

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Compliance with ethical standards

Conflict of interest Corrado P. Marini, Patrizio Petrone, Ana Soto-Sánchez, Esther García-Santos, Christy Stoller, and Juan Verde declare that they have not conflict of interest.

Informed consent This study is a retrospective chart review, and as such, there is no need for an informed consent. The New York Medical College Institutional Review Board approved the study design and methodology.

References

1. Ziegler DW, Agarwal NN. The morbidity and mortality of rib fractures. *J Trauma*. 1994;37:975–9.
2. Shorr RM, Crittenden M, Indeck M, Hartunian S, Cowley RA. Blunt thoracic trauma: analysis of 515 patients. *Ann Surg*. 1987;206:200–5.
3. Lee R, Bass S, Morris JJ, MacKenzie E. Three or more rib fractures as an indicator for transfer to a Level I trauma center: a population-based study. *J Trauma*. 1990;30:689–94.
4. Bergeron E, Lavoie A, Clas D, Moore L, Ratte S, Tetreault S, Lemaire J, Martin M. Elderly trauma patients with rib fractures are at greater risk of death and pneumonia. *J Trauma*. 2003;54:478–85.
5. Flagel BT, Luchette FA, Reed RL, Esposito TJ, Davis KA, Santaniello JM, Gamelli RL. Half-a-dozen ribs: the breakpoint for mortality. *Surgery*. 2005;138:717–23.
6. Bulger E, Arneson M, Mock C, Jurkovich G. Rib fractures in the elderly. *J Trauma*. 2000;48:1040–6.
7. Brasel KJ, Moore EE, Albrecht RA, deMoya M, Schreiber M, Karmy-Jones R, Rowell S, Namias N, Cohen M, Shatz DV, Biffl WL. Western Trauma Association Critical Decisions in Trauma: management of rib fractures. *J Trauma Acute Care Surg*. 2017;82:200–3.
8. Sanderson WC, Scherbov S, Gerland P. Probabilistic population aging. *PLoS ONE*. 2017;12(6):e0179171.
9. Zhao FZ, Wolf SE, Nakonezny PA, Minhajuddin A, Rhodes RL, Paulk ME, Phelan HA. Estimating geriatric mortality after injury using age, injury severity, and performance of a transfusion: The Geriatric Trauma Outcome Score. *J Palliat Med*. 2015;18(8):677–81.
10. Weaver AA, Gayzik FS, Stitzel JD. Biomechanical analysis of pulmonary contusion in motor vehicle crash victims: a crash injury research and engineering network (ciren) study. *Biomed Sci Instrum*. 2009;45:364–9.
11. 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.
12. Clark GC, Schechter WP, Trunkey DD. Variables affecting outcome in blunt chest trauma: flail chest vs. pulmonary contusion. *J Trauma*. 1988;28:298–304.
13. Stellin G. Survival in trauma victims with pulmonary contusion. *Am Surg*. 1991;57:780–4.
14. 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.
15. 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 outcome in older patients with blunt trauma. *Surgery*. 2017;161:1083–9.

16. 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.
17. Miller PR, Croce MA, Bee TK, Quaisi WG, Smith CP, Collins GL, Fabian TC. ARDS after pulmonary contusion: accurate measurement of contusion volume identifies high-risk patients. *J Trauma*. 2001;51:223–8.
18. Prunet B, Bourenne J, Davis JS, Bouzat P, Boutonnet M, Cordier PY, Renaudin P, Meaudre E, Michelet P. Patterns of invasive mechanical ventilation in patients with severe blunt chest trauma and lung contusion: a French multicentric evaluation of practices. *JICS*. 2019;20:46–52.
19. Allen GS, Coates NE. Pulmonary contusion: a collective review. *Am Surg*. 1996;62:895–900.
20. Dehgan N, de Mestral C, Mkee MD, Schemitsch EH, Nathens A. Flail chest injuries: a review of outcomes and treatment practices from the National Trauma Data Bank. *J Trauma Acute Care Surg*. 2014;76:462–8.
21. Raghavendran K, Notter RH, Davidson BA, Helinski JD, Kunkel SL, Knight PR. Lung contusion: inflammatory mechanisms and interaction with other injuries. *Shock*. 2009;32:122–30.
22. Relihan M, Litwin MS. Morbidity and mortality associated with flail chest injury: a review of 85 Cases. *J Trauma*. 1973;13:663–71.
23. Stawicki SP, Grossman MD, Hoey BA, Miller DL, Reed JF III. Rib fractures in the elderly: a marker of injury severity. *J Am Geriatr Soc*. 2004;52:805–8.