Stop flailing: The impact of bicortically displaced rib fractures on pulmonary outcomes in patients with chest trauma — an American Association for the Surgery of Trauma multi-institutional study

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BACKGROUND: Current evaluation of rib fractures focuses almost exclusively on flail chest with little attention on bicortically displaced fractures. Chest trauma that is severe enough to cause fractures leads to worse outcomes. An association between bicortically displaced rib fractures and pulmonary outcomes would potentially change patient care in the setting of trauma. We tested the hypothesis that bicortically displaced fractures were an important clinical marker for pulmonary outcomes in patients with nonflail rib fractures.

METHODS: This nine-center American Association for the Surgery of Trauma multi-institutional study analyzed adults with two or more rib fractures. Admission computerized tomography scans were independently reviewed. The location, degree of rib fractures, and pulmonary contusions were categorized. Univariate and multivariate logistic regression analyses were performed to identify independent predictors of pneumonia, acute respiratory distress syndrome (ARDS), and tracheostomy. Analyses were performed in nonflail patients and also while controlling for flail chest to determine if bicortically displaced fractures were independently associated with outcomes.

RESULTS: Of the 1,110 patients, 103 (9.3%) developed pneumonia, 78 (7.0%) required tracheostomy, and 30 (2.7%) developed ARDS. Bicortically displaced fractures were present in 277 (25%) of patients and in 206 (20.3%) of patients without flail chest. After adjusting for patient demographics, injury, and admission physiology, negative pulmonary outcomes occurred over twice as frequently in those with bicortically displaced fractures without flail chest (n = 206) when compared with those without bicortically displaced fractures—pneumonia (odds ratio [OR], 2.0; 95% confidence interval [CI], 1.1–3.6), ARDS (OR, 2.6; 95% CI, 1.0–6.8), and tracheostomy (OR, 2.7; 95% CI, 1.4–5.2). When adjusting for the presence of flail chest, bicortically displaced fractures remained an independent predictor of pneumonia, tracheostomy, and ARDS.

CONCLUSION: Patients with bicortically displaced rib fractures are more likely to develop pneumonia, ARDS, and need for tracheostomy even when controlling for flail chest. Future studies should investigate the utility of flail chest management algorithms in patients with bicortically displaced fractures. (*J Trauma Acute Care Surg.* 2020;89: 658–664. Copyright © 2020 American Association for the Surgery of Trauma.)

LEVEL OF EVIDENCE: Prognostic and epidemiological study, level III.

KEY WORDS: Rib fracture; bicortical displacement; chest trauma; trauma.

Rib fractures are identified in 10% to 25% of all trauma evaluations with an overall mortality of 10% to 16%.[1–6] The observed mortality may, in part, be related to frequently associated injuries including pulmonary contusion (17%), hemothorax (10%–27%), pneumothorax (28%–37%), blunt cardiac injury, great vessel injury, and intra-abdominal injury (9%–11%).[1,6–9] The observed mortality and morbidity may be due to rib fractures and associated lung injury including pneumonia, acute respiratory distress syndrome (ARDS), developed need for tracheostomy, and prolonged ventilation.[2,7]

Currently, there are three small randomized controlled trials (RCTs) evaluating surgical fixation versus nonoperative management for rib fractures.[10–12] These only include patients with flail chest and make no mention of those patients with bicortically displaced fractures. Radiological flail chest is defined as two fractures on three or more consecutive ribs, where clinical flail is paradoxical movement of the fractured segments with respirations.[13] Overall, these RCTs demonstrated decreased rates of pneumonia and shorter total ventilator time in patients with flail chest treated with surgical fixation when compared with no surgical intervention. Meta-analyses of these RCTs and other studies have also demonstrated reduced risk of pneumonia and decreased ventilator days.[8,14–16] In addition, there seems to be a reduced risk of death when surgical fixation is employed.[15]

None of these trials looked exclusively at patients with multiple displaced fractures that do not meet the definition of flail chest (radiological or clinical). Qiu et al.[17] evaluated a subgroup of patient with multiple fractures without flail chest. Those with multiple fractures who underwent surgical fixation had fewer hospital days (11.09 ± 1.88 vs. 15.93 ± 2.75 days, p = 0.013), decreased pain scores, and shorter time to return to normal activity. However, they did not specifically define degree of fracture displacement or quantify fracture pattern beyond nonflail rib fractures.

Bicortically displaced fractures refer to fractures that are severe enough to fracture through the entire rib but do not meet the criteria of flail segments. Bicortically displaced fractures include those severe fractures in only one location on the rib but may include multiple ribs that are fractured. Despite the pain and potential compromise in respiratory mechanics, there has been limited evaluation of bicortically displaced rib fractures without a flail segment. One recent prospective trial compared surgical fixation to nonoperative management in patients with rib fractures.[9] They included patients with flail chest and those with three or greater bicortically displaced rib fractures. These authors found decreased rates of pulmonary failure in the operative group (48.6% vs. 71.4%, p = 0.05) and decreased rates of tracheostomy in those patients who had surgical fixation. However, they did not evaluate those patients with nonflail fractures separately, making it difficult to know if this patient population (nonflail) is at greater risk than those with simple less severe fractures or if they might benefit from surgery. Their results suggest that patients with other patterns of rib fracture may benefit from repair.

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Several scoring systems have been created to help predict complications in patients with rib fractures.[18–21] However, these have yet to be validated or gain widespread acceptance. Of these scoring systems, only RibScore addresses displacement of the fracture as a factor associated with worse outcomes. The authors determined that, if three or more ribs were displaced, there was significantly greater risk of pneumonia, tracheostomy, and respiratory failure. The authors of the RibScore system suggest that patients with bicortically displaced rib fractures have high risk of adverse outcomes, even without the severity of flail chest.

There are currently no RCTs of outcomes in patients with bicortically displaced fractures. A recent review from de Moya et al.[22] suggests surgical fixation should be considered in patients with three or more severely displaced rib fractures (bicortical displacement); however, this is currently based on expert opinion. Given the paucity of data regarding nonflail severe rib fractures, we aimed to determine if there is an association between bicortically displaced fractures and pulmonary outcomes such as pneumonia, ARDS, and need for tracheostomy, because this may represent a subgroup of patients who benefit from more aggressive therapy. We hypothesize that bicortically displaced rib fractures are an important clinical marker for pulmonary outcomes separate from flail chest.

PATIENTS AND METHODS

Data Collection

In this retrospective cohort study, data were contributed from nine level I and level II US adult trauma centers. After each site obtained institutional review board approval, deidentified data of admissions from 2011 to 2016 were uploaded to the American Association for the Surgery of Trauma's web-based data repository. All patients who were 18 years or older sustaining blunt chest trauma causing two or more rib fractures based upon admission chest computerized tomography (CT) scan were included. Admission CT scan was defined as a chest CT performed within 24 hours of injury. Patients were not included if they did not survive at least 48 hours from time of admission. Patients with nonsurvivable head injuries, prolonged intracranial pressure management of more than 3 days, or those who required emergent craniotomy were excluded because these patients likely would require prolonged mechanical ventilation for their traumatic brain injury, which would confound the relationship between rib fracture extent and pulmonary outcomes.

World Health Organization's *International Classification of Diseases*, *Ninth Revision*, codes from 807.0 to 807.19 and 807.4 were used to identify patients with closed or open rib fractures specified by number or unspecified as well as those coded as flail chest in site trauma registries. Patient demographics, injury mechanism, comorbidities, substance use, admission physiology, initial resuscitation, injury severity, and regional Abbreviated Injury Scale (AIS) scores were collected retrospectively at the specific site and uploaded to the American Association for the Surgery of Trauma repository. Admission CT scans were uploaded in Digital Imaging and Communications in Medicine format to the web-based portal and independently reviewed by two coauthors (Y.B. and M.B.) at the primary site to categorize the number, severity, and location (anterior, posterior, and lateral) of rib fractures as well as pulmonary contusion using a standardized template.[23] The diagnosis of flail chest was determined by the coauthors based on these CT scan reviews. Fractures were defined as bicortically displaced if the displacement was at least the thickness of the rib. Operative fixation was determined through medical record review. Patient outcomes collected included mortality, pneumonia, ARDS, ventilator days, intensive care unit (ICU) length of stay, and need for tracheostomy. Pneumonia and ARDS were defined based on individual site definitions, yet all sites are within the Trauma Quality Improvement Project (TQIP). Currently, TQIP defines pneumonia in line with the Infectious Disease Society of America definitions of pneumonia; therefore, the criteria for pneumonia is consistent across the participating hospitals.[24]

Statistical Analysis

Data were expressed as mean with standard deviation for normally distributed data or median with interquartile range (IQR) for nonnormally distributed continuous variables. Student's *t* test was used to assess differences in means for continuous variables, and Pearson's χ^2 was used to assess for differences in proportions in categorical variables. Patients were stratified into those with any bicortically displaced fractures versus no bicortically displaced fractures. Because the variables collected in this analysis are part

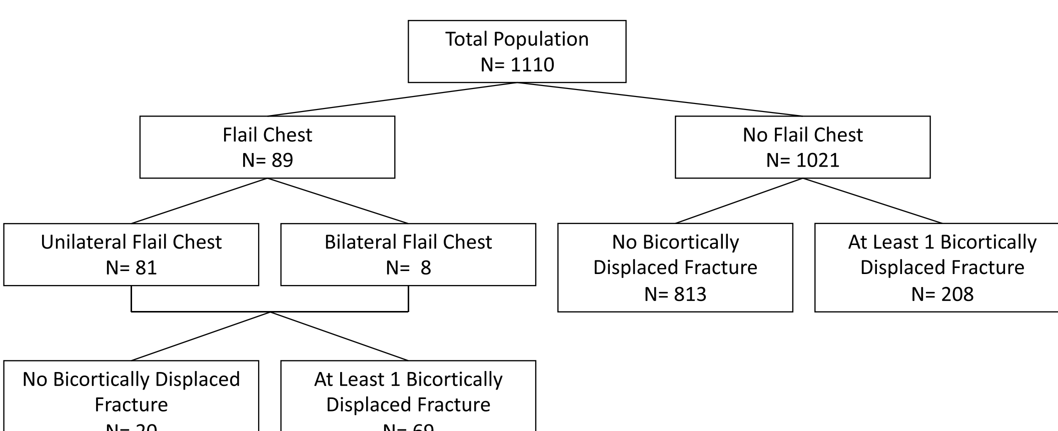

Figure 1. Diagram of patients included in analysis.

of registry required submissions to local, regional, and national data sets collected close to real time by trauma registrars, there were no missing data with respect to the outcomes of interest, and because all patients included required a chest CT scan as part of their inclusion criteria and all scans were reviewed and categorized, there were no missing data regarding the designation of flail chest and/or bicortically displaced rib fractures. Separate regression models were developed for pneumonia, ARDS, and the placement of tracheostomy using backwards stepwise method maintaining confounders if they resulted in more than a 10% change in the odds of association with the outcome of interest, had a p value of <0.1, or were thought to be clinically relevant. The treating facility was included in the multivariate analysis and was not found to alter the results and therefore was excluded from the final models. The analysis was repeated excluding flail chest patients from the analysis to obtain a true measure of the effect of bicortically displaced rib fractures on outcome in the absence of flail chest. When creating new models for the analysis of patients without flail, chest age was not a significant predictor of outcome and actually reduced the model accuracy from 0.774 to 0.763 and so was not included in these models (Table 3). Pulmonary contusion was included in the model to determine the contribution of rib fracture severity beyond the effect of pulmonary contusion on pulmonary related outcomes. Receiver operating curves with their 95% confidence intervals (CIs) for the models

TABLE 1. Characteristics of Patients With Flail Chest, Patients With Bicortically Displaced Fractures Without Flail and Patients With Neither Flail or Bicortically Displaced Fractures

Characteristic	+ Flail Chest (n = 89)	Flail Chest + Bicortically Displaced Fracture (n = 208)	Flail Chest − Bicortically Displaced Fracture (n = 813)
Age (IQR)	57.3 (19.0)*	58.4 (18.2)*,**	55.2 (19.5)**
Male, n (%)	61 (70)	140 (68.0)	550 (67.9)
Mechanism of injury			
Motor vehicle crash	40 (46.0%)	84 (40.8%)	387 (48.1%)
Fall	30 (34.5%)	75 (36.4%)	278 (34.5%)
Auto vs. pedestrian	4 (4.6%)	21 (10.2%)	58 (7.2%)
Other	13 (15.0%)	26 (12.6%)	82 (10.2%)
Body mass index (SD)	27.8 (7.5)†	28.2 (6.9)	27.8 (6.4)†
Comorbidities	n = 76	n = 159	n = 594
Myocardial infarction	5 (6.6%)	5 (3.1%)	19 (3.2%)
Stroke	4 (5.5%)	5 (3.1%)	18 (3.0%)
Congestive heart failure	3 (4.0%)	6 (3.8%)	21 (3.5%)
Chronic obstructive pulmonary Disease	4 (5.3%)	9 (5.7%)	37 (6.2%)
Home oxygen use	1 (1.3%)	1 (0.6%)	6 (1.0%)
Chronic renal failure	0 (0.0%)	2 (1.3%)	4 (0.7%)
Liver disease	1 (1.3%)	5 (3.1%)	17 (2.9%)
Insulin dependent diabetes mellitus	6 (7.9%)	19 (12.0%)	51 (8.6%)
Non–insulin dependent diabetes mellitus	6 (7.9%)	9 (5.7%)	38 (6.4%)
Malignancy	4 (5.3%)	10 (6.3%)	23 (3.9%)
Preinjury warfarin	5 (6.6%)	10 (6.3%)**	5 (0.8%)**
Smoker (n = 834)	14 (18.4%)	37 23.3%)	160 (26.9%)
AIS			
Head	0 (0–3)	0 (0–2)	0 (0–2)
Chest	3 (3–4)*†	3 (3–3)*,**	3 (2–3)**†
Abdomen	0 (0–2)	0 (0–1)	0 (0–0)
Spine	0 (0–2)	0 (0–1)	0 (0–2)
Lower extremity	0 (0–2)	0 (0–1)	0 (0–1)
ISS (IQR)	18 (14–24)*†	14 (10–22)*,**	14 (9–19)**†
No. packed red blood cells in first 24 h (IQR)	0 (0–0)	0 (0–0)	0 (0–0)
Liters crystalloid first 24 h, mean (SD)	1 (0–4)	0 (0–2)	1 (0–3)
Admit heart rate, mean (SD)	94 (21)	89 (20)	89 (20)
Admit systolic blood pressure, mean (SD)	136 (30)	135 (26)	137 (28)
Admission oxygen saturation (IQR)	97% (93%–99%)	97% (95%–99%)	97% (95%–99%)
Admission lactate (IQR)	3.0 (2.3–4.6) n = 34	2.6 (1.7–3.9) n = 75	2.2 (1.4–3.2) n = 222
Admission hematocrit, mean (SD)	39.1 (5.4)	39.1 (5.9)	39.4 (6.1)

*Statistically significant difference ($p < 0.05$) between + flail chest/− bicortically displaced fracture and − flail chest/+ bicortically displaced fracture groups.
**Statistically significant difference ($p < 0.05$) between − flail chest/+ bicortically displaced fracture and − flail chest/− bicortically displaced fracture groups.
†Statistically significant difference ($p < 0.05$) between + flail chest/− bicortically displaced fracture and − flail chest/− bicortically displaced fracture groups.

and Hosmer-Lemeshow test for goodness of fit were performed to assess model calibration.

RESULTS

A total of 1,110 patients met the inclusion criteria and had admission CT scans (Fig. 1). The population was older (mean, 59.9), predominantly male (68%), and moderately injured (mean Injury Severity Score [ISS], 15.8), and the mortality rate was 3.4% (n = 38). Comorbidity burden was relatively low for this patient population; however, 212 (25.4%) were smokers, and 51 (6.1%) had chronic obstructive pulmonary disease (Table 1). Of the entire population of patients (N = 1,110), 81 (7.3%) had a unilateral flail chest, 8 (0.7%) had bilateral flail chest, and 277 (25%) had at least one bicortically displaced rib fracture. Of the 1,021 patients who had no flail chest, 208 (20.3%) had at least one bicortically displaced rib fracture. Not surprisingly, the number of patients who had flail chest but did not have bicortically displaced rib fractures was small (n = 20), and so this population was not considered for any subanalyses but were included in the flail chest population for analyses related to flail chest. Pulmonary contusion was present in 405 patients (37.2%) and was bilateral in 188 (17.3%). Intubation was required within 24 hours of admission or at admission in 205 patients (18.5%), and an additional 55 patients required intubation after 24 hours. For those intubated within 24 hours of admission, the median number of ventilator days was 6 (IQR, 2–11). Compared with patients with less displaced rib fractures, those with bicortically displaced rib fractures (excluding flail chest) were slightly older, tended to have a higher rate or history of malignancy (not statistically significant, $p = 0.07$), had a higher chest AIS score, and had a higher ISS score but were otherwise similar in terms of comorbidities, admission physiology, and other regional abbreviated injury scores. Among nonflail chest patients who had bicortically displaced rib fractures, the average number of bicortically displaced rib fractures did not differ between those who did or did not develop pneumonia (pneumonia, 2.1 vs. no pneumonia, 2.0 [not significant]), need tracheostomy (tracheostomy, 2.0 vs. no tracheostomy, 2.0 [not significant]), or develop ARDS (ARDS, 2.4 vs. no ARDS, 2.0 [not significant]). Compared with nonflail patients, those with flail chest had significantly higher chest AIS and overall ISS scores, tended to have higher lower extremity AIS score, required significantly more packed red cell transfusions in the first 24 hours, had higher admission heart rate, and tended to have a higher lactate (Table 1).

TABLE 2. Associations With Negative Pulmonary Outcomes in Multivariate Analysis (Flail Chest and Bicortically Displaced Fracture Patients Combined)

Characteristics	Pneumonia OR (95% CI) (n = 742)	Tracheostomy OR (95% CI) (n = 742)	ARDS OR (95% CI) (n = 742)
Bicortically displaced fracture	2.0 (1.1–3.4)	2.5 (1.3–4.7)	2.5 (1.0–6.0)
Flail chest	2.2 (1.2–4.2)	2.1 (1.0–4.1)	2.9 (1.3–6.2)
Age	1.0 (1.0–1.0)	1.0 (1.0–1.0)	1.0 (1.0–1.0)
Male	1.7 (1.0–3.1)	1.5 (0.7–2.9)	0.8 (0.3–1.8)
Body mass index (missing 32.7%)	1.0 (1.0–1.07)	1.0 (1.0–1.1)	1.0 (1.0–1.1)
Preinjury warfarin (missing 24.9%)	2.4 (1.0–5.6)	1.8 (0.6–5.4)	2.1 (0.5–8.2)
Head AIS	1.4 (1.2–1.6)	1.5 (1.2–1.8)	0.8 (0.6–1.1)
Spine AIS	1.4 (1.2–1.8)	1.8 (1.4–2.3)	1.4 (1.0–1.9)
Admission heart rate	1.0 (1.0–1.0)	1.0 (1.0–1.0)	1.0 (1.0–1.0)
Admission oxygenation Saturation	1.0 (1.0–1.0)	1.0 (1.0–1.0)	1.0 (1.0–1.1)
Admission hematocrit	0.9 (0.9–1.0)	1.0 (0.9–1.0)	0.9 (0.9–1.0)

TABLE 3. Associations With Negative Pulmonary Outcomes in Multivariate Analysis (Bicortically Displaced Fracture Patients Only)

Characteristics	Pneumonia OR (95% CI) (n = 671)	Tracheostomy OR (95% CI) (n = 671)	ARDS OR (95% CI) (n = 671)
Bicortically displaced fracture	2.0 (1.1–3.6)	2.5 (1.3–4.7)	2.6 (1.01–6.8)
Male	1.9 (1.0–3.6)	1.5 (0.7–2.9)	1.2 (0.4–3.3)
Body mass index	1.0 (1.0–1.1)	1.0 (1.0–1.1)	1.0 (0.9–1.1)
Preinjury warfarin	2.9 (1.2–7.1)	1.8 (0.6–5.4)	2.1 (0.4–9.8)
Head AIS	1.3 (1.1–1.6)	1.5 (1.2–1.8)	0.8 (0.5–1.2)
Spine AIS	1.4 (1.1–1.7)	1.8 (1.4–2.3)	1.3 (0.8–1.9)
Admission heart rate	1.0 (1.0–1.0)	1.0 (1.0–1.0)	1.0 (1.0–1.0)
Admission oxygenation Saturation	1.0 (1.0–1.0)	1.0 (1.0–1.0)	1.0 (1.0–1.1)
Admission hematocrit	0.9 (0.9–1.0)	1.0 (0.9–1.0)	0.9 (0.9–1.0)

Besides the variable of interest (presence or absence of bicortically displaced fracture), the variables either resulted in a greater than 10% change in the odds of pneumonia, tracheostomy placement, or ARDS risk when removed from the model or were independent predictors of pneumonia and hence retained in the model. The variables that were significant or affected model accuracy and thus included in the model were the presence of flail chest, age, sex, body mass index, preinjury warfarin use, head AIS, abdomen AIS, spine AIS, admission heart rate, admission oxygen saturation, and admission hematocrit (Table 2). Models only incorporated data from those with no missing data for variables included in the model. The area under the curve for each of these multivariable models for the individual outcomes of pneumonia, ARDS, and tracheostomy placement was 0.77 (95% CI, 0.73–0.84), 0.78 (95% CI, 0.69–0.87), and 0.83 (95% CI, 0.77–0.88), respectively (Hosmer-Lemeshow respectively for each model: $\chi^2 = 739.3$, $p = 0.39$; $\chi^2 = 770.5$, $p = 0.14$; $\chi^2 = 754.9$, $p = 0.25$).

The odds of pneumonia were higher for patients with bicortically displaced fractures compared with those without bicortically displaced fractures while adjusting for the presence of flail chest (2.0; 95% CI, 1.1–3.4) (Table 2). Given the impact that flail chest has on this patient population and the resulting outcomes, regression models were generated while excluding flail chest from the model. Excluding patients with flail chest from the analysis resulted in similar risk of pneumonia (2.0; 95% CI, 1.1–3.6) (Table 3). The risk of ARDS for these patients with bicortically displaced fractures was also increased while adjusting for flail chest (2.5; 95% CI, 1.0–6.0) and when removing flail chest patients from the analysis (2.6; 95% CI, 1.0–6.8) (Tables 2 and 3). Similarly, the risk for tracheostomy was increased while adjusting for flail chest (2.5; 95% CI, 1.3–4.7) and when patients with flail chest were excluded (2.7; 95% CI, 1.4–5.2) (Tables 2 and 3).

DISCUSSION

In the evaluation and treatment of patients with rib fractures, the number of fractures, the severity of each fracture, and degree of associated injury clearly has impact on patient outcomes. However, current research is much more densely focused on flail chest than bicortically displaced rib fractures without flail. Evaluation of bicortically displaced rib fractures, not just the presence of flail, in patients with chest trauma is an important key in the management and treatment of patients with rib fractures because this injury pattern has impact on patient outcomes. Not surprisingly, elderly patients have greater risk of pulmonary complications (33%) when compared with younger patients (12%) with similar injuries.[5] As the number of fractures increases, the risk of complications increases as well, but it is often difficult to determine the degree to which these fractures themselves affect outcomes versus the underlying lung injury.[3,25] Also, there is no evaluation of bicortically displaced rib fractures in the elder trauma population.

In 2013, Dehghan et al.[26] evaluated the National Trauma Data Bank and identified 3,467 patients with flail chest. Of these patients, 82% required ICU stay and spent 12.1 days on mechanical ventilation, indicating high resource utilization. They also determined that 20.6% developed pneumonia and 13.8% developed ARDS. There seems to be a breakpoint of patient mortality that significantly increases when sustaining six or greater fractures; these patients are almost always admitted to the ICU.[2] These results remained true when controlling for pulmonary contusion and flail chest and remained similar when patients with flail chest were excluded. The current data evaluate the merit of surgical fixation in patients with flail chest almost exclusively diagnosed on CT. Because the interest of surgical fixation has grown since the 1980s, CT scans have improved to now show even more subtle findings in chest wall trauma.[27–29] The physiologic insult associated with bicortically displaced rib fracture may not be as severe as flail chest but still predicts worse outcomes.

Until now, there is very limited evaluation of bicortically displaced fractures because the focus has been on flail chest versus no flail, or the overall number of fractures present. It has been clearly demonstrated that patients with flail chest have increased risk of pneumonia and prolonged ICU stay. Because our goal was to evaluate patients with bicortically displaced rib fractures, we used a separate analysis to evaluate for the outcomes. In one model, we controlled for flail chest within the model by including it in the model but also analyzed the model with only those patients with bicortically displaced fractures without flail chest. The results continued to demonstrate worse outcomes in these patients. Patients with bicortically displaced rib fractures have worse outcomes than those without bicortical displacement. This remains true when both eliminating and controlling for flail chest. Another important finding of our study is that, although the presence of bicortically displaced rib fractures correlated with negative pulmonary outcomes, we did not see a higher number of bicortically displaced fractures in negative pulmonary outcome patients compared with patients without these outcomes. We can draw one of two conclusions from this—either our sample size was inadequate to detect a difference in mean number of fractures between those with and without negative outcomes, which is likely, or the presence of at least one bicortically displaced fracture is sufficient to contribute to the increased risk of negative outcomes more so than any additive effect of additional bicortically displaced fractures. Further research is needed to answer this question.

Bicortically displaced fractures independently predict the need for prolonged mechanical ventilation. This is in the setting of patients who have significant injury as demonstrated by an ISS IQR of 10 to 22. Our model included early physiologic and hematocrit levels, implying therefore that, because bicortically displaced rib fractures remained an independent predictor while adjusting for these parameters, there may be need for increased hospital recourses for these patients even if they show no significant physiologic derangements. It also may be that these patients will benefit from surgical fixation and other aggressive measures that are used for flail chest patients. Specific evaluation of the patients with rib fractures without flail chest should be evaluated because these patients still have high disease burden and the complications come with severe trauma.

This is a retrospective multi-institutional analysis, which affords certain strengths and limitations. Given the multiple institutions, there is likely variability in management of patients with rib fractures. We attempted to control for institution in the analysis; however, it is possible that treatment variability across institutions exists that could affect our results. We believe that this is unlikely, however, as there would need to be a preponderance of bicortically displaced fractures admitted to a few centers that would provide less aggressive treatment to those patients compared with nonbicortically displaced fracture patients for pneumonia to increase in these patients. The cause of pneumonia is often multifactorial, including injury and timing of intubation. To minimize bias, we chose a priori to exclude the need for early intubation from the model. Nevertheless, the variability in use of antibiotics, weaning protocols, pain management, mobilization, and aggressiveness in tracheostomy placement may influence the development of negative pulmonary outcomes by institution. Variability of the definition of pneumonia and ARDS between providers and hospitals could influence the outcomes, yet given the consistency of TIQP, this has been minimized. In an attempt to reduce center bias, we did add hospital into the model, which did not alter the results. In addition, although we did not standardize the definitions for pneumonia and ARDS, all participating sites contribute to the TQIP, so we suspect that there is reasonable consistency with the use of the standard TQIP definitions, which should limit center variation. It is possible that there is differential ascertainment bias if patients with bicortically displaced fractures were differentially identified as having complications compared with those who did not. Although this is always possible in retrospective data collection, those collecting the data were not aware of the nature of the analysis during the data collection, and therefore, the collection of negative outcomes should not have been differentially obtained. Finally, any patients with rib fractures have an element of underlying pulmonary injury that may or may not be radiographically evident. The early chest CT might underestimate the injury to the lung parenchyma and may not give an accurate clinical picture as the contusion evolves. Furthermore, the radiographic appearance of the injury may not reflect patient physiology.

Patients with bicortically displaced rib fractures may be a population that benefits from surgical fixation. Given that our sample size of nonflail bicortical displacement patients who underwent surgical fixation was small (n = 21), we were unable to determine if fixation was beneficial. Evaluation of patients with bicortically displaced fracture is an area for future research.

CONCLUSIONS

Chest trauma carries significant morbidity and mortality risk requiring significant resource utilization. It has been well established that flail chest is associated with worse outcomes; however, our results show the need to focus on treatment strategies for those with bicortically displaced fracture in the absence of flail chest. Patients with bicortically displaced rib fractures are more likely to develop pneumonia, ARDS, and need for tracheostomy. Future research should determine if surgical fixation is beneficial in patients with bicortically displaced rib fractures.

AUTHORSHIP

L.S. contributed in the literature search. L.S., R.N., A.C., T.E., M.M., J.N., and J.Y. contributed in the study design. L.S., Y.B., M.B., S.D., K.M., R.N., S.P., G.B., J.S., E.E., S.M.L., T.K., P.S., A.K., F.M., and A.T. contributed in the data collection. L.S. and R.N. contributed in the data analysis. L.S. contributed in the writing. L.S. and R.N. contributed in the revisions.

DISCLOSURE

The authors declare no conflicts of interest.

REFERENCES

1. Sirmali M, Turut H, Topcu S, Gulhan E, Yazici U, Kaya S, Tastepe I. A comprehensive analysis of traumatic rib fractures: morbidity, mortality and management. *Eur J Cardiothorac Surg*. 2003;24(1):133–138.
2. 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(4):717–723; discussion 23-5.
3. Kent R, Woods W, Bostrom O. Fatality risk and the presence of rib fractures. *Ann Adv Automot Med*. 2008;52:73–82.
4. Battle CE, Hutchings H, James K, Evans PA. The risk factors for the development of complications during the recovery phase following blunt chest wall trauma: a retrospective study. *Injury*. 2013;44(9):1171–1176.
5. Bulger EM, Arneson MA, Mock CN, Jurkovich GJ. Rib fractures in the elderly. *J Trauma*. 2000;48(6):1040–1046; discussion 6-7.
6. Ziegler DW, Agarwal NN. The morbidity and mortality of rib fractures. *J Trauma*. 1994;37(6):975–979.
7. Shorr RM, Crittenden M, Indeck M, Hartunian SL, Rodriguez A. Blunt thoracic trauma. Analysis of 515 patients. *Ann Surg*. 1987;206(2):200–205.
8. Coughlin TA, Ng JW, Rollins KE, Forward DP, Ollivere BJ. Management of rib fractures in traumatic flail chest: a meta-analysis of randomised controlled trials. *Bone Joint J*. 2016;98-B(8):1119–1125.
9. Pieracci FM, Lin Y, Rodil M, et al. A prospective, controlled clinical evaluation of surgical stabilization of severe rib fractures. *J Trauma Acute Care Surg*. 2016;80(2):187–194.
10. Tanaka H, Yukioka T, Yamaguti Y, Shimizu S, Goto H, Matsuda H, Shimazaki S. Surgical stabilization of internal pneumatic stabilization? A prospective randomized study of management of severe flail chest patients. *J Trauma*. 2002;52(4):727–732; discussion 32.
11. Granetzny A, Abd El-Aal M, Emam E, Shalaby A, Boseila A. Surgical versus conservative treatment of flail chest. Evaluation of the pulmonary status. *Interact Cardiovasc Thorac Surg*. 2005;4(6):583–587.
12. Marasco SF, Davies AR, Cooper J, Varma D, Bennett V, Nevill R, Lee G, Bailey M, Fitzgerald M. Prospective randomized controlled trial of operative rib fixation in traumatic flail chest. *J Am Coll Surg*. 2013;216(5):924–932.
13. Senekjian L, Nirula R. Rib fracture fixation: indications and outcomes. *Crit Care Clin*. 2017;33(1):153–165.
14. Leinicke JA, Elmore L, Freeman BD, Colditz GA. Operative management of rib fractures in the setting of flail chest: a systematic review and meta-analysis. *Ann Surg*. 2013;258(6):914–921.
15. Slobogean GP, MacPherson CA, Sun T, Pelletier ME, Hameed SM. Surgical fixation vs nonoperative management of flail chest: a meta-analysis. *J Am Coll Surg*. 2013;216(2):302–11 e1.
16. Schuurmans J, Goslings JC, Schepers T. Operative management versus non-operative management of rib fractures in flail chest injuries: a systematic review. *Eur J Trauma Emerg Surg*. 2017;43(2):163–168.
17. Qiu M, Shi Z, Xiao J, Zhang X, Ling S, Ling H. Potential benefits of rib fracture fixation in patients with flail chest and multiple non-flail rib fractures. *Indian J Surg*. 2016;78(6):458–463.
18. Pressley CM, Fry WR, Philp AS, Berry SD, Smith RS. Predicting outcome of patients with chest wall injury. *Am J Surg*. 2012;204(6):910–913; discussion 3-4.
19. Battle C, Hutchings H, Lovett S, et al. Predicting outcomes after blunt chest wall trauma: development and external validation of a new prognostic model. *Crit Care*. 2014;18(3):R98.
20. Chen J, Jeremitsky E, Philp F, Fry W, Smith RS. A chest trauma scoring system to predict outcomes. *Surgery*. 2014;156(4):988–993.
21. Chapman BC, Herbert B, Rodil M, et al. RibScore: a novel radiographic score based on fracture pattern that predicts pneumonia, respiratory failure, and tracheostomy. *J Trauma Acute Care Surg*. 2016;80(1):95–101.
22. de Moya M, Nirula R, Biffl W. Rib fixation: who, what, when? *Trauma Surg Acute Care Open*. 2017;2(1):e000059.
23. Livingston DH, Shogan B, John P, Lavery RF. CT diagnosis of rib fractures and the prediction of acute respiratory failure. *J Trauma*. 2008;64(4):905–911.
24. Kalil AC, Metersky ML, Klompas M, et al. Management of adults with hospital-acquired and ventilator-associated pneumonia: 2016 clinical practice guidelines by the Infectious Diseases Society of America and the American Thoracic Society. *Clin Infect Dis*. 2016;63(5):e61–e111.
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(1):8–17.
26. Dehghan N, de Mestral C, McKee 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(2): 462–468.
27. Davis S, Affatato A. Blunt chest trauma: utility of radiological evaluation and effect on treatment patterns. *Am J Emerg Med*. 2006;24(4): 482–486.
28. Peters S, Nicolas V, Heyer CM. Multidetector computed tomography-spectrum of blunt chest wall and lung injuries in polytraumatized patients. *Clin Radiol*. 2010;65(4):333–338.
29. Cho SH, Sung YM, Kim MS. Missed rib fractures on evaluation of initial chest CT for trauma patients: pattern analysis and diagnostic value of coronal multiplanar reconstruction images with multidetector row CT. *Br J Radiol*. 2012;85(1018):e845–e850.