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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-

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tus Classification System, have been useful in evaluating operative risk and estimating perioperative complications. Nevertheless, the ASA scale has poor inter-rater reliability [4-6] and is limited in its capability to precisely risk stratify patients with mild levels of comorbidity [7,8]. Recent years have witnessed an increased use of the concept of frailty as a predictor of patients' operative risk. Broadly, frailty is defined as an age-related syndrome characterized by declined physiological reserve across multiple organ systems. To date, several studies have reported frailty syndrome to be an independent risk factor for perioperative complications [9-12], while others have reported in specific populations that high frailty index scores are superior to the ASA in estimating mortality and complication rates [8,9,13]. Notably, frailty can be used to help surgeons quantifiably distinguish patients 'physiologic' and chronologic age.

Risk stratification using a frailty index offers a promising tool to identify patients most likely to experience complications to explicate inherent risks of surgery for health professionals, patients, and their families. While several reviews of frailty in surgical patients exist [10,11,14], to the best of our knowledge, this is the first review of frailty related to spine surgery. Hence, this study aims to provide a literature overview as it pertains to the frailty index and elective spine surgery.

Defining Frailty

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

Table 1. Comparison of frailty indices found in spine literature

mFI	ASD-FI	CCI
Cerebrovascular problems; respiratory problems; congestive heart failure; myocardial infarction; decreased peripheral pulses; arterial hypertension; cardiac problems; changes in everyday activity; clouding or delirium; history of stroke; history of diabetes mellitus	Documented by physician: >3 medical problems; body mass index (kg/m^2) <18.5 or >30.0; cancer; cardiac disease; currently on disability; depression; diabetes; hypertension; liver disease; lung disease; osteoporosis; peripheral vascular disease; pervious 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 dressed; difficulty getting in/out of bed; difficulty sleeping >6 hours; difficulty walking 91.44 m; difficulty with light activity; feeling downhearted/depressed most of the time; feeling tired most of the time; feeling worn out most of the time; general health (fair/poor); inability to bathe without assistance; inability 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	1-Point clinical conditions: myocardial infarct; congestive heart failure; peripheral vascular disease; cerebrovascular disease; dementia; chronic pulmonary disease; connective tissue disease; ulcer disease; mild liver disease; diabetes 2-Point clinical conditions: hemiplegia; moderate to severe renal disease; diabetes with end organ damage; any tumor; leukemia; lymphoma 3-Point clinical conditions: moderate to severe liver disease 6-Point clinical conditions: metastatic solid tumor; acquired immune deficiency syndrome
mFI=Σdeficits/11 total deficits	ASD-FI=Σdeficits/40 total deficits	CCI=Σpoints
Significantly frail: mFI ≥0.21 to 0.36[a]	Not frail: CD-FI <0.3; frail: CD-FI 0.3–0.5; severely frail: CD-FI >0.5 [34,36,45]	No comorbidities: CCI ≤1; minor comorbidities: CCI 2–3; severely comorbidities: CD-FI ≥4 [46]

mFI, modified frailty index; ASD-FI, Adult Spinal Deformity Frailty Index; CCI, Charlson Comorbidity Index; CD-FI, Cervical Deformity Frailty Index.
[a]Varies by study.

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% [29,30]. 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 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: morality 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: morality 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 re-intubation (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.

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Table 2. Continued

Reference	Procedure type	Study size/ database	Frailty index	Follow-up period	Study outcomes	Findings	Conclusions
Miller et al. [42] (2018)	Cervical spine deformity surgery	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 outcomes: 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). Institutional discharge and prolonged LOS did not correlate significantly with CD-FI.	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] (2016)	ASD surgery	1,001/ACS-NSQIP	mFI: significant frailty, mFI ≥0.27	30 Days	30-Day mortality 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%. Risk stratifying patients using mFI score of ≥0.18 was better predictor of reoperation than patient characteristics of age ≥60 yr and obesity class ≥III.	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] (2017)	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-arthrosis 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-arthrosis, wound dehiscence, and deep wound infection.
Miller et al. [43] (2018)	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.

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Table 2. Continued

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	ASD-FI: 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)	mFI: NF, mFI=0; 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.
Ondeck et al. [33] (2018)	PLF	16,495/ACS-NSQIP	ASA; mFI; mCCI—truncated version of the CCI	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	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%. Risk of any complication increases by odds ratio of 2.4 between mFI of 0 vs. 0.27. High frailty scores significant associated with greater risk of pulmonary complications but no significant association between high mFI score and UTI, VTE, LOS>5 days, return to operating room, nor mortality could be found.	High mFI scores were independently associated with all-cause complication rate and pulmonary complication rate.

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Table 2. Continued

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 in 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 score; 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/m^2). 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

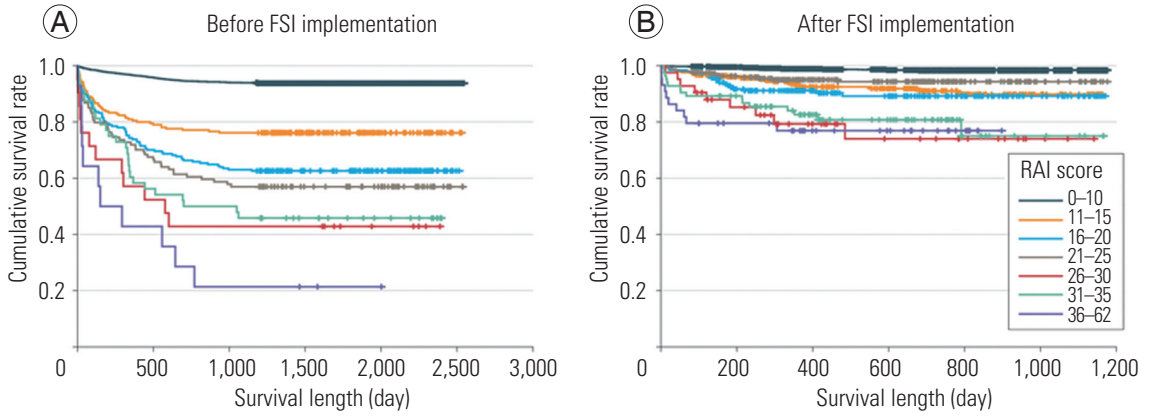
index could yield similar results.

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



No. at risk RAI score							
0–10	4,654	4,459	4,377	3,313	1,537	142	0
11–15	210	166	160	107	40	3	0
16–20	214	150	135	105	75	1	0
21–25	114	76	66	45	33	3	0
26–30	21	11	9	9	4	0	0
31–35	48	27	24	15	9	0	0
36–62	14	6	3	2	1	0	0

No. at risk RAI score							
0–10	2,922	2,560	2,027	1,707	1,178	506	0
11–15	340	261	176	139	64	27	0
16–20	192	153	110	83	53	26	0
21–25	254	224	155	125	49	17	0
26–30	42	32	20	13	9	3	0
31–35	84	71	49	35	11	5	0
36–62	44	31	22	18	8	0	0

Fig. 1. The implementation of a FSI at a single medical center resulted in significant improvement in postoperative survival among frail patients. The Kaplan–Meier survival curves of cohorts before (A) and after (B) the FSI implementation. Individuals are stratified into cohorts based on the RAI, a 14-item frailty index. Stratification demonstrates that survival benefit was highest in individuals with the highest levels of frailty. The sample included all 9,153 patients (5,275 before FSI implementation and 3,878 after FSI implementation). Mantel-Cox log rank tests for differences in the survival distribution are as follows (p<0.001 for overall difference before and after FSI implementation). Before FSI implementation, the lowest 2 strata of frailty were different from each other and from all the other strata (all p<0.001). There was no difference between the 16 to 20 and 21 to 25 RAI strata (p=0.31), although the 16 to 20 RAI stratum was different from the highest 3 strata of frailty (all p<0.05). The 21 to 25 RAI stratum was not different from the 26 to 30 (p=0.16) or the 31 to 35 (p=0.24) RAI stratum, but it was different from the 36 to 62 RAI stratum (p=0.004). Although the lines of the highest 3 strata diverge, the differences did not reach statistical significance (all p>0.05); however, this is likely attributable to the low numbers in these RAI strata. After FSI implementation, the lowest frailty stratum was different from all others (p<0.001), but there was no difference between the next RAI strata (e.g., 11–15, 16–20, and 21–25; all p>0.20), although these 3 were different from the top 3 strata (all p<0.03). There was no difference between the top 3 strata (e.g., 26–30, 31–35, and 36–62; all p>0.50), but they were all different from each of the lowest 3 strata (all p<0.05). Hash marks indicate censored data. FSI, Frailty Screening Initiative; RAI, Risk Analysis Index. Reprinted from Hall et al. JAMA Surg 2017;152:233-40, with permission of American Medical Association [47].

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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