Frailty Syndrome and the Use of Frailty Indices as a Preoperative Risk Stratification Tool in Spine Surgery: A Review

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This comprehensive narrative literature review aims to extract studies related to frailty indices and their use in elective spine procedures, as limited studies regarding frailty exist in the spine literature. Most studies are retrospective analyses of prospectively collected databases. Evidence suggests a positive correlation between frailty level and mortality rate, postoperative complication rate, length of stay, and the possibility of discharge to a skilled nursing facility; these correlations have been illustrated across various spine procedures. The leading index is the modified frailty index, which measures 11 deficits. The development of more comprehensive frailty indices, such as the Adult Spinal Deformity Frailty Index, are promising and have high predictive value regarding postoperative complication rate in patients with spinal deformity. However, a frailty index that combines clinical, radiographic, and laboratory measures awaits development. Perhaps, the use of a frailty index in preoperative risk stratification for elective spine procedures could serve multiple purposes, including screening for high-risk patients, enhancement of operative decision making, approximation of complication rate for informed decision making, and refinement of perioperative care. Further prospective studies are warranted to determine clinically meaningful interventions in frail individuals.

Keywords: Frailty; Adverse events; Elective surgical procedure; Spine; Mortality

Introduction

Precise prediction of how patients will tolerate elective spine surgery is a significant challenge for spine surgeons. Historically, surgeons have relied on clinical experience, general assessment of overall health, and American Society of Anesthesiologists (ASA) scores to ascertain the ability of patients to tolerate surgery. Limited tools exist to risk stratify patients during preoperative planning objectively. Reportedly, the United States population continues to age, resulting in more patients undergoing surgery at increasingly advanced ages with higher medical comorbidities [1]. Eventually, the demand for a geriatric risk stratification tool will be driven by market forces as healthcare shifts from a fee-for-service to value-based compensation model. In modern healthcare systems, spine surgeons are expected to face pressure to provide systemic value-based outcomes measures for which reimbursement could be fundamentally tied [2,3].

Previously designed tools, such as the ASA Physical Sta-
Broadly, frailty is defined as an age-related syndrome characterized by reduced physiological reserve across multiple organ systems with a resultant diminished resistance to stressors [15] and a decline in the threshold for decompensation [16]. In addition, frailty could overlap with common geriatric syndromes such as sarcopenia, malnutrition, cachexia, functional disability, and multiple comorbidities [10,14]. Frailty syndrome conceptually addresses the distinction between chronological age and physiological age; severely frail patients are not necessarily elderly and not all elderly individuals are frail.

1. Measuring frailty

Two major models of defining frailty are the frailty phenotype and the deficit accumulation model, also known as the frailty index. The frailty phenotype model summarizes the multidimensionality of frailty into the following:

- Cardiorespiratory problems: respiratory disease; congestive heart failure; peripheral vascular disease; history of stroke; history of myocardial infarction; decreased peri-
- Cerebrovascular problems: memory impairment; bladder incontinence; bowel incontinence; deteriorating health this year; difficulty climbing 1 flight of stairs; difficulty driving a car; difficulty getting in/out of bed; difficulty sleeping >6 hours; difficulty walking 9.14
- Cardiac problems: hypertension; peripheral pulses; arterial hypertension; congestive heart failure; moderate to severe cardiac disease; currently on disability; depression; diabetes; hypertension; liver disease; lung disease; renal disease; diabetes with end organ damage; any tumor; leukemia; lymphoma
- Neurological problems: history of stroke; history of diabetes
ease
- Mental health: feeling downhearted/depressed most of the time; feeling tired most of the time; feeling wear
ded; ability to cheer up often; inability to do normal work/schoolwork/ housework; inability to lift heavy objects; inability to travel >1 hour; inability to walk without assistive device; leg weakness; loss of balance; not in excellent health; personal care dependency; restricted activity level; restricted social life
- Nutritional status: current on disability; depression; diabetes; hypertension; liver disease; lung disease; renal disease; diabetes with end organ damage; any tumor; leukemia; lymphoma
- Documented by physician: >3 medical problems; body mass index (kg/m2) <18.5 or >30.0; cancer; chronic obstructive pulmonary disease; osteoporosis; peripheral vascular disease; previous blood clot (deep vein thrombosis/pulmonary embolism/stroke); smoking status
- Patient–reported (questionnaire): bladder incontinence; bowel incontinence; deteriorating health this year; difficulty climbing 1 flight of stairs; difficulty driving a car; difficulty getting in/out of bed; difficulty sleeping >6 hours; difficulty walking 9.14

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five measures (the Fried Frailty Criteria): unintentional weight loss; grip strength weakness; poor endurance; slow walking speed; and low physical activity; the presence of ≥3 indicates an individual is positive for the frailty phenotype. A study reported these biomarkers as meaningful, as they represent the downward physiologic spiral observed in frailty syndrome [17]. Several studies have proposed using single surrogate measures, such as grip strength or gait speed, as a marker for the frailty phenotype [18-24].

The deficit accumulation model counts the number of deficits in health across multiple organ systems to obtain a single score that is representative of the overall frailty level of patients. Although multiple frailty indices exist, those leading in the spine literature are as follows: modified frailty index (mFI); Charlson Comorbidity Index (CCI); Adult Spinal Deformity Frailty Index (ASD-FI); and Cervical Deformity Frailty Index (CD-FI) [17,25]. Table 1 compares three frailty indices found in the spine literature and lists the deficits measured in each index.

No consensus exists regarding which variables should be used to evaluate the frailty level in spine surgery. While some studies have used the medical history of patients to measure the frailty level, others have used a combination of medical, functional, and laboratory measures to evaluate a frailty score. Given the multifactorial nature of the syndrome, the general consensus is that no single biomarker, taken independently, is adequate for the frailty assessment [15]. Although both frailty index model and frailty phenotype measures have pros and cons, some have inferred that the frailty index model remains the most versatile with wide applicability for both research and clinical use, as it quantifies the concept of frailty [26,27].

2. Prevalence of frailty

The prevalence of frailty varies on the basis of the method used to measure it, the study population, and the threshold used to classify an individual as frail. A cohort study of community-dwelling elderly (age, 64–74 years) using the Fried Frailty Criteria reported the overall frailty prevalence to be 8.5% in females and 4.1% in males [28]. In the geriatric population undergoing general surgery procedures, studies have reported the frailty prevalence to be as high as 40%–50% [29]. In the degenerative spine disease (DSD) surgical population, using a threshold of mFI ≥0.27, the prevalence of clinically significant frailty has been reported to be approximately 4%, with frailty syndrome being 2 times as common in individuals aged >65 years [7]. Several frailty studies involving spine procedures reported the percentage of patients with, at least, mild frailty to be 48%–60% [7,8,31-35].

The Use of Frailty Indices in Non-Orthopedic Surgery

The effect of frailty on surgical outcomes has been investigated in non-orthopedic surgical populations. In addition, studies have shown the application of frailty indices to be useful in estimating postoperative mortality [36], complications [29], increased length of stay (LOS) [29], and discharge to a skilled nursing facility (SNF) [36,37]. Several studies have reported that the use of a frailty index exhibits better predictive value than ASA classification regarding 30-day all-cause postoperative mortality, 1-year all-cause mortality, and risk of nursing facility discharge [9,13,36]. Moreover, functional measures of frailty (i.e., ambulation deficits and inability to perform activities of daily living) reportedly predict short-term and mid-term mortality, as well as a multitude of in-hospital morbidities, prolonged LOS, and discharge to SNF, suggesting that preoperative ambulation deficits translate into elevated postoperative risk for pneumonia, re-intubation, prolonged urinary catheterization, and development of urinary tract infection—all of which combined could account for protracted recovery and higher mortality [38].

Frailty and Spine Surgery

Compared with non-orthopedic literature, few studies regarding frailty indices exist in the spine literature. Most of these studies regarding frailty indices are retrospective analyses of prospectively collected databases, in which a frailty index score is retrospectively evaluated using the preoperative medical history to correlate high frailty index scores with the elevated postoperative complication rate.

The evidence indicates that higher levels of frailty correlate with higher risk of mortality, postoperative complications, prolonged hospital LOS, and more probability of discharge to a rehabilitation facility in both general surgery and, precisely, spine surgical populations. The ability of a frailty index to estimate postoperative complications varies on the basis of the study population, invasiveness of the procedure, and index used to measure frailty. Table 2 summarizes pertinent studies in the spine literature, categorizing each study
Table 2. Summary table of literature pertaining to the frailty index and complication rates following elective spine surgery

| Reference       | Procedure type | Study size/database | Frailty index | Follow-up period | Study outcomes                                                                 | Findings                                                                                                                                                                                                 | Conclusions                                                                                                                                                                                                 |
|-----------------|----------------|---------------------|---------------|------------------|--------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Ali et al. [39] (2016) | All spine surgeries in ACS-NSQIP between 2006–2010 | 18,294/ACS-NSQIP | mFI: significant frailty, mFI ≥0.27 | 30 Days          | 30-Day rates of wound infection, any infection, Clavien-Dindo Class IV complications, and mortality | Found a dose-respond relationship between mFI and complication rate. As mFI increased from 0 to ≥0.27: mortality rate increased 0.1% to 2.3% (p<0.001), Clavien IV complication rate increased 0.8% to 7.1% (p<0.001), wound infection rate increased 1.7% to 4.1% (p<0.001), and overall infection rate increased 8.1% to 24.3% (p<0.001). | mFI score is an independent predictor of postoperative morbidity and mortality in this population. Study failed to demonstrate predictive superiority of inferiority of mFI relative to ASA classification system, but mFI score ≥0.27 had greater odds of developing Clavien-Dindo class IV complications compared to ASA. |
| Shin et al. [8] (2017) | ACDF | 6,148/ACS-NSQIP | mFI: significant frailty, mFI ≥0.27 | 30 Days          | 30-Day rates of mortality, Clavien-Dindo grade IV complications, any complications, HAC including surgical site infection, UTI, and VTE. | As mFI increased from 0 to ≥0.27: mortality rate increased 0.1% to 3.0% (p<0.001), Clavien IV complication rate increased 0.8% to 5.6% (p<0.001), HAC rate increased 1.4% to 4.1% (p=0.003), and total complication rate increased 2.0% to 9.0% (p<0.001). mFI ≥0.27 independently predicts Clavien IV complication rate (OR, 4.67; 95% CI, 2.27–9.62). | mFI score ≥0.27, age >75 yr and ASA class >3 were all found to be independent predictors of Clavien class 4 complications. Rates for all outcome variables assessed increased in a stepwise fashion with increasing mFI for both ACDF and PCF. |
| Shin et al. [8] (2017) | PCF | 817/ACS-NSQIP | mFI: significant frailty, mFI ≥0.36 | 30 Days          | 30-Day rates of mortality, Clavien-Dindo grade IV complications, any complications, HAC including surgical site infection, UTI, and VTE. | As mFI increased from 0 to ≥0.36: mortality rate increased 0.0% to 10.0% (p<0.001), Clavien IV complication rate increased 0.7% to 20.0% (p<0.001), HAC rate increased 3.1% to 7.7% (p<0.005), and total complication rate increased 4.1% to 35.0% (p<0.001). mFI ≥0.36 independently predicts Clavien IV complication rate (OR, 41.26; 95% CI, 6.62–257.15). | Age >75 yr and ASA class >3 were not found to be independent predictors of class 4 complications. |
| Medvedev et al. [41] (2016) | PCF | 5,627/ACS-NSQIP | Frailty Based Risk Score—comprised of 21 clinical, functional, and laboratory deficits. | 30 Days          | 30-Day rates of major and minor complications, readmission, and reoperation. Major complication defined as those that result in permanent sequelae or reoperation. Minor complications resolved without consequence. | Frailty score was a significant predictor of: ‘all complications’ (OR, 1.78; 95% CI, 1.61–1.96), readmission (OR, 1.40; 95% CI, 1.22–1.62), prolonged intubation (OR, 2.54; 95% CI, 2.00–3.22), and reintubation (OR, 2.34; 95% CI, 1.82–3.02). | Frailty score was found to be an independent predictor of reoperation, readmission, intubation related complications, unplanned re-intubation, and all-cause complication rate. |
| Reference            | Procedure type           | Study size/database          | Frailty index | Follow-up period | Study outcomes                                                                                                                                                                                                 | Findings                                                                                                                                                                                                 | Conclusions                                                                                                                                                                                                 |
|----------------------|--------------------------|-----------------------------|---------------|------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Miller et al. [42]   | Cervical spine deformity | 61/ISSG database for adult cervical spine deformity | CD-FI—uses 40 variables found in ISSG cervical deformity database; NF, CD-FI <0.2; frail, CD-FI 0.2–0.4; SF, CD-FI >0.4 | ≥1 Year | Primary outcome: incidence of major complications, defined as complications that were potentially life-threatening, required reoperation, or created permanent injury. Secondary outcome: hospital LOS, discharge disposition, and medical/surgical complication rates. | On multivariate logistic regression, odds of major complication were significantly greater for SF patients (OR, 43; 95% CI, 2.7–684) compared with NF patient. Greater frailty associated with greater odds of major complication (OR, 7.6; 95% CI, 1.5–38.4). | Increasing frailty was associated with increasing risk of major complications. Postoperative medical complications were more highly correlated with frailty than were surgical complications. LOS and discharge disposition not related to degree of frailty in this study. |
| Leven et al. [31]    | ASD surgery              | 1,001/ACS-NSQIP              | mFI: significant frailty, mFI=0.27 | 30 Days lorey and complications: including pneumonia, sepsis, DVT, PE, wound complications, deep infection, central nervous system complication, sepsis/septic shock, cardiac arrest, acute renal failure, UTI, reoperation. | As mFI increased from 0 to 0.27: mortality increased 0.3% to 10%, complication rate increased 35% to 60%, blood transfusion increased 32% to 55%, and PE/DVT increased 1.3% to 5% (all p<0.01), mFI of >0.36 (n=10 patients) correlated with 0% mortality and all-cause complication rate of 50%. | Patients with higher mFI scores had higher rates of mortality, blood transfusions, PE/DVT, and any postoperative complications (p<0.01). mFI of ≥0.27 shown to be optimal cutoff with respect to several complications, mortality, and reoperation risk. |                                                                                                                                                                                                 |
| Miller et al. [32]   | ASD surgery              | 417/ISSG—ASD prospective patient database | ASD-FI: NF, CD-FI <0.3; frail, CD-FI 0.3–0.5; SF, CD-FI >0.5 | ≥2 Years | Primary outcome: incidence of major complications, defined as complications that were potentially life-threatening, required reoperation, or created permanent injury. Secondary outcomes: incidence of deep wound infection rate, wound dehiscence incidence, LOS, PJK, pseudo-arthritis incidence, and reoperation rate. | When compared to NF reference group: frail group had significantly greater odds of any complication (p=0.02), major complication (p=0.006), and prolonged LOS (p=0.001); SF group has significantly greater odds of any complication (p=0.03), major complication (p=0.001), reoperation (p=0.02), prolonged LOS (p=0.001), deep wound infection (p=0.03), wound dehiscence (p=0.02), pseudoarthrosis (p=0.03), and PJK (p=0.02). | After controlling for complexity of procedure, frailty is independently associated with longer LOS and higher overall complication, major complication, and reoperation rates. Increasingly severe frailty is associated with increased postoperative incidence of PJK, pseudo-arthritis, wound dehiscence, and deep wound infection. |                                                                                                                                                                                                 |
| Miller et al. [43]   | ASD surgery              | 266/ESSG database           | ASD-FI (truncated to 36 variables): NF, CD-FI <0.3; frail, CD-FI 0.3–0.5; SF, CD-FI >0.5 | ≥2 Years | Primary outcome: major perioperative complications, defined as complications that substantially changed expected path to recovery, were potentially life threatening, required reoperation, or caused permanent injury. Secondary outcomes: length of hospital stay, reoperation, PJK, deep wound infection, and surgical/medical complications. | Compared to NF patients, frail and SF patients had higher odds of experiencing a major complication with OR 1.8 (95% CI, 1.0–33), and OR 2.6 (95% CI, 1.3–5.5), respectively. On multivariable analysis SF compared to NF patients had higher odds of developing PJK (OR, 7.0; 95% CI, 1.4–34), wound infection (OR, 9.7; 95% CI, 2.3–41) and reoperation (OR, 3.9; 95% CI, 1.7–8.9). Compared to NF, frail and SF patients had significantly longer hospital LOS. | Measurement of frailty using the ASD-FI in the ESSG database showed that frail and SF patients, compared to non-frail patients, had significantly greater odds of developing a major complication, PJK, deep wound infection, and reoperation. Elevated frailty was associated with longer hospital stays. |                                                                                                                                                                                                 |
| Reference        | Procedure type                                      | Study size/database | Frailty index | Follow-up period | Study outcomes | Findings                                                                                                                                                                                                 | Conclusions                                                                                                                                                                                                 |
|------------------|-----------------------------------------------------|---------------------|---------------|------------------|----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Reid et al. [34] (2018) | ASD surgery with ≥4 level instrumented fusion       | 332/ISSG-ASD database | Frailty index: NF, CD-FI <0.3; frail, CD-FI 0.3–0.5; SF, CD-FI >0.5 | ≥2 Years Postoperative HRQoL scores including ODI scores, SF-36 PCS scores, numeric back pain scores, and numeric leg pain scores; collected at 2 years postoperatively. Primary study outcome was if patients reached SCB for aforementioned scores. Baseline HRQoL and pain scores were significantly worse in frail patient groups than the non-frail group (p<0.0001). At 2-year follow-up patients in all frailty categories experienced improvement in HRQoL measures. Absolute changes between baseline and postoperative ODI, PCS, and leg pain scores were significantly greater the frail group. Regarding numeric back pain scores, frail and SF patients were less likely to reach SCB than NF patients. | Despite higher preoperative risk stratification scores, increased complication rates, and worse baseline HRQoL scores, frail patients undergoing ASD surgery were more likely to reach SCB for most HRQoL measures following compared to NF Group. SF were least likely to reach SCB for most HRQoL measures. |
| Yagi et al. [44] (2018) | Surgery for ASD, DS, and LSCS                        | 156 (ASD), 152 (DS), 173 (LSCS) | Frailty index: mFI; pre-frail, mFI <0.21; frail, mFI >0.21 CCI: no comorbidities, CCI £1; minor comorbidities, CCI 2–3; severely comorbidities, CD-FI ≥4 | ≥2 Years Primary outcome: postoperative clinical outcomes and complication rate. Secondary outcomes: sagittal alignments and incidence of PJK and failure. Postoperative ODI scores in ASD subjects deteriorated as mFI increased. In DS and LSCS subjects, clinical outcome scores improved regardless of CCI severity. In ASD surgery, major complication rate significantly increased with increasing mFI (36% in non-frail to 81% in frail group). In DS group, complication rate tended to increase with mFI and CCI, but increase was not significant. | Postsurgical clinical outcomes improved regardless of frailty score for DS and LSCS groups but declined significantly in ASD subjects with elevated frailty scores. Complication rate in ASD surgery worsened with increases in mFI and CCI. |
| Odeck et al. [33] (2018) | PLF                                                 | 16,495/ACS-NSQIP ASA; mFI; mCCI—truncated version of the CCI | Frailty index: mFI; ASA; 30 Days 30-Day rates of any AE, severe AEs (coma, cardiac arrest, death, DVT, myocardial infarction), minor AEs (acute kidney injury, anemia requiring transfusion, pneumonia, surgical site infection, UTI, dehiscence, infectious AEs, extended hospital LOS, and discharge to higher level of care. Both ASA and mFI outperformed the mCCI in discriminative ability across all adverse outcomes. ASA and mFI had statistically similar predictive value in 5 of 6 outcomes, but regarding LOS ASA outperformed mFI. | For PLF, the ASA and age have better discriminative abilities for perioperative adverse outcomes than the mFI and the mCCI. |
| Phan et al. [35] (2017) | Anterior lumbar interbody fusion                     | 3,920/ACS-NSQIP mFI  | Frailty index: mFI | 30 Days Death and any postoperative complication within 30 days. Complications categorized into larger cohorts such as: death, pulmonary complications, renal complications, etc. Other outcomes measured include LOS >5 days and return to operating room. As mFI increased from 0 to 0.27, there was significant stepwise increase in overall complication rate from 10.8% to 32.7%. High frailty scores significantly associated with greater risk of pulmonary complications but no significant association between high mFI score and UTI, VTE, LOS, and return to operating room, nor mortality could be found. | High mFI scores were independently associated with all-cause complication rate and pulmonary complication rate. |
| Reference                          | Procedure type | Study size/database               | Frailty index | Follow-up period | Study outcomes                                                                 | Findings                                                                                                                                                                                                 | Conclusions                                                                                                                                                                                                 |
|-----------------------------------|----------------|----------------------------------|---------------|-----------------|-------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Flexman et al. [7] (2016)         | DSD            | 52,671/ACS-NSQIP                 | mFI: significantly frail: mFI ≥0.27 | 30 Days         | 30-Day rates of death and major complications within 30 days (Clavien–Dindo grade ≥2), LOS, and discharge to facility. | The mFI was an independent predictor of 30-day rate of major complications (p<0.0005), infection (p=0.04), prolonged LOS (p<0.0005), discharge to higher level of care (p<0.0005), and death (p<0.05). The OR for death was 1.44 for every 0.1 increase in frailty score. | Frailty is an important predictor of clinically relevant outcomes in patients undergoing surgery for DSD. Also, the need for reoperation due to surgical site infection was strongly predicted by presence of frailty. |
| Charest-Morin et al. [40] (2018)  | Primary elective thoracolumbar surgery for non-complex DSD | 102/Spine Adverse Events Severity System ver. 2 | mFI: frail, mFI≥0.21 Sarcopenia measured by NTPA—obtained via computed tomography during preoperative assessment | Not provided | Occurrence of any perioperative AE including, but not limited to, dural tear, instrumentation failure, positioning-related complications; postoperative anemia, cardiac complications, wound infection, delirium, electrolyte abnormalities, pneumonia, neuropathic pain, UTI, and urinary retention. All AEs graded on scale of 1–6, with major events defined as grade 3 or higher. Secondary outcomes include hospital LOS, discharge to facility, and in-hospital mortality. | After controlling for invasiveness of procedure (using Spine Surgical Invasiveness Index, no relationship between NTPA and AEs (adjusted OR, 1.06; 95% CI, 0.91–1.23) nor between mFI and AEs (OR, 0.85 per 0.1 increase in mFI; 95% CI, 0.58–1.24) could be found. mFI, but not NTPA, was associated with increased risk of death (OR, 3.12 per 0.1 increase in mFI; 95% CI, 1.21–8.03). Neither mFI nor NTPA predicted LOS or discharge to facility. | Both mFI and NTPA were not predictive of AEs, LOS, or discharge to higher level of care. mFI, but not NTPA, predictive of death. Based on relatively low sample size, lack of surgical complexity, and low prevalence of frailty in study population, study is likely underpowered to detect relationship with respect to frailty and rate of AEs. |

mFI, modified frailty index; ASA, American Society of Anesthesiologists; ACDF, anterior cervical discectomy and fusion; HAC, hospital acquired conditions; UTI, urinary tract infection; VTE, venous thromboembolism; OR, odds ratio; CI, confidence interval; PCF, posterior cervical fusion; ISSG, International Spine Study Group; CD-FI, Cervical Deformity Frailty Index; NF, not frail; SF, severely frail; LOS, length of stay; ASD, adult spinal deformity; DVT, deep vein thrombosis; PE, pulmonary embolism; ASD-FI, Adult Spinal Deformity Frailty Index; PJK, proximal junctional kyphosis; ESSG, European Spine Study Group; HRQoL, health-related quality of life; ODI, Oswestry Disability Index; SF-36, 36-item Short-Form Health Survey; PCS, Physical Component Summary; SCB, substantial clinical benefit; DS, degenerative spondylolisthesis; LSCS, lumbar spinal canal stenosis; CCI, Charlson Comorbidity Index; AE, adverse event; PLF, posterior lumbar fusion; mCCI, modified Charlson Comorbidity Index; DSD, degenerative spine disease; NTPA, normalized total psoas area.
by the procedure type, and discusses the predictive capacity of the frailty index as it relates to postoperative complications associated with that specific procedure.

1. Postoperative mortality

Multiple studies have reported that increased frailty index scores correlate with postoperative mortality. From the ACS-NSQIP database, increasing mFI scores were found to be an independent predictor of 30-day mortality in the general spine surgery population [39], as well as in patients undergoing anterior cervical discectomy and fusion (ACDF) [8], posterior cervical fusion (PCF) [8], adult spinal deformity (ASD) procedures [31], and procedures for degenerative spine conditions [7]. Charest-Morin et al. [40] reported that the mFI was superior to the presence of sarcopenia in estimating mortality in 102 patients undergoing primary elective surgery for noncomplex DSD. Nevertheless, increased mFI scores did not correlate with increased 30-day mortality rates for patients undergoing anterior lumbar interbody fusion (ALIF) in one study [35].

2. Postoperative complications

Across various spine procedures, increasing frailty index scores correlated with higher rates of all-cause complications. In the ACS-NSQIP dataset, Ali et al. [39] reported a positive correlation between the mFI and the 30-day complication rate in the general spine surgical population; this correlation between the increasing frailty score and the 30-day all-cause complication rate has also been reported in patients undergoing ACDF [8], PCF [8,41], ALIF [35], and ASD surgery [31].

The preoperative stratification of patients into tiered risk categories using a frailty index score could offer a surgeon with a predictive tool for major life-threatening complications; this has been reported in the general spine surgery population [39], as well as in patients undergoing cervical spinal deformity surgery [42] and ASD surgery [32,43,44]. In these studies, individuals were assigned to tiered risk groups based on frailty index threshold values; assignment to a high-risk group was predictive of the postoperative complication rate.

Some studies reported that frailty syndrome correlated with an elevated risk of infection [7,32,39,43] and pulmonary complications [35,41]. Ali et al. [39] reported that in increasing frailty levels markedly elevated both wound infection rate and total postoperative infection rate in the general spine surgery population. Medvedev et al. [41], using a frailty-based risk score comprising of 20 items, reported that frailty index score was an independent predictor of unplanned re-intubation and elevated intubation-related complication rates. In ACS-NSQIP patients undergoing ALIF, Phan et al. [35] reported that elevated mFI correlated with a higher risk of pulmonary complications but not wound complications. These findings corroborated that of non-orthopedic frailty studies that demonstrate how frailty syndrome and deficits in preoperative mobility could translate into increased perioperative pulmonary and infection risk [38].

3. Reoperation rate

Frailty syndrome independently correlates with the reoperation rate in patients undergoing surgery for DSD [7], ASD [31,32,43], and PCF [41], while a study of patients undergoing ALIF failed to establish a marked correlation between the frailty score and the reoperation rate. In patients undergoing surgery for ASD, Leven et al. [31] reported that mFI scores of 0.09 compared with 0.18 exhibited a higher predictive value for reoperation than age >60 years and obesity class >III (body mass index >40 kg/m²). In DSD surgery, Flexman et al. [7] reported that the need for reoperation because of surgical site infection was robustly estimated by the presence of frailty.

4. Prolonged length of stay, institutional discharge, and readmission

To date, multiple studies of non-orthopedic surgeries have demonstrated a correlation of frailty syndrome with prolonged LOS and elevated risk of institutional discharge [13,29,36-38,45]. In the spine literature, the data are mixed, with conflicting data [7,32,35,40,42,43] on the correlation between frailty syndrome and prolonged LOS or institutional discharge.

Regarding readmission, high frailty-based risk scores correlated with increased 30-day readmission rates in patients undergoing PCF [41]. In ACDF, Phan et al. [46] reported a significant and independent correlation between ASA class 4, cardiac comorbidity, and prior stroke and 30-day rate of hospital admissions; considering several of these factors also correlated with high levels of frailty, future studies investigating readmission and the frailty
Frailty Indices as a Risk Stratification Tool

5. Quality of life in patients with adult spinal deformity

In the ASD literature, mixed results exist regarding whether frailty is useful in estimating the odds of functional improvement. A study of patients who underwent ASD surgery reported that the proportion of moderately frail patients to reach substantial clinical benefit (SCB) at the 2-year follow-up was higher than that of non-frail patients regarding several health-related quality of life measures, including the Oswestry Disability Index (ODI), the 36-item Short-Form Health Survey Physical Component Summary score, and numeric leg pain. Reportedly, severely frail patients were least likely to reach SCB [34]. Another study of frailty in ASD surgery did not find this correlation; rather the postsurgical ODI scores declined markedly as frailty and comorbidity level increased [44].

**Discussion**

In the surgical community, the concept of frailty and the use of the frailty index has been gradually gaining acceptance; it is imperative that spine surgeons recognize the correlation between frailty and perioperative risk in the geriatric population. Overall, the literature indicates that...
increasing levels of frailty, as measured by a frailty index, independently predict the postoperative mortality rate, complication rate, reoperation rate, prolonged LOS, and readmission rate.

Perhaps, a spine-specific frailty index could be a useful objective measure that could serve multiple purposes, including preoperative screening for high-risk patients and estimation of the complication rate for use in multidisciplinary conferences, especially for high-risk ASD patients. Reportedly, preoperative screening using a frailty index, followed by a multidisciplinary review of operative decision making, markedly improves postoperative mortality in elective surgery. Hall et al. [47] reported that the institution of a Frailty Screening Initiative (FSI) in patients undergoing elective surgery led to marked mortality benefit among significantly frail patients, with 30-day, 6-month, and 1-year mortality rates in frail patients falling from 12.2% to 3.8%, 23.9% to 7.7%, and 34.5% to 11.7%, respectively. Fig. 1 presents their Kaplan–Meier survival curve before and after the FSI implementation [47]. In the spine population, elevated frailty index scores have been reported as an independent predictor of surgical complications. Preoperative screening using a frailty index might identify high-risk patients, who subsequently qualify for case discussion in a multidisciplinary conference.

In complex ASD surgeries, the implementation of risk reduction protocols, such as the Seattle Spine Team Protocol, have accounted for decreased complication rates [48,49]. Sethi et al. [49] reported that the combined use of a multidisciplinary spinal surgery conference, a patient education course, dual operating surgeons, a dedicated complex spine anesthesia team, and enhanced intraoperative monitoring of laboratory measurements and vitals, led to a 51% decline in the 30-day complication rate for complex ASD surgery patients. The use of frailty index scores and the consequent estimation of mortality and complication rate could provide clinically pertinent information to the multidisciplinary team. In addition, objective risk stratification scores, such as the Seattle Spine Score for ASD surgery, have exhibited superiority in predictive capacity regarding the 30-day complication rate compared with an expert physician using medical history alone [50]. The frailty index is a conceptually similar model for objectively measuring risk and might benefit spine surgeons in the context of screening for high-risk geriatric patients, enhancing operative decision making, and refining postoperative care.

The spine literature offers limited information on the implementation of a frailty index. To the best of our knowledge, no prospective studies exist regarding frailty and spine surgery [42]. Without prospective data, we are limited in our ability to assess the impact of a frailty diagnosis on operative decisions and perioperative care. In addition, the ACS-NSQIP database studies are limited by 30-day follow-up and might not capture the level of surgical complexity. In ASD surgery patients, controlled for the complexity of the procedure, Miller et al. [32] reported an independent correlation between frailty and complication rate. However, Charest-Morin et al. [40] failed to demonstrate this correlation in DSD surgery.

The current body of literature predominantly uses the mFI, although recent studies have adopted alternative indices such as the CCI, CD-FI, or ASD-FI [32,34,42,44]. The mFI score evaluation is convenient from medical history, but indices that account for a higher number of variables and comprise relevant laboratory or functional measures have enhanced accuracy in measuring the frailty level. No consensus exists in the spine literature regarding which particular frailty index is optimal for risk stratification. Perhaps, a frailty index that combines clinical and medical history information, comorbidities, objective laboratory values, and radiographic parameters, such as the bone density, could be the most robust, predictive, accurate, and useful for spine surgeons.

Specialty-specific indices, such as the Metastatic Spinal Tumor Frailty Index, could predict postoperative outcomes with higher accuracy because of only selecting variables with the highest correlation to poor outcomes. Perhaps, the development of a spine-specific frailty index, which involves radiographic measures and/or relevant laboratory measures, might have improved the correlation between the index score and the complication rate.

Conclusions

In conclusion, currently available frailty indices are adequate in predicting the perioperative complication risk and could be useful in the preoperative screening of geriatric spine patients and guiding surgical management.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.
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References

1. Vincent GK, Velkoff VA. The next four decades: the older population in the United States: 2010 to 2050. Washington (DC): US Department of Commerce, Economics and Statistics Administration, US Census Bureau; 2010.
2. Porter ME. Value-based health care delivery. Ann Surg 2008;248:503-9.
3. Porter ME. A strategy for health care reform: toward a value-based system. N Engl J Med 2009;361:109-12.
4. Owens WD, Felts JA, Spitznagel EL Jr. ASA physical status classifications: a study of consistency of ratings. Anesthesiology 1978;49:239-43.
5. Haynes SR, Lawler PG. An assessment of the consistency of ASA physical status classification allocation. Anaesthesia 1995;50:195-9.
6. Mak PH, Campbell RC, Irwin MG; American Society of Anesthesiologists. The ASA physical status classification: inter-observer consistency. American Society of Anesthesiologists. Anaesth Intensive Care 2002;30:633-40.
7. 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.
8. Shin JI, Kothari P, Phan K, et al. Frailty index as a predictor of adverse postoperative outcomes in patients undergoing cervical spinal fusion. Spine (Phila Pa 1976) 2017;42:304-10.
9. Farhat JS, Velanovich V, Falvo AJ, et al. Are the frail destined to fail? Frailty index as predictor of surgical morbidity and mortality in the elderly. J Trauma Acute Care Surg 2012;72:1526-30.
10. Robinson TN, Walston JD, Brummel NE, et al. Frailty for surgeons: review of a national institute on aging conference on frailty for specialists. J Am Coll Surg 2015;221:1083-92.
11. Buigues C, Juarrós-Folgado P, Fernandez-Garrido J, Navarro-Martínez R, Cauli O. Frailty syndrome and pre-operative risk evaluation: a systematic review. Arch Gerontol Geriatr 2015;61:309-21.
12. Reisinger KW, van Vugt JL, Heggen JJ, et al. Functional compromise reflected by sarcopenia, frailty, and nutritional depletion predicts adverse postoperative outcome after colorectal cancer surgery. Ann Surg 2015;261:345-52.
13. Kim SW, Han HS, Jung HW, et al. Multidimensional frailty score for the prediction of postoperative mortality risk. JAMA Surg 2014;149:633-40.
14. Partridge JS, Harari D, Heshi JK. Frailty in the older surgical patient: a review. Age Ageing 2012;41:142-7.
15. Rodriguez-Manas L, Feart C, Mann G, et al. Searching for an operational definition of frailty: a Delphi method based consensus statement: the frailty operational definition-consensus conference project. J Gerontol A Biol Sci Med Sci 2013;68:62-7.
16. Bagshaw SM, McDermid RC. The role of frailty in outcomes from critical illness. Curr Opin Crit Care 2013;19:496-503.
17. Fried LP, Tangen CM, Walston J, et al. Frailty in older adults: evidence for a phenotype. J Gerontol A Biol Sci Med Sci 2001;56:M146-56.
18. Afilalo J, Eisenberg MJ, Morin JF, et al. Gait speed as an incremental predictor of mortality and major morbidity in elderly patients undergoing cardiac surgery. J Am Coll Cardiol 2010;56:1668-76.
19. Guo CB, Zhang W, Ma DQ, Zhang KH, Huang JQ. Hand grip strength: an indicator of nutritional state and the mix of postoperative complications in patients with oral and maxillofacial cancers. Br J Oral Maxillofac Surg 1996;34:325-7.
20. Robinson TN, Wu DS, Sauaia A, et al. Slower walking speed forecasts increased postoperative morbidity and 1-year mortality across surgical specialties. Ann Surg 2013;258:582-8.
21. Savva GM, Donoghue OA, Horgan F, O’Regan C, Cronin H, Kenny RA. Using timed up-and-go to identify frail members of the older population. J Gerontol A Biol Sci Med Sci 2013;68:441-6.
22. Syddall H, Cooper C, Martin F, Briggs R, Aihie Sayer A. Is grip strength a useful single marker of frailty? Age Ageing 2003;32:650-6.
23. Abellan van Kan G, Rolland Y, Bergman H, Morley JE, Kritchevsky SB, Vellas B. The I.A.N.A Task Force on frailty assessment of older people in clinical practice. J Nutr Health Aging 2008;12:29-37.
24. Vermeulen J, Neyens JC, van Rossum E, Spreeuwenberg MD, de Witte LP. Predicting ADL disability in community-dwelling elderly people using physical frailty indicators: a systematic review. BMC Geriatr 2011;11:33.

25. Velanovich V, Antoine H, Swartz A, Peters D, Rubinfeld I. Accumulating deficits model of frailty and postoperative mortality and morbidity: its application to a national database. J Surg Res 2013;183:104-10.

26. de Vries NM, Staal JB, van Ravensberg CD, Hobbelen JS, Olde Rikkert MG, Nijhuis-van der Sanden MW. Outcome instruments to measure frailty: a systematic review. Ageing Res Rev 2011;10:104-14.

27. Song X, Mitnitski A, Rockwood K. Prevalence and 10-year outcomes of frailty in older adults in relation to deficit accumulation. J Am Geriatr Soc 2010;58:681-7.

28. Syddall H, Roberts HC, Evandrou M, Cooper C, Bergman H, Aihie Sayer A. Prevalence and correlates of frailty among community-dwelling older men and women: findings from the Hertfordshire Cohort Study. Age Ageing 2010;39:197-203.

29. Makary MA, Segev DL, Pronovost PJ, et al. Frailty index is a significant predictor of complications and mortality after surgery for adult spinal deformity. Spine (Phila Pa 1976) 2016;41:E1394-401.

30. Miller EK, Neuman BJ, Jain A, et al. An assessment of frailty as a tool for risk stratification in adult spinal deformity surgery. Neurosurg Focus 2017;43:E3.

31. Ondeck NT, Bohl DD, Bovonratwet P, et al. Discriminative ability of commonly used indices to predict adverse outcomes after poster lumbar fusion: a comparison of demographics, ASA, the modified Charlson Comorbidity Index, and the modified Frailty Index. Spine J 2018;18:44-52.

32. Reid DB, Daniels AH, Ailon T, et al. Frailty and health-related quality of life improvement following adult spinal deformity surgery. World Neurosurg 2018;112:e548-54.
fusion. Spine (Phila Pa 1976) 2017;42:85-91.
47. Hall DE, Arya S, Schmid KK, et al. Association of a frailty screening initiative with postoperative survival at 30, 180, and 365 days. JAMA Surg 2017;152:233-40.
48. Sethi RK, Pong RP, Leveque JC, Dean TC, Olivar SJ, Rupp SM. The Seattle Spine Team approach to adult deformity surgery: a systems-based approach to perioperative care and subsequent reduction in perioperative complication rates. Spine Deform 2014;2:95-103.
49. Sethi R, Buchlak QD, Yanamadala V, et al. A systematic multidisciplinary initiative for reducing the risk of complications in adult scoliosis surgery. J Neurosurg Spine 2017;26:744-50.
50. Buchlak QD, Yanamadala V, Leveque JC, Edwards A, Nold K, Sethi R. The Seattle spine score: predicting 30-day complication risk in adult spinal deformity surgery. J Clin Neurosci 2017;43:247-55.