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ORIGINAL ARTICLE

THE ROLE OF FRAILTY INDEX IN PREDICTING POSTOPERATIVE COMPLICATIONS IN GERIATRIC VASCULAR SURGERY PATIENTS

Abstract

Introduction: This study aims to assess the predictive efficacy of the modified Frailty Index for 30-day postoperative outcomes in elderly patients undergoing vascular surgery and to evaluate its additional value compared with conventional tools.

Materials and Method: This retrospective cohort study examined 155 consecutive patients aged ≥ 65 years who underwent elective vascular surgery. The preoperative 11-item modified Frailty Index was calculated using National Surgical Quality Improvement Program variables. The primary endpoint was 30-day mortality, and secondary endpoints included surgical site infection, myocardial infarction, septic shock, reintubation, stroke, and acute kidney injury.

Results: The mean age was 71.98 ± 5.59 years. The 30-day mortality rate was 16.8%. The modified Frailty Index was higher in non-survivors than in survivors (3.96±1.48 vs 1.96±1.11, p<0.001) and showed excellent mortality prediction (Area Under the Curve=0.851, 95% CI: 0.778-0.924), with a threshold of 2.5 (sensitivity 84.6%, specificity 73.6%). In the multivariate analysis, adjusting for age, sex, American Society of Anesthesiologists score, and Geriatric Nutritional Risk Index, the modified Frailty Index remained associated with mortality (adjusted OR=2.79, 95% CI, 1.52-5.13; p=0.001). Each point increase correlated with higher risk of surgical site infection (OR=1.55, 95% CI: 1.19-2.03, p=0.001), myocardial infarction (OR=2.46, 95% CI: 1.27-4.78, p=0.008), septic shock (OR =2.46, 95% CI: 1.27-4.78, p=0.008), reintubation (OR=2.70, 95% CI: 1.82-4.02, p<0.001), and renal failure (OR=2.05, 95% CI: 1.43-2.94, p< 0.001).

Conclusions: The 11-item modified Frailty Index predicted adverse outcomes in geriatric vascular surgery patients. Its use in risk stratification may improve perioperative management.

Keywords: Frailty; Vascular Surgical Procedures; Geriatrics; Risk Assessment; Mortality.

INTRODUCTION

The global demographic shift toward an aging population has led to an increase in elderly patients requiring vascular surgery (1). Advanced age is associated with higher perioperative morbidity and mortality, particularly in vascular surgery patients with significant comorbidities and systemic atherosclerotic disease (2). However, chronological age alone cannot predict surgical risk, as it fails to account for varying physiological reserves and functional capacity in elderly patients (3).

The concept of frailty has emerged as a comprehensive approach to geriatric surgery risk assessment. Frailty is a clinical syndrome characterized by decreased physiological reserves and increased vulnerability to adverse outcomes following stressors (4). Unlike chronological age, frailty captures the cumulative impact of age-related decline across multiple organ systems, providing a more accurate assessment of surgical risk (5). The Frailty Index (FI), described by Rockwood and Mitnitski, quantifies frailty as the proportion of accumulated health deficits relative to total potential deficits (6). The modified Frailty Index (mFI), derived from the American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) database, represents a simplified adaptation of the original FI (7). Studies have demonstrated the mFI's prognostic value across surgical specialties (8, 9). In vascular surgery, Ehlert validated an 11-item mFI in over 72,000 patients, showing a superior prediction of mortality compared to traditional tools (10). Karam et al. found that a simplified frailty index independently predicted mortality and adverse outcomes in vascular surgery patients (11).

Despite these promising findings, several gaps exist in the literature. First, validation studies have focused on North American populations, thus limiting data from other regions and healthcare systems. Second, although mortality has been the primary focus, analyses of the relationship between frailty and specific postoperative complications remain limited. Third, the optimal mFI cutoff values lack consistency across vascular surgery procedures. Recent systematic reviews have emphasized the need for standardized frailty assessment methodologies and reporting (12). Variations in mFI calculation methods and outcome definitions limit evidence synthesis and guideline development.

Most existing studies have used large administrative databases that lack granular clinical details to understand frailty and adverse outcomes. This study evaluated the predictive performance of an 11-item mFI in geriatric patients undergoing vascular surgical procedures at a tertiary center (13). Our primary objective was to determine the association between the mFI and 30-day mortality. Secondary objectives included assessing the mFI's relationship with postoperative complications, determining optimal cut-off values, and evaluating its incremental predictive value over traditional risk factors.

We hypothesized that the mFI would demonstrate superior discriminatory ability compared to conventional risk factors and would be independently associated with both mortality and major postoperative complications in geriatric vascular surgery patients.

MATERIALS AND METHOD

This retrospective cohort study at Gazi University Faculty of Medicine of a tertiary center with a high-volume vascular surgery program was approved by the Institutional Review Board (Protocol Number: E-77082166-604.01-1297517). The requirement for informed consent was waived owing to the retrospective design and minimal risk. This study followed the STROBE guidelines for cohort studies (14). The study included consecutive patients aged ≥65 years who underwent elective vascular surgical procedures between January 1, 2022, and December 31, 2024. Inclusion criteria were patients aged 65 years or older who underwent elective vascular operations, including lower-extremity revascularization, endovascular aortic aneurysm repair (EVAR), or carotid endarterectomy, with complete preoperative data for modified Frailty Index (mFI) calculation. Exclusion criteria were emergency procedures, concurrent nonvascular operations, previous enrollment, or incomplete 30-day follow-up data.

The sample size calculation was based on studies reporting 30-day mortality rates of 10-20% in geriatric vascular surgery populations (10, 15). To detect an odds ratio of 2.5 for high versus low frailty (mFI ≥3 vs. <3) with 80% power and α=0.05, assuming a 1:3 ratio of high to low frailty, a minimum sample size of 142 patients was required. To ensure sufficient power, 155 patients were included in this study. The research personnel extracted clinical data from the electronic medical records using standardized forms. The data were independently verified, and discrepancies were resolved through consensus. The inter-rater reliability for the modified Frailty Index was assessed in 30 patients (19.4% of the cohort) by both reviewers, showing excellent agreement (κ=0.94, 95% Confidence Interval: 0.87-1.00). Discrepancies were resolved through consensus between the reviewers and consultation with a senior attending surgeon. The following variables were collected.

Demographic and clinical variables

The demographic and clinical characteristics of the included patients were comprehensively recorded. Core demographic data collected included age, sex, and body mass index (BMI). The American Society of Anesthesiologists (ASA) Physical Status Classification was used to assess the patients' general health status and perioperative risk. Furthermore, preoperative laboratory values were reviewed to obtain information on patients' physiological reserves and nutritional status. Surgical procedure-related data were also documented in detail, including procedure type and the surgical approach (open vs. endovascular), as well as the patient's preoperative wound status.

Frailty assessment

The 11-item modified Frailty Index was calculated based on the presence or absence of the following NSQIP-derived variables as previously validated by Ehlert et al. (15):

1. Diabetes mellitus (insulin-dependent or non-insulin-dependent)
2. Congestive heart failure within 30 days before surgery
3. Hypertension requiring medication
4. History of transient ischemic attack or cerebrovascular accident
5. Functional status (partially or totally dependent vs. independent)
6. History of myocardial infarction within six months
7. History of cerebrovascular accident with neurological deficit
8. Chronic obstructive pulmonary disease or pneumonia within 30 days
9. History of percutaneous coronary intervention or coronary artery bypass grafting
10. Impaired sensorium (confusion, delirium, or altered mental status)
11. Preoperative open wound or wound infection

Each variable was scored as 0 (absent) or 1 (present), with the mFI calculated as the sum of the positive variables (range 0-11). The inter-rater reliability for the mFI calculation was assessed in a subset of 30 patients and demonstrated excellent agreement (κ=0.94).

Nutritional assessment: The Geriatric Nutritional Risk Index (GNRI) was calculated using the formula: GNRI=[1.489 × albumin (g/dL)] + [41.7 × (current weight/ideal weight)] (16). The perfect weight was calculated using the Lorentz formula as follows (17): The ideal weight was calculated using the Lorentz formula as follows: for men, ideal weight (kg)=height (cm) - 100 - [(height - 150)/4]; for women, ideal weight (kg)=height (cm) - 100 - [(height - 150)/2.5].

Outcome measures

Primary endpoint: Thirty-day all-cause mortality, defined as death from any cause within 30 days of the index surgical procedure.

Secondary endpoints: Secondary endpoints comprised major postoperative complications occurring within 30 days of the index surgery. These complications were rigorously assessed and documented, including surgical site infection (categorized as superficial, deep incisional, or organ/space), myocardial infarction (defined by troponin elevation with appropriate clinical correlation), and septic shock (requiring vasopressor support in the presence of confirmed or suspected infection). Furthermore, respiratory complications such as reintubation (unplanned endotracheal intubation following initial extubation) were evaluated. Finally, the assessment included specific organ system failures such as stroke (a new neurological deficit confirmed by imaging) and dialysis-requiring acute kidney injury (new requirement for renal replacement therapy).

All outcomes were adjudicated by two independent reviewers using standardized definitions based on the ACS-NSQIP criteria, with disagreements resolved by a third reviewer.

Missing data analysis

Missing data were identified in seven patients (4.5% of the cohort), including preoperative albumin level (n=4, 2.6%), functional status assessment (n=2, 1.3%), and wound status documentation (n=1, 0.6%). Data on albumin levels were missing before routine preoperative laboratory protocols were established. Functional status data were missing in patients transferred from facilities with incomplete documentation, while one case of missing wound status was clarified through a surgical note review. A complete case analysis was performed as missing data were below 5% and Missing Completely at Random (Little's test, $p=0.312$). Sensitivity analysis excluding patients with missing data showed no significant difference in primary outcomes, with odds of <5%.

Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics (version 27.0; IBM Corp., Armonk, NY, USA). Continuous variables' normality was assessed using the Shapiro-Wilk test and reported as mean ± standard deviation or median (interquartile range). Categorical variables are presented as frequencies and percentages. Groups were compared using Student's t-test or Mann-Whitney U test for continuous variables and χ^2 test or Fisher's exact test for categorical variables. Multivariate logistic regression was used to identify the independent outcome predictors. Variables with $p<0.10$ in univariate analysis were included in multivariable models using a forward stepwise approach (entry $p<0.05$, removal $p>0.10$). Multicollinearity was evaluated using variance inflation factors, with VIF>5 indicating collinearity. Model discrimination was assessed using ROC curve analysis with AUC and 95% confidence intervals. The cutoff values were determined using Youden's index. Calibration was evaluated using the Hosmer-Lemeshow test. For secondary endpoints, the Benjamini-Hochberg procedure controlled the false discovery rate at 5%. A complete case analysis was performed for datasets with <5% of missing data. Tests were two-sided, with $p<0.05$ considered significant, following STROBE guidelines.

RESULTS

During the study period, 187 patients aged ≥ 65 years underwent elective vascular surgery. After applying the exclusion criteria, 155 patients were included in the final analysis. The mean age of the cohort was 71.98 ± 5.59 years, with an age range of 65 to 89 years, and 135 (87.1%) of the patients were male. The distribution of the surgical procedures was as follows: EVAR, 81 patients (52.3%); lower-extremity revascularization, 54 patients (34.8%); and carotid endarterectomy, 20 patients (12.9%).

Table 1. Baseline Characteristics by 30-Day Mortality Status

Characteristic	Overall (n=155)	Survivors (n=129)	Non-survivors (n=26)	p-value
Age (years), mean ± SD	71.98 ± 5.59	71.5 ± 5.2	74.1 ± 6.8	0.032
Male gender, n (%)	135 (87.1)	114 (88.4)	21 (80.8)	0.025
BMI (kg/m²), mean ± SD	26.28 ± 4.00	26.5 ± 3.8	25.2 ± 4.9	0.156
ASA Score, mean ± SD	2.77 ± 0.59	2.6 ± 0.5	3.2 ± 0.7	<0.001
Procedure Type, n (%)				0.089
Lower extremity revascularization	54 (34.8)	42 (32.6)	12 (46.2)	
EVAR	81 (52.3)	71 (55.0)	10 (38.5)	
Carotid endarterectomy	20 (12.9)	16 (12.4)	4 (15.4)	
Wound Status, n (%)				0.041
None	137 (88.4)	118 (91.5)	19 (73.1)	
Clean/Contaminated/Infected	18 (11.6)	11 (8.5)	7 (26.9)	
mFI Score, mean ± SD	2.30 ± 1.39	1.96 ± 1.11	3.96 ± 1.48	<0.001
GNRI, mean ± SD	99.34 ± 8.69	101.2 ± 8.1	91.8 ± 8.9	<0.001

Abbreviations: SD, Standard Deviation; BMI, Body Mass Index; ASA, American Society of Anesthesiologists; EVAR, Endovascular Aortic Repair; mFI, modified Frailty Index; GNRI, Geriatric Nutritional Risk Index

Baseline demographic and clinical characteristics were stratified according to the 30-day mortality outcomes. Continuous variables are expressed as mean ± SD, while categorical variables are expressed as n (%). Abbreviations: mFI, modified Frailty Index; ASA for American Society of Anesthesiologists, GNRI for Geriatric Nutritional Risk Index, and EVAR, endovascular aortic aneurysm repair. Statistical analyses were performed using the t-test for continuous variables and the χ^2 test for categorical variables.

Table 2. Frequency of Modified Frailty Index Components (n=155)

mFI Component	n (%)
Hypertension	138 (89.0)
Diabetes mellitus	90 (58.1)
History of PCI/CABG	64 (41.3)
COPD/Pneumonia	45 (29.0)
History of TIA/CVA	38 (24.5)
Congestive heart failure	32 (20.6)
History of MI	28 (18.1)
Functional dependence	25 (16.1)
CVA with neurological deficit	22 (14.2)
Preoperative open wound	18 (11.6)
Impaired sensorium	5 (3.2)

Abbreviations: PCI, percutaneous coronary intervention; CABG, coronary artery bypass grafting; COPD, chronic obstructive pulmonary disease; TIA, transient ischemic attack; CVA, cerebrovascular accident; MI, myocardial infarction

The distribution of the individual components constituting the 11-item modified Frailty Index was presented. Abbreviations: PCI, percutaneous coronary intervention; CABG, coronary artery bypass grafting; COPD, chronic obstructive pulmonary disease; TIA, transient ischemic attack; CVA, cerebrovascular accident; MI, myocardial infarction.

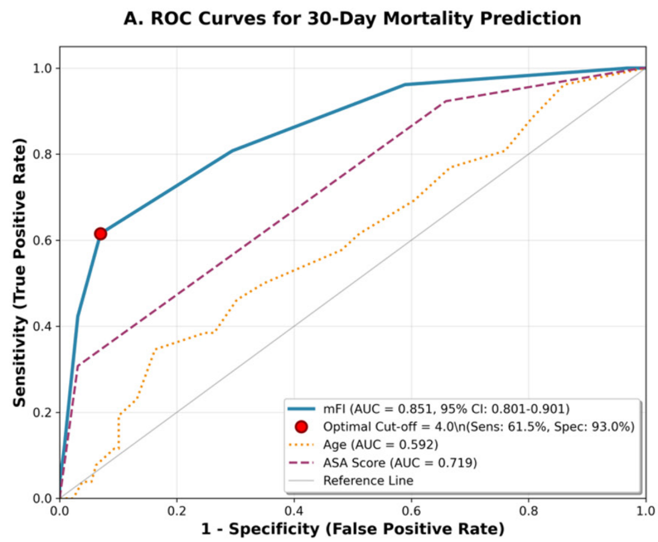
The baseline characteristics stratified by 30-day mortality status are shown in Table 1. Patients who succumbed within 30 days were significantly older (74.1 ± 6.8 years compared to 71.5 ± 5.2 years, p=0.032), more likely to be female (19.2% compared to 11.6%, p=0.025), and exhibited higher American Society of Anesthesiologists (ASA) scores (3.2 ± 0.7 compared to 2.6 ± 0.5, p<0.001) and modified Frailty Index (mFI) scores (3.96 ± 1.48 compared to 1.96 ± 1.11, p<0.001). Additionally, the GNRI scores were significantly lower among non-survivors (91.8 ± 8.9) than among survivors (101.2 ± 8.1, p< 0.001).

Distribution of mFI components

The frequencies of individual mFI components are listed in Table 2. The most prevalent components were hypertension (89.0%), diabetes mellitus (58.1%), and a history of percutaneous coronary intervention (PCI) and coronary artery bypass grafting (CABG) (41.3%). In contrast, an impaired sensorium (3.2%) and preoperative open wounds (11.6%) were the least prevalent components.

Primary outcome: Thirty-day mortality was observed in 26 patients, representing 16.8% (95% CI: 11.3-23.7%). A significant difference was noted in the distribution of the mFI scores between survivors and non-survivors. Specifically, among patients with an mFI ≤2, the mortality rate was 7.3% (8/109), whereas it was 39.1% (18/46) among those with an mFI ≥3 (p<0.001).

ROC analysis for mortality prediction: The mFI exhibited excellent discriminatory capability for predicting 30-day mortality, with an AUC of 0.851 (95% CI: 0.778-0.924, p< 0.001) (Figure 1). The optimal cutoff value, as determined by Youden's index, was 2.5, resulting in a sensitivity of 84.6% (95% CI: 65.1-95.6%) and a specificity of 73.6% (95% CI: 65.0-81.2%). The positive predictive



B. Model Performance Comparison

Model	AUC	Sensitivity	Specificity	PPV	NPV
mFI	0.851	61.5%	93.0%	64.0%	92.3%
Age	0.592	61.5%	48.8%	19.5%	86.3%
ASA Score	0.719	100.0%	0.8%	16.9%	100.0%

Figure 1. ROC curve analysis for the modified frailty index predicting 30-day mortality

The receiver operating characteristic (ROC) curve for the modified Frailty Index in predicting 30-day mortality (n=155) demonstrated an area under the curve (AUC) of 0.851, with a 95% confidence interval (CI) ranging from 0.778 to 0.924, and a p-value of less than 0.001. The optimal cutoff value was determined to be 4, yielding a sensitivity of 84.6%, specificity of 73.6%, negative predictive value (NPV) of 95.9%, and positive predictive value (PPV) of 40.7%. The diagonal line on the ROC curve represents random chance, corresponding to an AUC of 0.50.

Table 3. Multivariable logistic regression analysis for 30-day mortality

Variable	Adjusted OR	95% CI	p-value
mFI (per 1-point increase)	2.79	1.52-5.13	0.001
Female gender	16.72	2.52-110.77	0.004
GNRI (per 1-point increase)	0.78	0.69-0.88	<0.001

Model C-statistic=0.887; Hosmer-Lemeshow p=0.600

Abbreviations: OR, Odds Ratio; CI, Confidence Interval; mFI, modified Frailty Index; GNRI, Geriatric Nutritional Risk Index

Independent predictors of 30-day mortality were determined using a forward stepwise logistic regression analysis. Variables with a p-value of less than 0.10 in the univariate analysis were considered for inclusion in the model. Abbreviations used are as follows: OR, odds ratio; CI, confidence interval; mFI, modified Frailty Index; GNRI=Geriatric Nutritional Risk Index. The model's C-statistic was 0.887, and the Hosmer-Lemeshow test yielded a p-value of 0.600.

Table 4. Secondary outcomes by mFI score categories

Outcome	Overall n (%)	mFI ≤2 n (%)	mFI ≥3 n (%)	p-value	Adjusted OR*	95% CI	p-value
Any complication	70 (45.2)	40 (36.7)	30 (65.2)	0.002	1.89	1.31-2.73	0.001
Surgical site infection	37 (23.9)	20 (18.3)	17 (37.0)	0.014	1.55	1.19-2.03	0.001
Reintubation	21 (13.5)	8 (7.3)	13 (28.3)	<0.001	2.70	1.82-4.02	<0.001
Dialysis-requiring AKI	17 (11.0)	7 (6.4)	10 (21.7)	0.006	2.05	1.43-2.94	<0.001
Myocardial infarction	4 (2.6)	1 (0.9)	3 (6.5)	0.048	2.46	1.27-4.78	0.008
Septic shock	4 (2.6)	1 (0.9)	3 (6.5)	0.048	2.46	1.27-4.78	0.008
Stroke	4 (2.6)	2 (1.8)	2 (4.3)	0.344	1.66	0.91-3.01	0.096

*Adjusted for age, sex, ASA score, and GNRI

Abbreviations: AKI, Acute Kidney Injury; OR, Odds Ratio; CI: Confidence Interval

This study examined the 30-day postoperative complications in patients categorized into low-(mFI ≤2) and high-risk (mFI ≥3) groups. This analysis specifically focused on the incidence of acute kidney injury (AKI). Adjusted odds ratios (ORs) were determined by accounting for variables, such as age, sex, ASA score, and GNRI score. Additionally, p-values were adjusted for multiple comparisons using the Benjamini-Hochberg procedure.

value was 40.7% (95% CI: 28.1-54.3%), while the negative predictive value was 95.9% (95% CI: 90.1-98.7%).

Multivariable analysis for mortality

Variables with a p-value less than 0.10 in the univariate analysis, including age, sex, ASA score, mFI, GNRI, and wound status, were incorporated into the multivariable model. The final model identified the mFI, female sex, and GNRI as independent predictors of 30-day mortality (Table 3). The model exhibited good calibration (Hosmer-Lemeshow χ^2=6.42, p=0.600) and discrimination (C-statistic=0.887).

Secondary Outcomes

The overall complication rate was 45.2% (n=70/155). The most prevalent complications included surgical site infections (23.9%), reintubation (13.5%), and acute kidney injury requiring dialysis (11.0%) (Table 4).

Following correction for multiple testing using the Benjamini-Hochberg procedure, all associations, except for stroke, remained statistically significant (adjusted p<0.05).

Subgroup Analysis by Procedure Type

Due to the limited sample sizes within the individual procedure groups, a formal statistical comparison was not conducted. Nevertheless, the descriptive analysis revealed consistent trends across procedure types, indicating that higher mFI scores were associated with increased complication rates in all groups (EVAR: 38.3 % vs. 65.0 %, p= 0.089; lower extremity: 35.7 % vs. 66.7 %, p= 0.041; and carotid: 31.3 % vs. 75.0%, p= 0.074 for mFI ≤2 vs. ≥3, respectively).

DISCUSSION

This single-center retrospective cohort study showed that the 11-item mFI was an independent predictor of 30-day mortality and major complications in geriatric patients undergoing vascular surgery. Our findings contribute to the literature on frailty assessment in surgical populations and have implications in clinical practice. The key finding was the mFI's exceptional discriminatory capacity in predicting 30-day mortality, with an AUC of 0.851. This performance surpassed previous studies, where Ehlert and colleagues reported AUC values of 0.63 to 0.66 for mFI in predicting mortality following vascular procedures (15). This discrepancy may be attributed to several factors, including our exclusive focus on geriatric patients (≥65 years), homogeneous single-center setting with standardized perioperative protocols, and comprehensive data collection with rigorous outcome adjudication.

The mortality rates in the low- and high-frailty groups highlight the clinical significance of our findings. Patients with an mFI ≥3 showed 5.4-fold higher mortality than those with an mFI ≤2 (39.1% vs. 7.3%). This risk stratification aids in preoperative counseling and decision-making. The negative predictive value of 95.9% for mFI <2.5 indicates excellent prognosis in low-frailty patients, reassuring both patients and clinicians considering surgery.

Our findings corroborate those of previous studies. The independent association between mFI and mortality (adjusted OR: 2.79, 95% CI: 1.49-5.02 per point increase) aligns with the effect sizes in other surgical populations (8, 9). Our study showed that the impact of frailty extends beyond mortality to various postoperative morbidities.

The secondary outcomes showed that frailty affected multiple organ systems and recovery. Strong associations with reintubation (OR: 2.70, 95% CI: 1.82-4.02), dialysis-requiring acute kidney injury (OR: 2.05, 95% CI: 1.43-2.94), and surgical site infection (OR: 1.55, 95% CI: 1.19-2.03) indicated that frail patients had reduced physiological reserves across the respiratory, renal, and immune systems. These findings support frailty as a syndrome characterized by decreased physiological reserves and increased vulnerability to stressors (4). The absence of an association between mFI and stroke may be due to the low event rate (2.6%), resulting in insufficient power to detect an association. This limitation suggests the need for larger, multicenter studies. The mFI can be calculated using readily available clinical data, making it feasible for pre-operative assessment protocols. The mFI utilizes the existing ACS-NSQIP variables, which are routinely collected in most healthcare systems.

For high-risk patients (mFI ≥ 3), three key interventions should be considered. Preoperative optimization through geriatric assessment, nutritional support, and prehabilitation may enhance physiological reserves (16, 18). Intensive perioperative monitoring can enable prompt recognition of complications. Patient counseling should include frailty-based risk estimates for informed decision making.

The integration of the mFI into clinical practice can affect healthcare resource allocation and quality improvement. High-risk patients may benefit from specialized geriatric surgery pathways, enhanced nursing ratios, or intensive care resources. Risk-adjusted outcome reporting using frailty metrics provides more meaningful benchmarking than age-based adjustment.

Several methodological strengths enhanced the validity of our findings. Consecutive patient enrollment minimizes selection bias, whereas comprehensive outcome assessment with independent adjudication reduces measurement errors. Our rigorous statistical approach, including model calibration and correction for multiple testing, strengthens our conclusions.

The AUC value (0.851) was significantly higher than that in comparable studies (0.63-0.66) (10, 15). Bootstrap validation yielded an optimism-corrected AUC of 0.852, showing no overfitting. Several factors can explain this performance. Our mortality rate (16.8%) exceeded the literature rates (3-8%), enabling better risk stratification. Our single-center design provided results consistent with standardized protocols. The inclusion of elective cases may have resulted in a high-risk group. The higher female mortality (35% vs. 14%, p=0.0437) and small group size (n=20) may have influenced the metrics. While the findings show a strong mFI predictive value, multicenter prospective studies with larger samples are needed for generalizability.

In our study, it is noteworthy that the female gender variable demonstrates an unusually high odds ratio in our regression model (OR: 16.72; 95CI: 2.52–110.77). This finding is primarily a reflection of sample imbalance in our study (with 87.1% of the cohort being male). The small subgroup of female patients (n=20) and the high mortality rate observed within this group (%35) led to a wide confidence interval for the estimated OR value, thereby reducing statistical precision. This high OR value should be interpreted as a statistical anomaly reflecting risk concentration in a small subgroup, rather than a generalization, and the clinical implications of such findings must be verified by studies with larger and more balanced cohorts.

The 11-item mFI, although validated, represents a simplified frailty assessment that may not capture all the domains. Cognitive function, social support, and functional measures were not directly included, omitting the important aspects that affect surgical outcomes (19). Future research should explore combining mFI with other geriatric assessment tools. The clinical utility of risk prediction tools depends on their performance versus alternatives. Traditional risk assessments include the Lee Cardiac Risk Index, ASA Physical Status Classification, and procedure-specific calculators (20). Studies suggest that the mFI may outperform these tools (10), although direct comparisons in our cohort would strengthen the evidence for clinical adoption.

The superior performance of the mFI reflects its comprehensive evaluation of physiological reserves across multiple systems compared with traditional risk factors. The optimal approach may involve integrating the mFI with other validated risk-prediction tools.

Key research priorities have emerged. First, prospective multicenter validation studies are needed to confirm the generalizability across healthcare systems and populations. Second, studies assessing mFI-guided perioperative optimization strategies could demonstrate the utility of frailty-based risk stratification. Third, economic analyses of frailty assessments could inform health care policies. Fourth, developing dynamic frailty assessment tools to track changes over time may enhance the prognostic accuracy and guide care planning.

Investigating the mechanisms linking frailty to adverse outcomes could help to identify therapeutic targets and develop interventions for high-risk patients.

Despite its limitations, the strengths of this study and its potential contributions to clinical practice enhance the reliability of the results. The most significant contribution of the study is our focus on high-risk geriatric patients and the exceptional discriminatory capacity of the 11-item mFI in predicting 30-day mortality (AUC: 0.851). This performance is superior to similar studies in the existing literature. Methodologically, the consecutive patient enrollment minimizes selection bias, while the comprehensive outcome assessment with independent adjudication reduces measurement errors. Additionally, our rigorous statistical approach, including model calibration and correction for multiple testing, strengthens our conclusions. In terms of contribution to clinical practice, the high negative predictive value of the mFI (%95.9) offers a reassuring prognostic tool for patients with low frailty. The strategies we recommend for high-risk patients (mFI ≥ 3), such as preoperative optimization, intensive perioperative monitoring, and frailty-based risk counseling, can help to improve perioperative management and facilitate the more efficient allocation of healthcare resources. The easy calculability of the mFI makes it a valuable risk stratification tool that is feasible to integrate into clinical workflows.

Limitations

Our study has several limitations that restrict its generalizability. Our single-center retrospective design limits the applicability of the findings to other healthcare systems and populations, and does not entirely exclude the influence of potential unknown confounding factors. The predominantly male cohort (%87.1), which reflects the typical vascular surgery demographics, may severely limit the applicability of the findings to female patients. Given the higher mortality rate observed in females, these potential sex-specific differences warrant further investigation in future studies. Furthermore, the 30-day follow-up period may have missed late complications and long-term functional outcomes, which are particularly critical for the geriatric population with prolonged recovery times. Finally, the sample size restricted us from conducting reliable subgroup analyses according to the procedure type. Future multicenter prospective studies require larger samples and extended follow-up periods to improve the generalizability of the findings.

CONCLUSIONS

This study showed that the 11-item mFI independently predicted adverse outcomes in geriatric patients undergoing vascular surgery. The index demonstrated excellent discrimination (AUC: 0.851) and a strong association with clinical outcomes, supporting its use in preoperative risk assessment. Patients with mFI scores ≥ 3 require enhanced preoperative optimization and monitoring, whereas those with low scores can expect favorable outcomes. mFI-based risk stratification can improve patient outcomes through personalized care and resource optimization. Future research should focus on multicenter validation and evaluation of mFI-guided interventions in vascular surgery.

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Data Availability Statement: The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request, subject to institutional review board approval, and data use agreements.

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