Rib Fracture Frailty Index: A risk stratification tool for geriatric patients with multiple rib fractures

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BACKGROUND: Rib fractures are consequential injuries for geriatric patients (age, ≥65 years). Although age and injury patterns drive many rib fracture management decisions, the impact of frailty—which baseline conditions affect rib fracture-specific outcomes—remains unclear for geriatric patients. We aimed to develop and validate the Rib Fracture Frailty (RFF) Index, a practical risk stratification tool specific for geriatric patients with rib fractures. We hypothesized that a compact list of frailty markers can accurately risk stratify clinical outcomes after rib fractures.

METHODS: We queried nationwide US admission encounters of geriatric patients admitted with multiple rib fractures from 2016 to 2017. Partitioning around medoids clustering identified a development subcohort with previously validated frailty characteristics. Ridge regression with penalty for multicollinearity aggregated baseline conditions most prevalent in this frail subcohort into RFF scores. Regression models with adjustment for injury severity, sex, and age assessed associations between frailty risk categories (low, medium, and high) and inpatient outcomes among validation cohorts (odds ratio [95% confidence interval]). We report results according to Transparent Reporting of Multivariable Prediction Model for Individual Prognosis guidelines.

RESULTS: Development cohort (n = 55,540) cluster analysis delineated 13 baseline conditions constituting the RFF Index. Among external validation cohort (n = 77,710), increasing frailty risk (low [reference group], moderate, high) was associated with stepwise worsening adjusted odds of mortality (1.5 [1.2–1.7], 3.5 [3.0–4.0]), intubation (2.4 [1.5–3.9], 4.7 [3.1–7.5]), hospitalization ≥5 days (1.4 [1.3–1.5], 1.8 [1.7–2.0]), and disposition to home (0.6 [0.5–0.6], 0.4 [0.3–0.4]). Locally weighted scatterplot smoothing showed correlations between increasing RFF scores and worse outcomes.

CONCLUSION: The RFF Index is a practical frailty risk stratification tool for geriatric patients with multiple rib fractures. The mobile app we developed may facilitate rapid implementation and further validation of RFF Index at the bedside. (*J Trauma Acute Care Surg.* 2021;91: 932–939. Copyright © 2021 Wolters Kluwer Health, Inc. All rights reserved.)

LEVEL OF EVIDENCE: Prognostic study, level III.
KEY WORDS: Prediction tool; geriatric; rib fractures; frailty.

Frailty—the multidimensional loss of physiologic reserve to withstand stress—is associated with higher odds of complications and adverse discharge disposition among geriatric trauma patients.[1,2] Clinical decision making guided by frailty risk has been associated with improved outcomes for injured geriatric patients.[3,4] Potential for frailty to predict outcomes and guide management spurred development of many geriatric trauma frailty indices.[5]

Rib fractures are consequential injuries for geriatric patients.[6–8] Mitigating pulmonary complications and mortality requires a comprehensive approach incorporating multimodal analgesia, pulmonary therapy, and sometimes, surgical stabilization of rib fractures (SSRFs).[9,10] Today, two key variables drive critical management decisions: age (geriatric or nongeriatric) and injury pattern (e.g., flail chest). However, the impact of frailty on geriatric patients with rib fractures, and which baseline conditions affect rib fracture-specific outcomes, remains unclear. Generalizing existing geriatric frailty indices for patients with rib fractures is suboptimal because accurate risk stratification requires population-specific model development and validation.[11]

We aimed to develop a risk stratification tool specific for geriatric patients with rib fractures: the Rib Fracture Frailty (RFF) Index. Developed and validated using nationwide cohorts and according to established standards,[12,13] the RFF Index aims to be both valid and practical for bedside use. We hypothesized that a compact list of frailty markers—assessed at admission—can accurately risk stratify patients' clinical outcomes after suffering rib fractures. Finally, we built a mobile application to facilitate bedside use and prospective validation of the RFF Index.

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METHODS

Our study comprised three phases, mirroring validated risk stratification methodology.[14] First, we performed cluster analysis to identify patients with characteristics of frailty using predefined frailty markers (frail cluster). Second, we built the RFF index, which stratifies patients into low, medium, and high frailty risk categories according to RFF scores (tabulated from post hoc frailty-associated diagnoses associated with rib fracture-specific outcomes). Lastly, we performed internal and external validations. Supplemental Data 1 (http://links.lww.com/TA/C126) highlights our methodologic steps. We report our results in accordance with Transparent Reporting of Multivariable Prediction Model for Individual Prognosis or Diagnosis guidelines (Supplemental Data 2, http://links.lww.com/TA/C126).[13] Stanford Institutional Review Board approved this study.

Study Population

We evaluated encounters of geriatric patients (age, ≥65 years) admitted with acute multiple rib fractures (International Classification of Diseases, 10th revision [ICD-10] codes: S22.41XA, S22.41XB, S22.42XA, S22.42XB, S22.43XA, S22.43XB, S22.49XA, S22.49XB) using the 2016 and 2017 National Inpatient Sample (NIS), Agency for Healthcare Research and Quality's database that approximates a 20% stratified sample of all discharges from US hospitals.[15(p)] We excluded encounters with missing or unknown discharge disposition (<0.1%).

Development: Cluster Analysis

We performed cluster analysis on an 80% random cohort from NIS 2016. Clustering was performed using the following variables: (1) hospital length of stay (HLOS), (2) intubation 24 hours or more, (3) disposition to home (with or without home health), (4) inpatient mortality, and (5) encounter ICD-10 diagnoses (presence or absence). Gower method quantified similarity between individuals across these variables into a dissimilarity matrix.[16] Partitioning around medoids (PAM) algorithm clustered individuals based on Gower distances.[17] Silhouette analysis, which minimizes individual differences within a cluster while maximizing differences across neighboring clusters, optimized the number of clusters.

We identified the cluster of patients with frailty characteristics using a predefined list of frailty markers (Supplemental Data 3, http://links.lww.com/TA/C126). The cluster with highest prevalence of frailty markers was identified as the frail cluster. Standardized mean differences (SMDs) compared imbalance in cluster characteristics (SMD > 0.1 suggests substantial imbalance, which is favorable in clustering). We report SMD rather than *p* values because large sample sizes potentiate rejection of null hypotheses.[18]

Development: Rib Fracture Frailty Index

We defined four criteria for diagnoses constituting the RFF Index. First, we included diagnoses that were at least twice as prevalent in the frail cluster compared with other clusters. Second, we excluded external cause or nature of injury ICD-10 codes.[19] Third, we assigned points for diagnoses proportional to how strongly they predicted membership in the frail cluster. Points were derived from coefficients of a ridge regression model, including frail cluster membership as outcome and diagnoses as predictors. A multiplication factor converted coefficients to cumulate RFF scores ranging from 0 to 100. Lastly, ridge regression penalized coefficients of correlated predictors to account for correlated diagnoses.

Area under the receiver operating characteristic curve (AUROC) analysis assessed how well the ridge regression model discriminated between frail and nonfrail cluster membership. We stratified patients into low, intermediate, and high frailty risk (RFF classification) based on RFF score cutpoints that maximized likelihood ratios and AUROC.[20]

Validation

Internal (remaining 20% of NIS 2016 encounters) and external (NIS 2017 encounters) validation cohorts assessed how well RFF index predicts outcomes. Logistic regression estimated association between RFF index and five outcomes: (1) pneumonia, (2) intubation ≥24 hours, (3) prolonged HLOS (≥5 days), (4) mortality, and (5) disposition to home. Models were built with and without adjustment for Injury Severity Score (ISS; <15 or ≥15), age (5-year intervals), and sex.

Locally weighted scatterplot smoothing lines assessed a form of model calibration (associations between RFF scores and external validation cohort outcomes). Subgroup analysis assessed associations among patients who did and did not undergo SSRF.

Mobile Application Development

We integrated our risk prediction model within a mobile application ("RFF Index," Apple App store). Selecting frailty conditions that constitute the RFF Index outputs RFF scores, frailty risk category, and predicted outcome estimates in real time.

RESULTS

Development Cohort: Cluster Analysis

We identified 69,425 geriatric patients admitted with multiple traumatic rib fractures in 2016. Of these, 80% (n = 55,540) constituted our development cohort. Two clusters optimized PAM clustering (Table 1). Compared with nonfrail cluster patients, frail cluster patients were older but had similar injury severity and injury patterns (proportion with sternal fractures, flail chest, and isolated major thoracic injury [Abbreviate Injury Scale-chest ≥3 and nonchest regions <3]). Fewer frail cluster patients had pulmonary contusions (7% vs. 13%, SMD = 0.19). Frail cluster patients had longer HLOS (7.7 vs. 5.1, SMD = 0.38), lower proportion discharged to home (10% vs. 40%, SMD = 0.76), and higher inpatient mortality (13% vs. 1%, SMD = 0.47).

Development Cohort: Rib Fracture Frailty Index

Constituent Diagnoses

Thirteen preexisting conditions constituted the RFF Index (Table 2). The ridge regression model, including these conditions as predictors, discriminated frail cluster membership well, exhibiting an AUROC of 0.85.

Outcomes Associated With RFF Classification

TABLE 1. Characteristics of Adults Aged ≥65 Years With Multiple Rib Fractures Classified as Frail and Not Frail by PAM Clustering

	Frail (n = 27,548)	Not Frail (n = 27,992)	SMD
Demographic characteristics			
Age, mean (SD), y	79.9 (7.9)	77.8 (8.3)	0.27
Female, n (%)	13,318 (48.3)	14,263 (51.0)	0.05
Frailty diagnosis, n (%)	18,195 (66.0)	9,458 (33.8)	0.68
≥3 Frailty diagnoses, n (%)	1,538 (5.6)	250 (0.9)	0.27
Injury characteristics			
Sternal fracture, n (%)	939 (3.4)	1,388 (5.0)	0.08
Flail chest, n (%)	72 (0.3)	67 (0.2)	0.004
Pulmonary contusion, n (%)	1,933 (7.0)	3,527 (12.6)	0.19
ISS, mean (SD)	7.6 (7.1)	8.0 (6.9)	0.06
ISS ≥ 15, n (%)	3,410 (12.4)	3,416 (12.2)	0.005
Isolated major thoracic injury,* n (%)	3,943 (14.3)	4,371 (15.6)	0.04
Hospital characteristics			
Hospital type, n (%)			0.11
Rural	2,283 (8.3)	2,399 (8.6)	
Urban, nonteaching	6,232 (22.6)	5,626 (20.1)	
Urban, teaching	19,039 (69.1)	19,967 (71.3)	
Hospitalization characteristics			
HLOS: mean (SD), d	7.7 (8.7)	5.1 (4.8)	0.38
Intubated ≥24 h, n (%)	478 (1.7)	67 (0.2)	0.15
Disposition to home, n (%)	2,610 (9.5)	11,280 (40.3)	0.76
Mortality, n (%)	3,543 (12.9)	355 (1.3)	0.47

* Isolated major thoracic injury: Abbreviated Injury Scale chest ≥3 and nonchest regions <3.

TABLE 2. Conditions Constituting Rib Fracture Frailty Index

	Conditions	ICD-10 Codes	Points
General	"Do not resuscitate" status	Z66	12.6
	Malnourished	E43, E44, E46, R63, R64	8.4
	Dependent on supplemental O2/ dialysis/wheelchair	Z99	8.3
Neuro/psych	Dementia (excluding Alzheimer's)	G31, F01	4.2
	Anxiety disorder	F41	7.4
Cardiovascular	Heart failure	I50	10.9
	Atrial fibrillation/flutter	I48	5.9
	Ischemic heart disease or presence of cardiovascular implants/grafts	I24, Z95	8.3
Pulmonary	Chronic obstructive pulmonary disorder	J44	8.3
Renal	Chronic kidney disease	I12, N18	8.4
Gastrointestinal	Gastroesophageal reflux disease	K21	5.4
Musculoskeletal/ skin	Osteoarthritis	M19	6.3
	Pressure ulcer	L89	5.6

The optimal RFF score cutoffs discriminating between low and medium, and medium and high frailty risk were 13.6 and 25.2, respectively. Median RFF scores of nonfrail and frail cluster patients were 8.3 and 22.1, respectively. With increasing frailty risk, the development cohort had stepwise worsening odds of most adverse outcomes (Table 3). Compared with those at low frailty risk, patients at medium frailty risk did not have statistically significant differences in their odds of undergoing mechanical ventilation (1.8 [1.0–3.0]) or of mortality (1.1 [0.9–1.3]).

Validation

Internal (n = 13,885) and external (n = 77,710) validation cohorts had similar patient characteristics compared with the development cohort (Supplemental Data 4, http://links.lww.com/TA/C126).

Validation cohorts had stepwise worsening odds of adverse outcomes with increasing frailty risk (Table 3). Figure 1 presents association between RFF scores and external validation cohort outcomes. With increasing RFF scores, higher proportions of patients suffered adverse outcomes. However, above an RFF Index score of 50, these proportions could not be estimated as precisely (indicated by wider confidence intervals).

Stratified by injury severity and sex, outcomes were worse among patients with major injury (ISS, ≥15) compared with those with minor injury (ISS, <15; Fig. 2). The maximum RFF score among patients with major injury was 64. Association between RFF scores and outcomes had greater certainty (narrower confidence intervals) among patients with minor injury, especially those with RFF scores below 40. Among patients with minor injury, women had lower mortality and men had higher proportion discharged home. Notably, few external validation cohort patients were intubated for 24 hours or longer (n = 637); we did not assess stratified association between RFF scores and intubation 24 hours or longer.

TABLE 3. Odds of Adverse Outcomes Associated With Rib Fracture Frailty Index Classification

	Development		Internal Validation		External Validation	
	Unadjusted, OR (95% CI)	Adjusted,* OR (95% CI)	Unadjusted, OR (95% CI)	Adjusted,* OR (95% CI)	Unadjusted, OR (95% CI)	Adjusted,* OR (95% CI)
Pneumonia						
Low frailty risk	—	—	—	—	—	—
Medium frailty risk	1.4 (1.2–1.6)	1.5 (1.3–1.7)	2.4 (1.8–3.3)	2.4 (1.8–3.3)	1.2 (1.1–1.3)	1.2 (1.1–1.3)
High frailty risk	2.0 (1.7–2.3)	2.2 (1.9–2.5)	3.0 (2.2–4.0)	3.0 (2.2–4.1)	1.3 (1.2–1.4)	1.2 (1.1–1.4)
Intubated ≥ 24 h						
Low frailty risk	—	—	—	—	—	—
Medium frailty risk	1.8 (1.0–3.0)	1.9 (1.1–3.3)	1.1 (0.3–3.6)	1.2 (0.3–3.9)	2.3 (1.4–3.7)	2.4 (1.5–3.9)
High frailty risk	4.6 (2.9–7.7)	5.3 (3.2–8.8)	3.2 (1.2–8.9)	4.0 (1.4–11.6)	4.2 (2.7–6.5)	4.7 (3.1–7.5)
Hospitalization ≥ 5 d						
Low frailty risk	—	—	—	—	—	—
Medium frailty risk	1.2 (1.1–1.3)	1.3 (1.2–1.4)	1.7 (1.4–2.0)	1.7 (1.5–2.1)	1.3 (1.2–1.4)	1.4 (1.3–1.5)
High frailty risk	1.4 (1.3–1.6)	1.6 (1.4–1.8)	1.6 (1.4–2.0)	1.8 (1.5–2.2)	1.6 (1.5–1.7)	1.8 (1.7–2.0)
Mortality						
Low frailty risk	—	—	—	—	—	—
Medium frailty risk	1.1 (0.9–1.3)	1.2 (1.0–1.4)	1.5 (1.1–2.2)	1.7 (1.2–2.4)	1.4 (1.2–1.6)	1.5 (1.2–1.7)
High frailty risk	2.4 (2.0–2.8)	2.9 (2.4–3.4)	2.8 (2.0–3.9)	3.7 (2.6–5.3)	2.9 (2.5–3.3)	3.5 (3.0–4.0)
Disposition to home						
Low frailty risk	—	—	—	—	—	—
Medium frailty risk	0.7 (0.6–0.8)	0.7 (0.7–0.8)	0.6 (0.4–0.7)	0.5 (0.4–0.7)	0.5 (0.5–0.6)	0.6 (0.5–0.6)
High frailty risk	0.4 (0.4–0.5)	0.5 (0.4–0.5)	0.3 (0.2–0.4)	0.3 (0.2–0.4)	0.3 (0.3–0.4)	0.4 (0.3–0.4)

*Adjusted for injury severity score (< or ≥15), gender, and age (5-year increments).
Frailty risk: low (RFF score, 0–13.5), medium (RFF score, 13.6–25.1), high (RFF score, 25.2–100).

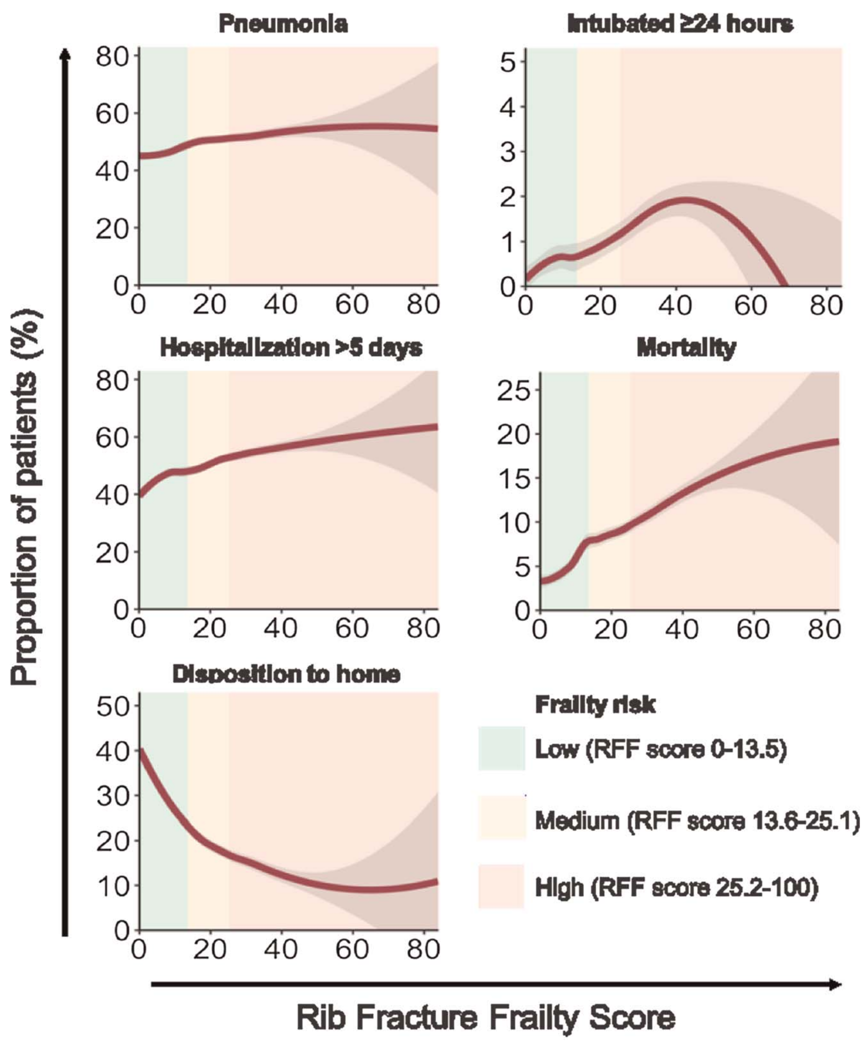

Figure 1. Association between Rib Fracture Frailty scores and outcomes of geriatric patients with multiple rib fractures (external validation cohort). LOWESS estimates with 95% confidence intervals (shade). LOWESS, Locally Weighted Scatterplot Smoothing.

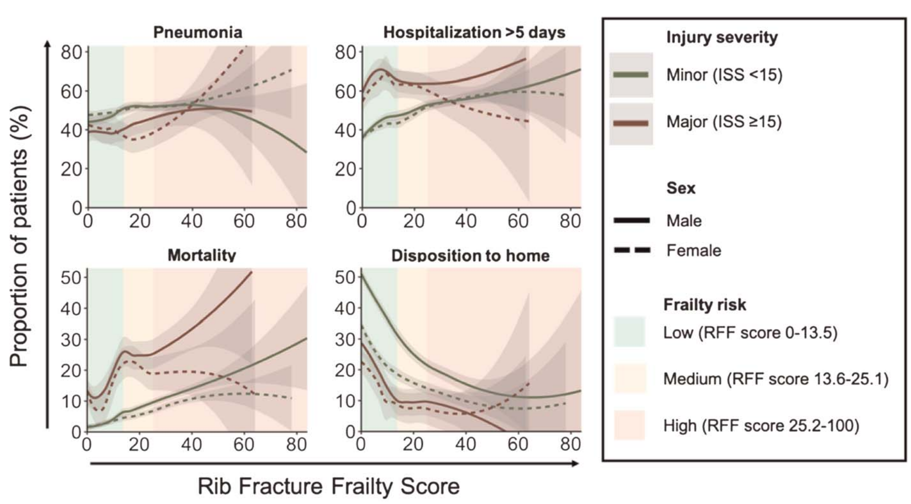

Figure 2. Association between Rib Fracture Frailty scores and outcomes of geriatric patients with multiple rib fractures (external validation cohort), stratified by injury severity and sex. LOWESS estimates with 95% confidence intervals (shade). The maximum RFF score of patients with major injury was 64.

Few external validation cohort patients underwent SSRF (n = 288); we could not assess reliable association between RFF scores and outcomes stratified by operative and nonoperative management. Compared with patients managed nonoperatively, patients who underwent SSRF had lower median RFF scores (8.3 [range, 0–42.0] vs. 12.6 [range, 0–83.9], $p < 0.001$).

Mobile Application

The RFF Index mobile application is available for free download from the Apple App store (Fig. 3).[21]

DISCUSSION

The RFF Index strongly discriminates between patients having characteristics of frailty and those without. Over 90,000 nationwide encounters validated the RFF Index's ability to risk stratify geriatric patients with rib fractures at increased odds of developing pneumonia, requiring mechanical ventilation, prolonged hospitalization, mortality, and adverse discharge disposition. The RFF Index is also practical, comprising a compact list of 13 conditions with intuitive cumulative scores ranging from 0 to 100. Our mobile application facilitates rapid bedside risk prediction.

Retrospectively assigned RFF scores shed light on the interplay between frailty and injury. While patients with minor injury had RFF scores up to 83, the maximum RFF score for patients with major injury was 64. This may reflect very frail patients expiring from major injury before admission (inpatient admission was an inclusion criterion). Lower RFF scores among patients who underwent SSRF compared with those who underwent nonoperative management may reflect surgeons considering operations for more robust geriatric patients. Baseline frailty had greater certainty in predicting adverse outcomes among patients with minor, compared with major, injury. This implies that with greater injury burden, baseline health is less likely to predict clinical outcomes—RFF Index may be especially valuable for geriatric patients with rib fractures as their dominant injury.

Our risk stratification tool integrates frailty into clinical decision making for patients with rib fractures. Current society guidelines predicate clinical decisions (e.g., intensive care unit admission, performing SSRF) on age and rib fracture severity.[10,22] The Western Trauma Association's guidelines recognize that recommending close monitoring based on a cutoff age (65 years) does not account for variation in baseline health among geriatric patients.[10] To our knowledge, the RFF Index is the first risk stratification tool identifying frailty markers associated with rib fracture-specific outcomes. Quantifying frailty may accelerate precision care (optimizing monitoring and interventions for the individual patient) in rib fracture management.

The RFF Index balances reliability and practicality. Most existing trauma frailty prediction models were developed using small, single-institution populations.[5] Generalizing these models to patients in other institutions or specific injuries requires validation and recalibration. Many indices include nonbaseline characteristics (e.g., injury burden) and may be impractical for bedside use, especially in resuscitation areas (e.g., require >50 variable inputs or detailed patient interview). The RFF Index reflects a nationally representative sample, includes only baseline conditions, and is specific for geriatric patients with rib fractures. Comprised of compact list of diagnoses, the RFF Index,

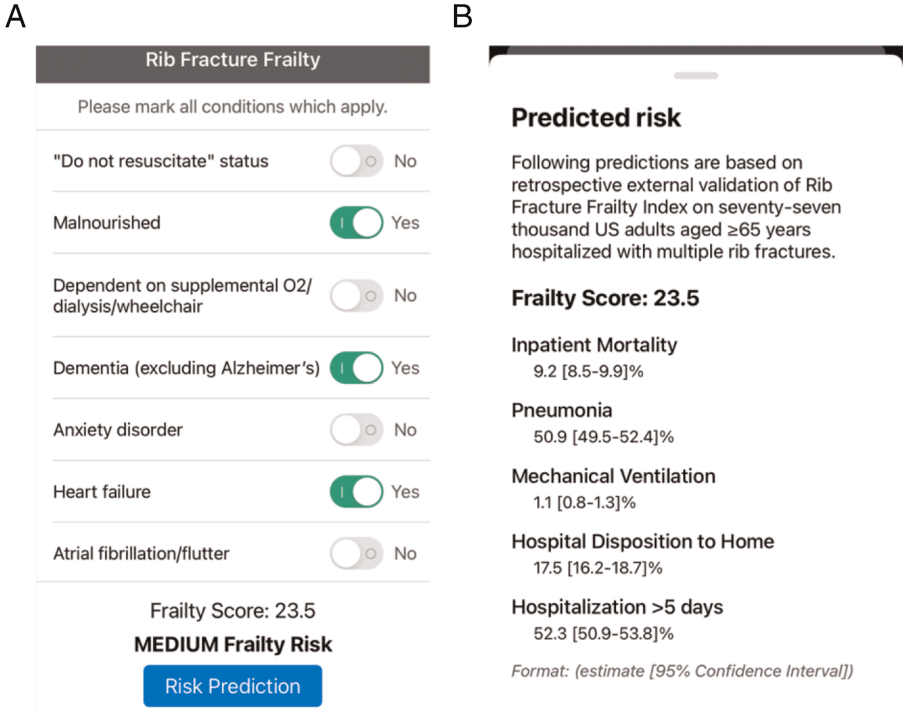

Figure 3. RFF Index user interface. (*A*), Frailty marker selection screen. (*B*) Outcome prediction screen.

especially the mobile application, is practical for bedside use and clinical outcomes research.

Our study has several limitations. First, using the RFF index has not been validated to improve outcomes. Even a perfect risk prediction model would have no clinical utility unless using the model translates to better outcomes. Institutional-level validation and recalibration are required to assess whether using the RFF Index for clinical decision making improves outcomes. We believe the RFF Index's practicality facilitates future validation studies. Second, the RFF index alone cannot dictate management. For example, a geriatric patient with medium frailty risk may be appropriate for intensive care unit monitoring at one hospital, but intermediate care unit monitoring at another hospital. The RFF Index quantifies frailty risk, one of several factors clinicians should use to guide management depending on available resources. Third, our model has limited practical applicability for patients with major multiple trauma. Our estimates had greater uncertainty among patients with major injury. With greater injury burden, baseline health likely has smaller role in dictating outcomes; RFF Index is unlikely to change management of major multiple-trauma patients. Fourth, "low frailty risk" classification requires cautious interpretation. Among patients with RFF score 0, 45% developed pneumonia, 39% were hospitalized >5 days, and inpatient mortality rate was 3%. All geriatric patients with multiple rib fractures require careful monitoring; RFF Index was designed to identify patients at especially high risk of adverse outcomes and not to provide reassurance to those with low frailty risk. Fifth, baseline conditions are retrospectively coded in NIS; both accuracy and completeness are limited to those of individual institutions' coders. A large national database informed model development and preliminary validation, but prospective validation studies are required to inform necessary model recalibrations. Lastly, a majority of our external validation cohort (approximately 75%) had high frailty risk; it is expected that a majority of elderly adults would have high frailty risk at the *population* level. However, the RFF Index remains a valuable tool to quantify frailty risk and inform shared clinician-patient decision making at the *individual level.* As a practical and more robust predictor of important clinical outcomes than age alone, we believe the RFF Index will facilitate prospective evaluation needed to address frailty's role within rib fracture management decisions.

Future studies should evaluate RFF Index's clinical utility for improving patient outcomes and optimizing resource allocation. Prospective validation studies should assess how frailty predicts outcomes in relation to other factors, such as injury patterns.

CONCLUSION

The RFF index is a practical frailty risk stratification tool for geriatric patients with multiple rib fractures. Three frailty risk tiers identify patients at increased odds of pulmonary complications, prolonged hospitalization, mortality, and adverse disposition. Frailty risk stratification may be especially helpful for guiding management of less-severely injured patients or those with rib fractures as dominant injuries. Whether using RFF index improves clinical outcomes requires further study; we expect our mobile application to facilitate prospective validation.

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DISCLOSURE

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