The Sequential Clinical Assessment of Respiratory Function (SCARF) score: A dynamic pulmonary physiologic score that predicts adverse outcomes in critically ill rib fracture patients

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BACKGROUND: Rib fracture scoring systems are limited by a lack of serial pulmonary physiologic variables. We created the Sequential Clinical Assessment of Respiratory Function (SCARF) score and hypothesized that admission, maximum, and rising scores predict adverse outcomes among critically ill rib fracture patients.

METHODS: Prospective cohort study of rib fracture patients admitted to the surgical intensive care unit (ICU) at a Level I trauma center from August 2017 to June 2018. The SCARF score was developed *a priori* and validated using the cohort. One point was assigned for: <50% predicted, respiratory rate >20, numeric pain score ≥5, and inadequate cough. Demographics, injury patterns, analgesics, and adverse pulmonary outcomes were abstracted. Performance characteristics of the score were assessed using the receiver operator curve area under the curve.

RESULTS: Three hundred forty scores were available from 100 patients. Median admission and maximum SCARF score was 2 (range 0-4). Likelihood of pneumonia ($p = 0.04$), high oxygen requirement ($p < 0.01$), and prolonged ICU length of stay ($p < 0.01$) were significantly associated with admission and maximum scores. The receiver operator curve area under the curve for the maximum SCARF score for these outcomes were 0.86, 0.76, and 0.79, respectively. In 10 patients, the SCARF score worsened from admission to day 2; these patients demonstrated increased likelihood of pneumonia ($p = 0.04$) and prolonged ICU length of stay ($p = 0.07$). Patients who developed complications maintained a SCARF score one point higher throughout ICU stay compared with patients who did not ($p = 0.04$). The SCARF score was significantly associated with both narcotic ($p = 0.03$) and locoregional anesthesia ($p = 0.03$) usage.

CONCLUSION: Admission, maximum, daily, and rising scores were associated with utilization of pain control therapies and development of adverse outcomes. The SCARF score may be used to guide therapies for critically ill rib fracture patients, with a proposed threshold greater than 2. (*J Trauma Acute Care Surg.* 2019;87: 1260–1268. Copyright © 2019 Wolters Kluwer Health, Inc. All rights reserved.)

LEVEL OF EVIDENCE: Prognostic study, level II.

KEY WORDS: Rib fractures; receiver operator characteristic area under the curve; scoring system; clinical variables.

Recent decades have brought significant improvements to the management of patients with rib fractures.[1] Early triage and standardized care pathways have been shown to reduce complications, such as prolonged length of stay (LOS), pneumonia (PNA), and mortality, as well as decrease healthcare expenditures.[2,3] Furthermore, novel treatment modalities, including locoregional analgesia,[4] narcotic alternatives, such as ketamine and lidocaine,[5] and surgical stabilization of rib fractures (SSRF)[6] are now routinely available at most trauma centers. Although these therapies have shown promise, concern has been raised that their widespread implementation has occurred without validated indications.[7]

Many scoring systems have been previously advanced to identify rib fracture patients at high risk of complications who may benefit from invasive therapies.[1,8–16] However, no one score is universally accepted. Challenges to developing a chest wall injury scoring system include a lack of universal nomenclature to characterize fractures, overreliance on demographic and radiographic parameters, and lack of validation.[17] Although static parameters, such as age, Injury Severity Score (ISS), number of fractures,[18] and preexisting comorbidities have been shown to increase the likelihood of complications,[1,9–15,19–23] these variables do not always correlate with an individual patient's dynamic pulmonary physiology, including response to therapies. Moreover, similar radiographic findings may demonstrate vastly different clinical phenotypes.

Because there are insufficient data linking objective clinical parameters to pulmonary complications, recommendations for therapies, such as locoregional anesthesia and SSRF, are based largely on either demographic or radiographic criteria.[24–26] Although some preliminary data exist addressing clinical parameters,[16,27,28] such reports are limited to a singular value recorded at a single time point early after injury. Trending pulmonary parameters over the course of hospitalization may be particularly important because both rib fractures and pulmonary contusions may evolve from insignificant to life threatening.[29]

The goal of this study was to develop a clinical, dynamic, pathophysiologic score that could identify high-risk rib fracture patients at admission, as well as recognize impending complications over the course of hospital stay. We termed this the Sequential Clinical Assessment of Respiratory Function (SCARF) score. We hypothesized that admission, maximum, and upward trending SCARF scores are all associated with increased incidence of complications, as well increased narcotic requirements.

METHODS

This was a prospective, observational cohort study of patients with one or more radiographically diagnosed rib fractures admitted to the surgical intensive care unit (ICU) at Denver Health Medical Center between August 2017 and June 2018. Denver Health is an American College of Surgeon's verified Level I trauma center with 550 beds and approximately 2,500 annual trauma admissions. Exclusion criteria were younger than 18 years and, upon admission, intubation, respiratory failure, or altered mental status rendering the patient unable to participate in incentive spirometry (IS), cough on demand, or verbal report of pain (determined by the clinical team).

The primary predictor variable, termed the SCARF score, was based on four clinical parameters: IS, respiratory rate (RR), numeric pain score (NPS), and strength of cough. These parameters were selected *a priori* by surgical ICU attendings, advanced practice providers, and respiratory therapists during a study meeting as: (1) clinically relevant, (2) commonly abstracted in the medical record, (3) reasonably objective. Each

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parameter was operationalized as binary: one point for present and zero for absent. The thresholds were: IS less than 50% of predicted based on a nomogram, including sex, height, and age; RR greater than 20 breaths per minute; NPS of 5 or greater on the Numeric Rating Scale[30]; and cough deemed inadequate to clear respiratory secretions by respiratory therapists not involved in the study. The score ranged from 0 to 4; each variable was weighted equally for simplicity. The score was collected at 10:00 AM daily in person or from electronic medical records. Patients were scored while in the ICU, and then followed throughout hospitalization for the development of complications.

Primary outcomes included PNA, fraction of inspired oxygen (F_iO_2) requirement greater than 50% (>6 L), respiratory failure, empyema, tracheostomy, prolonged ICU LOS, ICU readmission, and mortality. Pneumonia was diagnosed by clinical suspicion in nonintubated patients and by clinical suspicion plus quantitative microbiologic confirmation (>10^5 cfu/mL on bronchioalveolar lavage) in intubated patients. Respiratory failure was defined as need for greater than 24 hours of mechanical ventilation. Prolonged ICU LOS was defined as longer than the median ICU LOS for the sample. Secondary outcomes included daily narcotic requirements (collected at 10:00 AM) operationalized by equianalgesic dosing (narcotic equivalents).[31]

Demographic covariates included age (years), body mass index (BMI, kg/m^2), sex, ethnicity, and respiratory comorbidities (chronic obstructive pulmonary disease, asthma, and smoking status). Trauma mechanism, rib fracture patterns, associated injuries, and operative variables were collected. The ISS was provided by the Colorado Trauma Registry. Blunt Pulmonary Contusion (BPC18) score[32] and admission Glasgow Coma Scale score were also collected. Rib injury was further evaluated by the RibScore.[1]

Rib fracture therapies included nonnarcotic analgesics, such as nonsteroidal anti-inflammatory drugs, acetaminophen, gabapentin, ketamine, and locoregional methods (thoracic epidural catheter, indwelling paravertebral catheter, and rib blocks). We also abstracted thoracostomy tube placement and SSRF.

All statistical analyses were performed using Statistical Analysis Software version 9.4 (SAS Inc., Cary, NC). Continuous variables, including the SCARF score and daily narcotic equivalents, were analyzed for normality using the Kolmogorov-Smirnov test. Nonnormally distributed continuous variables are reported as median (range) and analyzed using the nonparametric Wilcoxon Rank Sum test. Categorical variables are displayed as number and analyzed using the χ^2 test, unless expected cell counts were less than 10, in which case the Fischer's exact test was used. Predictive ability of the SCARF score for each outcome was accessed using the receiver operator characteristic area under the curve (ROC AUC). Statistical significance was defined as p less than 0.05. The Colorado Multiple Institutional Review Board approved this study as institutional review board exempt.

RESULTS

Of 129 patients screened, 103 met inclusion criteria. Three patients were excluded within 24 hours of enrollment due to refusal to participate in IS or a decline in mental status rendering a SCARF score unattainable. One hundred patients remained for data collection and analysis.

Patient characteristics are summarized in Table 1. Nineteen patients received thoracostomy tubes and eight underwent SSRF on a median hospital day 2 (range, 1–3). Locoregional anesthesia was utilized in 36 patients on a median hospital day 1 (range, 1–7): 22 patients received thoracic epidural catheters, 15 received percutaneous indwelling pain catheters, and 4 received regional nerve blocks.

A total of 340 SCARF scores were recorded in 100 patients (340 ICU days). The distribution of these scores is shown in Figure 1A. The median SCARF score was 2 (range, 0–4). The median admission score was 2 (range, 0–4; distribution Fig. 1B) and the median maximum score was 2 (range, 0–4; distribution Fig. 1C).

Seven patients developed PNA on a median hospital day 7 (range, 2–24). The median admission SCARF score was 3

TABLE 1. Sample Characteristics

Variables	Mean (Range) or n (%) (Total, N = 100)
Demographics	
Age (yr)	52 (18–100)
Body mass index (kg/m^2)	26 (14–47)
Male	70 (70%)
Asthma	8 (8%)
Chronic obstructive pulmonary disease	7 (7%)
Tobacco use	27 (27%)
Injury patterns	
Mechanism	
Motor vehicle or motorcycle crash	40 (40%)
Fall	30 (30%)
Auto-bicycle	16 (16%)
Other	14 (14%)
ISS	17 (1–43)
Admission Glasgow Coma Scale score	15 (11–15)
Rib fracture patterns	
RibScore	1 (0–6)
Flail chest	23 (23%)
≥ 6 fractures	23 (23%)
≥ 3 bicortically displaced fractures	38 (38%)
Bilateral fractures	31 (31%)
First rib fracture	26 (26%)
Additional thoracic injuries	
Pneumothorax	33 (33%)
Hemothorax	19 (19%)
Sternal fracture	24 (24%)
Clavicle fracture	10 (10%)
Scapular fracture	36 (36%)
Blunt pulmonary contusion score (up to 18)	2.34 (0–15)
Additional nonthoracic injuries	
Spine fracture	36 (36%)
Pelvic fracture	15 (15%)
Long bone fracture	28 (28%)
Solid organ injury	11 (11%)
Blunt cerebrovascular injury	8 (8%)
Intracranial hemorrhage	9 (9%)
Facial fracture	17 (17%)

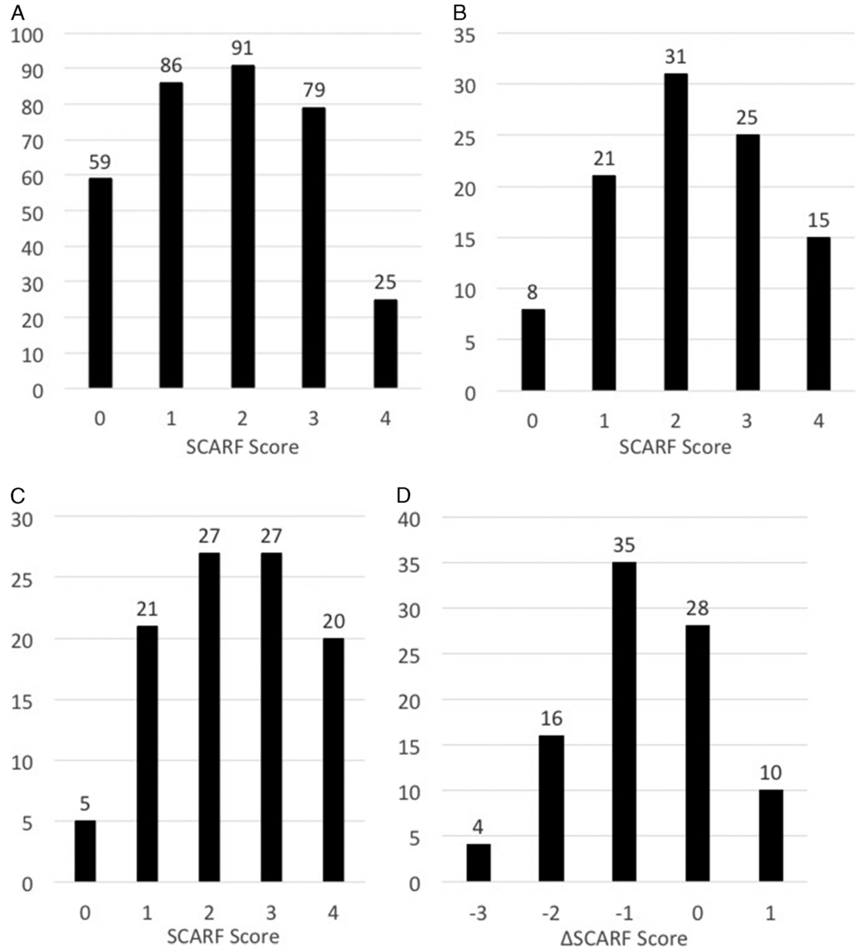

Figure 1. (*A*), Distribution of the 340 SCARF scores. KS D = 0.17, $p < 0.01$. (*B*), Distribution of the admission SCARF scores. KS D = 0.16, $p < 0.01$. (*C*), Distribution of the maximum SCARF Score. KS D = 0.18, $p < 0.01$. (*D*), Distribution of ΔSCARF score. KS D = 0.19, $p < 0.01$. ΔSCARF, Delta SCARF; KS D, Kolmogorov-Smirnov D statistic.

(range, 2–4) for patients who developed PNA versus 2 (range, 0–4) for patients who did not ($p = 0.04$). The median maximum SCARF score was 4 (range, 3–4) for patients who developed PNA versus 2 (range, 0–4) for patients who did not ($p < 0.01$). The likelihood of developing PNA as a function of both admission ($p = 0.40$) and maximum ($p < 0.01$) SCARF scores is shown in Figure 2*A* and B. No patient with an admission score less than 2 or a maximum score less than 3 developed PNA. The ROC curves for the outcome of PNA are shown in Figure 2*C* and D: the admission and maximum SCARF scores demonstrated fair (0.71) and good (0.86) predictive ability, respectively.

The median ICU LOS was 3 days (range, 1–31), and therefore, the variable was dichotomized into patients with ICU LOS longer than 3 days (n = 46) and ICU LOS of 3 days or less (n = 54). The median admission SCARF score was 3 (range, 0–4) for patients with ICU LOS longer than 3 days versus 2 days (range, 0–4) for patients with ICU LOS of 3 days or less ($p < 0.01$). The median maximum SCARF score was 3 (range 1-4) for patients with ICU LOS > 3 days vs. 2 (range, 0–4) for patients with ICU LOS of 3 days or less ($p < 0.01$). Likelihood of staying in the ICU for more than 3 days as a function of admission ($p < 0.01$) and maximum ($p < 0.01$) SCARF scores is shown in Figure 3*A* and B. In both cases, a score of zero conferred a low risk; 1 to 2, a moderate risk; and 3 to 4, a high risk of the outcome. The ROC curves for the outcome of ICU LOS longer than 3 days are shown in Figure 3*C* and D: both admission (0.70) and maximum (0.76) had fair predictive ability.

Twenty patients required F_iO_2 greater than 50%, or 6 L, at some point during their ICU stay. The median admission SCARF score was 3 (range, 1–4) for patients with high O_2 requirement versus 2 (range, 0–4) for patients without high O_2 requirement ($p < 0.01$). The median maximum SCARF score was 3 (range, 2–4) for patients with high O_2 requirement versus 2 (range, 0–4) for patients without ($p < 0.01$). The likelihood of high O_2 requirement as a function of admission ($p < 0.01$) and maximum ($p < 0.01$) SCARF scores is shown in Figure 4*A* and B. The ROC curves for this outcome are shown in Figure 4*C* and D: both admission (0.74) and maximum (0.79) had fair predictive ability.

The incidence of respiratory failure was low (n = 4) and occurred on a median ICU day 3 (range, 2–5). The admission SCARF scores of these four patients were 2, 3, 4, and 4. The maximum SCARF scores were 3, 4, 4, and 4. The likelihood of respiratory failure as a function of both admission and

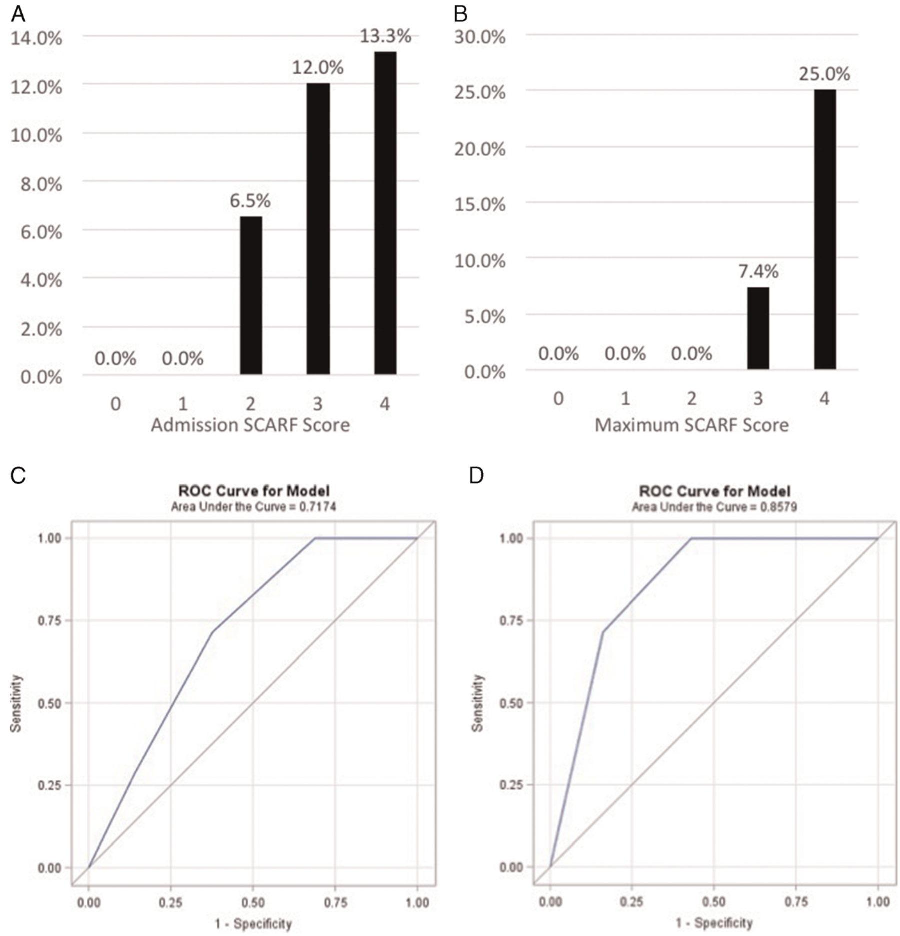

Figure 2. (*A*), Likelihood of pneumonia for admission SCARF scores. $p = 0.39$. (*B*), Likelihood of pneumonia for maximum SCARF scores. $p < 0.01$. (*C*), ROC curve for outcome of pneumonia for admission SCARF scores. (*D*), ROC curve for outcomes of pneumonia for maximum SCARF scores.

maximum SCARF scores trended toward, but did not reach, statistical significance ($p = 0.11$ and 0.10, respectively).

Additional pulmonary outcomes included three patients who required tracheostomy on a median hospital day 6 (maximum SCARF score 3, 4, and 4), three patients who developed empyema on a median hospital day 5 (maximum SCARF score 2, 3, and 4), six patients who were readmitted to the ICU (maximum SCARF score 3, 3, 3, 3, 4, and 4), and one mortality. No patient with a score less than 2 developed any of these complications.

The SCARF score trend throughout ICU stay also revealed a direct relationship with likelihood of study outcomes. In each case, and on each day, the SCARF score remained approximately one point higher for those who developed an outcome, as compared with those who did not. The change in the SCARF score from admission (ICU day 1) to ICU day 2 was defined as ΔSCARF. Ninety-three patients had data available to calculate ΔSCARF. This distribution is shown in Figure 1D; the median value was −1 (range, −3 to 1). Fifty-five (59.1%) patients demonstrated a decrease (improvement) in the score from day 1 to day 2, 10 patients (10.8%) demonstrated an increase (worsening) in the score, and the remaining 28 (30.1%) demonstrated no change. Among patients in whom ΔSCARF decreased, the median decrease was one point (range, 1–3). Among those in whom ΔSCARF increased, the score increased by one point in all cases.

Patients in whom the SCARF score worsened had an over threefold likelihood of developing pneumonia as compared with patients in whom the score did not worsen (20.0% vs. 6.0%, respectively, $p = 0.04$). Furthermore, patients in whom the SCARF score worsened were more likely to remain in the ICU for greater than 3 days as compared to those in whom the score did not worsen (70.0% vs. 47.0%, respectively, $p = 0.07$). There was no relationship between trajectory of the SCARF score and likelihood of high oxygen requirement. For the nine patients who experienced PNA, respiratory failure, tracheostomy, and empyema, the median SCARF score increased by one point the day prior to the occurrence of the outcome (Fig. 5).

Over 340 patient ICU days, the median daily narcotic equivalent was 2 (range, 0–34). Overall, for the 340 SCARF scores and daily narcotic requirement variable pairs, the Pearson's correlation coefficient was 0.12 ($p = 0.02$). The median daily narcotic requirement as a function of the SCARF score is shown in Figure 6. There was a significant increase in the amount of daily narcotics consumed with increasing SCARF score ($p = 0.03$). Also, the median maximum SCARF score was higher in patients

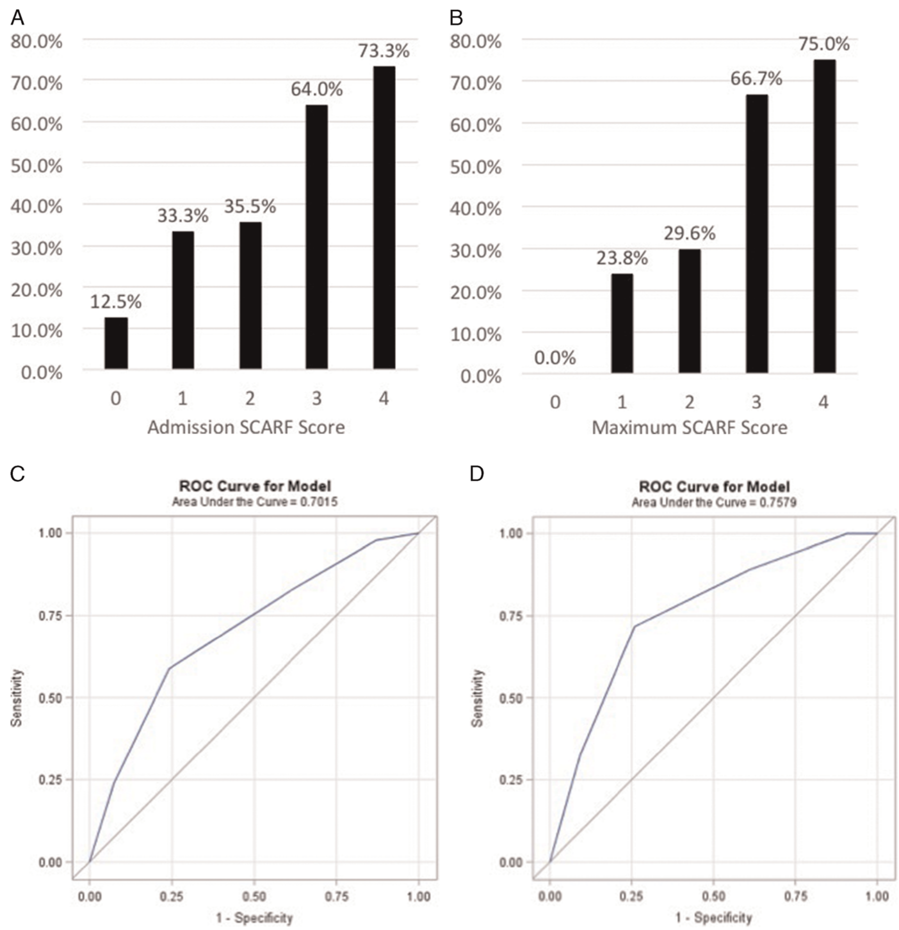

Figure 3. (*A*), Likelihood of prolonged ICU LOS for admission SCARF scores. $p < 0.01$. (*B*), Likelihood of prolonged ICU LOS for maximum SCARF scores. $p < 0.01$. (*C*), ROC curve for outcome of prolonged ICU LOS for admission SCARF scores. (*D*), ROC curve for outcome of prolonged ICU LOS for maximum SCARF score.

who received locoregional anesthesia as compared with those who did not (3 vs. 2, respectively, $p = 0.03$).

Finally, we investigated the association of demographic and radiographic variables with the SCARF score. Age, ISS, and BPC18 were not associated with either admission or maximum SCARF score. Radiographic flail chest was associated with the maximum, but not the admission SCARF score ($p = 0.04$ and 0.20, respectively). The RibScore was associated with both admission and maximum SCARF scores ($p < 0.01$ and 0.04, respectively). Specifically, patients with a RibScore greater than 3 had a median admission SCARF score of 3 (range, 1–4), compared with 2 (range, 0–4) in patients with a RibScore of 3 or less. In general, the SCARF score outperformed both the RibScore and flail chest in predicting adverse outcomes; the ROC AUCs for both the RibScore and flail chest were in the 0.60 to 0.70 range for the outcomes of pneumonia, prolonged ICU LOS, and high O_2 requirement (curves not shown).

DISCUSSION

In this prospective cohort study, we report the SCARF score as a physiologic, dynamic tool to assess clinical performance in patients with rib fractures. Each of the four variables was selected based on relationship with pulmonary reserve in prior investigations.[1,14,19,27,33–35] Our goal was to account for unmeasured variability in existing demographic and radiologic scoring systems, with the ultimate intention of informing both therapeutic and disposition decisions for rib fracture patients.

In our analysis, both admission and maximum SCARF scores demonstrated good predictive ability for PNA, high oxygen requirement, and prolonged ICU LOS. Additional outcomes such as respiratory failure and tracheostomy only occurred in patients with a score greater than 2. Trends in the score predicted complications in two ways. First, patients who ultimately developed complications consistently had a score one point higher than those who did not. Second, patients in whom the score increased were more likely to develop a complication as compared with patients in whom the score decreased or remained the same. Specifically, we found a one point spike in the SCARF score the day before pulmonary complications occurred. The SCARF score was also related to both narcotic and locoregional anesthesia use. Together, these findings have practical relevance in targeting patients with high scores for more aggressive interventions, both on admission and at the time of an increase in score.

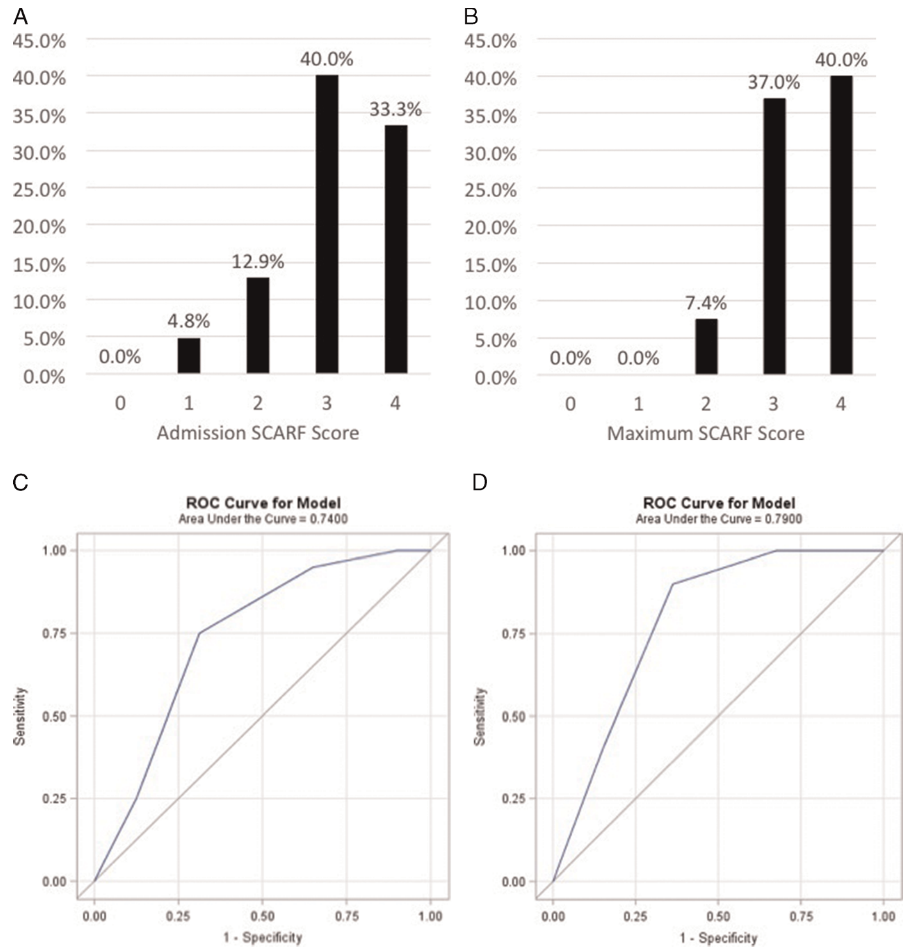

Figure 4. (*A*), Likelihood of $FiO_2 > 50\%$ for admission SCARF scores. $p < 0.01$. (*B*), Likelihood of $FiO_2 > 50\%$ for maximum SCARF scores. $p < 0.01$. (*C*), ROC curve for outcome of $FiO_2 > 50\%$ for admission SCARF score. (*D*) ROC curve for outcome of $FiO_2 > 50\%$ for maximum SCARF score.

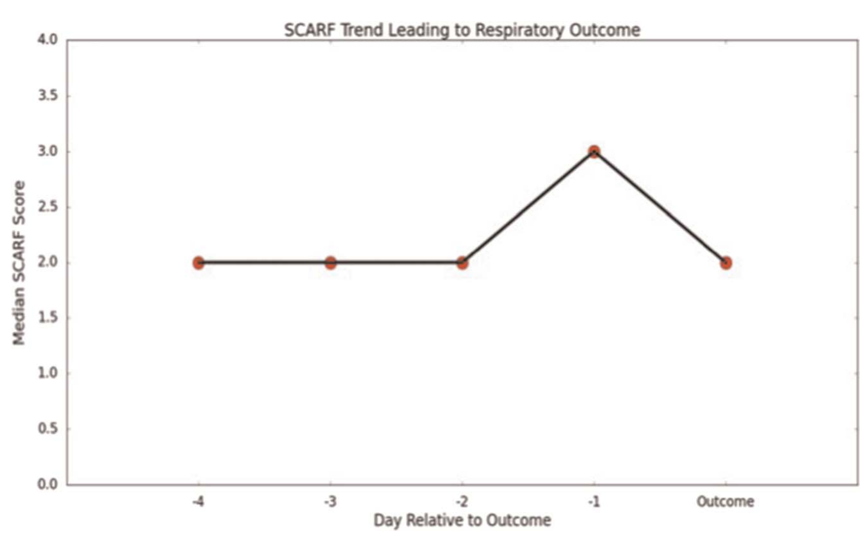

Figure 5. SCARF trend leading up to pulmonary outcome.

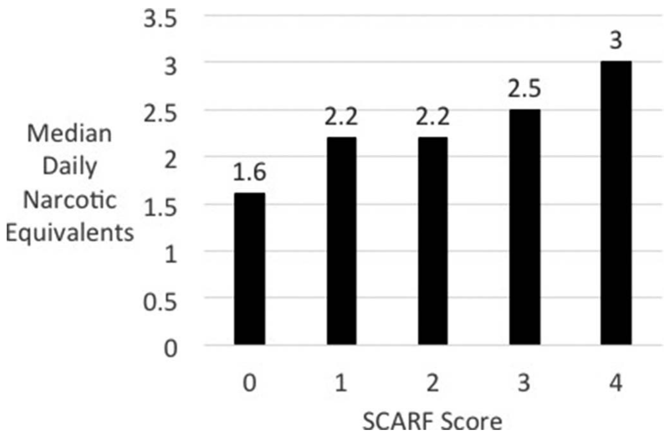

Figure 6. Median Daily Narcotic Equivalents as a function of SCARF score. $p = 0.03$.

Scoring systems represent a common language through which patients with similar injuries may be managed in a standardized fashion. Several rib fracture scoring systems have been developed and incorporate a combination of both demographic and radiologic parameters. The first was the Chest Wall Organ Injury Scale,[10] a comprehensive score based on radiographic findings, age, and pulmonary contusion. Pape et al.[11] published the Thoracic Injury Score, which included anatomic and radiographic variables, as well as P_aO_2:F_iO_2. The Rib Fracture Score[12] and Chest Trauma Score[14] combine radiographic and demographic variables. Battle et al.[15] published another score that included demographic variables and hemoglobin oxygen saturation. Finally, the RibScore[1] is entirely radiographic.

Although these scores may be helpful in directing patient management,[8,36] most are measured at a singular time point, have not been validated extensively, and are not specific to rib fractures. Accordingly, they explain only some of the variability in patient outcomes. For example, the RibScore successfully predicted only one third of the variability of respiratory failure.[1] The remaining variability in outcomes for similar fracture patterns must be explained by differences in both phenotypic expression of the injury and response to therapies. For instance, two similarly aged patients with radiographic flail chest would have similar Rib Fracture Score, Chest Trauma Score, and RibScores, but could demonstrate vastly different reactions to their injury and thus risk of complications. Quantification of this reaction is needed to improve current prognostication and has been recognized as a critical component in offering SSRF.[37] Although some preliminary, retrospective work has been done,[16,27,28] our study represents the first prospective attempt to incorporate multiple clinical variables, collected serially, into a scoring system.

The importance of dynamic, clinical information to guide therapies in rib fracture patients is underscored by two findings. First, the SCARF score was not correlated with certain demographic and radiographic variables, such as age, ISS, and BPC18 that are included in many scoring systems. Second, the SCARF score, in general, returned a higher ROC AUC than both demographic and radiographic variables, such as the RibScore.

Additional practical observations may be gleamed. First, the median SCARF score in all cases (i.e., admission, maximum, and serial) was 2. Nearly all patients in whom complications developed had a score of 3 or 4, and scores remained in the 2 to 3 range, compared with the 1 to 2 range for patients without complications. A SCARF score of 3 or greater on admission, or at maximum, represented a greater than 60% probability of developing one or more adverse outcomes. The median maximum SCARF score in patients who developed PNA, respiratory failure, and required tracheostomy was four in all cases. By contrast, patients with a SCARF score of zero were at very low risk of complications. We thus recommend risk-stratifying patients into three groups: low risk (SCARF score zero); intermediate risk (SCARF score, 1–2); and high risk (SCARF score, 3–4). A persistently high-risk SCARF score, along with radiographic findings, may represent a useful threshold for implementation of more aggressive therapies including ICU admission, locoregional pain control, and SSRF.

Our data showed a one-point spike in median scores of patients who developed PNA, respiratory failure, empyema, or required tracheostomy 1 day prior to the occurrence of that outcome. Furthermore, median admission scores for pulmonary outcomes were all lower than their respective maximums, signifying an upward trend prior to complication onset. The 10 patients in whom the SCARF score worsened from admission to day 2 had a markedly increased risk of developing complications. Thus, the direction of the score over time, in addition to the absolute value, should be considered.

There are several study limitations to discuss. Inherent to using clinical variables is some degree of subjectivity. In particular, we did not validate assessment of cough between therapists. However, utilizing several variables as opposed to a single variable to predict outcomes should mitigate this phenomenon patially.[27,28] Our sample was a relatively small cohort from a single trauma center limiting generalizability. External validation may clarify the extent of this limitation. There was also a relatively low incidence of pulmonary complications. This is likely explained by excluding those intubated on admission, thereby often eliminating patients with severe chest wall injuries. The SCARF scores were only trended while in the ICU; this could have missed important trends in the score that occurred after transfer. Furthermore, the score was only recorded daily. More frequent intervals may provide more conclusive data on SCARF trends in relation to outcomes. Finally, we only evaluated associations between clinical variables and patient outcomes. It remains to be seen whether using the SCARF score as a clinical tool actually reduces morbidity and mortality and if intervening to decrease the score translates into a decreased risk of complications. In practice, patients will likely benefit most from a comprehensive risk assessment by combining demographic, radiographic, and clinical variables.

In conclusion, we report the SCARF score as a dynamic, pulmonary physiologic gauge of patients' clinical response to rib fractures. The admission, maximum, and trend in SCARF score were each associated with both development of complications and analgesic consumption. Scores of 3 or greater were particularly ominous. We suggest incorporation of the SCARF score into disposition decisions and daily assessment of patients' clinical status with respect to allocating resources. Finally, we recommend that future trials of interventions for rib fracture patients incorporate this, or a similar clinical metric, into both inclusion criteria and response to therapy.

AUTHORSHIP

Study concept and design: K.S.H. and F.M.P. Data collection: K.S.H., K.N.L., and A.K. Data analysis: K.S.H. and F.M.P. Article drafting: K.S.H., K.N.L., and F.M.P. Critical revisions: K.S.H., K.N.L., A.K., J.H., E.E.M., C.C.B., and F.M.P.

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DISCLOSURE

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