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Clinical Studies

The 5-factor modified frailty index (mFI-5) predicts adverse outcomes after elective anterior cervical discectomy and fusion (ACDF)

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ABSTRACT

Background: Anterior cervical discectomy and fusion (ACDF) is a reliable procedure commonly performed in older patients with degenerative diseases of the cervical spine. Over 130,000 procedures are performed every year with an annual increase of 5%, and overall morbidity rates can reach as high as 19.3%, indicating a need for surgeons to gauge their patients' risk for adverse outcomes. Frailty is an age-associated decline in functioning of multiple organ systems and has been shown to predict adverse outcomes following various spine procedures. There have been several proposed frailty indices of various factors including the 11-factor modified frailty index (mFI-11), which has been shown to be an effective tool for predicting complications in patients undergoing ACDF. However, there is a paucity of literature assessing the utility of the 5-factor modified frailty index (mFI-5) as a risk stratification tool for patients undergoing ACDF. The purpose of this study was to analyze the predictive capability of the mFI-5 score for 30-day postoperative adverse events following elective ACDF.

Methods: A retrospective review was performed using the National Surgical Quality Improvement Program (NSQIP) database from 2010 through 2019. Patients older than 50 years of age who underwent elective ACDF were identified using Current Procedural Terminology ([CPT] codes 22554, 22551, 22552, and 63075). Exclusion criteria removed patients under the age of 51, as well as those with fractures, sepsis, disseminated cancer, a prior operation in the last 30 days, ascites, wound infection, or an emergency surgery. Patients were grouped using mFI scores of 1, 2, and 3+. Univariate analysis, using chi-squared and one-way analysis of variance (ANOVA) tests, was conducted to compare demographics, comorbidities, and postoperative complications across the varying cohorts based on mFI-5 scores. Multivariate logistic regression, including patient demographics and preoperative comorbidities as covariates, was performed to evaluate if mFI-5 scores were independent predictors of 30-day postoperative adverse events. Covariates including race, BMI, sex, ASA, and comorbidities were included in regression models.

Results: The 45,991 patients were identified and allocated in cohorts based on mFI-5 score. Rates for superficial surgical site infection (SSI), organ/deep space SSI, pneumonia, progressive renal insufficiency, acute renal failure (ARF), urinary tract infection (UTI), stroke/cardiovascular accident (CVA), cardiac arrest requiring cardiopulmonary resuscitation (CPR), myocardial infarction, bleeding requiring transfusions, deep vein thrombosis/thrombophlebitis, sepsis, septic shock, readmissions, reoperation, and mortality incrementally increased with mFI-5 scores from 0 to 3+. Multivariate regression analysis revealed that mFI-5 scores 1 to 3+ increased the odds, in a stepwise manner, of total complications, cardiac arrest requiring CPR, pneumonia and mortality. MFI-5 scores of 2 and 3+ were independent predictors of readmission (2: OR=1.5, p<.001; 3+: OR=2.0, p<.001) and myocardial infarction (2: OR=3.4, p=.001; 3+: OR=6.9, p<.001). A score of 3+ increased the odds

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of ARF (OR=9.7, p=.022), septic shock (OR=3.6, p=.036), UTI (OR=2.1, p=.007), bleeding requiring transfusions (OR=2.1, p=.016), and reoperations (OR=1.7, p=.004).

Conclusion: mFI-5 score is a quick and viable option for surgeons to use as an assessment tool to stratify high risk patients undergoing elective ACDF, as increasing mFI-5 scores showed significantly higher rates of all adverse outcomes accounted for in this study, except for deep incisional SSI, wound disruption, and PE. Additionally, moderate to severe mFI-5 scores of 2 or 3+ were independent predictors for 30-day postoperative ARF, UTI, MI, bleeding requiring transfusions, septic shock, reoperation, and readmissions following elective ACDF surgery in adults over 50 years old.

Introduction

Anterior cervical discectomy and fusion (ACDF) is a commonly performed procedure for patients living with degenerative spinal diseases, with over 130,000 procedures performed every year and annual increases of 5% [4]. ACDF has long been regarded as an effective technique for achieving favorable clinical and functional outcomes and is associated with low rates of complications in comparison to alternative techniques [1,2]. Despite its widespread popularity, ACDF still carries a risk of surgical complications, reoperations, and mortality. A retrospective study by Fountas et al reported an overall morbidity rate of 19.3%, indicating a need for surgeons to gauge patient risk for adverse outcomes when recommending surgical intervention [3]. The rates of short-term surgical complications are even more pronounced amongst the elderly population who often suffer from degenerative cervical pathologies [10]. This is supported by Capua et al. who found that increasing age was significantly associated with several 30-day postoperative outcomes, including pulmonary complications, cardiac complications, and sepsis in over 20,000 patients undergoing ACDF [11].

Currently, there are limited measures that assess the risk of morbidity and mortality in patients undergoing ACDF, including body mass index (BMI), American Society of Anesthesia (ASA) classification, and age. With the increasing number of procedures performed, mean age at time of procedure, and rates of complications positively correlated with age [8], the ability to stratify patient risk preoperatively is imperative.

Frailty is a clinical condition of the aging population defined as a state of poor homeostasis regulation during and following a stressor, including surgery, that may result in the decline and failure of multiple physiologic systems leading to adverse outcomes [11]. The modified frailty index (mFI) is an assessment tool that accounts for frailty, which is quantified by a combination of factors of functional status and comorbidities. The modified 5-item (mFI-5) and 11-item frailty index (mFI-11) are the most commonly cited indices in spine surgery and have been shown to have high predictive value for postoperative complication rates in patients undergoing spinal procedures, especially in the elderly [5–7,9,12,13].

Despite the mFI-5 being a simpler and quicker method of risk stratifying adverse outcomes relative to the mFI-11, there is a lack of studies that investigate the efficacy of mFI-5, and how it compares to other predictors such as age, BMI, and ASA grade, following ACDF [5,6,14,15]. Few studies have found frailty to be predictive of postoperative complications, but have utilized a different frailty index from the mFI-5 or focused on other spinal procedures [6,16]. However, the mFI-5 in addition to conciseness, relies on information commonly known by the patient and is readily available in medical records. Therefore, the purpose of this study was to determine the capability of the mFI-5 score to predict 30-day adverse outcomes following elective ACDF.

Methods

Data Source and Patient Population

Patients over the age of 50 years undergoing elective primary ACDF from 2010 to 2019 were identified from the American College of Surgeon's National Surgical Quality Improvement Program (ACS NSQIP) (Chicago, Illinois, United States) using Current Procedural Terminology (CPT) codes 22554, 22551, 22552, and 63075. Cases including concurrent posterior surgery, >3 operative levels, the thoraco-lumbar spine, or a revision procedure were excluded. CPT code 22552 was used to determine the number of operative levels. In order to further isolate those undergoing surgery for degenerative diseases, patients diagnosed with a fracture, neoplasm, or infection were also excluded using Internal Classification of Diseases, 10th Revision, Clinical Modification (ICD-10-CM) codes. Cases with missing values for outcome variables, emergency surgeries, a prior operation in the last 30 days, ascites, and wound infection were also omitted. The applications of inclusion and exclusion criteria are illustrated in Fig. 1.

Outcomes

Each patient's mFI-5 score, ranging from 0 to 5, was calculated using the following variables, made available in the NSQIP database, each adding a single point to the patient's score: (1) congestive heart failure (CHF); (2) history of chronic obstructive pulmonary disease (COPD); (3) hypertension requiring medication; (4) insulin-dependent or non-insulin dependent diabetes mellitus; and (5) totally- or partially- dependent preoperative functional status (Table 1). Due to low frequency of patients with an mFI-5 score of either 4 or 5, patients with these scores were grouped with a score of 3 for a collective group of 3 or more (3+). Patient demographics including sex, age, BMI, ASA score, and preoperative conditions were obtained and are outlined in Table 2.

Data points of 30-day postoperative complications, readmissions, reoperations, and mortality were gathered using NSQIP outcome data. Both minor and major complications were included in the analysis, including postoperative superficial, deep and organ/deep space surgical site infections (SSIs), pneumonia, unplanned intubations, pulmonary embolism (PE), ventilator use greater than 48 hours, progressive renal insufficiency, acute renal failure (ARF), urinary tract infections (UTI), stroke/cerebrovascular accident (CVA), cardiac arrest, myocardial infarction (MI), bleeding requiring transfusion, deep vein thrombosis (DVT), sepsis, and septic shock.

Statistical Analysis

All statistical analyses were conducted using SPSS version 24.0 (IBM Corp., Amonk, NY, USA). Patients were allocated to one of four frailty groups: not frail (mFI=0), mild frailty (mFI=1), moderate frailty (mFI=2), and severe frailty (mFI=3+). Percentages were calculated for all dichotomous and categorical variables and were compared using chi-squared or Fisher exact tests. Mean values with standard deviations were calculated for continuous variables and were compared using one-way analysis of variance (ANOVA) tests. Assessment of demographics, comorbidities, and postoperative complications between the mFI-5 cohorts was done through univariate analysis.

Multivariate logistic regression was performed to assess if mFI-5 scores were independent predictors of 30-day postoperative mortality, readmissions, reoperations, any complications, and specific aforementioned complications. Preoperative variables including race, BMI, sex, ASA score, obesity, operative time >4 hours, dyspnea, alcohol

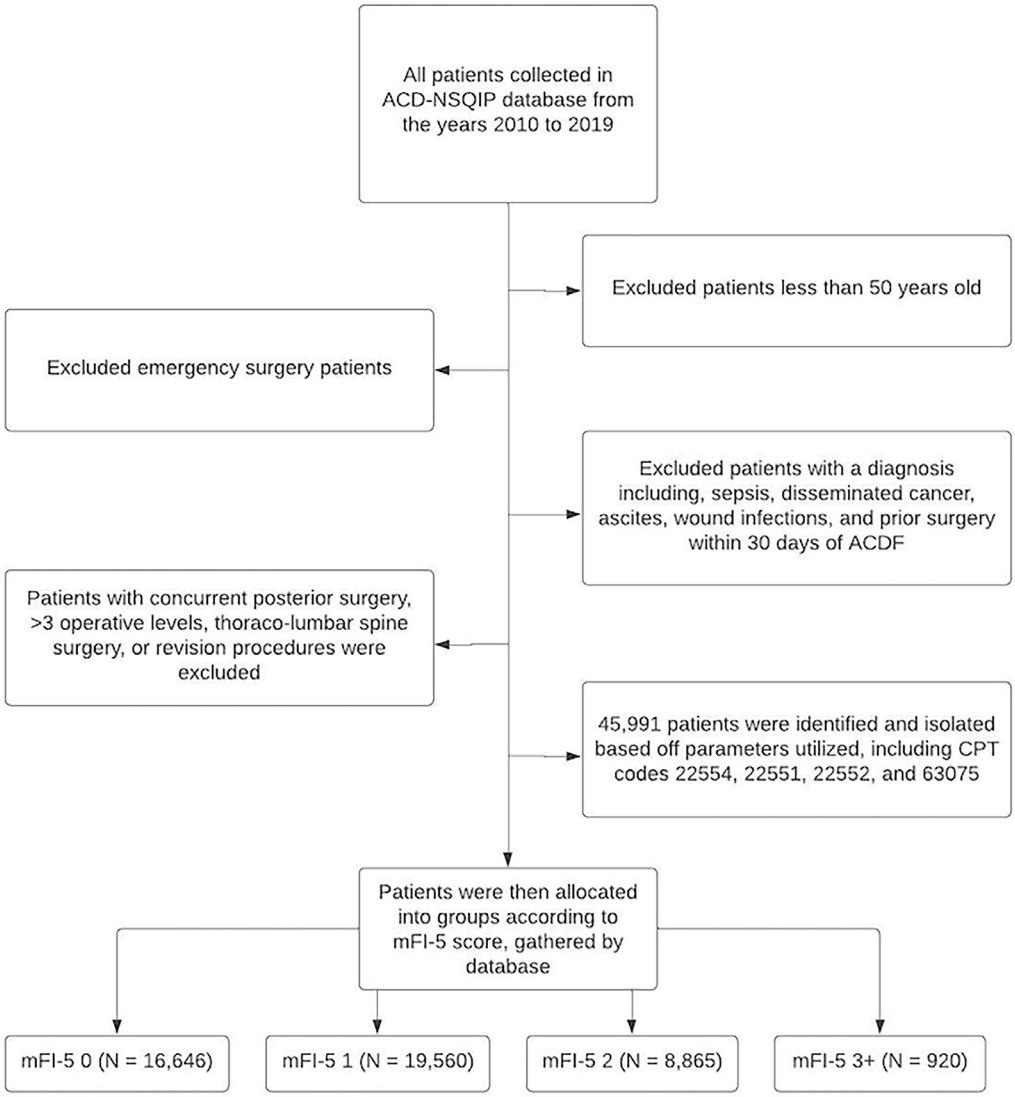

Fig. 1. Flow chart of methodology based on inclusion and exclusion criteria for frailty study.

Table 1
MFI-5 variables mapped to NSQIP variables for score calculations.

mFI-5	NSQIP
Diabetes Mellitus (+1)	History of diabetes mellitus
Increased blood pressure requiring medication (+1)	Hypertension requiring medication
Functional Status (+1)	Functional status (non-independent)
COPD (+1)	History of COPD
Heart Failure (+1)	History of congestive heart failure

mFI-5 = 5-Item Modified Frailty Index; NSQIP = National Surgical Quality Improvement Program; COPD = Chronic Obstructive Pulmonary Disease.

use, steroid use, bleeding disorder, preoperative transfusions and recent weight loss were included in the regression models. Odds ratios, 95% confidence intervals, and p-values (less than .05 was considered statistically significant) for each variable were calculated from the regression. Similar multivariate logistic regressions were performed for age as a predictor of adverse events. As age is a continuous variable, the odds ratios, confidence intervals, and p-values yielded represent the increased (or decreased) predictability with each subsequent year of age when starting at 51.

Results

The 45,991 patients with complete data sets who underwent elective ACDF were identified and included in this study. Patients were distributed amongst mFI-5 cohorts as follows: 0 (n=16,646), 1 (n=19,560), 2 (n=8,865), and 3+ (n=920). The proportions of evaluated complications are illustrated in Table 3. As the mFI-5 score increased from 0 to 3+, there was an associated incremental, step-wise increase in rates of superficial SSI (0.2% to 0.5%), organ/deep space surgical site infection

Table 2
The study cohort (N=45,991).

	mFI-5=0	mFI-5=1	mFI-5=2	mFI-5=3+
Body mass index mean and standard deviation (kg/m^2)	28.56±5.77	30.62±6.39	32.60±6.90	33.26±7.49
Range	76.18–8.46=67.72	96.95–8.25=88.70	84.05–8.32=75.73	64.99–15.36=49.63
Age mean and standard deviation (years)*	59.43±7.01	62.63±8.04	63.70±7.99	64.95±8.19
Range	89–51=38	89–51=38	89–51=38	89–51=38
Sex (N)				
Male	7972	10379	4940	472
Female	8674	9181	3925	448
Race (N)†				
White	15053	16651	7117	727
Black or African American	1119	2422y 487	1471	167
Asian, American Indian, Alaska Native, native Hawaiian or Pacific Islander	394		167	26
ASA classification				
I	628	53	10	0
II	10830	8310	1733	59
III	5188	11197	7122	861

* Note that the NSQIP database marks anyone as over 89 years of age as 90+, hence why the upper ranges per mFI-5 subgroup are capped at 89.
† Unknown/Not Reported patient races were excluded from data pool.

Table 3
Proportions of complications across frailty levels.

	0	1	2	3+	p-value
N=45,991	16,646	19,560	8,865	920	
Total complications	2.3%	3.7%	4.8	11.1%	**<.001**
Superficial SSI	0.2%	0.2%	0.4%	0.5%	**.003**
Deep incisional SSI	0.1%	0.2%	0.2%	0%	.222
Organ/deep space SSI	0.08%	0.1%	0.2%	0.3%	**.015**
Wound disruption	0.07%	0.1%	0.08%	0.2%	.401
Pneumonia	0.4%	0.9%	1.3%	3.5%	**<.001**
Pulmonary embolism	0.2%	0.3%	0.3%	0.3%	.403
Progressive renal insufficiency	0.01%	0.04%	0.1%	0%	**<.001**
Acute renal failure	0.01%	0.03%	0.1%	0.3%	**<.001**
Urinary tract infection	0.5%	0.7%	0.8%	2.1%	**<.001**
Stroke/CVA	0.05%	0.1%	0.2%	0.2%	**<.001**
Cardiac arrest requiring CPR	0.06%	0.2%	0.2%	1.3%	**<.001**
Myocardial infarction	0.07%	0.2%	0.4%	0.9%	**<.001**
Bleeding transfusions	0.3%	0.6%	0.6%	1.8%	**<.001**
DVT/thrombophlebitis	0.3%	0.3%	0.4%	1.0%	**.011**
Sepsis	0.1%	0.3%	0.4%	0.8%	**<.001**
Septic shock	0.05%	0.1%	0.1%	0.5%	**<.001**
Readmission	2.5%	3.6%	5.4%	8.0%	**<.001**
Reoperation	1.4%	1.9%	2.4%	3.8%	**<.001**
Death	0.07%	0.2%	0.4%	1.6%	**<.001**

SSI = Surgical Site Infection; CVA = Cerebrovascular Accident; CPR = Cardiopulmonary Resuscitation; DVT = Deep Vein Thrombosis
Note: p-values <.05 were bolded.

(0.06% to 0.3%), pneumonia (0.4% to 3.5%), ARF (0.01% to 0.4%), UTI (0.5% to 2.3%), cardiac arrest requiring CPR (0.05% to 0.9%), MI (0.06% to 1%), sepsis (0.1% to 0.6%), septic shock (0.04% to 0.5%), related readmission (2.5% to 8.4%), reoperation (1.4% to 3.8%), and mortality (0.07% to 1.5%).

Odds ratios and 95% confidence intervals for mFI-5 scores and covariates in predicting adverse events were drawn from multivariate logistic regression models and are depicted in Table 4. These values were compared to an mFI-5 score of 0.

An mFI-5 score of 2 (OR: 1.3, CI: 1.1–1.5, p-value=.011) and 3+ (OR: 2.8, CI: 2.1–3.7, p-value<.001) were significant predictors of total complications in a stepwise manner. Similarly, readmissions were independently predicted by an mFI-5 score of 2 and 3+ in a stepwise manner (2 vs 0: OR=1.5, CI: 1.3–1.7, p<.001; 3+ vs 0: OR=2.0, CI: 1.5–2.6, p<.001). An mFI-5 score of 3+ (OR: 1.8, CI: 1.2–2.7, p-value=.007) was a significant predictor of reoperation. Lastly, death was significantly associated with an increased mFI score (1 vs 0: OR=2.1, CI: 1.1–4.1, p=.030; 2 vs 0: OR=2.9, CI: 1.4–5.8, p=.004; 3+ vs 0: OR=9.4, CI: 4.1–21.7, p<.001).

An mFI score of 3+ (OR: 3.2, CI: 1.1–8.7, p-value=.027) was a significant predictor for superficial SSI. An mFI-5 score of 1 (OR: 1.5, CI: 1.1–2.1, p-value=.017), 2 (OR: 1.9, CI: 1.3–2.7, p-value<.001), and 3+ (OR: 4.3, CI: 2.6–7.1, p-value<.001) were all independent predictors of pneumonia in a stepwise manner. UTI was independently associated with an mFI-5 score of 3+ (OR: 2.5, CI: 1.4–4.3, p-value=.001). Finally, an mFI-5 score of 3+ (OR: 4.7, CI: 1.2– 8.5, p-value=.025) was a significant predictor of septic shock. mFI-5 scores of 1 (OR: 2.4, CI: 1.004–5.6, p-value=.049), 2 (OR: 3.4, CI: 1.3–8.5, p-value=.010), and 3+ (OR: 9.5, CI: 3.1–24.8, p-value<.001) were independent predictors of cardiac arrest requiring CPR in a stepwise manner. mFI-5 scores of 2 (OR: 3.9, CI: 1.7–8.6, p-value=.001) and 3+ (OR: 8.7, CI: 3.1–24.8, p-value<.001) were significant predictors of MI. Acute renal failure was significantly associated with an mFI score of 3+ (OR: 9.4, CI: 1.4–65.6, p-value=.023). Lastly, an mFI-5 score of 3+ (OR: 2.4, CI: 1.2–4.7, p-value=.013) was independently associated with bleeding requiring transfusion.

Severe frailty, denoted by a score of 3+, was not found to be a significant predictor for deep incision surgical site infection, organ/deep space surgical site infection, wound disruption, PE, renal insufficiency, stroke/CVA, or sepsis.

Discussion

Frailty is an age-associated decline in function that can lead to postoperative consequences, including increased risk of morbidity and mortality [13]. The ability to quantify frailty in especially at risk patients (i.e., elderly) is captured with indices like the mFI-5, and have been shown to predict adverse outcomes in patients undergoing spine surgery [7,13]. Despite the lack of literature on the risk stratification of ACDF patients using frailty indices, there may exist a possible utility for the mFI-5 when predicting postoperative outcomes, as shown by our data. This study found that mFI-5 scores were independent predictors for total complications, pneumonia, ARF, UTI, cardiac arrest requiring CPR, MI, bleeding requiring transfusions, septic shock, reoperation, related readmissions, and mortality.

Table 4
Multivariate logistic regression utilizes to determine impact of mFI-5 score and age on adverse post-operative outcomes.

Effect	Odds ratio	95% Confidence interval	p-value
Total complications			
mFI-5: 1 vs. 0	1.2	1.0–1.3	**.034**
mFI-5: 2 vs. 0	1.3	1.1–1.5	**.002**
mFI-5: 3+ vs. 0	2.5	2.0–3.2	**<.001**
Age	1.04	1.03–1.04	**<.001**
Superficial SSI			
mFI-5: 1 vs. 0	1.0	0.6–1.6	.989
mFI-5: 2 vs. 0	1.7	1.0–3.0	.054
mFI-5: 3+ vs. 0	2.4	0.9–6.5	.085
Age	0.963	0.937–0.989	**.006**
Deep incisional SSI			
mFI-5: 1 vs. 0	0.9	0.5–1.6	.730
mFI-5: 2 vs. 0	1.1	0.5–2.1	.887
mFI-5: 3+ vs. 0	0	0.0–0.0	.991
Age	1.01	0.984–1.045	.352
Organ/space SSI			
mFI-5: 1 vs. 0	1.4	0.7–2.8	.296
mFI-5: 2 vs. 0	2.0	0.9–4.1	.080
mFI-5: 3+ vs. 0	2.6	0.7–9.9	.149
Age	1.0	0.970–1.032	.968
Wound disruption			
mFI-5: 1 vs. 0	0.9	0.4–2.2	.874
mFI-5: 2 vs. 0	1.0	0.3–2.9	.955
mFI-5: 3+ vs. 0	2.7	0.5–13.7	.225
Age	0.99	0.94–1.03	.630
Pneumonia			
mFI-5: 1 vs. 0	1.4	1.0–1.9	**.025**
mFI-5: 2 vs. 0	1.7	1.2–2.3	**.002**
mFI-5: 3+ vs. 0	3.4	2.2–5.4	**<.001**
Age	1.06	1.05–1.07	**<.001**
Pulmonary embolism			
mFI-5: 1 vs. 0	1.1	0.7–1.6	.808
mFI-5: 2 vs. 0	0.8	0.5–1.4	.407
mFI-5: 3+ vs. 0	0.8	0.3–2.9	.788
Age	1.03	1.004–1.05	**.023**
Renal insufficiency			
mFI-5: 1 vs. 0	2.3	0.5–11.0	.314
mFI-5: 2 vs. 0	7.6	1.6–37.1	**.012**
mFI-5: 3+ vs. 0	0	0.0–0.0	.992
Age	1.06	1.01–1.12	**.020**
Acute renal failure			
mFI-5: 1 vs. 0	2.0	0.4–9.8	.419
mFI-5: 2 vs. 0	4.8	1.0–24.2	.058
mFI-5: 3+ vs. 0	9.7	1.4–67.4	**.022**
Age	1.02	0.97–1.07	.551
UTI			
mFI-5: 1 vs. 0	1.1	0.8–1.4	.616
mFI-5: 2 vs. 0	1.0	0.7–1.4	.876
mFI-5: 3+ vs. 0	2.1	1.2–3.6	**.007**
Age	1.05	1.04–1.07	**<.001**
Stroke/CVA			
mFI-5: 1 vs. 0	1.7	0.7–3.7	.211
mFI-5: 2 vs. 0	2.9	1.2–6.8	**.015**
mFI-5: 3+ vs. 0	2.0	0.4–10.1	.386
Age	1.04	1.01–1.07	**.023**
Cardiac arrest requiring CPR			
mFI-5: 1 vs. 0	2.5	1.2–5.0	**.013**
mFI-5: 2 vs. 0	2.6	1.2–5.9	**.018**
mFI-5: 3+ vs. 0	11.7	4.6–29.4	**<.001**
Age	1.06	1.04–1.1	**<.001**
Myocardial infarction			
mFI-5: 1 vs. 0	1.2	0.6–2.5	.615
mFI-5: 2 vs. 0	3.4	1.6–7.2	**.001**
mFI-5: 3+ vs. 0	6.9	2.5–18.5	**<.001**
Age	1.07	1.05–1.1	**<.001**
Bleeding transfusions			
mFI-5: 1 vs. 0	1.1	0.8–1.6	.525
mFI-5: 2 vs. 0	1.0	0.7–1.5	.991
mFI-5: 3+ vs. 0	2.1	1.2–3.9	**.016**
Age	1.04	1.02–1.1	**<.001**

(*continued on next page*)

Table 4 (*continued*)

Effect	Odds ratio	95% Confidence interval	p-value
Sepsis			
mFI-5: 1 vs. 0	1.4	0.8–2.3	.266
mFI-5: 2 vs. 0	1.6	0.9–2.9	.252
mFI-5: 3+ vs. 0	2.3	0.9–5.7	.113
Age	1.1	1.03–1.1	**<.001**
Septic shock			
mFI-5: 1 vs. 0	1.5	0.7–3.3	.329
mFI-5: 2 vs. 0	0.8	0.3–2.3	.713
mFI-5: 3+ vs. 0	3.6	1.1–11.9	**.036**
Age	1.06	1.02–1.1	**.002**
Reoperation			
mFI-5: 1 vs. 0	1.1	0.9–1.3	.366
mFI-5: 2 vs. 0	1.2	0.97–1.5	.097
mFI-5: 3+ vs. 0	1.7	1.2–2.6	**.004**
Age	1.03	1.02–1.03	**<.001**
Readmission			
mFI-5: 1 vs. 0	1.1	0.98–1.3	.095
mFI-5: 2 vs. 0	1.5	1.3–1.7	**<.001**
mFI-5: 3+ vs. 0	2.0	1.5–2.6	**<.001**
Age	1.03	1.02–1.03	**<.001**
Death			
mFI-5: 1 vs. 0	2.1	1.1–4.1	**.030**
mFI-5: 2 vs. 0	2.9	1.4–5.8	**.004**
mFI-5: 3+ vs. 0	9.4	4.1–21.7	**<.001**
Age	1.1	1.08–1.13	**<.001**

SSI = Surgical Site Infection; CVA = Cerebrovascular Accident; CPR = Cardiopulmonary Resuscitation; DVT = Deep Vein Thrombosis
Note: p-values <.05 were bolded.

Our results are similar to existing studies highlighting the utility of frailty indices in risk stratification for patients undergoing ACDF. Shin et al. queried the NSQIP database in an effort to assess the predictive capability of mFI-11 for postoperative complications in patients undergoing ACDF and posterior cervical fusion [6]. They found that rates of any complications, Clavien-Dindo IV complications, hospital acquired conditions, and mortality increased with mFI score. Clavien-Dindo IV complications included sequelae that our study also accounted for, including cardiac arrest, MI, septic shock, and PE. They also demonstrated that a high mFI score was an independent predictor of Clavien IV complications (OR=4.67; CI: 2.27–9.62; p<.001). Despite these findings, they analyzed the odds of these complications arising collectively, as opposed to our study which looked at each complication separately. Therefore, a high mFI score may predict higher rates of Clavien IV complications, however, the same cannot be said about each of the complications that are catagorized under the Clavien IV classification.

Similarly, Momtaz et al found that Clavien IV complications, as well as wound, cardiac, renal, and pulmonary complications were significantly associated with higher mFI-8 scores in patients who underwent ACDF [17]. Although our model differed from these two studies in the number of frailty factors considered, the association between frailty and postoperative outcomes is a reliable one, which shows its promise and utility in risk stratification.

Literature studying the relative predictive capability of mFI-5 in ACDF patients for adverse outcomes is scarce. Zreik et al. is the only study to date that has evaluated this association and compared mFI-5 to other current metrics, including age, ASA grade, and BMI [16]. They found that an mFI-5 score of ≥2 was a significant predictor for minor, major, and any complications. Using a receiver operating characteristic curve (ROC), the authors found that mFI-5 had comparable discriminatory performance to age and ASA classification for minor, major, and any complications. However, the frailty index was inferior to age and ASA classification for predicting extended LOS and discharge disposition (non-home discharge). Zreik et al. did not assess multivariable models for each individual complication, but rather grouped them into one of three categories: minor, major, and any complications. Allotting these adverse outcomes into larger groups may mask a real association for one or several specific complications behind the overall association.

This present study analyzed each complication individually in order to avoid the possible dampening of predictive capabilities of the mFI-5 associated with grouping complications. Furthermore, while our assessment found age to be a significant predictor for adverse outcomes (all p<0.05, except for ARF, wound disruption, and organ/space SSI), ASA classification was rarely found to be a predictor, which is similar to other studies [18,19], but contrary to Zreik et al. Our analysis showed that an ASA grade of 1 or 2 were significant predictors for readmissions and for total complications (p<0.05) and an ASA of 2 was predictive of reoperation (p<0.05). For each individual complication, however, ASA was not found to be a significant predictor of these outcomes. Additionally, our analysis showed that ASA and age yielded lower odds ratio values relative to those of mFI-5 for all complications, except for wound disruption and deep incisional SSI. Although our study did not compare the predictive capabilities of each metric relative to mFI-5, our findings call into question the accuracy of ASA classification in predicting adverse outcomes.

With the use of modified frailty indices, the number of factors considered may vary. Though initially starting with 11 factors, spine surgeons are now finding that a simpler 5 factor model has predictive capabilities comparable to other frailty indices, while being less cumbersome and aiding with daily clinical use [13,21–23]. Kweh et al. compared the two most commonly used frailty indices, mFI-11 and mFI-5, and found that both were significant predictors of adverse outcomes for posterior instrumented spinal surgery. Additionally, the ROC areas for both indices were comparable, Spearman's rank correlation coefficient was reassuring, and DeLong test to compare area under curve between the two indices was not statistically significant for all complications, major complications, surgical site infection, and 6-month mortality [21].

Furthermore, although ACDF is one of the most common treatments for cervical spine pathologies, complications are still possible which can lead to lengthier hospital stays and increased costs [24,25]. In a retrospective cohort study of 144,514 patients, Elsamadicy et al. found 20.7% of patients undergoing ACDF experienced an extended length of

stay. Additionally, patient comorbidities, including diabetes, hypertension, congestive heart failure, and chronic pulmonary disease (all items of the mFI-5) were significantly associated with a higher cost of admission [25]. These results suggest that mFI-5 scores can predict adverse outcomes and help healthcare systems optimize patient health and mitigate risk, both physical and financial, during the preoperative period.

The present study is not without limitations. The retrospective nature of database studies allow for an associative relationship to be determined rather than establishing causality. Furthermore, as with database studies, this study is subjected to incorrect CPT coding and data limited to variables that are provided in the registry, based on preset, already established definitions of variables and criteria. This limitation is of paramount importance as surgical intervention must be patient specific and cannot always be generalized to a single database parameter. Additionally, the NSQIP database only tracks up to the 30-day postoperative period, which limits our analysis. Lastly, the mFI-5 index is a limitation of measuring frailty. Other prognosticators of frailty, with the support of routine preoperative or baseline radiographic imaging characteristics and laboratory values, would make any findings regarding the predictability of the mFI-5 more impactful [20]. Future studies should aim to utilize the mFI-5 index in a prospective manner and track individual adverse outcomes, including readmissions, reoperations, and mortality, 30-day postoperative complications and compare its predictive capabilities with other metrics. To better elucidate the efficacy of the predictability of mFI-5, relative to other prognosticators like age, future studies may allocate age groups to earn a better understanding and compare odds ratio with mFI-5 in a more discrete manner.

Despite these limitations, the current study is one of the first to assess the predictive capability of the mFI-5 index for post-ACDF adverse outcomes. The scarcity of literature that attempts to observe an association highlights the novelty of this study's findings which successfully risk stratified patients who have underwent ACDF. This study shows that the mFI-5 may guide surgeons when indicating patients for ACDF in an accurate, yet concise manner, and may even serve purpose when medically and surgically optimizing patients in the preoperative period.

Conclusion

Moderate to severe mFI-5 scores of 2 or 3+ were an independent predictor for 30-day postoperative ARF, UTI, MI, bleeding requiring transfusions, septic shock, reoperation, and readmissions following elective ACDF surgery in adults over 50 years old. A statistically significant stepwise increase in mFI-5 score was displayed by total complications, pneumonia, cardiac arrest, and mortality. The mFI-5 is an accurate and concise index that may aid spine surgeons in predicting postoperative outcomes of high-risk patients and mitigate complications.

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Declaration of competing interests

The authors declare no conflicts of interest regarding our work, "The 5-Factor Modified Frailty Index (mFI-5) Predicts Adverse Outcomes After Elective Anterior Cervical Discectomy and Fusion (ACDF)" to be published in North American Spine Society Journal (NASSJ).

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