RibScore: A novel radiographic score based on fracture pattern that predicts pneumonia, respiratory failure, and tracheostomy

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Author Disclosures

Brandon C. Chapman: research support, Haemonetics and TEM. Ernest E. Moore: research support, Haemonetics and TEM. The remaining authors have nothing to disclose.

Reviewer Disclosures

Reviewer #2: consultant, Atox Bio LTD, Arsenal Inc, and New Health Sciences. The remaining reviewers have nothing to disclose.

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Submitted: May 10, 2015, Revised: July 29, 2015, Accepted: August 20, 2015.
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This study was part of the oral presentation at the 35th annual meeting of the Surgical Infection Society, April 15–18, 2015, in Westlake Village, California.
Supplemental digital content is available for this article. Direct URL citations appear in the printed text, and links to the digital files are provided in the HTML text of this article on the journal's Web site (www.jtrauma.com).
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DOI: 10.1097/TA.0000000000000867

BACKGROUND: There is currently no scoring system for rib fractures that relates detailed anatomic variables to patient outcomes. Our objective was to develop and validate a radiographic rib fracture scoring system based on computed tomographic chest findings.

METHODS: We reviewed our trauma registry from September 2012 to April 2014 for all blunt trauma patients with one or more rib fractures visualized on chest computed tomography. We identified the following six candidate radiographic variables and tested their individual associations with pneumonia, respiratory failure, and tracheostomy: (1) six or more rib fractures, (2) bilateral fractures, (3) flail chest, (4) three or more severely (bicortical) displaced fractures, (5) first rib fracture, and (6) at least one fracture in all three anatomic areas (anterior, lateral, and posterior). We developed the "RibScore" by assigning 1 point for each variable, which was validated among the sample using univariate analyses, test performance characteristics, and the receiver operating characteristic area under the curve *c* statistic.

RESULTS: A total of 385 patients with one or more rib fractures were identified; 274 (71.2%) were males, median age was 48 years, and median Injury Severity Score (ISS) was 17. Of these patients, 156 had six or more rib fractures, 120 had bilateral fractures, 46 had flail chest, 32 had three or more severely displaced fractures, 91 had a first rib fracture, and 58 had fractures in all three anatomic areas. Each RibScore component variable was associated with the three pulmonary outcomes by univariate analysis ($p < 0.05$). The median RibScore was 1 (range, 0–6). The distribution of the RibScore was as follows: score of 0, 41.9%); score of 1, 23.9%; score of 2, 15.4%; score of 3, 9.9%; score of 4, 7.6%; and score of five, 1.3%. RibScore was linearly associated with pneumonia ($p < 0.01$), acute respiratory failure ($p < 0.01$), and tracheostomy ($p < 0.01$). The receiver operating characteristic areas under the curve for the outcomes were 0.71, 0.71, and 0.75, respectively.

CONCLUSION: The RibScore predicts adverse pulmonary outcomes and represents a standardized assessment of fracture severity that may be used for communication and prognostication of the severely injured trauma patient. (*J Trauma Acute Care Surg*. 2016;80: 95–101. Copyright © 2016 Wolters Kluwer Health, Inc. All rights reserved.)

LEVEL OF EVIDENCE: Prognostic study, level III.

KEY WORDS: Trauma; rib fractures; pneumonia; respiratory failure; tracheostomy.

Rib fractures are present in approximately 10% of trauma patients and are a marker of injury severity. Among patients with rib fractures, 90% will have associated injuries, 50% will require operative and intensive care unit care, 33% will develop pulmonary complications, 33% will require discharge to an extended care facility, and 12% die before hospital discharge.[1] Factors associated with increased morbidity and mortality from rib fractures include age,[2–9] number of rib fractures,[2–7,10–12] flail chest,[3] bilateral rib fractures,[7] pulmonary contusions,[7] development of pneumonia,[2] and preexisting comorbidities.[2,13]

Rib fractures result in pulmonary embarrassment via several mechanisms. Pain results in splinting, atelectasis, and impaired clearance of secretions. Altered chest wall mechanics distort normal costovertebral and diaphragmatic muscle exertion. Finally, fracture fragments may penetrate the parietal pleura resulting in pneumothorax, hemothorax, and pulmonary parenchymal lacerations.

TABLE 1. Comparison of the Individual Components of the OIS Chest Wall Grade, RFS, and CTS With the RibScore

	OIS Chest	RFS	CTS	RibScore
Rib fracture variables				
No. ribs fractured	•	•	•	•
Flail chest	•			•
Bilateral fractures	•	•	•	•
Degree of displacement				•
Fracture location				•
First rib fractured				•
Non–rib fracture variables				
Age	•	•	•	
Pulmonary contusion	•		•	
Clavicle/scapula/sternal fractures	•			

During the last several decades, substantial progress has been made in the management of patients with rib fractures, including locoregional anesthesia, pulmonary toilet, and rib-specific surgical stabilization systems. Allocation of these resources to patients with rib fractures should ideally be based on a validated, objective severity scoring system. Such a system would also assist in both prognostication and decisions regarding patient management. Finally, variables within the scoring system should be available for abstraction early in the patient's course, be easily communicated to referral centers, and account for complexities in fracture patterns. Current chest injury scoring systems, such as the Rib Fracture Score (RFS),[14,15] Organ Injury Scale (OIS) Chest Wall grade,[16] and Chest Trauma Score (CTS),[17,18] do not characterize fracture patterns beyond the number of fractures and bilaterality (Table 1).

Our objective was to develop a radiographic rib fracture scoring system to both predict adverse pulmonary outcomes and guide therapeutic decision making specific to rib fractures, such as placement of epidural and paravertebral pain catheters and surgical stabilization of rib fractures (SSRF). We hypothesized that this scoring system, henceforth referred to as the RibScore, would predict pneumonia, respiratory failure, and tracheostomy.

PATIENTS AND METHODS

This was a retrospective cohort study conducted at Denver Health Medical Center, an American College of Surgeons–verified, state-certified Level I trauma center, from September 1, 2012, to April 30, 2014. Patients sustaining blunt trauma and diagnosed with one or more rib fractures on computed tomography (CT) of the chest as part of their initial diagnostic evaluation in the emergency department were included. Our exclusion criteria were patients without a chest CT or with an incomplete medical record pertaining to outcomes. All patients were managed by a group of eight acute

TABLE 2. Association of Individual RibScore Variables With Outcome Measures

Variable	Pneumonia, n (%)	Respiratory Failure, n (%)	Tracheostomy, n (%)
≥6 ribs fractured			
Present (n = 155)	33 (21.3)	68 (43.9)	39 (25.2)
Absent (n = 230)	19 (8.3)	56 (24.3)	21 (9.1)
Flail chest			
Present (n = 46)	11 (23.9)	29 (63.0)	17 (37.0)
Absent (n = 339)	41 (12.1)	95 (28.0)	43 (12.7)
Bilateral fractures			
Present (n = 120)	23 (19.2)	51 (42.5)	28 (23.3)
Absent (n = 265)	29 (10.9)	73 (27.5)	32 (12.1)
First rib fracture			
Present (n = 91)	21 (23.1)	44 (48.3)	26 (28.6)
Absent (n = 294)	31 (10.5)	80 (27.2)	34 (11.6)
≥3 displaced fractures			
Present (n = 32)	11 (34.4)	22 (68.8)	15 (46.8)
Absent (n = 353)	41 (11.6)	102 (28.9)	45 (12.7)
Fracture in each anatomic area			
Present (n = 58)	14 (24.1)	37 (63.8)	19 (32.8)
Absent (n = 327)	38 (11.6)	87 (26.6)	41 (12.5)

$p < 0.05$ for all associations tested.

care surgeons using a standardized protocol, which involves escalating levels of intervention for both analgesia and pulmonary toilet based on clinical variables.

The primary independent variable was the RibScore. Candidate variables for construction of the RibScore were identified a priori by the authors. We sought to identify variables that were (1) objectively available on the initial CT of the chest and (2) either known or hypothesized to be associated with worse pulmonary outcomes. We identified six such variables as follows: (1) six or more ribs fractured,[6] (2) bilateral fractures,[7] (3) flail chest,[3] (4) three or more severely (bicortical) displaced fractures, (5) first rib fracture,[19] and (6) at least one fracture in each of three anatomic areas (anterior, lateral, and posterior).[20] The RibScore assigns 1 point for each of the aforementioned six variables and thus ranges from 0 to 6.

Flail chest was defined as three or more consecutive ribs fractured in two or more places. A severely displaced fracture was defined as displacement greater than the diameter of the rib with a total loss of contact between the proximal and the distal segment. The ribs were divided into three anatomic segments as follows: anterior, lateral, and posterior. The posterior segment encompassed the head and neck of the rib to the costal angle, the lateral segment was from the costal angle to the serratus anterior insertion tubercle, and the anterior segment was from the serratus anterior insertion tubercle to the distal end of the rib.

Covariates included age, sex, mechanism of injury, Injury Severity Score (ISS), and associated injuries (head, face, scapula, clavicle, sternum, pulmonary, abdomen, pelvis, and spine). Patients without injuries to the head, face, abdomen, and pelvis were considered to have isolated rib fractures. For purposes of comparison with the RibScore, we also calculated the OIS Chest Wall grade,[16] RFS,[14,15] and CTS[17,18] for all patients.

There were three outcomes variables as follows: (1) pneumonia, (2) respiratory failure, and (3) tracheostomy. Pneumonia in the nonventilated patient was defined as two or more of the following: productive cough, temperature greater than 38.4°C, leukocytosis of greater than 11,000/μL, and new or worsening chest x-ray infiltrate. Pneumonia in the ventilated patient was defined same as earlier plus a bronchoalveolar lavage growing greater than or equal to 10^5 colony-forming units per milliliter of at least one organism. Respiratory failure was defined as the need for mechanical ventilation for more than 48 hours during the index hospitalization. The decision to perform tracheostomy was at the discretion of the attending surgical intensivist.

Statistical analyses were performed using SAS version 9.0 (SAS Inc., Carey, NC). Continuous variables were assessed for normality using the Kolmogorov-Smirnov test. Normally distributed continuous data are expressed as mean (range), and nonnormally distributed data are expressed as median (interquartile range). Categorical data are expressed as n (%). Associations between the individual variables in the RibScore and the outcome variables were assessed using the χ^2 test. We assessed the relationship between the RibScore and pulmonary outcomes by operationalizing the former as nonnormally distributed, continuous (Wilcoxon rank-sum test), and categorical (χ^2 test). We assessed for a linear trend between the RibScore (categorical) and pulmonary outcomes using the χ^2_{trend} variable.

Test performance characteristics for the RibScore at each threshold were then calculated, including sensitivity, specificity, positive predictive value, and negative predictive value. A receiver operating characteristic area under the curve (ROC AUC) *c* statistic was then calculated for the RibScore for each of the three outcomes. We similarly computed the ROC AUC for the OIS Chest Wall grade, CTS, and RFS for each of the three outcomes. Because age has been associated with adverse pulmonary outcomes in patients with rib fractures[2–9] and because it is the only variable included in each of the existing

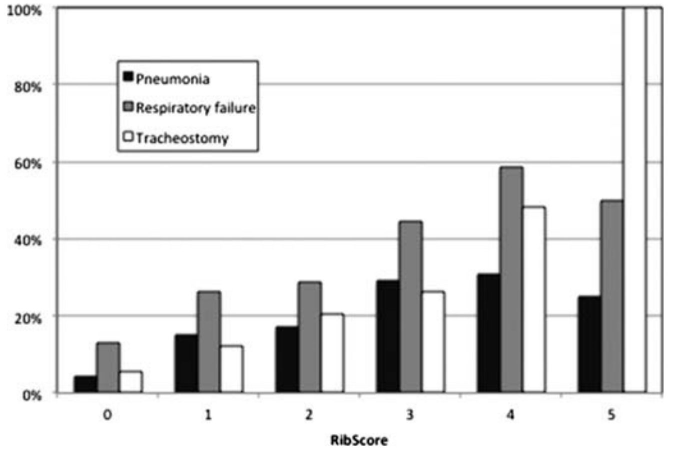

Figure 1. Likelihood of outcomes as a function of RibScore. $p < 0.05$ (χ^2) for each outcome.

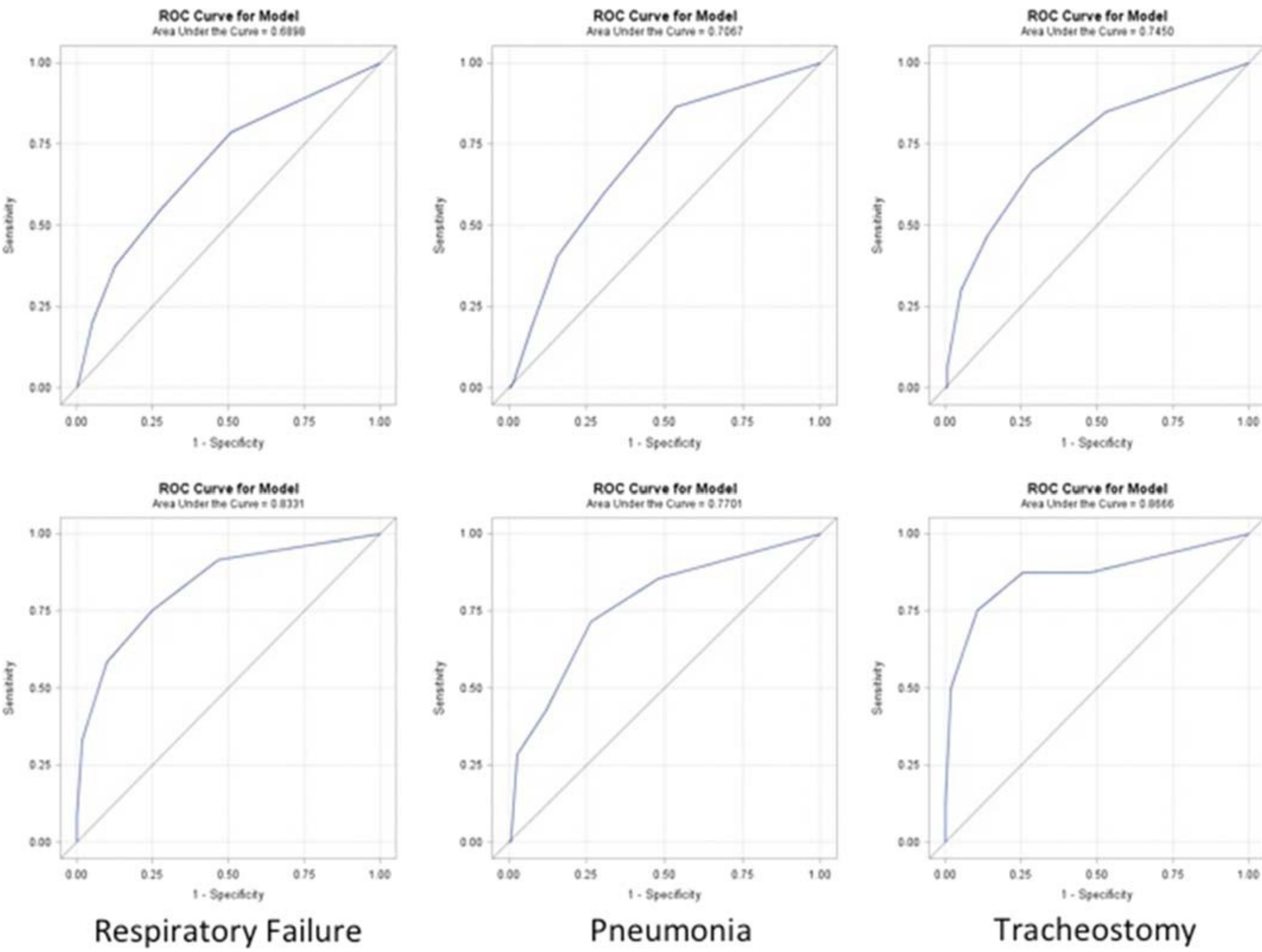

Figure 2. ROC AUC graphs for all patients (*top*) as well as those patients with isolated rib fractures (*bottom*).

chest wall scores that were examined, we next added age (in years) to the predictive models along with the RibScore. The age variable was operationalized as both continuous and binomial categorical with a cutoff of 65 years. Finally, we repeated the ROC analyses in the subgroup of patients with isolated rib fractures to eliminate possible confounding caused by covariates associated with the outcomes (e.g., brain injury). Statistical significance was defined as $p < 0.05$. This study was approved by the Colorado Multi-institutional Internal Review Board.

RESULTS

A total of 385 patients met inclusion criteria. Median age was 48 years (33–61 years), and 273 (71%) patients were male. The median ISS was 17 (10–24), and the most common mechanisms of injury were motor vehicle collision (n = 204, 53%), fall (n = 81, 21%), auto-pedestrian accident (n = 34, 9%), and other (n = 66, 17%). Among all patients, the following injuries were noted: 143 pulmonary contusions (37.1%), 140 spinal injuries (36.3%), 107 head injuries (27.8%), 80 abdominal injuries (20.8%), 72 facial fractures (18.7%), 69 pelvic injuries (17.9%), 25 clavicle fractures (7.0%), 15 sternum fractures (3.9%), and 13 scapula fractures (3.4%). A total of 181 patients (47.0%) had isolated rib fractures. A thoracic epidural catheter was placed in 38 patients (9.9%), a paravertebral pain catheter in 38 patients (9.9%), and 10 patients (2.6%) underwent SSRF.

Among the sample, 156 patients (40.5%) had six or more ribs fractured, 120 (31.2%) had bilateral fractures, 46 (11.9%) had flail chest, 32 (8.3%) had three or more severely displaced fractures, 91 (23.6%) had a first rib fracture, and 58 (15.1%) had fractures in all three anatomic areas. The median RibScore was 1 (range, 0–6). Only one patient had a RibScore of 6 and was excluded from the analysis because of the inability to glean meaningful statistical information. The distribution of the RibScore in all patients was as follows: score of 0 (n = 161, 41.9%); score of 1 (n = 92, 23.9%); score of 2 (n = 59, 15.4%); score of 3 (n = 38, 9.9%); score of 4 (n = 29, 7.6%); and score of 5 (n = 5, 1.3%). The distribution of the RibScore in patients with isolated rib fractures was as follows: score of 0 (n = 91, 50.3%); score of 1 (n = 39, 21.5%); score of 2 (n = 27, 14.9%); score of 3 (n = 17, 9.4%); score of 4 (n = 6, 3.3%); and score of 5 (n = 1, 0.5%). Each of the RibScore component variables

TABLE 3. Test Performance Characteristics of RibScore for the Outcomes Tested

RibScore Threshold	Sensitivity, %	Specificity, %	PPV, %	NPV, %
Pneumonia				
0	100	0	13.5	N/A
1	86.5	43.2	19.2	95.4
2	57.7	66.4	21.1	90.9
3	44.2	83.5	29.5	90.6
4	23.1	91.9	30.8	88.4
5	3.8	98.5	28.6	86.8
Respiratory failure				
0	100	0	32.2	N/A
1	78.2	47.5	41.5	82.1
2	54.0	71.3	47.2	76.5
3	39.5	88.9	62.8	75.6
4	24.2	96.6	76.9	72.8
5	4.8	99.6	85.7	68.8
Tracheostomy				
0	100	0.0	15.6	N/A
1	85.0	43.7	21.8	94.0
2	65.0	68.3	27.5	91.4
3	50.0	85.2	38.5	90.2
4	33.3	94.2	51.3	88.4
5	10.0	99.7	85.7	85.7

NPV, negative predictive value; PPV, positive predictive value.

was associated individually with pneumonia, respiratory failure, and tracheostomy (Table 2). The likelihood of receiving a paravertebral catheter ($p < 0.01$), a thoracic epidural ($p < 0.01$), and an SSRF ($p < 0.01$) also increased with increasing RibScore.

Patients with pneumonia had a median RibScore higher than those of patients without pneumonia (2 vs. 1, respectively, $p < 0.01$), patients with acute respiratory failure had a median RibScore higher than those without acute respiratory failure (2 vs. 1, respectively, $p < 0.01$), and patients who underwent tracheostomy had a median RibScore higher than those who did not undergo tracheostomy (2 vs. 1, respectively, $p < 0.01$). Furthermore, when analyzed as a categorical variable, there was a significant association between increasing RibScore and each of the outcomes (χ^2_{trend} $p < 0.05$ for each outcome, Fig. 1).

The ROC AUCs for the entire sample as well as those patients with isolated rib fractures are depicted in Figure 2. Among all patients, the ROC AUC *c* statistics for pneumonia, respiratory failure, and tracheostomy were 0.71, 0.72, and 0.75, respectively. In patients with isolated chest wall injury, the ROC AUC *c* statistics increased to 0.77, 0.83, and 0.87, respectively.

Test performance characteristics for the RibScore at each threshold among all patients are shown Table 3. The most informative threshold for the RibScore (the left uppermost point of the ROC curves) seemed to be 4; a RibScore of 4 or higher had greater than 90% specificity for pneumonia, respiratory failure, and tracheostomy.

Based on the degree of the univariate associations between the individual RibScore variables and pulmonary outcomes (Table 2), we repeated the ROC AUC analyses using a modified, weighted RibScore. Specifically, we constructed a modified RibScore that assigned 2 points for six or more ribs fractures and 2 points for three or more severely displaced fractures. The remaining four variables were still assigned 1 point each. (The modified RibScore thus ranged from 0 to 8.) However, the ROC AUC *c* statistics for pneumonia (0.75), respiratory failure (0.71), and tracheostomy (0.71) were not substantially changed. In addition, the addition of age to the RibScore did not result in a significant improvement in the ROC curves (see Table, Supplemental Digital Content 1, http://links.lww.com/TA/A654).

We next calculated the ROC AUC *c* statistics among our sample for the OIS Chest Wall grade, RFS, and CTS. As shown in Table 4, the RibScore had a superior ROC AUC *c* statistics compared with these previously published chest wall injury scoring systems.

DISCUSSION

In this retrospective cohort study, we constructed and analyzed a totally radiographic rib fracture severity scoring system that incorporates detailed anatomic fracture pattern information. The six variables included in the RibScore were each correlated significantly with pneumonia, respiratory failure, and tracheostomy. Furthermore, the composite RibScore was significantly and linearly correlated with these outcomes. The ROC AUC *c* statistics for the outcomes analyzed were in the range of 0.70 to 0.90, indicating favorable discriminative ability. These results persisted both after accounting for patient age and within the subgroup of patients with isolated rib fractures. Finally, the RibScore performed as least as well as the other chest wall scoring systems with which it was compared.

In addition to significant linear associations with adverse pulmonary outcomes, the RibScore has the additional advantages of objectivity, detail, ease of abstraction, and timeliness of information, as all of the variables become known within the first few hours of presentation to the emergency department. Although an appropriate RibScore threshold for selecting patients for potential interventions seemed to be 4, future prospective studies will be required to validate its use for this purpose.

It is well documented that the number of rib fractures correlates exponentially with both morbidity and mortality, particularly in the elderly.[2–7,10–12] For each additional rib fracture in patients 65 years or older, the risk of pneumonia increases by 27% and risk of death by 19%.[9] However, limitation of fracture pattern description to only the total number of ribs fractured likely results in oversimplification of the diverse array of potential fracture patterns as well as their impact on patient

TABLE 4. Comparison of the ROC C Statistic for Each Scoring System

	OIS Chest	RFS	CTS	RibScore
Respiratory failure	0.61	0.61	0.62	0.69
Pneumonia	0.60	0.66	0.63	0.71
Tracheostomy	0.66	0.68	0.67	0.75

OIS Chest, OIS chest wall grade.

outcomes. For example, a patient with nondisplaced fractures of posterior Ribs 2 to 7 (six fractures) will likely not encounter the same degree of respiratory embarrassment as a patient with severely displaced lateral and anterior fractures of Ribs 4 to 6 (three fractures with a flail segment).

Existing chest wall trauma scoring systems have attempted to address this limitation by incorporating additional fracture pattern variables, such as bilaterality and flail chest.[14–18] However, these scoring systems have yielded variable discriminative abilities,[15] require additional clinical and demographic information that may not be available real time, and do not account for detailed fracture information, such as both degree of displacement and location. These limitations may partially account for the higher discriminative ability observed for the RibScore in this study.

There are several potential advantages to using a radiographic score that includes more detailed anatomic information regarding the fracture pattern. The location of the fractures (both in a superior to inferior direction and medial to lateral direction) may influence the decision to pursue locoregional analgesia with a thoracic epidural catheter as opposed to a percutaneous paraspinous catheter.[21] Furthermore, the decision to perform SSRF is based to some degree on detailed fracture information, such as flail chest and degree of displacement.[22] Finally, abstraction of the variables necessary to calculate the RibScore will allow for a refined understanding of which fracture pattern variables contribute most to morbidity and mortality and thus which patients should be offered interventions such as SSRF.

The majority of complications resulting from rib fractures are related to chest wall pain and splinting, which limits pulmonary function, promoting atelectasis and increasing the risk of pneumonia. Adequate pain control minimizes these complications by allowing deep breathing and improved respiratory function. An aggressive rib fracture multidisciplinary clinical pathway focusing efforts on respiratory therapy, pain control, physical therapy, and nutrition services has been shown to decrease mechanical ventilator-dependent days, length of stay, infectious morbidity, and mortality in a prospective observational cohort study,[23] suggesting a benefit to accurate early risk stratification of patients with chest trauma.

Each of the six variables used to calculate the RibScore was correlated with the outcomes to a different degree. However, when we modified the RibScore to account for weighting of variables, the results were similar to the model in which each variable was assigned 1 point. This result suggests that not one variable was driving the relationship to the pulmonary outcomes; rather, each variable was independently contributing to the score. Accordingly, assigning a single point to each variable simplifies the calculation. Interestingly, although age was correlated with adverse outcomes, the addition of the age variable to the RibScore did not improve its discriminative ability. Because of this finding and the aforementioned advantages, we elected to maintain the score as a totally radiograph one.

Several study limitations must be recognized, the first being the study scope. Our intention was to create a radiographic, rib-specific scoring system to guide interventions unique to rib fractures. Injuries to additional chest structures, such as the clavicle, scapula, sternum, and lung, were purposefully excluded from the development of this score. As enthusiasm for interventions such as paracostal nerve blocks, continuous catheter analgesic infusion, and SSRF grows, an objective scoring system is needed to evaluate impact on outcomes.

An additional limitation to this study is the exclusion of patients with chest trauma who did not undergo chest CT, either because of minor mechanism or instability. Furthermore, we did not control for patients who had care withdrawn early in their hospital course, which may impact tracheostomy as an outcome. Subsequent therapeutic interventions, such as the use of epidurals or SSRF, may have impacted patient outcomes and introduced bias. However, the number of patients who underwent these interventions in our sample was relatively low. The three pulmonary outcomes examined are likely interrelated, and the decision to perform tracheostomy was not standardized. Finally, our sample consisted of a relatively small, homogenous cohort of trauma patients from a single center. We are currently validating the RibScore among a national sample of patients with rib fractures, including interobserver variability in the abstraction of the variables. Analysis of a larger sample will also help elucidate the impact of a RibScore of 6.

In conclusion, the RibScore can provide rapid, objective prognostication for patients with rib fractures, including likelihood of pneumonia, respiratory failure, and tracheostomy. As such, it may be used to prompt early institution of specific therapeutic modalities and may also in the future help better define their respective indications. In addition, the RibScore may identify patients who are at high risk for failure to wean from mechanical ventilation and guide decision making on the timing of tracheostomy. The RibScore may also be used for standardized communication of the trauma patient between providers, akin to existing anatomic scoring systems for solid organ injury.[24,25]

AUTHORSHIP

B.C.C., B.H., R.T.S., W.B., J.J., C.C.B., C.B., C.F., E.E.M., G.J.J., and F.M.P. designed this study. B.C.C. and B.H. performed the literature search. B.C.C., B.H., M.R., and J.S. collected and analyzed data. All authors contributed to data interpretation. B.C.C., B.H., M.R., R.T.S., W.B., J.J., C.C.B., C.B., C.F., E.E.M., G.J.J., and F.M.P wrote the manuscript. All authors participated in critical revision.

DISCLOSURE

All authors declare no conflicts of interest.

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