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The revised cardiac risk index is associated with morbidity and mortality independent of injury severity in elderly patients with rib fractures[☆]

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ABSTRACT

Background: Risk factors for mortality and in-hospital morbidity among geriatric patients with traumatic rib fractures remain unclear. Such patients are often frail and demonstrate a high comorbidity burden. Moreover, outcomes anticipated by current rubrics may reflect the influence of multisystem injury or surgery, and thus not apply to isolated injuries in geriatric patients. We hypothesized that the Revised Cardiac Risk Index (RCRI) may assist in risk-stratifying geriatric patients following rib fracture.
Methods: All geriatric patients (age $\geq$65 years) with a conservatively managed rib fracture owing to an isolated thoracic injury (thorax AIS $\geq$1), in the 2013-2019 TQIP database were assessed including demographics and outcomes. The association between the RCRI and in-hospital morbidity as well as mortality was analyzed using Poisson regression models while adjusting for potential confounders.
Results: 96,750 geriatric patients sustained rib fractures. Compared to those with RCRI 0, patients with an RCRI score of 1 had a 16% increased risk of in-hospital mortality [adjusted incidence rate ratio (adj-IRR), 95% confidence interval (CI): 1.16 (1.02-1.32), p=0.020]. An RCRI score of 2 [adj-IRR (95% CI): 1.72 (1.44-2.06), p<0.001] or $\geq$3 [adj-IRR (95% CI): 3.07 (2.31-4.09), p<0.001] was associated with an even greater mortality risk. Those with an increased RCRI also exhibited a higher incidence of myocardial infarction, cardiac arrest, stroke, and acute respiratory distress syndrome.
Conclusions: Geriatric patients with rib fractures and an RCRI $\geq$1 represent a vulnerable and high-risk group. This index may inform the decision to admit for inpatient care and can also guide patient and family counseling as well as computer-based decision-support.

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Background

Damage to the thoracic cage and its contents is common in the injured patient and often drives care in a critical care setting.[1–3] Due to injury evolution, or the impact of aging on inflammatory cascades, the severity of intrathoracic viscera injury may be under-appreciated at admission, while in others, the full extent of the injury complex does not become evident until 48-

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72 hours after injury.[4–8] While the pattern of evolution of tissue damage and loss of function in many patients may be predictable, identifying which of those patient will subsequently decompensate is less clear.[1,9,10] Cardiopulmonary complications such as hospital-acquired pneumonia, acute respiratory insufficiency or failure, hemorrhagic pulmonary contusion, or delayed fracture-associated hemorrhage appears to increase with the number of ribs fractured, fracture location, more severely impaired chest wall mechanics; complications are also associated with patient factors including advanced age, cognitive impairment, and medical comorbidities.[1,6,11–14] Such patients are often triaged to enhanced monitoring locations such as the ICU to mitigate the devastating consequences of unmonitored decompensation.[10] Elderly patients, who are often frail and demonstrate a high comorbidity burden, are at higher risk of developing complications and are less likely to regain their baseline function due to diminished physiologic reserve. Relatedly, a Delphi Consensus Survey conducted by the National Trauma Research Action Plan, identified geriatric rib fracture management within the top three prioritized areas of Geriatric Traumatology.[15]

The Revised Cardiac Risk Index (RCRI) was initially developed to predict 30-day postoperative myocardial infarction, cardiac arrest, or mortality following noncardiac surgery [16,17]. The RCRI has subsequently been validated after emergency abdominal surgery,[18–20] isolated severe traumatic brain injury,[21] as well as in traumatic hip fracture patients,[22,23] the latter serving as a population that also suffers from frailty and a high comorbidity burden. The RCRI has not been assessed as a stratification tool following rib fracture but may reflect the aggregated impact of multimorbidity in a reliable fashion. We hypothesized that the RCRI accurately risk-stratifies geriatric patient mortality after traumatic rib fracture without concomitant injuries.

Methods

All variables were retrieved from the Trauma Quality Improvement Program (TQIP) dataset. These included outcomes such as length of stay, in-hospital mortality and complications, as well as demographic data regarding patient age, sex, race, presence of flail chest and other thoracic injuries, the highest thorax Abbreviated Injury Score (AIS), surgical interventions, and comorbidities. All geriatric patients (65 years or older) registered in the TQIP database between 2013 and 2019 who suffered one or more rib fractures owing to an isolated thoracic injury (thorax AIS $\geq$1 with an AIS $\leq$1 in all other regions), that were managed conservatively (i.e. non-operatively), were included. All patients who underwent thoracic surgery (including rib fracture fixation) were excluded. Since an AIS score of 6 is usually not considered survivable, patients with a thorax AIS of 6 were also excluded. The need for approval by the institutional review board was waived for this study since it only made use of aggregated anonymized retrospective data. All aspects of the study complied with both the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines and Declaration of Helsinki.

Calculation of the RCRI

The RCRI uses six independent and routinely acquired variables: high-risk surgery (any intraperitoneal, intrathoracic, and suprainguinal vascular procedure), history of cerebrovascular disease, renal insufficiency (defined as acute kidney injury or chronic kidney disease), diabetes mellitus, ischemic heart disease, as well as congestive heart failure (Figure 1).[19,21,24–26] Each patient received one point for each variable present. Since this cohort consisted of patients with conservatively managed rib fractures, no patients were included that underwent high-risk surgery; accordingly, the maximum possible score was 5.

Statistical analysis

Patients were sorted into 4 groups based on their RCRI score: RCRI 0, RCRI 1, RCRI 2, RCRI $\geq$3. Demographics and other clinical features pertaining to the patients were aggregated and compared to highlight differences between the groups. Categorical variables were presented as counts along with percentages. Continuous variables were summarized using a median and interquartile range (IQR) since they were non-normally distributed. For the categorical variables, the Chi-square test or Fisher's exact test was used to calculate the statistical significance of differences between the groups, while the Kruskal-Wallis test was applied to continuous variables. The primary outcome of interest was in-hospital mortality. Secondary outcomes consisted of complications recorded in TQIP; these included myocardial infarction, cardiac arrest with CPR, stroke, and acute respiratory distress syndrome (ARDS).

The association between in-hospital mortality and the RCRI was analyzed using a Poisson regression model with robust standard errors. Adjustments were made for age, sex, race, the presence of a flail chest, sternal fracture, pneumothorax, hemothorax, or pulmonary contusion as well as comorbidities. The comorbidities included were hypertension, peripheral vascular disease, dementia, chronic obstructive pulmonary disease, smoking status, liver cirrhosis, drug use disorder, alcohol use disorder, major psychiatric illnesses, coagulopathy, cancer receiving chemotherapy, and metastatic cancer. This analysis was repeated with each of the previously listed complications replacing in-hospital mortality as the outcome. The associations estimated by the models were presented as incident rate ratios (IRRs) and 95% confidence intervals (CIs).

Further, a subgroup analysis was also performed on patients with isolated rib fractures, in which the former analyses were repeated. Isolated rib fracture(s) was defined as the presence of a rib fracture without any intrathoracic injury (pneumothorax, hemothorax, or pulmonary contusion).

Multiple imputation by chained equations was used to manage missing values. Statistical significance was defined as a two-sided p-value $<$0.05. Analyses were performed using the statistical software R 4.1.1 (R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/).

Table 1

Results

The study population consisted of 96,750 conservatively managed rib fracture patients. Patients with a high RCRI score were less often white [RCRI $\geq$3: 81.7% vs RCRI 0: 88.6%, p $<$0.001] and more often male [RCRI $\geq$3: 62.3% vs RCRI 0: 51.9%, p $<$0.001], but there was no clinically significant difference in the median age of the patients. Most comorbidities increased in prevalence at higher RCRI scores, with the exceptions being substance use disorders and patients receiving chemotherapy for cancer (Table 2). Patients with a higher RCRI also generally required a slightly longer hospital stay [RCRI $\geq$3: 5 days vs RCRI 0: 4 days, p $<$0.001]. Moreover, crude in-hospital mortality increased progressively for each additional point on the RCRI [RCRI $\geq$3: 6.0% vs RCRI 0: 1.8%, p $<$0.001]. The same trend was observed in the crude rates of myocardial infarction, cardiac arrest with CPR, stroke, and ARDS, which all increased along with the RCRI score (Table 3).

After adjusting for the previously mentioned covariates, the risk of in-hospital mortality consistently increased with higher RCRI scores. Compared to RCRI 0, patients with RCRI 1 had a 16% higher risk of in-hospital mortality [adjusted IRR 1.16, 95% CI 1.02-1.32, p = 0.20], while patients with RCRI $\geq$3 exhibited a 207% higher

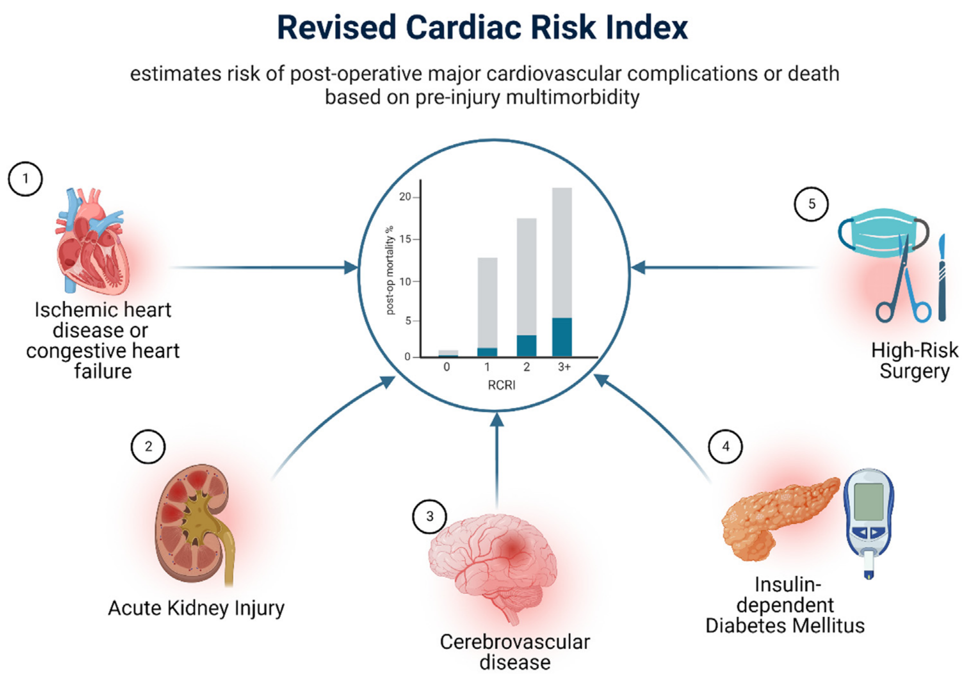

Fig. 1. The Revised Cardiac Risk Index, after Lindenauer et al.[24]

Table 1
Patient demographics and clinical features in geriatric patients with conservatively managed rib fractures

	RCRI 0 (N = 61,442)	RCRI 1 (N = 27,872)	RCRI 2 (N = 6,241)	RCRI ≥3 (N = 1,195)	P-value
Age, median [IQR]	77 [70-83]	77 [71-83]	77 [72-83]	77 [71-83]	<0.001
Sex, n (%)					<0.001
Female	29,557 (48.1)	12,101 (43.4)	2,588 (41.5)	451 (37.7)	
Male	31,870 (51.9)	15,765 (56.6)	3,653 (58.5)	744 (62.3)	
Missing	15 (0.0)	6 (0.0)	0 (0.0)	0 (0.0)	
White, n (%)	54,460 (88.6)	23,799 (85.4)	5,269 (84.4)	976 (81.7)	<0.001
Black, n (%)	2,596 (4.2)	1,549 (5.6)	395 (6.3)	124 (10.4)	<0.001
Asian, n (%)	1,182 (1.9)	676 (2.4)	146 (2.3)	19 (1.6)	<0.001
American Indian, n (%)	171 (0.3)	110 (0.4)	34 (0.5)	7 (0.6)	<0.001
Pacific islander, n (%)	76 (0.1)	54 (0.2)	21 (0.3)	7 (0.6)	<0.001
Other, n (%)	2,132 (3.5)	1,319 (4.7)	318 (5.1)	55 (4.6)	<0.001
Missing	512 (0.8)	214 (0.8)	33 (0.5)	5 (0.4)	
Thorax AIS, n (%)					<0.001
1	6,223 (10.1)	3,157 (11.3)	830 (13.3)	169 (14.1)	
2	15,442 (25.1)	6,929 (24.9)	1,531 (24.5)	314 (26.3)	
3	38,284 (62.3)	17,255 (61.9)	3,771 (60.4)	704 (58.9)	
4	1,206 (2.0)	462 (1.7)	98 (1.6)	8 (0.7)	
5	287 (0.5)	69 (0.2)	11 (0.2)	0 (0.0)	
Flail chest, n (%)	1,385 (2.3)	578 (2.1)	136 (2.2)	10 (0.8)	0.004
Sternal fracture, n (%)	4,294 (7.0)	1,539 (5.5)	221 (3.5)	25 (2.1)	<0.001
Pneumothorax, n (%)	15,264 (24.8)	5,053 (18.1)	898 (14.4)	131 (11.0)	<0.001
Hemothorax, n (%)	7,585 (12.3)	3,079 (11.0)	691 (11.1)	125 (10.5)	<0.001
Pulmonary contusion, n (%)	5,586 (9.1)	2,217 (8.0)	486 (7.8)	88 (7.4)	<0.001

RCRI, Revised Cardiac Risk Index; IQR, Interquartile Range; AIS, Abbreviated Injury Score

risk of in-hospital mortality [adjusted IRR 3.07, 95% CI 2.31-4.09, p <0.001]. Relatedly, the risk of complications also increased at higher RCRI scores. A patient with RCRI ≥3 had a 4 times higher risk of myocardial infarction [adjusted IRR 4.15, 95% CI 1.29-13.34, p = 0.017], an 11 times higher risk of cardiac arrest with CPR [adjusted IRR 10.81, 95% CI 6.48-18.03, p <0.001], and a 6 times higher risk of ARDS [adjusted IRR 5.59, 95% CI 2.30-13.57, p <0.001], compared to those with RCRI 0. A statistically significant increased risk of stroke was only detected for patients with RCRI 1 [adjusted IRR 5.30, 95% CI 1.90-14.82, p = 0.002] and RCRI 2 [adjusted IRR 9.85, 95% CI 3.14-30.94, p <0.001] (Table 4).

A total of 65,375 did not have any intrathoracic injury, i.e. constituted the isolated rib fracture cohort. In this subgroup the analyses detected that an RCRI score ≥2 remained associated with an increased risk of in-hospital mortality (RCRI 2: adj-IRR 1.71, p <0.001; RCRI ≥3: adj-IRR 3.18, p <0.001). There was also an increased risk for in-hospital risk of myocardial infarction (RCRI 2: adj-IRR 6.86, p <0.001; RCRI ≥3: adj-IRR 8.81, p = 0.005) and cardiac arrest with CPR (RCRI 2: adj-IRR 3.53, p <0.001; RCRI ≥3: adj-IRR 12.74, p <0.001). Isolated rib fracture patients with an RCRI score ≥3 also exhibited an excess risk of significantly higher risk of developing ARDS (RCRI ≥3: adj-IRR 8.04, p = 0.003) (Table 5).

Discussion

Outcome assessments for surgical patients occur in the elective pre-operative setting, the urgent or emergency setting, and after injury with or without the need for operative or procedural inter-

Table 2
Comorbidities in geriatric patients with conservatively managed rib fractures

	RCRI 0 (N = 61,442)	RCRI 1 (N = 27,872)	RCRI 2 (N = 6,241)	RCRI ≥3 (N = 1,195)	P-value
Hypertension, n (%)	35,084 (57.1)	21,490 (77.1)	4,990 (80.0)	957 (80.1)	<0.001
Myocardial infarction, n (%)	0 (0.0)	862 (3.1)	755 (12.1)	379 (31.7)	<0.001
Congestive heart failure, n (%)	0 (0.0)	4,296 (15.4)	3,282 (52.6)	959 (80.3)	<0.001
Peripheral vascular disease, n (%)	618 (1.0)	609 (2.2)	243 (3.9)	83 (6.9)	<0.001
Cerebrovascular disease, n (%)	0 (0.0)	2,676 (9.6)	1,812 (29.0)	534 (44.7)	<0.001
Dementia, n (%)	5,896 (9.6)	2,830 (10.2)	676 (10.8)	124 (10.4)	0.002
COPD, n (%)	8,752 (14.2)	5,059 (18.2)	1,619 (25.9)	349 (29.2)	<0.001
Current smoker, n (%)	6,392 (10.4)	2,488 (8.9)	556 (8.9)	94 (7.9)	<0.001
Liver cirrhosis, n (%)	469 (0.8)	426 (1.5)	122 (2.0)	24 (2.0)	<0.001
Drug use disorder, n (%)	930 (1.5)	380 (1.4)	84 (1.3)	13 (1.1)	0.191
Alcohol use disorder, n (%)	2,896 (4.7)	873 (3.1)	167 (2.7)	22 (1.8)	<0.001
Major psychiatric illness, n (%)	6,495 (10.6)	3,207 (11.5)	812 (13.0)	167 (14.0)	<0.001
Diabetes mellitus, n (%)	0 (0.0)	18,785 (67.4)	5,144 (82.4)	1,103 (92.3)	<0.001
Coagulopathy, n (%)	3,794 (6.2)	2,765 (9.9)	876 (14.0)	162 (13.6)	<0.001
Chronic kidney disease, n (%)	0 (0.0)	949 (3.4)	1,215 (19.5)	619 (51.8)	<0.001
Acute kidney injury, n (%)	0 (0.0)	205 (0.7)	194 (3.1)	81 (6.8)	<0.001
Currently receiving chemotherapy for cancer, n (%)	485 (0.8)	209 (0.7)	35 (0.6)	5 (0.4)	0.118
Metastatic cancer, n (%)	781 (1.3)	364 (1.3)	105 (1.7)	21 (1.8)	0.026

RCRI, Revised Cardiac Risk Index; COPD, Chronic Obstructive Pulmonary Disease

Table 3
Crude outcomes in geriatric patients with conservatively managed rib fractures

	RCRI 0 (N = 61,442)	RCRI 1 (N = 27,872)	RCRI 2 (N = 6,241)	RCRI ≥3 (N = 1,195)	P-value
Length of stay, median [IQR]	4.0 [2.0-6.0]	4.0 [3.0-6.0]	5.0 [3.0-8.0]	5.0 [3.0-9.0]	<0.001
Missing, n (%)	602 (1.0)	240 (0.9)	66 (1.1)	13 (1.1)	
In-hospital mortality, n (%)	1,078 (1.8)	582 (2.1)	224 (3.6)	72 (6.0)	<0.001
Missing	4 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	
Myocardial infarction, n (%)	74 (0.1)	63 (0.2)	22 (0.4)	7 (0.6)	<0.001
Cardiac arrest with CPR, n (%)	175 (0.3)	115 (0.4)	43 (0.7)	25 (2.1)	<0.001
Stroke, n (%)	64 (0.1)	51 (0.2)	19 (0.3)	4 (0.3)	<0.001
ARDS, n (%)	87 (0.1)	73 (0.3)	25 (0.4)	8 (0.7)	<0.001

RCRI, Revised Cardiac Risk Index; ARDS, Acute Respiratory Distress Syndrome

Table 4
Incident rate ratios for adverse outcomes based on the RCRI score in geriatric patients with conservatively managed rib fractures

Outcome	RCRI 0	RCRI 1 IRR (95% CI)	P-value	RCRI 2 IRR (95% CI)	P-value	RCRI ≥3 IRR (95% CI)	P-value
In-hospital mortality	Reference	1.16 (1.02-1.32)	0.020	1.72 (1.44-2.06)	<0.001	3.07 (2.31-4.09)	<0.001
Myocardial infarction	Reference	1.78 (1.07-2.96)	0.027	4.42 (2.44-8.01)	<0.001	4.15 (1.29-13.34)	0.017
Cardiac arrest with CPR	Reference	1.66 (1.18-2.35)	0.004	2.76 (1.71-4.45)	<0.001	10.81 (6.48-18.03)	<0.001
ARDS	Reference	1.81 (1.16-2.82)	0.009	2.62 (1.40-4.92)	0.003	5.59 (2.30-13.57)	<0.001

IRRs are calculated using Poisson regression models with robust standard errors. Missing values were managed using multiple imputation by chained equations. Analyses were adjusted for age, sex, race, highest abbreviated injury score in each region, the presence of a flail chest, sternal fracture, pneumothorax, hemothorax, or pulmonary contusion as well as hypertension, peripheral vascular disease, dementia, chronic obstructive pulmonary disease, smoking status, liver cirrhosis, drug use disorder, alcohol use disorder, major psychiatric illnesses, coagulopathy, cancer receiving chemotherapy, metastatic cancer, and advanced directives limiting care.
RCRI, Revised Cardiac Risk Index; IRR, Incident Rate Ratio; CI, Confidence Interval; ARDS, Acute Respiratory Distress Syndrome

vention. Both the American College of Surgeons National Surgical Quality Improvement Program and the Veteran's Affairs Surgical Quality Improvement Program offer morbidity and mortality calculators to assess patient risk for specific outcomes. [27–29] However, these assessment tools were developed principally for elective procedures and may not adequately reflect the risk that injured patients may bear. Following injury, the Trauma Quality Improvement Program offers a similar assessment tool that has been built using aggregate and robust data leveraging preexisting assessors of outcomes such as the Trauma Score (TS), the Revised Trauma Score (RTS), the Trauma and Injury Severity Score (TRISS), and the New Injury Severity Score (NISS) tools. [1,30–33] The performance fidelity of these tools is less than ideal for patients with single system injury, but they may perform better with multiple injuries and higher ISS. Furthermore, advanced age and the interplay of comorbidities may also degrade accurate prediction in the elderly.

Unsurprisingly, and especially for the elderly, other tools have surfaced for use in elective surgery risk prediction including those that incorporate frailty into their metrics. Assessment tools for morbidity and mortality risk after elective surgery are well embedded in pre-operative evaluations and include age, the American Society of Anesthesiologists physical status classification, as well as a host of scoring systems including, but not limited to, that of NSQIP or VASQIP, P-POSSUM, E-PASS, SURPASS, NELA risk calculator, Charlson Comorbidity Index, and the machine learning-based POTTER score.[27–29,34,35] Additional more tightly focused scoring systems explore the risk of post-operative pneumonia, or surgical site infection. Cardiac risk assessment for non-cardiac surgery is indelibly tied to the Goldman score and its revision as the Lee-Goldman score two decades later.[36] Indeed, a detailed assessment of cardiac risk is essential as a high-risk profile should inform specific pre-operative evaluations to determine if risk reduction is possible. Patients with urgent or emergent conditions can seldom pursue such evaluations and may instead undergo more invasive monitoring to detect adverse events. Shifts in patient comorbidities may not reflect the same profiles that generated older risk assessment models.

Table 5
Incident rate ratios for adverse outcomes based on the RCRI score in geriatric patients with conservatively managed, isolated rib fractures (N=65,375)

Outcome	RCRI 0	RCRI 1 IRR (95% CI)	P-value	RCRI 2 IRR (95% CI)	P-value	RCRI ≥3 IRR (95% CI)	P-value
In-hospital mortality	Reference	1.11 (0.92-1.33)	0.266	1.71 (1.33-2.20)	<0.001	3.18 (2.21-4.60)	<0.001
Myocardial infarction	Reference	2.15 (0.86-5.38)	0.103	6.86 (2.65-17.81)	<0.001	8.81 (1.94-40.02)	0.005
Cardiac arrest with CPR	Reference	1.07 (0.55-2.09)	0.843	3.53 (1.77-7.05)	<0.001	12.74 (6.27-25.90)	<0.001
ARDS	Reference	1.81 (0.71-4.58)	0.214	3.02 (0.97-9.39)	0.056	8.04 (2.06-31.31)	0.003

An isolated rib fracture is defined as the presence of a rib fracture without any intrathoracic injuries. IRRs are calculated using Poisson regression models with robust standard errors. Missing values were managed using multiple imputation by chained equations. Analyses were adjusted for age, sex, race, highest abbreviated injury score in each region, the presence of a flail chest, sternal fracture, as well as hypertension, peripheral vascular disease, dementia, chronic obstructive pulmonary disease, smoking status, liver cirrhosis, drug use disorder, alcohol use disorder, major psychiatric illnesses, coagulopathy, cancer receiving chemotherapy, metastatic cancer, and advanced directives limiting care.
RCRI, Revised Cardiac Risk Index; IRR, Incident Rate Ratio; CI, Confidence Interval; ARDS, Acute Respiratory Distress Syndrome

Cardiac ultrasound has advanced our understanding of the interplay of structural and functional abnormalities defining entities such as hypertrophic obstructive cardiomyopathy (HOCM) and Takotsubo cardiomyopathy among others. Vastly improved knowledge of the right ventricle (RV) shifted management from using the RV as a "pass through" mechanism to a chamber that benefits from ionotropic support, and increasingly mechanical support techniques, especially in conjunction with left ventricular failure.[37] Heart failure is now assessed based on the degree of ejection fraction (EF) preservation. As physiology was revealed, new therapeutics blossomed including afterload reducing agents, minimally invasive approaches to valve repair, and implanted devices for rhythm control or rescue. Extracorporeal techniques as rescue therapy or a bridge to organ transplantation are commonplace. So too are undesirable sequelae of non-cardiac therapeutics such as chemotherapy-impaired EF. In contrast, tobacco use (at least in the US) is decreasing, as are occupational exposures.[38,39] Improved glycemic control relies on a host of approaches such as insulin pumps, novel agents, and pancreas transplantation. Many of these elements were not present, or were much less accessible, when older risk models were being developed. Accordingly, cardiac risk tools merited revision.

The RCRI represents one such revision of cardiac risk assessment tools. It is optimally modified to be readily deployable at the bedside without the need for advanced machine learning or artificial intelligence support. The RCRI interweaves the cardiac system and related systems that impact cardiac function. How well the RCRI performs after injury remains opaque. It is therefore most ideal to assess RCRI performance within the context of single system injury. Such a focused approach reduces confounding from other injuries. Certainly, the high-risk group for adverse outcomes driven by cardiac risk are the elderly with less reserve to traumatic stress– the focus of this study.

Our data show an escalating association between multimorbidity (as estimated by RCRI) and post-injury complications as well as mortality, following isolated traumatic rib fractures with and without concomitant intrathoracic organ injury in the elderly patient. When AIS Chest grade is accounted for in regression models, this association appears to persist. The risk of death, cardiac adverse events, and ARDS all increase linearly with increasing RCRI in the current study. Therefore, our data support using the RCRI as a risk stratifying tool in the elderly with rib fractures. How well the RCRI will perform after multi-system injury, or the need for emergency operation for thoracic injuries remains to be studied.

Since the elderly represent an increasing proportion of injured patients presenting to US trauma centers, having a reliable way to assess their risk is warranted. Predominant mechanisms of injury in this group include falls, auto-pedestrian impact, and motor vehicle collisions with blunt assault occurring much less frequently. The elderly are much less impacted by the increase in firearm violence that has permeated the US in concert with the pandemic and public health measures.[40] This study demonstrates that, at least for elderly patients sustaining rib fractures, their in-hospital risk profile is accurately represented by the RCRI. Other metrics such as the PIC score drive the location of inpatient care and may dovetail with the RCRI to assess the need for admission.[10] While the RCRI will assess likely trajectories, some courses may be strongly influenced by the adequacy and the method of analgesia. For instance, an opioid rich analgesic routine may lead to acute respiratory depression while one that principally relies on non-opioid multi-modal analgesia avoids such risks. Neither of these treatment approaches are captured in post-injury risk assessment tools. Moreover, newer methods of analgesia such as cryoablation may substantially influence outcomes by supporting excellent pulmonary hygiene by eliminating rib fracture associated pain.[41–43] Since the RCRI rapidly and strongly identifies discrete risk profiles in the geriatric trauma patient, it seems suitable for incorporation into electronic health records to provide computer aided decision support.

Important limitations that impact the results of our study flow from its retrospective assessment of an administrative dataset. Therefore, the results should be interpreted as associative and hypothesis generating rather than definitive. The interaction between number of rib fractures and outcomes is mired in controversy. While some studies have demonstrated a positive association between the number of rib fractures and patient outcomes, others have failed to do so, focusing more on derangements of ventilatory mechanics associated with an unstable chest wall and underlying pulmonary contusion. The inquiry focus in this manuscript was on the multimorbidity burden, as assessed by risk stratification tools such as RCRI. Acknowledging that to cross-tabulate the cohort by number of rib fractures would substantially increase the complexity of the statistical analysis, while decreasing its power and clinical utility, we instead used the Abbreviated Injury Scale and the presence of flail chest, as well other underlying injuries (pneumothorax, hemothorax, pulmonary contusion etc) as aggregated measures of thoracic injury severity, presuming them to be co-linear with number of ribs fractured. This methodology is more translatable to actual bedside application.

We also did not assess whether the RCRI led to any cardioprotective therapies, but that was not the goal of the study. There has been data suggesting that therapies such as beta-blockade could mitigate the physiological stress reaction to the traumatic injury which might cause adverse cardiac outcomes and increased mortality in geriatric patients with hip fractures. The protective association of beta-blockade therapy increased with increasing cardiac risk.[44] We sought to assess whether the RCRI accurately predicted risk in elderly patients with unisystem and limited injury. While it was not possible to find evidence of a statistically significant association between RCRI 1 and adverse outcomes in the subgroup analysis, this does not necessarily indicate that such an association does not exist. A significant proportion of patients were removed when excluding intrathoracic injuries, which further reduced the already relatively small event rate. This result may consequently indicate a lack of statistical power rather than a lack of a clinically relevant relationship. Nonetheless, this study explicitly excludes all polytraumatized patients, and thus interpretation of the data should be limited to emergency management of elderly patients with traumatic rib fractures. Finally, we did not compare the RCRI to other assessment tools, but this exploratory study intended only to determine if the RCRI was suitable to use following injury in a specific subset of injured patients.

Conclusion

The RCRI is an easy and rapid indicator for risk stratification of elderly patients presenting with rib fractures who are managed conservatively. Patients with an elevated RCRI should be deemed high-risk and specifically assessed for the need for advanced monitoring or cardioprotective therapies during inpatient care. This study suggests that the RCRI is a good candidate for risk assessment following complex unisystem injury in geriatric patients.

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Author Contributions

GAB: study design, analysis and interpretation of data, drafting and revision of manuscript

CCD: study design, interpretation of data, drafting and revision of manuscript

LJK: analysis and interpretation of data, drafting and revision of manuscript

BS: study design, data acquisition, interpretation of data, drafting and revision of manuscript

NDM: study design, interpretation of data, drafting and revision of manuscript

AMI: interpretation of data, drafting and revision of manuscript

YC: analysis and interpretation of data, drafting and revision of manuscript

MPF: study design, analysis and interpretation of data, drafting and revision of manuscript

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Declaration of Competing Interest

The authors have no conflicts of interest to declare and have received no financial benefit in the execution of this study.

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