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# Comparison of individual and composite radiographic markers of frailty in trauma☆

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ABSTRACT

*Background:* Clinical frailty scores usually involve questionnaires or physical testing. Many trauma patients are not able to participate in these. Radiographic measurement of frailty may be a viable alternative. Individual radiographic markers of frailty have been investigated, such as sarcopenia or osteopenia. The ideal radiographic variable (or variables) to measure frailty in trauma is unknown.

*Study design:* A retrospective review was performed of restrained drivers ages 40 and greater at a single institution from 2010-2015. Multiple markers of radiographic frailty were measured including: sarcopenia, osteopenia, vascular calcifications, sarcopenic obesity, emphysema, renal volume, cervical spine degeneration, and cerebral atrophy. Frailty was defined as the worst quartile for each radiographic variable, and these values were summed to create a composite marker of frailty. The primary outcome was discharge disposition. We hypothesized that a composite frailty score would be associated with discharge disposition while individual markers would not be associated with discharge disposition.

*Results:* Overall 489 patients were included in this study. Cerebral atrophy ($p = 0.05$), renal volume ($p = 0.004$), sarcopenia ($p = 0.05$), vascular calcifications ($p = 0.02$) and sarcopenic obesity ($p = 0.01$) were associated with discharge disposition. Pearson's correlation coefficients between radiographic frailty markers were all less than 0.4. Youden's Index was 0.26 ($p < 0.001$) at a composite score of 3. In multivariable analysis, the composite score of 3 or greater was associated with poor discharge disposition (OR 2.39, 95% CI 1.10–5.18, $p = 0.03$).

*Conclusions:* Individual radiographic frailty markers are inadequate markers of frailty, as they may miss patients who are frail. This study also suggests that a composite radiographic frailty score may better predict patient outcome than individual radiographic markers of frailty.

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## Introduction

Chronological age has traditionally been used as a surrogate marker for overall health and resilience, with age and mortality associated in traumatic injury [1,2]. Wide variability in health is present within any chronologic age, and age no longer aptly portrays underlying strength and resilience. The phenotype of "frailty" accounts for this variability of health within chronological age [3]. Frailty includes physical qualities which quantify the physiology of aging such as muscle strength, bone strength, body mass index (BMI), infection susceptibility, risk of delirium, and physical ability [3].

Many described frailty measurements cannot be applied to all trauma patients. Clinical frailty scores and even trauma specific scoring often involve physical tests or clinical questionnaires [4,5]. For example, patients with traumatic brain injuries may be unable participate in questionnaires due to their injury. This leaves a substantial gap in our ability to measure frailty in trauma patients.

Radiographic markers provide an ideal measurement of frailty in patients who are unable to participate in clinical frailty scoring systems, as radiographic measures require no patient participation. Isolated radiographic frailty measures such as osteopenia and sarcopenia have been investigated and have been found to be associated with outcomes in trauma patients [6,7]. However, these

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isolated radiographic measures of frailty do not encompass the spectrum of physiologic changes in frailty, and the ideal radiographic frailty measurement remains unknown and unstandardized.

The primary aim of this study was to compare both individual and composite markers of frailty to discharge disposition. The secondary aim of the study was to evaluate the predictive power of a composite marker of frailty with the outcome of discharge disposition. We hypothesized that a composite frailty score would be associated with outcomes in motor vehicle crash patients while individual markers of frailty would not.

## Materials and methods

The University of Maryland Institutional Review Board (IRB) first approved this review. A retrospective review of restrained drivers in motor vehicle crashes with airbag deployment was performed from 2010 to 2015 at the R Adams Cowley Shock Trauma Center. This specific patient population was chosen to control for force applied during the trauma. Patients aged 40 years and older were included (rather than only elderly patients) to allow development of appropriate histograms; collection of only elderly patients or too many non-frail patients would both have potential to skew the radiographic measures. This cut-off point of 40 years of age was at the authors' discretion. Elderly was defined as age 60 years and greater [8,9].

The primary outcome was a composite marker of discharge disposition. Good discharge disposition was defined as discharge from the initial hospitalization to either home or an acute rehabilitation facility, while poor discharge disposition was discharge to a subacute rehabilitation facility, skilled nursing facility, hospice facility, ventilator rehabilitation facility, or the morgue. Decision for discharge disposition is at the discretion of our therapists and physicians and is without a standardized protocol. There was no secondary outcome measured given the focus of this study on statistical development; certainly outcomes such as failure to rescue have been associated with frailty as well [10,11].

Computerized tomography (CT) images were reviewed using TeraRecon Aquarias version 4.4 (TeraRecon, Foster City, CA). CT data acquisition was performed by trained evaluators (M.R. and K. S). CT images were reviewed de-novo for this study. Eight radiographic frailty measurements were evaluated: sarcopenia, osteopenia, vascular calcification, sarcopenic obesity, emphysema, renal volume, cervical spine degeneration, and cerebral atrophy. Many of the frailty measurements had been measured prior [12–19]. Measurement methods for variables in this study are described in Fig. 1.

These radiographic frailty measurements were chosen to reflect multiple physiologic traits of frailty. Osteopenia and sarcopenia were chosen to reflect bone and muscle strength. Vascular calcifications were chosen to represent loss of cardiovascular compliance and emphysema loss of pulmonary reserve. Cervical spine degeneration with osteophytes was chosen to reflect loss of flexibility, and cerebral atrophy loss of mental acuity. Sarcopenic obesity accounted for gaining body fat coupled with losing physiologic strength.

Univariate analysis was performed for patient demographics, injury characteristics, radiographic frailty measurements, and outcomes. Radiographic frailty measurements were visually assessed for normality. Bivariate analysis was performed using chi-square testing, t-tests, and Wilcoxon rank sum testing where appropriate. Pearson's correlation coefficients were calculated for inter-variable correlation. Probability levels of $p < 0.05$ were considered statistically significant. Appropriate cut-off values for Injury Severity Score (ISS) and admission Glascow Coma Scale (GCS) Score were created based on the distribution of these scores in our patient population. Statistical analysis was performed using SAS version 9.4 (Copyright © 2014, SAS Institute Inc., SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA).

Each radiographic frailty measurement was stratified into quartiles as reasonable breakpoints would allow, with "frail" defined as the worst quartile as previously described [6]. A "frail" value was given a score of 1 and "not frail" a score of 0 for each of the eight radiographic frailty measurements. These 0 or 1 values

| Radiographic Variable | Description of Measurement Technique | Frailty Cutpoint |
|---|---|---|
| Sarcopenia | Bilateral psoas muscle cross-sectional area at L3 level normalized for height ($cm^2/m^2$) | ≤ 5.21 |
| Osteopenia | Attenuation value for trabecular vertebral bone at L3 (Houndsfeld units) | 0-125 |
| Vascular Calcifications | Fraction of calcification for abdominal aorta cross sections averaged from T12-L3 (no units) | ≥ 0.0961 |
| Sarcopenic Obesity | Total adipose cross sectional area divided by total skeletal muscle area at L3 (no units) | > 3.30 |
| Emphysema | Fraction of pulmonary bullae cross sectional area (-1024 to -950 HU) in total lung parenchyma (-1024 to -500 HU) at pulmonary artery bifurcation (no units) | >0.00331 |
| Renal Volume | Volume using multilevel manual tracings normalized for height ($cm^3/m^2$) | ≤ 75 |
| Cervical Spine Degeneration | Osteophytes scored for C2-C7 using 0-3 scale and summed for maximum value of 15. 0 = no osteophytes, 1 = <2mm, 2 = 2-4mm, 3 = >4mm. Largest osteophyte at each cervical level used for scoring (no units) | ≥ 7 |
| Cerebral Atrophy | Ratio of combined lateral ventricle midpoint width to cranial width in same plane (no units) | >0.2137 |

**Fig. 1.** Methodology for measuring each radiographic frailty variable.
cm centimeter, m meter, L3 third lumbar vertebrae, T12 twelfth thoracic vertebrae, C2 second cervical vertebrae, C7 seventh lumbar vertebrae.

were summed to create a composite frailty score. This composite score then ranged from 0 to 8, with "0" representing the least frail value and "8" representing most frail. A receiver operator characteristic (ROC) curve was constructed comparing the continuous composite score to discharge disposition. To determine the composite score best defining frailty a Youden's Index was calculated for each composite score cutpoint. A Youden's Index can be calculated along a ROC curve and determine the best value for the test measured by the ROC. A similar ROC was created for age.

Binary logistic regression was conducted to determine if the composite score was associated with poor discharge disposition following adjustment by patient and injury characteristics. Characteristics in bivariate analysis with a p-value <0.2 and those felt a priori clinically significant were placed into the model. Model variables included: age 60 and greater, ISS 9 and greater, admission GCS 3-14, sex, not African American race, systolic blood pressure (SBP) less than 100 mmHg, heart rate (HR) 100 beats per minute or greater, and a composite score 3 or greater. A similar model was created using age as a continuous variable.

A binary logistic regression model with calculation of standardized coefficient estimates and computation of partial correlation for logistic regression [20] between each independent variable (the individual radiographic markers of frailty and the composite score) and the outcome measure (discharge disposition) was also undertaken. Variance inflation factors (VIFs) were computed to assess multicollinearity between independent variables. Calculation of standardized coefficients allows for direct comparisons between predictor variables with regard to the magnitude of their effect on outcome. Thus the predictor with the highest standardized estimate in absolute value would be considered most predictive of the outcome and the lowest standardized estimate in absolute value would be least predictive of outcome. Similarly, calculation of a partial correlation for logistic regression describes the explanatory value of each predictive variable after adjustment for the other variables in the model. The independent variable that yields the largest contribution to the model would have the highest partial correlation. A partial correlation of 0 represents a variable that has very little predictive value for the outcome measure.

## Results

Overall 489 patients were included. Elderly patients comprised 190/489 (39%) of the patient cohort and male patients 291/489 (60%). An ISS 9 or greater was seen in 219/489 (45%) patients. Vital sign abnormalities were not commonly seen, with 8/489 (2%) patients presenting with a SBP less than 100 mmHg and 106/489 (22%) patients with a HR 100 beats per minute or greater. Poor discharge disposition was seen in 49/489 (10%) of patients. Multiple demographics, admission values, and outcomes varied significantly with discharge disposition (Table 1).

Cervical spine calcifications, osteopenia, sarcopenia, sarcopenic obesity, renal volume, and cerebral atrophy were normally distributed, while emphysema and vascular calcifications were not normally distributed (Supplemental Digital Content 1, panels A–H). Multiple radiographic frailty measurements were associated with discharge disposition, including cerebral atrophy (p = 0.05),

**Table 1**
Demographic and presenting variables for motor vehicle crash patients.

| | Poor Disposition (n = 49, 10.0%) | Good Disposition (n = 440, 90.0%) | p-value |
|---|---|---|---|
| **Age, N(%)** | | | |
| ≥60 years | 30/190 (16%) | 160/190 (84%) | <0.001 |
| <60 years | 19/299 (6%) | 280/299 (94%) | |
| **Sex, N(%)** | | | |
| Male | 21/291 (7%) | 270/291 (93%) | 0.01 |
| Female | 28/198 (14%) | 170/198 (86%) | |
| **Race, N(%)** | | | |
| African American | 4/105 (4%) | 101/105 (96%) | 0.06 |
| Other Race | 5/38 (13%) | 33/38 (87%) | |
| Caucasian | 40/346 (12%) | 306/346 (88%) | |
| **BMI, N(%)** | | | |
| <25 | 11/117 (9%) | 106/117 (91%) | 0.41 |
| 25–29.9 | 14/180 (8%) | 166/180 (92%) | |
| 30–34.9 | 11/100 (11%) | 89/100 (89%) | |
| ≥35 | 13/92 (14%) | 79/92 (86%) | |
| **Injury Severity Score, N(%)** | | | |
| ≤ 8 | 6/270 (2%) | 264/270 (98%) | <0.001 |
| 9–15 | 11/118 (9%) | 107/118 (91%) | |
| 16–24 | 15/58 (26%) | 43/58 (74%) | |
| ≥25 | 17/43 (40%) | 26/43 (60%) | |
| **Admission GCS Score, N(%)** | | | |
| 3–14 | 15/60 (25%) | 45/60 (75%) | <0.001 |
| 15 | 34/429 (8%) | 395/429 (92%) | |
| **Hypotension on Admission, N(%)** | | | |
| SBP < 100 mmHg | 5/8 (63%) | 3/8 (38%) | <0.001 |
| SBP ≥ 100 mmHg | 44/481 (9%) | 437/481 (91%) | |
| **Tachycardia on Admission, N(%)** | | | |
| HR ≥ 100 beats per minute | 16/106 (15%) | 90/106 (85%) | 0.05 |
| HR < 100 beats per minute | 33/383 (9%) | 350/440 (91%) | |
| **Length of Stay, N(%)** | | | <0.001 |
| 1–2 days | 8/306(3%) | 298/306 (97%) | |
| 3–7 days | 16/115 (14%) | 99/115 (86%) | |
| 8–14 days | 12/38 (32%) | 26/38 (68%) | |
| ≥15 days | 13/30 (43%) | 17/30 (57%) | |
| **ICU Length of Stay, N(%)** | | | <0.001 |
| 0 days | 26/423 (6%) | 397/423 (94%) | |
| 1–7 days | 10/36 (28%) | 26/36 (72%) | |
| ≥8 days | 13/30 (43%) | 17/30 (57%) | |

N number, BMI body mass index, GCS Glascow Coma Scale, SBP systolic blood pressure, HR heart rate, ICU intensive care unit.

**Table 2**
Radiographic markers of frailty in motor vehicle crash patients compared with disposition.

| | Poor Disposition (n = 49, 10.0%) | Good Disposition (n = 440, 90.0%) | p-value |
|---|---|---|---|
| **Cervical Spine Degeneration, N(%)** | | | |
| 0 | 1/23 (4%) | 22/23 (96%) | 0.60 |
| 1 | 4/43 (9%) | 39/43 (91%) | |
| 2 | 5/57 (9%) | 52/57 (91%) | |
| 3 | 5/79 (6%) | 74/79 (94%) | |
| 4 | 9/72 (13%) | 63/72 (88%) | |
| 5 | 6/72 (8%) | 66/72 (92%) | |
| 6 | 10/62 (16%) | 52/62 (84%) | |
| ≥7 | 9/81 (11%) | 72/81 (89%) | |
| **Cerebral Atrophy, Mean (SD)** | 0.20 (0.05) | 0.19 (0.05) | 0.05 |
| **Renal Volume, Mean (SD)** | 80.28 (18.03) | 88.59 (19.40) | 0.004 |
| **Sarcopenia, Mean (SD)** | 6.16 (1.89) | 6.83 (2.25) | 0.05 |
| **Osteopenia, Mean (SD)** | 148.40 (47.94) | 161.30 (51.44) | 0.09 |
| **Emphysema, Median (IQR)** | 0 (0-0.01) | 0 (0-0) | 0.94 |
| **Vascular Calcifications, Median (IQR)** | 0.03 (0-0.11) | 0 (0-0.05) | 0.02 |
| **Sarcopenic Obesity, Mean (SD)** | 3.05 (1.43) | 2.56 (1.22) | 0.01 |
| **Composite Score, N(%)** | | | |
| <3 | 24/352 (7%) | 328/352 (93%) | <0.001 |
| ≥3 | 25/137 (18%) | 112/137 (82%) | |

SD standard deviation, IQR interquartile range.

renal volume (p = 0.004), sarcopenia (p = 0.05), vascular calcification (p = 0.02) and sarcopenic obesity (p = 0.01) (Table 2). Only emphysema, osteopenia, and cervical spine degeneration were not significantly associated with discharge disposition. Pearson's correlation coefficients between individual radiographic frailty measurements were all less than 0.4, meaning that the individual radiographic frailty measurements were not highly correlated (Table 3). All Pearson's correlations coefficients which should have an inverse relationship did, with negative values for the Pearson's correlations coefficients. Of the Pearson's correlations coefficients which should have a positive correlation, the pairs of sarcopenic obesity and cervical spine degeneration, cerebral atrophy and sarcopenic obesity, and emphysema and sarcopenic obesity did not have the appropriate positive correlation.

The ROC curve for the composite score had an area under the curve (AUC) of 0.66 (Fig. 2, panel A). The Youden's index was 0.26 for a composite score of 2 (p < 0.001) and 0.26 for a composite score of 3 (p < 0.001). Given that the Youden's Index was the same for multiple composite score measurements, poor disposition percentage was used to differentiate between these measurements. Poor disposition was noted in 25/137 (18%) of patients with a composite score of 3 or greater, and in 36/242 (15%) of patients with a composite score of 2 or greater (p < 0.001). A composite score of 3 or greater was then defined as "frail." We also created a ROC curve for age. The ROC curve for age yielded an AUC of 0.69 (Fig. 2, Panel B). For this ROC the Youden's Index was 0.29 with an age of 64 years or higher (p < 0.001).

A multivariable logistic regression was constructed to determine if the composite score of 3 or greater remained a significant risk factor for poor discharge disposition following adjustment by important demographic and admission values. Patients with a composite score of 3 or greater were more than twice as likely as those with a composite score of less than 3 to have a poor disposition (odds ratio (OR) 2.39, 95% confidence interval (CI) 1.10–5.18, p = 0.03). Covariates that were also significantly associated with poor disposition included: ISS 9 and greater (OR 7.35, 95% CI 2.965–18.231, p < 0.001), GCS score 3–14 (OR 3.39, 95% CI 1.530–7.494, p = 0.003), female sex (OR 2.31, 95% CI 1.16–4.58, p = 0.02), and SBP less than 100 mmHg (OR 12.52, 95% CI 2.47–63.58, p = 0.002). Age 60 years and greater (OR 1.61, 95% CI 0.73–3.50, p = 0.23), not African American race (OR 2.65, 95% CI 0.78–8.95, p = 0.12), and HR 100 beats per minute or greater (OR 1.80, 95% CI 0.85–3.79, p = 0.12) were not significantly associated with poor disposition.

Further multivariable logistic regression was performed to assess age as a continuous variable with the composite score using the above variables. In this regression, the composite score was no longer associated with poor discharge disposition (OR 1.56, 95% CI 0.64–3.81, p = 0.32). Age as a continuous variable (OR 1.037, 95% CI 1.01–1.07, p = 0.02), ISS 9 and greater (OR 6.92, 95% CI 2.78–17.24, p < 0.001), GCS score 3–14 (OR 3.46, 95% CI 1.54–7.75, p = 0.002), female sex (OR 2.65, 95% CI 1.31–5.37, p = 0.007), and SBP less than 100 mmHg (OR 12.21, 95% CI 2.39–62.33, p = 0.003) were all significantly associated with poor discharge disposition, while not African American race, HR 100 beats per minute or greater were not (data not shown).

Binary logistic regression was then performed using the composite score and the 8 individual radiographic frailty markers as independent variables to compare the relative ability of each of the radiographic frailty markers to predict the outcome of

**Table 3**
Pearson's correlation coefficients between radiographic frailty measurements.

| | Sarcopenic Obesity | Cervical Spine Degeneration | Cerebral Atrophy | Renal Volume | Emphysema | Sarcopenia | Osteopenia | Vascular Calcifications |
|---|---|---|---|---|---|---|---|---|
| Sarcopenic Obesity | 1.00 | | | | | | | |
| Cervical Spine Degeneration | −0.08 | 1.00 | | | | | | |
| Cerebral Atrophy | −0.05 | 0.37 | 1.00 | | | | | |
| Renal Volume | −0.23 | −0.14 | −0.11 | 1.00 | | | | |
| Emphysema | −0.10 | 0.08 | 0.10 | −0.03 | 1.00 | | | |
| Sarcopenia | −0.26 | −0.12 | −0.14 | 0.21 | −0.01 | 1.00 | | |
| Osteopenia | −0.13 | −0.22 | −0.23 | 0.05 | −0.004 | 0.15 | 1.00 | |
| Vascular Calcifications | 0.08 | 0.31 | 0.39 | −0.13 | 0.07 | −0.18 | −0.39 | 1.00 |

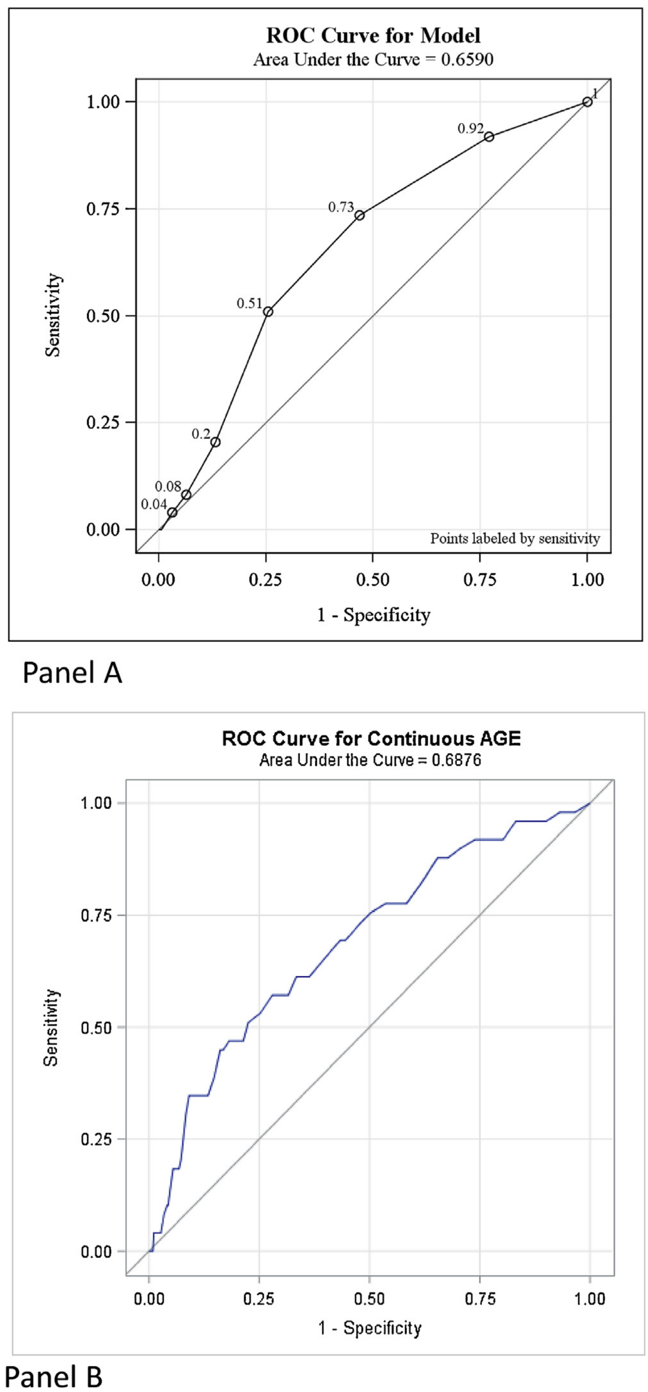


**Fig. 2.** ROC curve for the composite score (Panel A) and age (Panel B).

discharge disposition (Table 4). Computation of VIFs, all of which were below an often recommended threshold of 5.0, indicated that multicollinearity between the independent variables was not an issue; the VIF for the composite score was 3.3 and each of the individual marker variables had VIFs below 1.5. Thus all of the independent variables were included in the model. Analysis of the parameter estimates indicated that none of the radiographic frailty markers were significantly associated with discharge disposition. The composite score had the highest standardized estimate and partial correlation, meaning the composite score was the most predictive variable of discharge disposition. The only other individual radiographic marker of frailty with a non-zero partial correlation was renal volume.

## Discussion

Frailty better describes the physiologic traits that encompass aging than chronologic age. Prior research has produced excellent clinical frailty scores [4,5]. However, there is not likely one frailty measure applicable to all patients. Previously developed clinical frailty scores often require participation in physical testing (such as grip strength and a walking speed test) or questionnaire use [4,5]. Not all trauma patients will be able to participate in clinical frailty scores. Radiographic frailty measures may be able to augment these clinical scores.

The values for individual radiographic markers of frailty in this paper produced normal distributions for these markers where normality would be expected (i.e.: sarcopenia, osteopenia). This is important as it indicates an appropriate population sampling and allows assignment of “frail” and “not frail” values. Previous research looking at frailty using radiographic markers has often extrapolated from non-trauma populations [21,22] or has evaluated only elderly patients [23]. This may not reflect the range of values seen in a trauma population. Data distribution in this study however, appears appropriate.

The benefits of this study are multifold. Foremost this study provides evidence that single radiographic markers of frailty are not likely appropriate for measuring frailty. While they are widely accessible, the standardization of radiographic markers of frailty has been lacking. It appears that single radiographic markers of frailty may miss frail patients, given that individual markers of frailty were not strongly correlated with each other. Frailty may present with different factors in different individuals. For example one frail patient may have sarcopenia and cerebral atrophy, while another frail patient may have osteopenia and vascular calcifications. Both patients are frail, but use of only sarcopenia to measure frailty will miss the second frail patient.

Additionally, not all individual radiographic markers of frailty occurred with the appropriate (positive or inverse) correlation, indicating that these radiographic markers do not all occur in tandem. This could reinforce the concept that single radiographic markers of frailty should not be used to define frailty, or mean that

**Table 4**
Pearson’s correlation coefficients between radiographic frailty measurements.

| Radiographic Frailty Variable | Odds Ratio | 95% Confidence Interval | p-value | Standardized Estimate | Partial Correlation |
|---|---|---|---|---|---|
| Composite Score | 2.71 | 0.88–8.30 | 0.08 | 0.25 | 0.06 |
| Cerebral Atrophy | 1.33 | 0.62–2.85 | 0.46 | 0.07 | 0 |
| Cervical Spine Degeneration | 0.58 | 0.24–1.40 | 0.23 | −0.11 | 0 |
| Renal Volume | 1.84 | 0.89–3.82 | 0.10 | 0.14 | 0.05 |
| Emphysema | 1.08 | 0.52–2.24 | 0.83 | 0.02 | 0 |
| Sarcopenia | 0.75 | 0.36–1.59 | 0.46 | −0.07 | 0 |
| Osteopenia | 0.67 | 0.31–1.46 | 0.31 | −0.10 | 0 |
| Vascular Calcifications | 1.32 | 0.59–2.97 | 0.50 | 0.05 | 0 |
| Sarcopenic Obesity | 1.05 | 0.50–2.19 | 0.90 | 0.01 | 0 |

the common factor of frailty may not link all of the variables which we have chosen together (i.e.: sarcopenic obesity may not be a characteristic of frailty). Future research will be needed to create a composite radiographic frailty score inclusive of only those variables which represent the phenotype of frailty.

Multiple markers of frailty were associated with discharge disposition when examined alone. This similarly suggests that use of a single marker of radiographic frailty, rather than a composite frailty score or with clinical scales of frailty, may not adequately encompass the frail population and will miss frail patients.

The second benefit of this study is providing an initial description of a composite score measuring radiographic frailty, and suggesting that a composite marker of frailty is likely a better method of describing radiographic frailty than a single marker of frailty. However, it would be naïve to think that we could perfect a multifaceted measure such as this on the first try. Further work will investigate how to optimize creation of a composite score for radiographic frailty measurement, such as through examining the optimal patient distribution (elderly only vs. an expanded population as in this study), removing less influential radiographic markers of frailty (i.e.: emphysema), and how to weight these individual markers of frailty appropriately.

While the composite score was significantly associated with discharge disposition, the AUC of 0.66 with ROC analysis for the composite score is low. The eight radiographic markers of frailty in this study were felt to represent physiology of aging but do not encompass all characteristics of frailty. This leads to an imperfect AUC. A single composite frailty score may also not perfectly predict outcome when used in isolation. For example, calculation of an AUC in emergency general surgery patients showed similar AUC values for the American Society of Anesthesiologists (ASA) score, Lee score and Eagle score. These scores were augmented with addition of a frailty measure, indicating that frailty only partially stratifies patient risk [4].

Additionally, the Youden's index for the composite score is low at 0.26, and would be more assuring if it were higher. Multiple prior studies looking at creating frailty scores have not calculated optimal points from the ROC with the Youden's Index [4,5]. This study attempted to create a categorical value for "frail," as we felt this increases clinical and research applicability. The authors acknowledge the low Youden's index in using the specific composite score created in this study to define frailty. Interestingly the Youden's Index and AUC for age were not demonstrably better. This specific composite score should not be used to determine frail status, but rather show that a composite marker of frailty is likely a better predictor of outcome than a single marker of radiographic frailty.

Inclusion of other variables associated with discharge disposition, such as ISS, SBP, GCS and gender would potentially have improved the composite score AUC by providing more accurate prediction. We chose not to investigate these variables and to limit the composite score to just markers of frailty, as we were not attempting in this study to perfectly predict outcome, but to rather develop a meaningful radiographic marker of reflective of the specific traits of frailty.

Limitations of this study include its retrospective nature. The sample size may limit the ability to fit a model when using a larger number of predictors as we have done, and may be overfitted. Calculation of these radiographic markers of frailty requires radiographic software and manual measurement of each of the radiographic frailty measurements. The time and resources required are not insignificant and not available at all institutions. Additionally, measurement of radiographic markers of frailty by our methods require CT imaging which not all trauma patients will have; we do not advocate obtaining CT imaging for frailty stratification.

The choice of 40 years of age as the cutoff for inclusion also merits discussion. Including many younger patients or only elderly patients will both influence measurement of frailty. The 40 years of age cut point was per the authors' discretion. If only elderly patients had been included, we would have potentially missed patients who are frail. However, if many younger patients were included, we would potentially overestimate the number of frail elderly patients. There are downsides to any age inclusion cutoff.

## Conclusion

Measurement of frailty is an evolving field in trauma without defined criteria. With aging of the population, risk stratification and targeted therapies by frailty status will likely become more widespread. This study suggests that single radiographic markers of frailty are insufficient to quantify frailty, as they may miss frail patients. Furthermore, this study suggests that a composite radiographic marker of frailty will better identify frail patients and predict outcome than individual radiographic markers of frailty.

## Conflict of interest statement

The authors have no conflicts of interest to disclose.

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## Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.injury.2018.11.004.

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