





Orthopedic Frailty Score and adverse outcomes in patients with surgically managed isolated traumatic spinal injury

Ahmad Mohammad Ismail ,^{1,2} Frank Hildebrand,³ Maximilian Peter Forssten ,^{1,2} Marcelo A F Ribeiro Jr.,^{4,5} Parker Chang,⁶ Yang Cao,⁷ Babak Sarani ,⁶ Shahin Mohseni ,^{1,4}

¹School of Medical Sciences, Örebro University, Örebro, Sweden

²Department of Orthopedic Surgery, Örebro University Hospital, Örebro, Sweden

³Department of Orthopedics, Trauma, and Reconstructive Surgery, Uniklinik RWTH Aachen, Aachen, Germany

⁴Department of Surgery, Sheikh Shakhboub Medical City, Abu Dhabi, UAE

⁵Pontifical Catholic University of Sao Paulo, Sao Paulo, Brazil

⁶Center for Trauma and Critical Care, The George Washington University, Washington, District of Columbia, USA

⁷Clinical Epidemiology and Biostatistics, School of Medical Sciences, Faculty of Medicine and Health, Örebro University, Örebro, Sweden

Correspondence to

Dr Shahin Mohseni; mohsenishahin@yahoo.com

The abstract of this paper was accepted for a poster presentation at the 82nd Annual Meeting of AAST and Clinical Congress of Acute Care Surgery held in Anaheim, California in September 2023.

Received 28 September 2023
Accepted 24 June 2024

© Author(s) (or their employer(s)) 2024. Re-use permitted under CC BY-NC. No commercial re-use. See rights and permissions. Published by BMJ.

To cite: Mohammad Ismail A, Hildebrand F, Forssten MP, et al. *Trauma Surg Acute Care Open* 2024;**9**:e001265.

ABSTRACT

Background With an aging global population, the prevalence of frailty in patients with traumatic spinal injury (TSI) is steadily increasing. The aim of the current study is to evaluate the utility of the Orthopedic Frailty Score (OFS) in assessing the risk of adverse outcomes in patients with isolated TSI requiring surgery, with the hypothesis that frailer patients suffer from a disproportionately increased risk of these outcomes.

Methods The Trauma Quality Improvement Program database was queried for all adult patients (18 years or older) who suffered an isolated TSI due to blunt force trauma, between 2013 and 2019, and underwent spine surgery. Patients were categorized as non-frail (OFS 0), pre-frail (OFS 1), or frail (OFS ≥2). The association between the OFS and in-hospital mortality, complications, and failure to rescue (FTR) was determined using Poisson regression models, adjusted for potential confounding.

Results A total of 43 768 patients were included in the current investigation. After adjusting for confounding, frailty was associated with a more than doubling in the risk of in-hospital mortality (adjusted incidence rate ratio (IRR) (95% CI): 2.53 (2.04 to 3.12), $p < 0.001$), a 25% higher overall risk of complications (adjusted IRR (95% CI): 1.25 (1.02 to 1.54), $p = 0.032$), a doubling in the risk of FTR (adjusted IRR (95% CI): 2.00 (1.39 to 2.90), $p < 0.001$), and a 10% increase in the risk of intensive care unit admission (adjusted IRR (95% CI): 1.10 (1.04 to 1.15), $p = 0.004$), compared with non-frail patients.

Conclusion The findings indicate that the OFS could be an effective method for identifying frail patients with TSIs who are at a disproportionate risk of adverse events.

Level of evidence Level III.

INTRODUCTION

Traumatic spinal injury (TSI) encompasses a range of damage to the spinal column, including the spinal cord, nerve roots, osseous structures, and discoligamentous components.^{1–3} The most common cause of TSI is blunt trauma, typically from motor vehicle accidents, followed by falls and sport injuries. The consequences of spinal column injury may include mechanical instability, impaired movements, and harm to the neural structures, which can result in partial or complete paralysis. A subset of TSI, known as traumatic spinal cord injury, is

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ With an aging global population, the prevalence of frailty in patients with traumatic spinal injury is steadily increasing.

WHAT THIS STUDY ADDS

⇒ The Orthopedic Frailty Score could be an effective method for identifying frail patients with traumatic spinal injuries who are at a disproportionate risk of adverse events.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ The Orthopedic Frailty Score is a simple and efficient tool that could help identify patients with traumatic spinal injury who require improved preoperative optimization, increased levels of postoperative monitoring, or other interventions that may potentially improve postoperative outcomes.

characterized by neurological deficits subsequent to mechanical forces experienced by the spinal cord.^{1–5} Historically, TSI was more prevalent among men in their 40s, but with an aging global population, the average age of those affected by TSI continues to rise.^{1 5–8} It is predicted that a significant proportion of new TSI cases will occur in older patients, a group who is particularly at risk of adverse events after injury due to the higher prevalence of frailty and other medical conditions.^{5 9–14}

Although timely surgical intervention has been shown to lower morbidity and mortality,^{15–17} patients who undergo spinal surgery after trauma are at risk of postoperative complications and death.^{5 11 14 18} Healthcare providers might improve patient outcomes by identifying frailty and prioritizing those who are more susceptible to adverse outcomes for prompt, comprehensive and multidisciplinary management.^{18 19} This approach might also aid in the efforts to optimize resource utilization for maximum benefit and ensure the best possible outcomes for this vulnerable patient population.¹⁹

Frailty is a syndrome marked by decreased physiologic reserve and increased vulnerability to external stressors. This condition is more prevalent in older individuals and various tools have been proposed to characterize and measure it.^{11 18 20} The latest systematic review on frailty in TSIs found that

Table 1 Demographics of patients with surgically managed isolated traumatic spine injuries

| | Non-frail (N=38 237) | Pre-frail (N=4411) | Frail (N=1120) | P value |
|---|----------------------|--------------------|----------------|---------|
| Age, median (IQR) | 53 (36–66) | 76 (65–85) | 85 (76–87) | <0.001 |
| Sex, n (%) | | | | <0.001 |
| Female | 11 880 (31.1) | 1661 (37.7) | 476 (42.5) | |
| Male | 26 347 (68.9) | 2748 (62.3) | 644 (57.5) | |
| Missing | 10 (0.0) | 2 (0.0) | 0 (0.0) | |
| Race, n (%) | | | | |
| White | 29 278 (76.6) | 3652 (82.8) | 999 (89.2) | <0.001 |
| Black | 4589 (12.0) | 432 (9.8) | 59 (5.3) | <0.001 |
| Asian | 830 (2.2) | 103 (2.3) | 16 (1.4) | 0.178 |
| American Indian | 349 (0.9) | 15 (0.3) | 1 (0.1) | <0.001 |
| Pacific Islander | 109 (0.3) | 11 (0.2) | 1 (0.1) | 0.562 |
| Other | 2429 (6.4) | 147 (3.3) | 25 (2.2) | <0.001 |
| Missing | 422 (1.1) | 31 (0.7) | 9 (0.8) | |
| Hypertension, n (%) | 12 914 (33.8) | 2989 (67.8) | 849 (75.8) | <0.001 |
| Previous myocardial infarction, n (%) | 287 (0.8) | 85 (1.9) | 36 (3.2) | <0.001 |
| Congestive heart failure, n (%) | 0 (0.0) | 1005 (22.8) | 523 (46.7) | <0.001 |
| History of peripheral vascular disease, n (%) | 177 (0.5) | 81 (1.8) | 39 (3.5) | <0.001 |
| Cerebrovascular disease, n (%) | 519 (1.4) | 290 (6.6) | 85 (7.6) | <0.001 |
| Dementia, n (%) | 469 (1.2) | 401 (9.1) | 246 (22.0) | <0.001 |
| Non-independent functional status, n (%) | 0 (0.0) | 1531 (34.7) | 768 (68.6) | <0.001 |
| Institutionalized, n (%) | 0 (0.0) | 430 (9.7) | 420 (37.5) | <0.001 |
| History of malignancy, n (%) | 0 (0.0) | 282 (6.4) | 81 (7.2) | <0.001 |
| COPD, n (%) | 2016 (5.3) | 655 (14.8) | 196 (17.5) | <0.001 |
| Current smoker, n (%) | 9726 (25.4) | 574 (13.0) | 61 (5.4) | <0.001 |
| Chronic renal failure, n (%) | 307 (0.8) | 210 (4.8) | 66 (5.9) | <0.001 |
| Diabetes mellitus, n (%) | 5659 (14.8) | 1469 (33.3) | 403 (36.0) | <0.001 |
| Cirrhosis, n (%) | 302 (0.8) | 57 (1.3) | 19 (1.7) | <0.001 |
| Coagulopathy, n (%) | 951 (2.5) | 360 (8.2) | 144 (12.9) | <0.001 |
| Drug use disorder, n (%) | 2623 (6.9) | 156 (3.5) | 14 (1.3) | <0.001 |
| Alcohol use disorder, n (%) | 3409 (8.9) | 298 (6.8) | 31 (2.8) | <0.001 |
| Major psychiatric illness, n (%) | 3785 (9.9) | 700 (15.9) | 208 (18.6) | <0.001 |
| Advanced directive limiting care, n (%) | 511 (1.3) | 302 (6.8) | 176 (15.7) | <0.001 |

Non-frail, pre-frail, and frail are defined as OFS 0, OFS 1, and OFS ≥ 2 .
COPD, chronic obstructive pulmonary disease; OFS, Orthopedic Frailty Score.

frailty, regardless of the specific index or measure employed, is associated with a heightened risk of morbidity and mortality in patients undergoing spine surgery.¹⁸ Nonetheless, many of these indices are impractical to use in the clinical setting or otherwise fail to adequately capture frailty, due to primarily measuring comorbidity burden or fitness for surgery. The Orthopedic Frailty Score (OFS), a novel frailty score that has been proposed to measure frailty using only five dichotomous variables, has shown promising results when applied to patients with traumatic hip fracture.^{21 22} The aim of the current study is to evaluate the utility of the OFS in assessing the risk of adverse outcomes in patients with TSI, with the hypothesis that frailer patients suffer from a disproportionately increased risk of these outcomes.

METHODS

All information necessitated by the subsequent analyses was appropriated from the American College of Surgeons Trauma Quality Improvement Program (TQIP) database. Data retrieved included: age, sex, race, the Abbreviated Injury Scale (AIS) score for each body region, comorbidities, presence of an advanced directive limiting care, injury characteristics, type of surgery, discharge disposition, and complications. Patients registered in TQIP between 2013 and 2019 were considered for inclusion if

they were an adult (18 years or older) who suffered an isolated TSI as a consequence of a blunt force trauma, which required surgical intervention. An isolated TSI was defined as a spine AIS score of ≥ 2 and an AIS score of ≤ 1 in the remaining regions. Patients were excluded if they had a missing OFS or if they had an AIS score of 6 in any region.

All aspects of the current investigation comply with the Declaration of Helsinki as well as the Strengthening the Reporting of Observational Studies in Epidemiology guidelines.²³

Calculating the OFS

The OFS is a recently validated score that was originally developed for measuring frailty and predicting short-term mortality in patients with hip fracture. The OFS was calculated based on the five dichotomous variables: congestive heart failure, a history of malignancy (local or metastatic, excluding non-invasive skin cancer), institutionalization (admitted from a nursing home, long-term care facility, or other group living arrangement), non-independent functional status (ie, requiring assistance with activities of daily life), and an age ≥ 85 years old. A patient received 1 point for each variable present, with the maximum possible score being 5. Patients with an OFS ≥ 2 were considered frail, according to the original study.^{21 22}

Table 2 Clinical characteristics of patients with surgically managed isolated traumatic spine injuries

| | Non-frail (N=38 237) | Pre-frail (N=4411) | Frail (N=1120) | P value |
|-------------------------------|----------------------|--------------------|----------------|---------|
| Head AIS, n (%) | | | | 0.070 |
| Injury not present | 32 945 (86.2) | 3748 (85.0) | 954 (85.2) | |
| 1 | 5292 (13.8) | 663 (15.0) | 166 (14.8) | |
| Face AIS, n (%) | | | | <0.001 |
| Injury not present | 31 751 (83.0) | 3505 (79.5) | 871 (77.8) | |
| 1 | 6486 (17.0) | 906 (20.5) | 249 (22.2) | |
| Neck AIS, n (%) | | | | 0.438 |
| Injury not present | 37 726 (98.7) | 4351 (98.6) | 1100 (98.2) | |
| 1 | 511 (1.3) | 60 (1.4) | 20 (1.8) | |
| Spine AIS, n (%) | | | | <0.001 |
| 2 | 14 198 (37.1) | 1635 (37.1) | 465 (41.5) | |
| 3 | 14 072 (36.8) | 1723 (39.1) | 462 (41.2) | |
| 4 | 7248 (19.0) | 808 (18.3) | 160 (14.3) | |
| 5 | 2703 (7.1) | 241 (5.5) | 33 (2.9) | |
| Missing | 16 (0.0) | 4 (0.1) | 0 (0.0) | |
| Thorax AIS, n (%) | | | | 0.428 |
| Injury not present | 35 902 (93.9) | 4158 (94.3) | 1059 (94.6) | |
| 1 | 2335 (6.1) | 253 (5.7) | 61 (5.4) | |
| Abdomen AIS, n (%) | | | | <0.001 |
| Injury not present | 37 120 (97.1) | 4324 (98.0) | 1104 (98.6) | |
| 1 | 1117 (2.9) | 87 (2.0) | 16 (1.4) | |
| Upper extremity AIS, n (%) | | | | 0.365 |
| Injury not present | 34 206 (89.5) | 3924 (89.0) | 991 (88.5) | |
| 1 | 4031 (10.5) | 487 (11.0) | 129 (11.5) | |
| Lower extremity AIS, n (%) | | | | 0.208 |
| Injury not present | 34 535 (90.3) | 4017 (91.1) | 1020 (91.1) | |
| 1 | 3702 (9.7) | 394 (8.9) | 100 (8.9) | |
| External/other AIS, n (%) | | | | <0.001 |
| Injury not present | 36 567 (95.6) | 4269 (96.8) | 1084 (96.8) | |
| 1 | 1670 (4.4) | 142 (3.2) | 36 (3.2) | |
| Level of spine injury, n (%) | | | | |
| Cervical | 23 171 (60.6) | 2934 (66.5) | 718 (64.1) | <0.001 |
| Thoracic | 10 492 (27.4) | 1230 (27.9) | 338 (30.2) | 0.113 |
| Lumbar | 10 904 (28.5) | 797 (18.1) | 209 (18.7) | <0.001 |
| Spinal cord injury, n (%) | | | | |
| Cervical | 12 210 (31.9) | 1367 (31.0) | 259 (23.1) | <0.001 |
| Thoracic | 2150 (5.6) | 239 (5.4) | 51 (4.6) | 0.274 |
| Lumbar | 1892 (4.9) | 87 (2.0) | 26 (2.3) | <0.001 |
| Level of spine surgery, n (%) | | | | |
| Cervical | 27 809 (72.7) | 3311 (75.1) | 794 (70.9) | 0.001 |
| Thoracic | 21 062 (55.1) | 2245 (50.9) | 559 (49.9) | <0.001 |
| Lumbar | 17 922 (46.9) | 1645 (37.3) | 389 (34.7) | <0.001 |

Non-frail, pre-frail, and frail are defined as OFS 0, OFS 1, and OFS ≥ 2 . AIS, Abbreviated Injury Scale; OFS, Orthopedic Frailty Score.

Statistical analysis

Patients were separated into cohorts based on their OFS: non-frail (OFS 0), pre-frail (OFS 1), and frail (OFS ≥ 2).²² As a consequence of continuous variables being non-normally distributed, they were summarized as medians and IQRs, whereas categorical variables were instead organized as counts and percentages. The Kruskal-Wallis test was employed to evaluate the statistical significance of differences between continuous variables and either the χ^2 test or Fisher's exact test was applied, as appropriate, to categorical variables. The primary outcome of interest was in-hospital mortality, with the secondary outcomes consisting of any in-hospital complication (myocardial infarction, cardiac arrest

with cardiopulmonary resuscitation, stroke, deep vein thrombosis, pulmonary embolism, acute respiratory distress syndrome, pneumonia, or surgical site infection), failure to rescue (FTR), as well as intensive care unit (ICU) admission. FTR was defined as in-hospital mortality after a complication.

Poisson regression models were used to determine the association between frailty and the previously mentioned adverse outcomes, adjusted for covariates available to minimize potential confounding. When constructing the models, in-hospital mortality, complications, or FTR was set as the response variable, whereas the explanatory variables consisted of frailty (measured using the OFS), as well as age, sex, race, highest AIS in each

Table 3 Crude outcomes in patients with surgically managed isolated traumatic spine injuries

| | Non-frail (N=38 237) | Pre-frail (N=4411) | Frail (N=1120) | P value |
|--------------------------------|----------------------|--------------------|----------------|---------|
| In-hospital mortality, n (%) | 562 (1.5) | 271 (6.1) | 133 (11.9) | <0.001 |
| Any complication, n (%) | 2001 (5.2) | 429 (9.7) | 101 (9.0) | <0.001 |
| Myocardial infarction, n (%) | 69 (0.2) | 28 (0.6) | 15 (1.3) | <0.001 |
| Cardiac arrest with CPR, n (%) | 366 (1.0) | 96 (2.2) | 25 (2.2) | <0.001 |
| Stroke, n (%) | 69 (0.2) | 22 (0.5) | 8 (0.7) | <0.001 |
| DVT, n (%) | 551 (1.4) | 112 (2.5) | 19 (1.7) | <0.001 |
| Pulmonary embolism, n (%) | 274 (0.7) | 41 (0.9) | 7 (0.6) | 0.266 |
| ARDS, n (%) | 252 (0.7) | 41 (0.9) | 10 (0.9) | 0.087 |
| Pneumonia, n (%) | 811 (2.1) | 141 (3.2) | 36 (3.2) | <0.001 |
| Surgical site infection, n (%) | 118 (0.3) | 28 (0.6) | 7 (0.6) | <0.001 |
| Failure to rescue, n (%) | 259 (0.7) | 114 (2.6) | 43 (3.8) | <0.001 |
| ICU admission, n (%) | 20993 (54.9) | 2781 (63.0) | 695 (62.1) | <0.001 |

Non-frail, pre-frail, and frail are defined as OFS 0, OFS 1, and OFS \geq 2.

ARDS, acute respiratory distress syndrome; CPR, cardiopulmonary resuscitation; DVT, deep vein thrombosis; ICU, intensive care unit; OFS, Orthopedic Frailty Score.

region, level of injury, presence of spinal cord injury, level of spine surgery, comorbidities (hypertension, previous myocardial infarction, history of peripheral vascular disease, cerebrovascular disease, dementia, chronic obstructive pulmonary disease, smoking status, chronic renal failure, diabetes mellitus, cirrhosis, coagulopathy, drug use disorder, alcohol use disorder, major psychiatric illness), and advanced directives limiting care. Due to the generally short length of stay, no correction was required for time dependence in the Poisson regression analysis. Results are presented as adjusted incidence rate ratios (IRRs) and corresponding 95% CIs were calculated with robust SEs.

A two-sided p value less than 0.05 was considered statistically significant. Among patients included in the current dataset, <2% had any form of missing data. Subsequently, data that were missing were assumed to be missing at random. To manage missing data, multiple imputation by chained equations was employed; logistic regression was used for sex and race whereas a proportional odds model for the spine AIS. Analyses were performed using the *tidyverse*, *haven*, *mice*, and *sandwich* packages in the statistical software R V.4.2.2 (R Foundation for Statistical Computing, Vienna, Austria).²⁴

RESULTS

After applying the listed inclusion and exclusion criteria, a total of 43 768 patients remained for further analysis. According to their OFS, 87.3% were non-frail (N=38 237), 10.1% were pre-frail (N=4411) and 2.6% were frail (N=1120). Pre-frail and frail patients were generally older (76 and 85 vs. 53 years old, $p<0.001$), more likely to be female (37.7% and 42.5% vs. 31.1%, $p<0.001$), more likely to have advanced directives

limiting care (6.8% and 15.7% vs. 1.3%, $p<0.001$), and exhibited a higher prevalence of almost all comorbidities, compared with non-frail patients. The only conditions that decreased in prevalence in frailer patients were active smoker, drug use disorder, and alcohol use disorder (table 1). Frail patients were also less severely injured on average compared with non-frail patients (spine AIS \geq 4: 17.2% vs. 26.1%, $p<0.001$). Consequently, although frail patients were more likely to have a cervical spine injury compared with non-frail patients (64.1% vs. 60.6%, $p<0.001$), they were in fact less likely to have suffered a cervical *spinal cord* injury (23.1% vs. 31.9%, $p<0.001$) (table 2).

Prior to adjustment, both pre-frail and frail patients exhibited higher rates of in-hospital mortality (6.1% and 11.9% vs. 1.5%, $p<0.001$), complications (9.7% and 9.0% vs. 5.2%, $p<0.001$), FTR (2.6% and 3.8% vs. 0.7%, $p<0.001$), and ICU admission (63.0% and 62.1% vs. 54.9%, $p<0.001$), compared with non-frail patients. The majority of the specific complications measured were also more prevalent among pre-frail and frail patients (table 3). After adjusting for confounding, frailty was associated with a more than doubling in the risk of in-hospital mortality (adjusted IRR (95% CI): 2.53 (2.04 to 3.12), $p<0.001$), a 25% higher overall risk of complications (adjusted IRR (95% CI): 1.25 (1.02 to 1.54), $p=0.032$), a doubling in the risk of FTR (adjusted IRR (95% CI): 2.00 (1.39 to 2.90), $p<0.001$), and a 10% increase in the risk of ICU admission (adjusted IRR (95% CI): 1.10 (1.04 to 1.15), $p=0.004$), compared with non-frail patients (table 4).

Table 4 IRRs for adverse outcomes in patients with surgically managed isolated traumatic spine injuries

| Adverse outcome | Non-frail | Pre-frail IRR (95% CI) | P value | Frail IRR (95% CI) | P value |
|-----------------------|-----------|------------------------|---------|---------------------|---------|
| In-hospital mortality | Reference | 1.62 (1.38 to 1.90) | <0.001 | 2.53 (2.04 to 3.12) | <0.001 |
| Any complication | Reference | 1.33 (1.19 to 1.49) | <0.001 | 1.25 (1.02 to 1.54) | 0.032 |
| Failure to rescue | Reference | 1.59 (1.24 to 2.04) | <0.001 | 2.00 (1.39 to 2.90) | <0.001 |
| ICU admission | Reference | 1.09 (1.06 to 1.12) | <0.001 | 1.10 (1.04 to 1.15) | 0.004 |

Non-frail, pre-frail, and frail are defined as OFS 0, OFS 1, and OFS \geq 2.

IRRs are calculated using Poisson regression models with robust SEs. Missing values were managed using multiple imputation by chained equations. All analyses were adjusted for age, sex, race, highest Abbreviated Injury Scale in each region, level of injury, presence of spinal cord injury, level of spine surgery, hypertension, previous myocardial infarction, history of peripheral vascular disease, cerebrovascular disease, dementia, chronic obstructive pulmonary disease, smoking status, chronic renal failure, diabetes mellitus, cirrhosis, coagulopathy, drug use disorder, alcohol use disorder, major psychiatric illness, and advanced directives limiting care.

ICU, intensive care unit; IRRs, incidence rate ratios; OFS, Orthopedic Frailty Score.

DISCUSSION

The world is undergoing a demographic shift with an increasing proportion of elderly individuals in the population, a trend attributed to factors such as advances in medical technology and improved living conditions. In developed countries, the elderly population is growing faster than the general population, and this trend is expected to continue.^{25–27} This shift is also reflected in the population affected by trauma and subsequent TSIs.^{1–5,14} Historically, TSI was most commonly seen in men in their 40s; however, TSIs are now becoming more prevalent in older patients who are more vulnerable to adverse outcomes often due to underlying frailty or comorbidities.^{5,9–14} It is crucial for healthcare providers to confront this challenge to provide adequate support and resources for this ever-growing population who is now being affected by TSI in higher rates.

In view of the limited nature of healthcare resources, particularly in universal healthcare systems where the demand for these resources exceeds the supply, the proper allocation of resources such as personnel, operating rooms, equipment, and access to high levels of care such as ICUs, presents a significant challenge and is of utmost importance.^{28–30} Hence, it is imperative that effective approaches are adopted to efficiently allocate resources and provide optimal care to all patients. One potential strategy could be to identify frail patients who may require the most resources and additional intervention early on, for example, improved preoperative optimization, expedited surgery, additional or extended prophylaxis against postoperative adverse outcomes, increased levels of postoperative monitoring, as well as orthogeriatric care, to implement targeted strategies that could mitigate the most costly adverse events.

Frailty is a clinical state where patients exhibit a lower physiological capacity to handle external stressors due to a deterioration in multiple organ systems. This results in a heightened likelihood of suffering from postoperative complications and mortality.^{5,18} Although frailty is often considered a hallmark of aging, it is important to note that it is an independent process and not an inevitable outcome of aging.

In the current study, we could demonstrate that patients who were considered frail, according to the OFS, were at a higher risk of overall complications, ICU admission, FTR, as well as in-hospital mortality, compared with non-frail patients. These results are in line with previous studies that investigate the association between frailty and postoperative outcomes in patients with TSI.^{5,11,18} According to a 2020 systematic review conducted by Chan *et al*, which included 32 studies conducted between 1946 and 2020, eight different frailty indices or measures were used during this time period. The frailty indices that were analyzed in the studies include the 11-point modified Frailty Index (mFI-11), Adult Spinal Deformity Frailty Index (ASDFI), psoas size, Metastatic Spine Tumor Frailty Index, Cervical Deformity Frailty Index, 5-item modified Frailty Index (mFI-5), Hospital Frailty Risk Score, and the FRAIL Scale. Of these, mFI-11 and ASDFI were the most frequently studied and the results of the review indicated that all of these frailty indices or measures were associated with an increased risk of postoperative morbidity and mortality.¹⁸ The largest study included in the systematic review was a multicenter, ambispective study that analyzed 52 671 patients and used the mFI-11. This study showed that a higher mFI-11 score was associated with an increased risk of adverse events (OR 1.58 (1.51 to 1.64) per 0.10 increase in the mFI score) and mortality (OR 2.05 (1.69 to 2.47)).³¹ Additionally, a recent article published in 2022 found that the Risk Analysis Index and its recalibrated version were superior in predicting

postoperative outcomes compared with the mFI-5 in TSI.⁵ Finally, although the Trauma-Specific Frailty Index has not yet been tested specifically in patients with TSI,³² it has been found in the geriatric trauma population to be significantly associated with an increased risk of mortality, complications, unfavorable discharge, readmission, and fall recurrence.³³ Nevertheless, a challenge with the previously studied frailty indices or measures is their difficult to implement in clinical practice due to time-consuming and at times not readily available data at the time of admission. The OFS, which is based on five variables that are easily obtained upon arrival in the emergency room, offers a practical solution. However, there are some limitations that are important to take into consideration.

The OFS was initially developed using a cohort of patients with hip fractures and not TSI. Nonetheless, the findings of this study, along with other research, suggest this frailty score is also applicable to patients with TSI.²⁰ This is not surprising given the similarities between these two populations in terms of age, comorbidity burden, and degree of frailty. Patients with TSI, however, are a diverse patient population with varying prognoses based on factors such as the type of injury and existing comorbidities, with subgroups such as patients with ankylosing spondylitis and diffuse idiopathic skeletal hyperostosis presenting unique challenges.^{11,12,18} The current study did not account for these variables. Additionally, data on the impact of frailty on health-related quality of life outcomes were not available. These limitations are primarily a result of the study's retrospective design. Furthermore, the presence of other weaknesses of retrospective study designs cannot be completely eliminated, such as the possibility of residual confounding, the reliance on the accuracy of data recorded in the dataset, and the unavailability of other variables not contained in the dataset, including the cause of death, preoperative optimization, and intraoperative factors. Despite these limitations, the present study possesses several advantages, one of which being the utilization of a relatively extensive national sample population comprising patients who received treatment at more than 875 trauma centers throughout the USA. Due to the wide range of information capture by this dataset, adjustments could be made to account for differences in a substantial number of preadmission comorbidities as well as racial and demographic variations.

CONCLUSION

The findings indicate that the OFS could be an effective method for identifying frailty in patients with TSI who are at a disproportionate risk of adverse postoperative events.

Contributors FH, MAFR, BS, and SM conceived the idea. MPF, BS and SM acquired the data. AMI, MPF, and YC conducted the analysis. AMI, FH, MPF, MAFR, PC, YC, BS, and SM interpreted the data. AMI, MPF, FH, and SM drafted the article. MAFR, PC, YC, and BS contributed critical revisions of the article. AMI, FH, MPF, MAFR, PC, YC, BS, and SM approved the final version of the article and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. SM is the acting guarantor.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

Patient consent for publication Not applicable.

Ethics approval The requirement for ethical approval by an institutional review board was waived for the current study due to all analyses making use of an anonymized, retrospective dataset.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data may be obtained from a third party and are not publicly available. Trauma Quality Improvement Program's research data

may be used for informational and research purposes with approval from the ACS Committee on Trauma.

Open access This is an open access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited, appropriate credit is given, any changes made indicated, and the use is non-commercial. See: <http://creativecommons.org/licenses/by-nc/4.0/>.

ORCID iDs

Ahmad Mohammad Ismail <http://orcid.org/0000-0003-3436-1026>

Maximilian Peter Forssten <http://orcid.org/0000-0003-3583-3443>

Babak Sarani <http://orcid.org/0000-0001-6247-3004>

Shahin Mohseni <http://orcid.org/0000-0001-7097-487X>

REFERENCES

- Kumar R, Lim J, Mekary RA, Rattani A, Dewan MC, Sharif SY, Osorio-Fonseca E, Park KB. Traumatic spinal injury: global epidemiology and worldwide volume. *World Neurosurg* 2018;113:e345–63.
- Zhang S, Wadhwa R, Haydel J, Toms J, Johnson K, Guthikonda B. Spine and spinal cord trauma: diagnosis and management. *Neurol Clin* 2013;31:183–206.
- Looby S, Flanders A. Spine trauma. *Radiol Clin North Am* 2011;49:129–63.
- Ahuja CS, Wilson JR, Nori S, Kotter MRN, Druschel C, Curt A, Fehlings MG. Traumatic spinal cord injury. *Nat Rev Dis Primers* 2017;3:17018.
- Conlon M, Thommen R, Kazim SF, Dicipinigit AJ, Schmidt MH, McKee RG, Bowers CA. Risk analysis index and its recalibrated version predict postoperative outcomes better than 5-factor modified frailty index in traumatic spinal injury. *Neurospine* 2022;19:1039–48.
- Ahn H, Bailey CS, Rivers CS, Noonan VK, Tsai EC, Fourney DR, Attabib N, Kwon BK, Christie SD, Fehlings MG, et al. Effect of older age on treatment decisions and outcomes among patients with traumatic spinal cord injury. *CMAJ* 2015;187:873–80.
- van den Berg MEL, Castellote JM, Mahillo-Fernandez I, de Pedro-Cuesta J. Incidence of spinal cord injury worldwide: a systematic review. *Neuroepidemiology* 2010;34:184–92.
- Khan O, Badhiwala JH, Wilson JRF, Jiang F, Martin AR, Fehlings MG. Predictive modeling of outcomes after traumatic and nontraumatic spinal cord injury using machine learning. *Neurospine* 2019;16:678–85.
- O'Lynnger TM, Zuckerman SL, Morone PJ, Dewan MC, Vasquez-Castellanos RA, Cheng JS. Trends for spine surgery for the elderly: implications for access to healthcare in North America. *Neurosurgery* 2015;77 Suppl 4:S136–41.
- Halaweish I, Alam HB. Changing demographics of the American population. *Surg Clin North Am* 2015;95:1–10.
- Carlile CR, Rees AB, Schultz JD, Steinle AM, Nian H, Smith MD, Guillaumondegui O, Archer KR, Pennings JS, Zuckerman SL, et al. Predicting mortality in elderly spine trauma patients. *Spine (Phila Pa 1976)* 2022;47:977–85.
- Lakomkin N, Mikula AL, Pinter ZW, Wellings E, Alvi MA, Scheitler KM, Pennington Z, Lee NJ, Freedman BA, Sebastian AS, et al. Perioperative risk stratification of spine trauma patients with ankylosing spinal disorders: a comparison of 3 quantitative indices. *J Neurosurg Spine* 2022;37:722–8.
- Nagassima Rodrigues Dos Reis K, McDonnell JM, Ahern DP, Evans S, Gibbons D, Butler JS. Changing demographic trends in spine trauma: the presentation and outcome of major spine trauma in the elderly. *Surgeon* 2022;20:e410–5.
- Shibahashi K, Nishida M, Okura Y, Hamabe Y. Epidemiological state, predictors of early mortality, and predictive models for traumatic spinal cord injury: a multicenter nationwide cohort study. *Spine (Phila Pa 1976)* 2019;44:479–87.
- Donovan WH. Operative and nonoperative management of spinal cord injury. *Paraplegia* 1994;32:375–88.
- Tator CH, Duncan EG, Edmonds VE, Lapczak LI, Andrews DF. Comparison of surgical and conservative management in 208 patients with acute spinal cord injury. *Can J Neurol Sci* 1987;14:60–9.
- Pearson K. On the criterion that a given system of deviations from the probable in the case of a correlated system of variables is such that it can be reasonably supposed to have arisen from random sampling. In: Kotz S, Johnson NL, eds. *Breakthroughs in statistics: methodology and distribution* Vol. Vol. 1992. Springer, New York, NY. 11–28.
- Chan V, Wilson JRF, Ravinsky R, Badhiwala JH, Jiang F, Anderson M, Yee A, Wilson JR, Fehlings MG. Frailty adversely affects outcomes of patients undergoing spine surgery: a systematic review. *Spine J* 2021;21:988–1000.
- McDonald CL, Berreta RS, Alsoof D, Anderson G, Kutschke MJ, Diebo BG, Kuris EO, Daniels AH. Three-column osteotomy for frail versus nonfrail patients with adult spinal deformity: assessment of medical and surgical complications. *World Neurosurg* 2023;171:e714–21.
- Shafafy R, Valsamis EM, Luck J, Dimock R, Rampersad S, Kieffer W, Morassi GL, Elsayed S. Predictors of mortality in the elderly patient with a fracture of the odontoid process. *Bone Joint J* 2019;101-B:253–9.
- Forssten MP, Cao Y, Trivedi DJ, Ekestubbe L, Borg T, Bass GA, Mohammad Ismail A, Mohseni S. Developing and validating a scoring system for measuring frailty in patients with hip fracture: a novel model for predicting short-term postoperative mortality. *Trauma Surg Acute Care Open* 2022;7:e000962.
- Forssten MP, Mohammad Ismail A, Ioannidis I, Wretenberg P, Borg T, Cao Y, Ribeiro MAF, Mohseni S. The mortality burden of frailty in hip fracture patients: a nationwide retrospective study of cause-specific mortality. *Eur J Trauma Emerg Surg* 2023;49:1467–75.
- WMA - The World Medical Association. WMA declaration of Helsinki – ethical principles for medical research involving human subjects. Available: <https://www.wma.net/policies-post/wma-declaration-of-helsinki-ethical-principles-for-medical-research-involving-human-subjects/> [Accessed 21 Sep 2020].
- R Development Core Team. R. A language and environment for statistical computing. 2008. Available: <http://www.R-project.org/>
- Ageing well: a global priority. *Lancet* 2012;379:1274.
- Wang X-Q, Chen P-J. Population ageing challenges health care in China. *Lancet* 2014;383:870.
- United Nations, Department of Economic and Social Affairs, Population Division. *World population ageing, 2019 highlights*. 2019.
- Committee on Improving the Quality of Health Care Globally, Board on Global Health, Board on Health Care Services. *Crossing the global quality chasm: improving health care worldwide*. Washington, D.C National Academies Press; 2018. Available: <https://doi.org/10.17226/25152>
- Hoyler M, Finlayson SRG, McClain CD, Meara JG, Hagander L. Shortage of doctors, shortage of data: a review of the global surgery, obstetrics, and anesthesia workforce literature. *World J Surg* 2014;38:269–80.
- Drennan VM, Ross F. Global nurse shortages-the facts, the impact and action for change. *Br Med Bull* 2019;130:25–37.
- Flexman AM, Charest-Morin R, Stobart L, Street J, Ryerson CJ. Frailty and postoperative outcomes in patients undergoing surgery for degenerative spine disease. *Spine J* 2016;16:1315–23.
- Joseph B, Pandit V, Zangbar B, Kulvatunyou N, Tang A, O'Keeffe T, Green DJ, Vercauysse G, Fain MJ, Friese RS, et al. Validating trauma-specific frailty index for geriatric trauma patients: a prospective analysis. *J Am Coll Surg* 2014;219:10–7.
- Joseph B, Saljuqi AT, Amos JD, Teichman A, Whitmill ML, Anand T, Hosseinpour H, Burruss SK, Dunn JA, Najafi K, et al. Prospective validation and application of the trauma-specific frailty index: results of an American association for the surgery of trauma multi-institutional observational trial. *J Trauma Acute Care Surg* 2023;94:36–44.