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Age or Frailty: What Predicts Outcomes in Geriatric Patients With Rib Fractures?

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ABSTRACT

Introduction: Age and frailty are associated with poor outcomes in geriatric patients with rib fractures. To date, no studies have assessed the *relative and independent* association of each factor using a large national dataset. We therefore sought to determine whether age, frailty, or their combined consideration most effectively predicts outcomes in geriatric patients with rib fractures.

Methods: The 2017-2023 TQIP database was queried for all geriatric patients (age ≥65 y) who sustained at least one rib fracture. A multivariate analysis with propensity score matching was performed to examine the difference in outcomes between geriatric adults with low frailty or high frailty based on the modified frailty index. A logistic model controlling for sex, race, vital signs, injury scores, and comorbidities was conducted to test for association between age, frailty, and mortality.

Results: In total, 203,131 geriatric patients were included. Matched geriatric patients with high frailty had higher overall mortality compared to low-frailty patients ($P < 0.001$). When directly compared with a multivariate analysis, age (odds ratio: 1.379, $P < 0.001$) and high frailty (odds ratio: 1.806, $P < 0.001$) were independently associated with increased risk of mortality. High frailty was associated with longer lengths of stay, higher rates of ICU admission, and more discharges to skill nursing facilities ($P < 0.001$).

Conclusions: These results suggest that both advanced age and high frailty are both independently associated with higher mortality and worse outcomes following rib fractures in geriatric patients. Improving outcomes in geriatric rib fractures will require attention to both chronological and physiological ages.

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Introduction

Rib fractures place trauma patients at risk of significant morbidity and even mortality.[1,2] As the population of trauma patients continues to increase in average age, rib fractures have emerged as a strong predictor of morbidity and mortality in geriatric trauma patients.[3,4]

When addressing the geriatric trauma patient, two crucial factors come into play. The first factor is the chronological age. Bulger *et al.* not only showed that patients over 65 y with more than 4 rib fractures were more likely to suffer complications than younger patients, but they also showed that for every additional rib fracture in an elderly patient, there was a 27% increase in the risk of pneumonia and a 19% increase in mortality.[5] More recently, a 2018 study reported a 9.4% mortality rate in geriatric trauma patients who were admitted with one or more rib fractures.[6] Although the definition of "geriatric" trauma varies, age ≥65 y remains the most commonly used threshold in national trauma datasets, clinical guidelines, and prior rib fracture literature.

The second important factor for geriatric trauma patients with rib fractures is the physiological age, or frailty, which is defined as the multidimensional syndrome of loss of reserves (energy, physical ability, cognition, and health).[7] In the broader scope of trauma patients, frailty has been shown to predict worse outcomes irrespective of their particular injuries.[8] In geriatric trauma patients who have suffered rib fractures, several studies have suggested that frailty serves as a prognostic indicator for unfavorable outcomes. For example, in their 2019 study, Schmoekel *et al.* demonstrated that frailty was a stronger predictor of outcomes than severity of rib fractures.[9] However, this study was single institutional and may lack generalizability. Choi *et al.* also found that frail patients had more complications from rib fractures than their nonfrail counterparts.[10] Nonetheless, the study utilized the National Inpatient Sample, which captures only a minority of all trauma admissions across the United States (US).

While both age and frailty have been established as predictors of outcomes in geriatric patients, their relative weight remains less clear. When Feng *et al.* compared frail and nonfrail patients, they found that while frail patients were at higher risk of longer length of stay (LOS), more nonrespiratory complications, and higher likelihood of discharge to a skilled nursing facility (SNF), age was more predictive of mortality than frailty.[7] Once again, the study was a single institutional study and lacked broader applicability. They also assessed frailty using a clinical opinion scale rather than an objective metric.

To date, no large database study or multicenter trial has explored the relative and joint prognostic utility of age and frailty in predicting outcomes in geriatric trauma patients who have suffered rib fractures. The objective of this study was to address these gaps by examining the association of age, frailty, and clinical outcome in a large, multicenter database. We hypothesized that chronological age and frailty would provide independent and complementary prognostic information, together improving risk stratification for mortality and adverse clinical outcomes in geriatric patients with rib fractures.

Methods

Study design and patient population

A 7-y (2017-2023) retrospective analysis of the TQIP database was conducted (Fig. 1). The TQIP database contains data from nearly 900 US trauma centers.[11] Institutional review board approval was exempted for this study because TQIP only contains deidentified patient information.

Patients who had a rib fracture diagnosis were captured (Supplemental Table 1). Patients were excluded if they were of pediatric age, had advanced directives that limited their care (i.e., only if directives limited life-sustaining treatment), suffered penetrating injury, had any nonthoracic abbreviated injury score (AIS) >2, were missing data for one or more variables in the regression analysis, or were less than 65 y of age. We stratified patients into "low frailty" (0-2 comorbidities) and "high frailty" (≥3 comorbidities) groups based on the five-factor modified frailty index (mFI-5). The mFI-5 is a comorbidity-based frailty stratification tool that has validity evidence for use in large databases including the National Surgical Quality Improvement Program and TQIP.[12-14] The 5 variables comprising the index include: 1) chronic obstructive pulmonary disease (COPD); 2) congestive heart failure (CHF); 3) diabetes; 4) hypertension (HTN) requiring medications; and 5) functionally dependent health status. Each mFI-5 component was coded as present or absent based on corresponding TQIP comorbidity variables, with one point assigned for each present condition, yielding a total score ranging from 0 to 5. The mFI-5 was selected a priori because it is validated for use in large national trauma datasets such as TQIP, relies on consistently captured admission comorbidity variables, and enables reproducible frailty assessment at scale; in contrast, trauma- or rib fracture–specific frailty indices incorporate functional, psychosocial, or ICD-based elements that are not uniformly available or reliably coded in TQIP. Consistent with prior trauma literature, the mFI-5 was analyzed as a dichotomous variable to enhance interpretability and clinical applicability in a large national database. Frailty was categorized as low (0-2) *versus* high (≥3) to avoid overclassification driven by common age-associated comorbidities and ensure that the high-frailty group reflected clinically meaningful physiologic vulnerability.

The study was reported according to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines (Supplemental Table 2).[15]

Data extraction

The TQIP database was queried for patients meeting the inclusion criteria, and relevant data were extracted by the research team. The following patient characteristics were collected: demographics (age, sex, and race), comorbidities (alcoholism, anticoagulation use, bleeding disorder, cerebrovascular accident [CVA], COPD, chronic renal failure, cirrhosis, CHF, current smoker, chemotherapy, dementia, diabetes, disseminated cancer, functionally dependent health status, HTN, myocardial infarction [MI], peripheral arterial disease

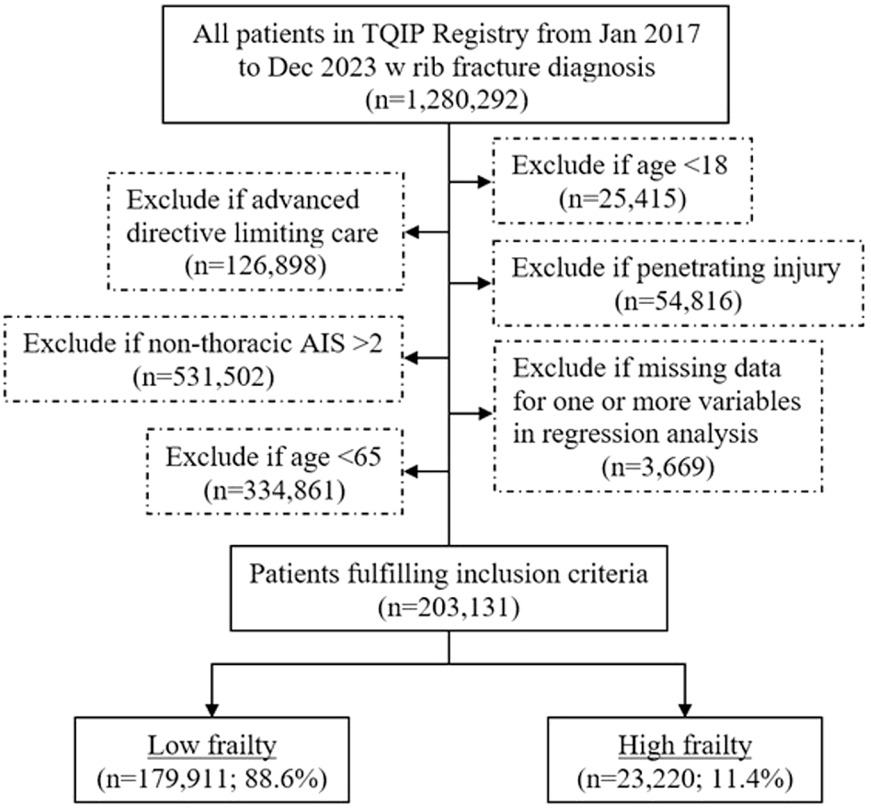

Fig. 1 – Study flow diagram.

[PAD], steroid use, and substance use disorder), injury mechanism (motor vehicle trauma-occupant, motor vehicle trauma-motorcycle occupant, motor vehicle trauma-bicycle, motor vehicle trauma-pedestrian, motor vehicle trauma-other, fall, assault, and other injury), ED vital signs (systolic blood pressure [SBP], heart rate [HR], and respiratory rate [RR]), injury scores (injury severity score [ISS], thoracic-abbreviated injury score [thoracic-AIS], and Glasgow coma scale [GCS]), and rib fracture pathology (one rib closed, one rib open, multiple ribs closed, multiple ribs open, flail chest, pneumothorax, hemothorax, pneumohemothorax, and rib plating [Supplemental Table 1]).

The primary outcome collected was in-hospital mortality. ED and 24-h mortality were also collected. Secondary outcomes collected included need for ICU admission, need for mechanical ventilation, hospital LOS, ICU LOS, ventilator days, and discharge disposition (care facility, home). Hospital complications were also collected (alcohol withdrawal, acute kidney injury [AKI], acute respiratory distress syndrome [ARDS], cardiac arrest with CPR, catheter-associated urinary tract infection [CAUTI], central line–associated blood stream infection [CLABSI], deep surgical site infection (SSI), deep vein thrombosis [DVT], delirium, MI, pulmonary embolism [PE], pressure ulcer, severe sepsis, CVA, superficial SSI, unplanned admission to ICU, unplanned visit to OR, and ventilator-associated pneumonia [VAP]).

Data analysis

Demographics and outcomes were compared between high- and low-frailty patients using Wilcoxon rank-sum testing (continuous) and Chi-square testing (categorical).[16] Continuous data were reported as medians with interquartile ranges (IQRs), and categorical data were reported as percentages.

A logistic regression model was used to create 2 matched groups of high-frailty *versus* low-frailty patients using a 1:1 greedy matching scheme.[17] The groups were matched on exact age, exact thoracic-AIS, gender, race, select comorbidities (alcoholism, CVA, renal failure, cirrhosis, smoking, and MI), and injury parameters (AIS-thoracic, pneumothorax, hemothorax, pneumohemothorax, flail chest, single rib fracture, multiple rib fractures, or rib plating procedure). The standardized mean differences (SMDs) after matching were used to assess balance between groups, with SMDs less than 0.1 indicating sufficient balance in baseline covariates between the matched groups, which was achieved in this study[18] (Supplemental Table 3). Logistic multivariate analyses were conducted to determine the impact of these variables on mortality, the primary outcome.[19] Of note, the odds ratio (OR) for age was modeled for each 10-y increase in age and each 1-point increase in AIS-thoracic. All other variables in the model were categorical.

Significance was set at $P < 0.05$. All analyses were performed using SAS software version 9.4.

Table 1 – Comparison of geriatric patient characteristics by frailty before propensity score matching.

Variables	High frailty (n = 23,220)	Low frailty (n = 179,911)	OR (95% CI)	P value
Age, y, median [IQR]	77 (72-83)	75 (69-81)		<0.001
Male, *n* (%)	12,879 (55.5)	104,820 (58.3)	0.89 (0.87-0.92)	<0.001
Race, *n* (%)				
White	20,652 (88.9)	159,895 (88.9)	1.01 (0.96-1.05)	0.763
Black	1232 (5.3)	8039 (4.5)	1.20 (1.13-1.27)	<0.001
American Indian	102 (0.4)	721 (0.4)	1.10 (0.88-1.35)	0.385
Asian	365 (1.6)	3839 (2.1)	0.73 (0.66-0.82)	<0.001
Pacific Islander	40 (0.2)	312 (0.2)	0.99 (0.70-1.38)	0.968
Other	869 (3.7)	7417 (4.1)	0.90 (0.84-0.97)	0.006
Comorbidity, *n* (%)				
Alcoholism	1167 (5.0)	9415 (5.2)	0.96 (0.90-1.02)	0.181
Anticoagulant	9845 (42.4)	36,179 (20.1)	2.92 (2.84-3.01)	<0.001
Bleeding disorder	665 (2.9)	2336 (1.3)	2.24 (2.05-2.45)	<0.001
CVA	1950 (8.4)	6208 (3.5)	2.57 (2.43-2.70)	<0.001
Chronic obstructive pulmonary disease	12,065 (52.0)	15,342 (8.5)	11.60 (11.25-11.96)	<0.001
Chronic renal failure	1532 (6.6)	3468 (1.9)	3.59 (3.38-3.82)	<0.001
Cirrhosis	729 (3.1)	2517 (1.4)	2.28 (2.10-2.48)	<0.001
CHF	10,591 (45.6)	6528 (3.6)	22.27 (21.49-23.09)	<0.001
Current smoker	3334 (14.4)	18,643 (10.4)	1.45 (1.39-1.51)	<0.001
Chemotherapy	224 (1.0)	1412 (0.8)	1.23 (1.06-1.42)	0.004
Dementia	3001 (12.9)	13,092 (7.3)	1.89 (1.81-1.97)	<0.001
Diabetes	16,440 (70.8)	34,924 (19.4)	10.07 (9.76-10.38)	<0.001
Disseminated cancer	388 (1.5)	1825 (1.0)	1.46 (1.30-1.64)	<0.001
Functionally dependent health status	14,005 (60.3)	17,494 (9.7)	14.11 (13.68-14.55)	<0.001
Hypertension	22,188 (95.6)	107,934 (60.0)	14.34 (13.46-15.29)	<0.001
MI	550 (2.4)	2067 (1.1)	2.09 (1.89-2.30)	<0.001
PAD	1454 (6.3)	2736 (1.5)	4.33 (4.05-4.62)	<0.001
Steroid use	972 (4.2)	2875 (1.6)	2.69 (2.50-2.90)	<0.001
Substance use disorder	536 (2.3)	3589 (2.0)	1.16 (1.06-1.27)	0.001
Mechanism of injury, *n* (%)				
Fall	18,044 (77.7)	101,053 (56.2)	2.73 (2.64-2.82)	<0.001
MVT-occupant	3657 (15.7)	45,307 (33.7)	0.56 (0.54-0.58)	<0.001
MVT-motorcycle occupant	252 (1.1)	6767 (3.9)	0.28 (0.25-0.32)	<0.001
MVT-bicycle	21 (0.0)	1644 (0.9)	0.10 (0.06-0.15)	<0.001
MVT-pedestrian	155 (0.7)	3338 (1.9)	0.36 (0.30-0.42)	<0.001
MVT-other	370 (1.6)	5466 (3.1)	0.52 (0.46-0.58)	<0.001
Assault	90 (0.4)	1209 (0.7)	0.58 (0.46-0.71)	<0.001
Other injury	631 (2.7)	15,127 (9.2)	0.30 (0.27-0.32)	<0.001
Vitals, median (IQR)				
Systolic BP (mmHg)	141 (123-161)	143 (126-162)		<0.001
Pulse (bmp)	81 (70-93)	81 (70-93)		0.222
Respiratory rate (/min)	18 (16-20)	18 (16-20)		<0.001
Injury scores, median (IQR)				
GCS	15 (15-15)	15 (15-15)		<0.001
ISS	10 (8-13)	10 (9-14)		<0.001
AIS-thoracic	3 (2-3)	3 (2-3)		0.748
Rib fracture pathology, *n* (%)				
One rib fx, closed	4303 (18.6)	30,529 (17.0)	1.11 (1.07-1.15)	<0.001
One rib fx, open	12 (0.1)	74 (0.0)	1.26 (0.62-2.33)	0.462

(*continued*)

Table 1 – (*continued*)

Variables	High frailty (n = 23,220)	Low frailty (n = 179,911)	OR (95% CI)	P value
Multiple rib fx, closed	18,339 (79.0)	143,927 (80.0)	0.94 (0.91-0.97)	<0.001
Multiple rib fx, open	30 (0.1)	223 (0.1)	1.04 (0.69-1.53)	0.831
Flail chest	765 (3.3)	7712 (4.3)	0.76 (0.70-0.82)	<0.001
Pneumothorax	2388 (10.3)	33,056 (18.4)	0.51 (0.49-0.53)	<0.001
Hemothorax	1575 (6.8)	12,047 (6.7)	1.01 (0.96-1.07)	0.619
Hemopneumothorax	1248 (5.4)	13,826 (7.7)	0.68 (0.64-0.72)	<0.001
Rib plating	305 (1.3)	3666 (2.0)	0.64 (0.57-0.72)	<0.001

95% CI = 95% confidence interval; AIS = abbreviated injury score; BP = blood pressure; CHF = congestive heart failure; CVA = cerebrovascular accident; GCS = Glasgow coma scale; IQR = interquartile range; MI = myocardial infarction; OR = odds ratio; PAD = peripheral arterial disease.

Table 2 – Comparison of geriatric patient outcomes by frailty before propensity score matching.

Variables, n (%)	High frailty (n = 23,220)	Low frailty (n = 179,911)	OR (95% CI)	P value
Mortality, n (%)				
Death in ED	50 (0.2)	1160 (0.6)	0.33 (0.25-0.44)	<0.001
24 h	1072 (4.6)	3852 (2.1)	2.21 (2.06-2.37)	<0.001
In-hospital	1186 (5.1)	5237 (2.9)	1.80 (1.68-1.92)	<0.001
Hospital LOS, day, median (IQR)	5.0 (2.9-8.8)	3.8 (1.9-6.8)		<0.001
ICU admission, n (%)	9506 (40.9)	64,820 (36.0)	1.23 (1.20-1.27)	<0.001
ICU LOS, d, median (IQR)	4 (2-6)	3 (2-5)		<0.001
Mechanical ventilation, n (%)	1973 (8.5)	11,131 (6.2)	1.41 (1.34-1.48)	<0.001
Vent days, day, median (IQR)	4 (2-9)	4 (2-9)		<0.001
Complications, n (%)				
Cardiac arrest	331 (1.4)	1557 (0.9)	1.66 (1.47-1.87)	<0.001
MI	89 (0.4)	373 (0.2)	1.85 (1.45-2.34)	<0.001
Ventilator-associated pneumonia	81 (0.3)	453 (0.3)	1.39 (1.08-1.76)	0.007
ARDS	74 (0.3)	430 (0.2)	1.33 (1.03-1.71)	0.022
Acute kidney injury	367 (1.6)	1225 (0.7)	2.34 (2.08-2.64)	<0.001
Cerebrovascular accident	92 (0.4)	420 (0.2)	1.70 (1.34-2.14)	<0.001
Deep vein thrombosis	138 (0.6)	903 (0.5)	1.19 (0.98-1.42)	0.064
Pulmonary embolism	49 (0.2)	531 (0.3)	0.71 (0.52-0.96)	0.024
Delirium	746 (4.5)	2486 (2.2)	2.14 (1.96-2.32)	<0.001
Catheter urinary tract infection	51 (0.2)	313 (0.2)	1.26 (0.92-1.70)	0.122
Catheter blood stream infection	6 (0.0)	55 (0.0)	0.84 (0.30-1.96)	0.695
Surgical site infection, deep	5 (0.0)	46 (0.0)	0.84 (0.26-2.11)	0.715
Surgical site infection, superficial	7 (0.0)	44 (0.0)	1.23 (0.47-2.76)	0.607
Severe sepsis	183 (0.8)	633 (0.4)	2.25 (1.90-2.66)	<0.001
Alcohol withdrawal	158 (0.7)	1327 (0.7)	0.92 (0.78-1.09)	0.336
Pressure ulcer	176 (0.8)	694 (0.4)	1.97 (1.66-2.33)	<0.001
Unplanned admit to ICU	1290 (5.6)	4974 (2.8)	2.07 (1.94-2.20)	<0.001
Unplanned visit to OR	13 (0.2)	111 (0.2)	1.13 (0.59-2.02)	0.667
Discharge locations, n (%)				
Long-term care	10,983 (48.3)	62,209 (36.3)	1.64 (1.59-1.69)	<0.001
Home	9543 (41.9)	100,102 (58.4)	0.52 (0.50-0.53)	<0.001

95% CI = 95% confidence interval; ARDS = acute respiratory distress syndrome; IQR = interquartile range; LOS = length of stay; MI = myocardial infarction; OR = odds ratio.

Results

Unmatched demographics by frailty

A total of 203,131 geriatric patients suffered at least one rib fracture in the 2017-2023 TQIP database. Of those patients, 179,911 (88.6%) had low frailty and 23,220 (11.4%) had high frailty. The characteristics of low-frailty *versus* high-frailty patients are shown in Table 1. High-frailty patients were older than low-frailty patients (77 *versus* 75 y, $P < 0.001$). A lower percentage of high-frailty patients were male (55.5% *versus* 58.3%, $P < 0.001$), although there was no difference in the percentage of White patients by group (88.9% *versus* 88.9%, $P = 0.763$). All comorbidities were more common among high-frailty patients except for alcoholism (all $P < 0.001$). High-frailty patients were more likely to suffer a fall (77.7% *versus* 56.2%, $P < 0.001$) and less likely to suffer injuries from all other mechanisms than low-frailty patients (all $P < 0.001$). Patients with high frailty had lower SBPs (141 *versus* 143, $P < 0.001$) but similar HRs (81 *versus* 81, $P = 0.222$) to patients with low frailty on admission. There were no differences in AIS-thoracic scores between groups (3 *versus* 3, $P = 0.748$).

High-frailty patients were more likely to suffer a single closed rib fracture (18.6% *versus* 17.0%, $P < 0.001$) and less likely to suffer multiple closed rib fractures (79.0% *versus* 80.0%, $P < 0.001$) or flail chest (3.3% *versus* 4.3%, $P < 0.001$) than low-frailty patients. High-frailty patients were less likely to have a pneumothorax (10.3% *versus* 18.4%, $P < 0.001$) or hemopneumothorax (5.4% vs 7.7%, $P < 0.001$) than low-frailty patients. There was no difference in the number of patients suffering hemothoraces between groups (6.8% *versus* 6.7%, $P = 0.619$). A lower percentage of high-frailty patients underwent rib plating than low-frailty patients (1.3% *versus* 2.0%, $P < 0.001$).

Unmatched outcomes by frailty

The outcomes of low-frailty *versus* high-frailty patients are shown in Table 2. High-frailty patients had a higher 24-h (4.6% *versus* 2.1%, $P < 0.001$) and overall mortality (5.1% *versus* 2.9%, $P < 0.001$) than low-frailty patients despite a lower mortality rate in the ED (0.2% *versus* 0.6%, $P < 0.001$). High-frailty patients had longer hospital LOS (5.0 d *versus* 3.8 d, $P < 0.001$) and were more likely to require ICU admission (40.9% *versus* 36.0%, $P < 0.001$) than low-frailty patients. A higher percentage of high-frailty patients required mechanical ventilation than low-frailty patients (8.5% *versus* 6.2%, $P < 0.001$). Cardiac arrest (1.4% *versus* 0.9%, $P < 0.001$), MI (0.4% *versus* 0.2%, $P < 0.001$), VAP (0.3% *versus* 0.3%, $P = 0.007$), ARDS (0.3% *versus* 0.2%, $P = 0.022$), AKI (1.6% *versus* 0.7%, $P < 0.001$), CVA (0.4% *versus* 0.2%, $P < 0.001$), delirium (4.5% *versus* 2.2%, $P < 0.001$), severe sepsis (0.8% *versus* 0.4%, $P < 0.001$), pressure ulcer (0.8% *versus* 0.4%, $P < 0.001$), and unplanned admission to ICU (5.6% *versus* 2.8%, $P < 0.001$) were all more common among high-frailty patients. There was no difference in DVT (0.6% *versus* 0.5%, $P = 0.064$), CAUTI (0.2% *versus* 0.2%, $P = 0.122$), CLABSI (0.0% *versus* 0.0%, $P = 0.695$), deep SSI (0.0% *versus* 0.0%, $P = 0.715$), superficial SSI (0.0% *versus* 0.0%, $P = 0.607$), alcohol withdrawal (0.7% *versus* 0.7%, $P = 0.336$), or unplanned visit to OR (0.2% *versus* 0.2%, $P = 0.667$) between groups. PE was more common among low-frailty patients (0.2% *versus* 0.3%, $P = 0.024$). High-frailty patients were more likely to be discharged to a long-term care facility than low-frailty patients (48.3% *versus* 36.3%, $P < 0.001$).

Matched demographics by frailty

After 1:1 propensity score matching, 2 similar groups of patients were created with low *versus* high frailty ($n = 23,219$). The characteristics of matched low-frailty *versus* high-frailty patients are shown in Table 3. High-frailty patients were younger than low-frailty patients (77 *versus* 78 y, $P = 0.042$). There was no difference in the percentage of male patients between groups (55.5% *versus* 55.4%, $P = 0.941$). There were fewer White patients in the high-frailty group than low-frailty group (88.9% *versus* 89.7%, $P = 0.008$). All comorbidities were more common among high-frailty patients except for alcoholism, CVA, chronic renal failure, cirrhosis, current smoker, chemotherapy, and MI (all $P < 0.001$). High-frailty patients were more likely to suffer a fall (77.7% *versus* 62.8%, $P < 0.001$) and less likely to suffer injuries from all other mechanisms than low-frailty patients (all $P < 0.01$). Patients with high frailty had lower SBPs (141 *versus* 144, $P < 0.001$) but similar HRs (81 *versus* 81, $P = 0.321$) to patients with low frailty on admission. There were no differences in AIS-thoracic scores between groups (3 *versus* 3, $P = 0.748$).

There were no differences in the number of patients who suffered a single closed rib fracture (18.5% *versus* 18.6%, $P = 0.914$), multiple closed rib fractures (79.0% *versus* 79.0%, $P = 0.900$), or flail chest (3.3% *versus* 3.0%, $P = 0.106$) between groups. There were no differences in the number of patients who suffered pneumothorax (10.3% *versus* 10.0%, $P = 0.333$), hemopneumothorax (5.4% *versus* 5.1%, $P = 0.253$), or hemothorax (6.8% *versus* 6.5%, $P = 0.248$) between groups. There was no difference in the number of patients who underwent rib plating between groups (1.3% *versus* 1.2%, $P = 0.226$).

Matched outcomes by frailty

The outcomes of matched low-frailty *versus* high-frailty patients are shown in Table 4. High-frailty patients had a higher 24-h (4.6% *versus* 2.3%, $P < 0.001$) and overall mortality (5.1% *versus* 2.9%, $P < 0.001$) than low-frailty patients despite a lower mortality rate in the ED (0.2% *versus* 0.4%, $P < 0.001$). High-frailty patients had longer hospital LOS (5.0 d *versus* 3.9 d, $P < 0.001$) and were more likely to require ICU admission (40.9% *versus* 35.2%, $P < 0.001$) than low-frailty patients. A higher percentage of high-frailty patients required mechanical ventilation than low-frailty patients (8.5% *versus* 5.7%, $P < 0.001$). Cardiac arrest (1.4% *versus* 0.8%, $P < 0.001$), MI (0.4% *versus* 0.2%, $P < 0.001$), VAP (0.3% *versus* 0.2%, $P < 0.001$), ARDS (0.3% *versus* 0.2%, $P = 0.008$), AKI (1.6% *versus* 0.6%, $P < 0.001$), CVA (0.4% *versus* 0.2%, $P = 0.002$), delirium (4.5% *versus* 2.2%, $P < 0.001$), CAUTI (0.2% *versus* 0.1%, $P = 0.049$), severe sepsis (0.8% *versus* 0.3%, $P < 0.001$), pressure ulcer (0.8% *versus* 0.4%, $P < 0.001$), and unplanned admission to ICU (5.6% *versus* 2.7%, $P < 0.001$) were all more common among high-frailty patients. There was no difference in DVT (0.6% *versus* 0.5%, $P = 0.055$), PE (0.2% *versus* 0.2%, $P = 0.556$), CLABSI (0.0% *versus* 0.0%,

Table 3 — Comparison of geriatric patient characteristics by frailty after propensity score matching.

Variables	High frailty ($n = 23,219$)	Low frailty ($n = 23,219$)	OR (95% CI)	P value
Age, y, median [IQR]	77 (72-83)	78 (72-83)		0.042
Male, *n* (%)	12,878 (55.5)	12,870 (55.4)	1.00 (0.97-1.04)	0.941
Race, *n* (%)				
White	20,652 (88.9)	20,829 (89.7)	0.92 (0.87-0.98)	0.008
Black	1231 (5.3)	1119 (4.8)	1.11 (1.02-1.20)	0.018
American Indian	102 (0.4)	64 (0.3)	1.60 (1.16-2.22)	0.003
Asian	365 (1.6)	402 (1.7)	0.91 (0.78-1.05)	0.178
Pacific Islander	40 (0.2)	28 (0.1)	1.43 (0.86-2.41)	0.145
Other	869 (3.7)	805 (3.5)	1.08 (0.98-1.20)	0.111
Comorbidity, *n* (%)				
Alcoholism	1167 (5.0)	1146 (4.9)	1.01 (0.94-1.11)	0.654
Anticoagulant	9844 (42.4)	5738 (24.7)	2.24 (2.15-2.33)	<0.001
Bleeding disorder	664 (2.9)	355 (1.5)	1.90 (1.66-2.17)	<0.001
CVA	1949 (8.4)	1,884 (8.1)	1.04 (0.97-1.11)	0.273
Chronic obstructive pulmonary disease	12,065 (52.0)	2274 (9.8)	9.96 (9.47-10.48)	<0.001
Chronic renal failure	1531 (6.6)	1478 (6.4)	1.04 (0.96-1.12)	0.318
Cirrhosis	729 (3.1)	686 (3.0)	1.06 (0.96-1.19)	0.246
CHF	10,591 (45.6)	1107 (4.8)	16.75 (15.68-17.90)	<0.001
Current smoker	3333 (14.4)	3289 (14.2)	1.02 (0.96-1.07)	0.559
Chemotherapy	224 (1.0)	203 (0.9)	1.10 (0.91-1.34)	0.307
Dementia	3001 (12.9)	2180 (9.4)	1.43 (1.35-1.52)	<0.001
Diabetes	16,439 (70.8)	4646 (20.0)	9.69 (9.28-10.12)	<0.001
Disseminated cancer	343 (1.5)	261 (1.1)	1.32 (1.12-1.56)	<0.001
Functionally dependent health status	14,004 (60.3)	3069 (13.2)	9.98 (9.53-10.45)	<0.001
Hypertension	22,187 (95.6)	14,742 (63.5)	12.36 (11.55-13.24)	<0.001
MI	550 (2.4)	526 (2.3)	1.05 (0.93-1.18)	0.459
PAD	1454 (6.3)	500 (2.3)	3.04 (2.74-3.37)	<0.001
Steroid use	972 (4.2)	398 (1.7)	2.51 (2.22-2.83)	<0.001
Substance use disorder	536 (2.3)	421 (1.8)	1.28 (1.12-1.46)	<0.001
Mechanism of injury, *n* (%)				
Fall	18,043 (77.7)	14,576 (62.8)	2.07 (1.99-2.16)	<0.001
MVT-occupant	3657 (15.8)	5434 (23.4)	0.61 (0.58-0.64)	<0.001
MVT-motorcycle occupant	252 (1.1)	522 (2.2)	0.48 (0.41-0.56)	<0.001
MVT-bicycle	21 (0.1)	144 (0.6)	0.15 (0.09-0.23)	<0.001
MVT-pedestrian	155 (0.7)	338 (1.5)	0.45 (0.37-0.55)	<0.001
MVT-other	370 (1.6)	592 (2.5)	0.62 (0.54-0.71)	<0.001
Assault	90 (0.4)	129 (0.6)	0.70 (0.53-0.92)	0.008
Other injury	631 (2.7)	1484 (6.4)	0.40 (0.36-0.44)	<0.001
Vitals, median (IQR)				
Systolic BP (mmHg)	141 (123-161)	144 (127-163)		<0.001
Pulse (bmp)	81 (70-93)	81 (70-92)		0.321
Respiratory rate (/min)	18 (16-20)	18 (16-20)		<0.001
Injury scores, median (IQR)				
GCS	15 (15-15)	15 (15-15)		0.538
ISS	10 (8-13)	10 (8-14)		<0.001
AIS-thoracic	3 (2-3)	3 (2-3)		0.257
Rib fracture pathology, *n* (%)				
One rib fx, closed	4303 (18.5)	4312 (18.6)	1.00 (0.95-1.05)	0.914
One rib fx, open	12 (0.1)	13 (0.1)	0.92 (0.38-2.19)	0.841

(*continued*)

Table 3 – (*continued*)

Variables	High frailty (n = 23,219)	Low frailty (n = 23,219)	OR (95% CI)	P value
Multiple rib fx, closed	18,338 (79.0)	18,349 (79.0)	1.00 (0.95-1.04)	0.900
Multiple rib fx, open	30 (0.1)	17 (0.1)	1.77 (0.94-3.41)	0.058
Flail chest	765 (3.3)	704 (3.0)	1.09 (0.98-1.21)	0.106
Pneumothorax	2388 (10.3)	2325 (10.0)	1.03 (0.97-1.09)	0.333
Hemothorax	1575 (6.8)	1513 (6.5)	1.04 (0.97-1.12)	0.248
Hemopneumothorax	1248 (5.4)	1193 (5.1)	1.05 (0.97-1.14)	0.253
Rib plating	305 (1.3)	276 (1.2)	1.11 (0.94-1.31)	0.226

95% CI = 95% confidence interval; AIS = abbreviated injury score; BP = blood pressure; CHF = congestive heart failure; CVA = cerebrovascular accident; GCS = Glasgow coma scale; IQR = interquartile range; MI = myocardial infarction; OR = odds ratio; PAD = peripheral arterial disease.

Table 4 – Comparison of geriatric patient outcomes by frailty after propensity score matching.

Variables, n (%)	High frailty (n = 23,219)	Low frailty (n = 23,219)	OR (95% CI)	P value
Mortality, n (%)				
Death in ED	50 (0.2)	91 (0.4)	0.55 (0.38-0.78)	<0.001
24 h	1072 (4.6)	538 (2.3)	2.04 (1.83-2.27)	<0.001
In-hospital	1186 (5.1)	667 (2.9)	1.82 (1.65-2.01)	<0.001
Hospital LOS, d, median (IQR)	5.0 (2.9-8.8)	3.9 (2.0-6.8)		<0.001
ICU admission, n (%)	9506 (40.9)	8176 (35.2)	1.28 (1.23-1.32)	<0.001
ICU LOS, d, median (IQR)	4 (2-6)	3 (2-5)		<0.001
Mechanical ventilation, n (%)	1973 (8.5)	1327 (5.7)	1.53 (1.42-1.65)	<0.001
Vent days, d, median (IQR)	4 (2-9)	4 (2-8)		<0.001
Complications, n (%)				
Cardiac arrest	331 (1.4)	182 (0.8)	1.83 (1.52-2.21)	<0.001
MI	89 (0.4)	48 (0.2)	1.86 (1.29-2.70)	<0.001
Ventilator-associated pneumonia	81 (0.3)	35 (0.2)	2.32 (1.54-3.55)	<0.001
ARDS	74 (0.3)	45 (0.2)	1.65 (1.12-2.44)	0.008
Acute kidney injury	367 (1.6)	129 (0.6)	2.87 (2.34-3.54)	<0.001
Cerebrovascular accident	92 (0.4)	54 (0.2)	1.71 (1.21-2.44)	0.002
Deep vein thrombosis	138 (0.6)	108 (0.5)	1.28 (0.99-1.66)	0.055
Pulmonary embolism	49 (0.2)	55 (0.2)	0.89 (0.59-1.33)	0.556
Delirium	746 (4.5)	370 (2.2)	2.12 (1.87-2.42)	<0.001
Catheter urinary tract infection	51 (0.2)	33 (0.1)	1.55 (0.98-2.47)	0.049
Catheter blood stream infection	6 (0.0)	8 (0.0)	0.75 (0.21-2.47)	0.593
Surgical site infection, deep	5 (0.0)	5 (0.0)	1.00 (0.23-4.35)	1.000
Surgical site infection, superficial	7 (0.0)	2 (0.0)	3.50 (0.67-34.54)	0.096
Severe sepsis	183 (0.8)	74 (0.3)	2.48 (1.89-3.30)	<0.001
Alcohol withdrawal	158 (0.7)	147 (0.6)	1.08 (0.85-1.36)	0.527
Pressure ulcer	176 (0.8)	82 (0.4)	2.16 (1.65-2.84)	<0.001
Unplanned admit to ICU	1290 (5.6)	636 (2.7)	2.09 (1.89-2.30)	<0.001
Unplanned visit to OR	13 (0.2)	12 (0.2)	1.01 (0.43-2.43)	0.978
Discharge locations, n (%)				
Long-term care	10,982 (48.3)	8888 (40.0)	1.40 (1.35-1.45)	<0.001
Home	9543 (41.9)	12,062 (54.3)	0.61 (0.59-0.63)	<0.001

95% CI = 95% confidence interval; ARDS = acute respiratory distress syndrome; IQR = interquartile range; LOS = length of stay; MI = myocardial infarction; OR = odds ratio.

Table 5 – Matched logistic model with estimated odds ratios for risk of death, matched.

Comparison	OR (95% CI)	P value
High frailty	1.806 (1.638-1.991)	<0.001
Age (10-y ↑)	1.379 (1.281-1.484)	<0.001
Male gender	1.528 (1.382-1.690)	<0.001
Race, *n* (%)		
Black *versus* White	1.003 (0.803-1.253)	0.940
Other *versus* White	1.025 (0.837-1.256)	0.841
Comorbidities		
Alcoholism	1.019 (0.819-1.268)	0.865
CVA	1.022 (0.861-1.212)	0.804
Renal disease	2.007 (1.721-2.341)	<0.001
Cirrhosis	2.468 (2.013-3.025)	<0.001
Smoking	1.122 (0.973-1.293)	0.114
MI	1.091 (0.813-1.464)	0.561
Injury specifics		
AIS-thorax (1-point ↑)	1.522 (1.391-1.665)	<0.001
Hemothorax	2.155 (1.869-2.486)	<0.001
Pneumothorax	1.654 (1.446-1.892)	<0.001
Hemopneumothorax	1.895 (1.602-2.243)	<0.001
Single rib fracture	1.714 (1.183-2.484)	0.004
Multiple rib fractures	1.285 (0.895-1.845)	0.175
Flail chest	1.811 (1.270-2.583)	0.001
Rib plating procedure	0.829 (0.589-1.169)	0.285

95% CI = 95% confidence interval; AIS = abbreviated injury score; CVA = cerebrovascular accident; MI = myocardial infarction; OR = odds ratio.

$P = 0.593$), deep SSI (0.0% *versus* 0.0%, $P = 1.000$), superficial SSI (0.0% *versus* 0.0%, $P = 0.096$), alcohol withdrawal (0.7% *versus* 0.6%, $P = 0.527$), or unplanned visit to OR (0.2% *versus* 0.2%, $P = 0.978$) between groups. High-frailty patients were more likely to be discharged to a long-term care facility than low-frailty patients (48.3% *versus* 40.0%, $P < 0.001$).

Multivariable regression

The multivariable regression analysis for in-hospital mortality is shown in Table 5 and Figure 2. High frailty (OR 1.806, $P < 0.001$), 10-y increase in age (OR 1.379, $P < 0.001$), male gender (OR 1.528, $P < 0.001$), renal disease (OR 2.007, $P < 0.001$), and cirrhosis (OR 2.468, $P < 0.001$) were associated with increased risk of mortality. Injury-specific parameters associated with an increased risk of mortality include one-point increase in AIS-thoracic (OR 1.522, $P < 0.001$), hemothorax (OR 2.155, $P < 0.001$), pneumothorax (OR 1.654, $P < 0.001$), hemopneumothorax (OR 1.895, $P < 0.001$), single rib fracture (OR 1.714, $P = 0.004$), and flail chest (OR 1.811, $P = 0.001$).

Discussion

Thus far, there has been no extensive database study or multicenter trial investigating the utility of age and frailty as predictors of outcomes in trauma patients with rib fractures. The goal of our study was to leverage the TQIP database to address these knowledge gaps. We have shown that both age and frailty are independently associated with an increased risk of mortality with high frailty carrying a slightly higher odds ratio for mortality (1.806) compared to each 10-y increase in age (1.379). They are complementary predictors of mortality

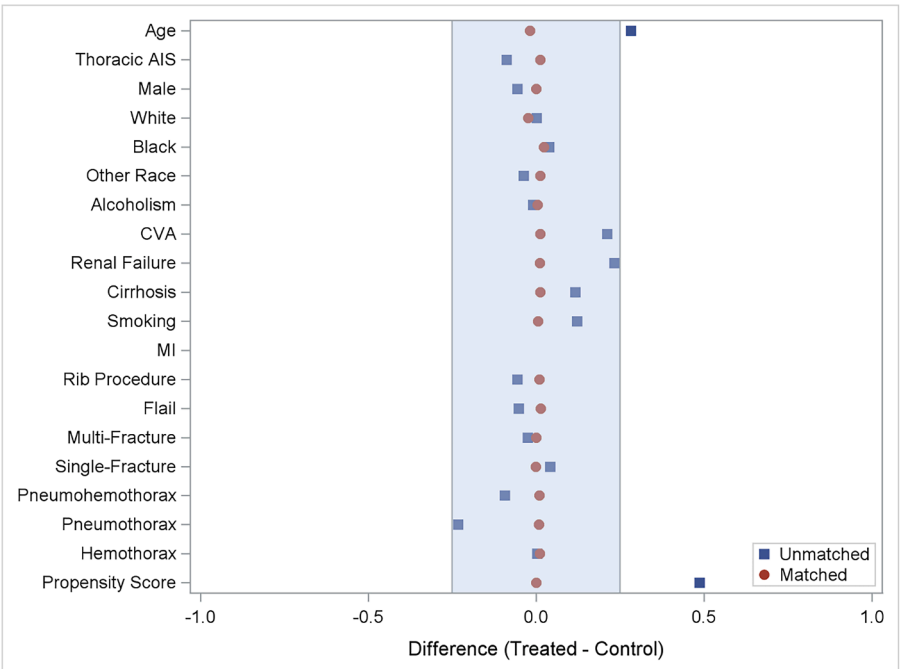

Fig. 2 – Logistic regression model showing the odds ratio and 95% confidence interval for listed variables on mortality.

following geriatric rib fractures. Furthermore, frailty is associated with multiple adverse outcomes including prolonged hospital LOS, admission to the ICU, and increased likelihood of discharge to skilled care facilities. Interestingly, in our matched comparison by frailty groups, high-frailty patients suffered worse outcomes despite being slightly younger (77 *versus* 78 y, $P = 0.042$). While patients in the high frailty group had lower ED mortality, they had higher 24-h and in-hospital mortality than patients in the low frailty group. This may be because highly frail patients cannot mount a successful response to trauma and succumb to complications of the insult rather than dying initially.

Traditionally, the mFI-5 has been used to separate patients into nonfrail, frail (one comorbidity), and severely frail (≥2 comorbidities) groups.[20] However, this index has been criticized for overcategorizing patients as severely frail, given that 75% of American adults over 65 y have HTN and 30% have diabetes.[21] In this study, specifically, 64% of the total sample had HTN and 25% had diabetes. We stratified patients into 2 categories for this study: "low frailty" (0-2 comorbidities) and "high frailty" (≥3 comorbidities). We selected a higher threshold (3 comorbidities) to ensure that the high frailty group reflected clinically meaningful physiologic vulnerability rather than common age-associated comorbidity alone.

While the definition of "geriatric" is arbitrary, we chose 65 y of age as our cutoff. A survey of members of the American Association for the Surgery of Trauma found that only 40% of respondents felt that age >65 y alone was an appropriate cutoff with 30% suggesting age >55 y with major comorbidities or age >65 y without.[22] Our group's own work in blood transfusion has suggested that age 63 y can be used as a cutoff for defining geriatric trauma patients.[23] Ultimately, defining who should be considered a "geriatric" patient is nuanced and likely varies with specific clinical scenario. Sensitivity analyses using alternative age thresholds could be considered in future work. Nevertheless, we chose 65 given the prevailing convention.

Our data demonstrate a clear link between advanced age and higher mortality following rib fractures. This is consistent with multiple studies that have similarly found advanced age to be a risk factor for higher mortality following rib fracture.[4,9] The physiology of the aged alone is enough to confer higher mortality despite an objectively equal or lower overall injury burden.[24,25] Similarly, among geriatric patients, increased frailty conveys an increased risk of mortality and worse outcomes in this study. Our matched analysis showed higher overall mortality in the high frailty group, which was corroborated with the multivariate regression. Several prior studies have also demonstrated that frailty is associated with increased mortality[8,26,27]; however, these studies only examined the effect of frailty on a set of patients who were all geriatric aged without considering the intersection of frailty with age. Six studies that utilized a multivariable regression to analyze the impacts of frailty and age were identified by a 2023 meta-analysis of frailty in elderly trauma patients.[28] All 6 studies reported an association with frailty and adverse outcomes.[27,29-33] Only 2 showed simultaneous associations with increased age.[30,33] A more recent study of geriatric patients requiring massive blood transfusion in the TQIP database also demonstrated independent associations of increased age and frailty on mortality.[20] Ultimately, our data suggest that frailty may be useful to stratify risk in the geriatric patient presenting with rib fractures. When choosing which patient may require higher initial resource utilization to reduce the risk of mortality, and when having discussions with family about prognosis, advanced age and frailty must be recognized and strongly considered.

Frail geriatric patients require higher resources. In our study, high frailty was associated with higher resource utilization, and patients with high frailty showed increased likelihood of requiring ICU admission and mechanical ventilation. These results suggest that frailty may be useful as a screening tool, either on initial evaluation or in the ICU, as a predictor for need for respiratory support.[34]

The pairwise comparisons suggest a clear link between frailty and adverse discharge disposition, similar to other studies.[7,27,35] Halevi *et al.* showed that the comorbidities with highest risk of discharge to facility were chronic renal failure, CVA, CHF, dementia, and liver disease.[36] When developing the rib fracture frailty index, dementia, anxiety, CHF, A fib, CAD, COPD, CKD, GERD, and OA were identified as strong predictors of patients in the "frailty group," which was defined as patients with prolonged LOS, prolonged intubation, and discharge to a skilled facility. Four of the 5 components of the mFI-5 are the presence of key medical comorbidities, namely HTN, CHF, COPD, and diabetes. The presence of these major comorbidities certainly decreases patients' "physiologic reserve," as they alone can require inpatient admission and intensive outpatient resources to remedy. When coupled with the sudden physiologic insult of a major traumatic injury, it comes as a little surprise that many of these patients are unable to adequately compensate, and that they often require significant intervention to survive and recover from the injury. Frailty, perhaps, may best be used as a measure to screen for these high-risk patients, an approach that has been trialed with some success.[30,34]

Our study has several noteworthy limitations. As a retrospective observational analysis of the data entered into TQIP, we are unable to draw any causal implications. Perhaps most importantly, the usage of TQIP limited us to the variables that are reported in the database. For example, TQIP does not quantify the number of rib fractures sustained; while it has been clearly demonstrated that the number of rib fractures correlates to rising mortality in geriatric patients,[1,2,5] TQIP only reports rib fractures as "single" or "multiple," precluding granular analysis and matching based on the number of fractured ribs. In our regression analysis, we found that having a single rib fracture is associated with an increased risk of mortality, whereas having multiple rib fractures is not. The location of rib fractures (upper *versus* midzone *versus* lower) and fracture type and degree of displacement are all pertinent to outcomes yet are missing from TQIP. It is possible that these confounding variables could explain this finding.[37,38] TQIP also does not include whether a patient presented to the hospital directly from home or a facility, which could impact outcomes. Similarly, we do not have access to institution-specific data which prohibit the investigation of regional disease and treatment patterns. The definition of one particular exclusion—advanced directives limiting care—changed during the study period. In years 2022-2023, this variable

represented patients with advanced directives that have limited care. However, in years 2017-2021, this variable represented patients with advanced directives that may or may not have limited care. We excluded patients tagged with the variable advanced directives that have limited care, although we note that this introduced bias into our sample. Nevertheless, we believe that the overall impact of this definitional change on our findings is modest because advanced directives are uncommon among trauma patients, and earlier exclusion of frail patients with directives not limiting care would tend to dilute the observed association between frailty and outcomes. Thus, any bias introduced is likely conservative, underestimating rather than overstating the association between frailty and outcomes. Similarly, patients who were missing racial data were excluded given the presence of this variable in the regression model. While we only excluded 2534/205,665 patients (1%), there were differences between those excluded and those included. These small differences are likely insignificant clinically but remain an important limitation (Supplemental Table 4). Additionally, we chose mortality as the study's primary outcome. While other complications more directly linked to rib fractures such as respiratory failure requiring mechanical ventilation, VAP, and ARDS were described (all more common in the high frailty group), survival is the most critical patient outcome.

Specific measures of strength and functional status, a key component of many frailty indices, are also lacking within the TQIP database, and measuring these for further study would likely require the development of a large local dataset. For example, the trauma-specific frailty index (TSFI) predicts poor short-term outcomes and outcomes at 3 mo postinjury in a prospective, multi-institutional study.[39] However, the TSFI includes an assessment of daily activities (e.g. assistance with managing money) and health attitudes (e.g. feeling less useful) that are not available in TQIP. Other indices such as the rib fracture frailty index are based on ICD codes.[10] This could be applied to TQIP in the future and compared to the performance of the mFI-5. Furthermore, while we utilized ICU admission as a secondary outcome, we do not know if these patients were appropriately triaged. This specific question remains outside of the scope of this specific study but is ripe for future investigation as it relates to patient age and frailty. Opportunities exist for further study in this area, such as implementing screening programs for frailty in high-volume trauma centers to allow for more accurate assessment and sorting of patients into frailty groups and targeting ancillary services toward high-risk patients to allow early intervention and hopefully improvement in outcomes. Physiologic parameters including incentive spirometry and forced vital capacity—data that are not captured in large database studies—may be useful additions to clinical decision-making in future research.

Clinical utility of findings

Our results show that chronological age remains a critical risk factor in geriatric trauma and should not be supplanted by frailty. Rather, both serve as complementary predictors, each with direct clinical relevance in the management of geriatric rib fracture patients. Practical applications include:

- Incorporating frailty screening into standard trauma admission protocols for older patients, including rib fracture pathways. This should include key comorbidities such as those in the mFI-5 (CHF, COPD, DM, HTN, and functionally dependent health status) when more complex assessments (including TSFI) are not practical, especially in elderly and obtunded patients.
- Supporting resource allocation and promoting early multidisciplinary involvement (ICU triage, respiratory support, and geriatric and palliative care consultation). Attention to only chronological age overtriages patients to ICUs.[40]
- Guiding prognostic discussions with patients and families, providing more individualized and accurate counseling by integrating both age and frailty. Frail and/or elderly patients are not only more likely to die from their injuries but have an increased likelihood of a nonhome discharge.

Conclusions

In conclusion, the results from our analysis of the TQIP data show that both chronological age and frailty are associated with a worse survivorship following rib fractures. Frailty was associated with increased overall LOS, increased length of ICU stay, longer ventilator time, and a higher likelihood of discharge to rehabilitation facilities. These findings highlight the importance of targeted treatments and interventions for geriatric patients—especially those who are frail—to decrease the morbidity and mortality associated with geriatric traumatic rib fractures. Our findings provide robust, national-level evidence that both age and frailty are essential, complementary considerations in geriatric trauma care. Operationalizing both factors can improve clinical decision-making, strengthen patient and family counseling, and inform system-level planning. Improving outcomes in this population will require attention to both chronological and physiological ages.

Supplementary Materials

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jss.2026.02.026.

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CRediT authorship contribution statement

Kevin Todd: Writing – original draft, Project administration, Investigation, Conceptualization. **Joseph C. L'Huillier:** Writing – original draft, Methodology, Investigation, Conceptualization. **Kabir Jalal:** Writing – original draft, Methodology, Formal analysis, Conceptualization. **Heather J. Logghe:** Writing – original draft, Project administration, Conceptualization. **Jeffrey M. Jordan:** Writing – review & editing, Investigation. **William Flynn:** Writing – review & editing, Methodology, Conceptualization. **Weidun Alan Guo:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Conceptualization.

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