# The Risk Analysis Index Has Superior Discrimination Compared With the Modified Frailty Index-5 in Predicting Worse Postoperative Outcomes for the Octogenarian Neurosurgical Patient

**Alyssa G. Yocky, BS[*], Oluwafemi P. Owodunni, MD, MPH[‡], Evan N. Courville, MD[‡], Syed Faraz Kazim, MD, PhD[‡], Meic H. Schmidt, MD, MBA[‡], Susan L. Gearhart, MD, MEHP[#], Diana L. Greene-Chandos, MD[§¶], Naomi George, MD, MPH[‖¶], Christian A. Bowers, MD[‡]**

*Department of Neurosurgery, University of New Mexico School of Medicine, Albuquerque, New Mexico, USA; [‡]Department of Neurosurgical Surgery, University of New Mexico Hospital, Albuquerque, New Mexico, USA; [§]Department of Neurology, University of New Mexico Hospital, Albuquerque, New Mexico, USA; [‖]Department of Emergency Medicine, University of New Mexico Hospital, Albuquerque, New Mexico, USA; [¶]Center for Adult Critical Care, University of New Mexico Hospital, Albuquerque, New Mexico, USA; [#]Department of Surgery, The Johns Hopkins Medicine, Baltimore, Maryland, USA

**Correspondence:** Christian A. Bowers, MD, Department of Neurosurgery, University of New Mexico Health Sciences Center, 1 University New Mexico, MSC10 5615, Albuquerque, NM 87131, USA. Email: CABowers@salud.unm.edu

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**BACKGROUND AND IMPORTANCE:** Healthcare systems continuously strive to improve quality and value of care. Advances in surgical technologies, enhanced perioperative surgical planning, and multidisciplinary care strategies are increasing the number of elective procedures in the geriatric population. However, frail older adults are still more likely to have poor postoperative outcomes. We examined the impact of frailty on postoperative outcomes, we compared the discriminative thresholds for the Risk Analysis Index (RAI), modified Frailty Index-5 (mFI-5), and increasing patient age.

**CLINICAL PRESENTATION:** Octogenarian patients undergoing spine, cranial, and other procedures captured in the American College of Surgeons National Surgical Quality Improvement Program between 2012 and 2020 were included. We used receiver operating characteristic curve to examine discriminative thresholds of RAI, mFI-5, and increasing patient age. Multivariable analyses were performed. Our primary outcomes were 30-day mortality, extended length of stay (eLOS [≥75th percentile]), and continued inpatient care >30 days (pLOS). Secondary outcomes were skilled care facility (skilled nursing facility [SNF]) discharges and readmissions.

**DISCUSSION:** In total, 20 710 octogenarians were included, with a mean age of 83 years (SD, 2.5) and a men (52.7%) and White (79.8%) majority. The RAI had higher predictive discriminative thresholds for 30-day mortality (C-statistic of 0.743), eLOS (C-statistic: 0.692), and pLOS (C-statistic: 0.697) compared with the mFI-5 (C-statistic: 0.574, 0.556, and 0.550, respectively), and increasing patient age (C-statistic: 0.577, 0.546, and 0.504, respectively), $P < .001$. On multivariable analyses, RAI showed a larger effect size with adverse postoperative outcomes by increasing frailty strata than mFI-5 and increasing patient age. Nonetheless RAI showed decreased risk for SNF discharges.

**CONCLUSION:** We found that RAI was a more accurate predictor than mFI-5 and increasing patient age for 30-day mortality, eLOS, and pLOS in octogenarian neurosurgery patients. More research is needed on RAI's performance in different specialized neurosurgical populations. Moreover, it is increasingly clear that comprehensive risk assessment strategies tailored to optimize perioperative care should be prioritized to potentially improve outcomes for this at-risk population.

**KEY WORDS:** Geriatrics, Frailty, Risk analysis index, Modified frailty index, 30-day mortality, Length of stay, Postoperative outcomes

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**ABBREVIATIONS: CHF,** congestive heart failure; **COPD,** chronic obstructive pulmonary disease; **eLOS,** extended length of stay; **pLOS,** continued inpatient care >30 days; **HTN,** hypertension; **LOS,** length of hospital stay; **mFI-5,** modified Frailty Index-5; **RAI,** Risk Analysis Index; **SNF,** skilled nursing facility.

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In what has been termed a "silver tsunami," the global population of persons aged 80 years or older is projected to triple by 2050.[1] This phenomenon has also been observed in the United States and is thought to result from comparatively increased life expectancy coupled with overall lower birth rates.[1] These dynamics could have far-reaching implications when considering health care utilization and expenditures because it creates a vulnerable population with greater health issues, predisposed to higher rates of impairment, and needs for health care services.[2,3] Demographic, social, mental, and health care needs of an aging population are interrelated.[4] Understanding this intersectionality helps illustrate the scale of the challenge attributed to comorbidities and the propensity for loss of independence.[5,6]

The ever-evolving healthcare sector offers a wealth of novel opportunities for achieving improved quality and value of the health care delivered. An increasing number of elective procedures are being performed in the geriatric population, a trend attributed to advancements in surgical technologies and perioperative surgical planning made possible by multidisciplinary care strategies and the rising implementation of clinical practice guidelines to aid decision making.[5,7,8] Unfortunately, older patients are among the most at-risk for adverse postoperative outcomes; the evidence supports a direct correlation between increasing patient age and a higher risk of perioperative mortality and morbidity as frailty increases with increasing age.[9,10] These complications contribute to the already high financial burden of geriatric surgical care, to the patient, and health care system.[11,12]

Frailty has been described as an intermediary stage between independent functioning and total functional reserve before dependence.[13,14] Therefore, frailty is as an age-related increase in vulnerability to stressors because of a decline in physiological reserve that predisposes to loss of independence or to death.[13-15] It is often referred to as a syndrome because of the multiple physiologic systems affected by frailty and the wide variability in phenotypical presentations as a result of variable genetic and environmental factors.[13,16] Although there is no clear conceptual standard for identifying and classifying frailty, quality improvement efforts continue to evaluate actionable risk assessment strategies to be used in clinical settings.[15] Specialists from a wide range of fields have acknowledged frailty's importance in determining clinical outcomes and the potential of prehabilitation to mitigate poor outcomes in frail patients.[8] Neurosurgery studies have shown that frailty predicts postoperative mortality, complications, extended length of stay (eLOS), and discharge to a higher level of care facility (skilled nursing facility [SNF]).[11,12,17-19]

The Risk Analysis Index (RAI) is a validated tool for predicting poor postoperative outcomes in frail patients. It stratifies patients into risk tiers based on a weighted scale that takes into account key domains of frailty.[16-18,20-24] The modified Frailty Index-5 (mFI-5) has also been demonstrated to predict poor outcomes and is superior to patient age alone. It evaluates frailty through the assessment of health and functional domains.[17,18,20,21,25-33]

The RAI has been continuously validated for use in neurosurgery patients and has been recommended for preoperative use in both low-risk and high-risk procedures.[19,22,34,35] However, there have been no specific studies to determine the efficacy of RAI in octogenarian patients undergoing neurosurgical procedures. We hypothesized that RAI would be a reliable predictor of 30-day mortality, eLOS, and continued inpatient care >30 days (pLOS). In addition, RAI would be a better predictor of poor postoperative outcomes than mFI-5. Therefore, we sought to compare the predictive thresholds and discriminatory ability of RAI, mFI-5, and increasing patient age. In addition, we will investigate their independent associations to our primary and secondary postoperative outcomes.

## METHODS

### Study Population

The American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) participant use files were retrospectively reviewed. We included 20 710 older patients older than 80 years who received neurosurgical procedures, between 2012 and 2020. The ACS-NSQIP database contains nonidentifiable information and provides waiver for consent to participating sites. Nonetheless, our study was deemed exempt and approved by our Institutional Review Board, and we remained compliant with the guidelines specified in the ACS-NSQIP data user agreement.

### Risk Assessment Indices

The frailty scores for both RAI and mFI-5 were calculated retrospectively using relevant variables from the ACS-NSQIP database (**Supplemental Digital Content 1**, http://links.lww.com/NEUOPEN/A65). The RAI is the result of extensive work to develop a mortality risk index.[14] This frailty index is a 14-item validated risk stratification instrument.[14] Demographic, clinical, cognitive status, and functional independence are all weighted for a cumulative frailty score (**Supplemental Digital Content 1**, http://links.lww.com/NEUOPEN/A65).[14] Each characteristic is given a score between 0 and 81, and the final score is divided into 4 categories: 0–20 (robust), 21–29 (normal), 31–40 (frail), and ≥41 (severely frail). **Supplemental Digital Content 2**, http://links.lww.com/NEUOPEN/A66, presents sensitivity and specificity cutoffs for RAI.

The mFI-5 considers 5 characteristics that have been rigorously tested and published on.[17] Functional independence, congestive heart failure, diabetic mellitus, chronic obstructive pulmonary disease, and medication-requiring hypertension make up mFI-5. The highest possible mFI-5 score "5" is used to evaluate each patient (**Supplemental Digital Content 1**, http://links.lww.com/NEUOPEN/A65). Frailty is stratified into 4 categories: 0 (robust), 1 (normal), 2 (frail), and 3–5 (severely frail). The sensitivity and specificity cutoffs for mFI-5 can be found in **Supplemental Digital Content 3**, http://links.lww.com/NEUOPEN/A67. The thresholds for increasing patient age are presented in **Supplemental Digital Content 4**, http://links.lww.com/NEUOPEN/A68.

### Postoperative Outcomes

The primary outcomes for this study include 30-day mortality rate, eLOS, and pLOS. A cumulation of counts of "year of death," designations of "expired" for discharge disposition, and "end of life/withdrawal of care" define 30-day mortality. eLOS is hospital stay ≥75th percentile of our median population distribution (≥7 days) and continued inpatient care >30 days (pLOS). Our secondary outcomes include SNF discharges and 30-day readmissions.

### Statistical Analysis

Mean (standard deviation-SD) and median (interquartile range-IQR) were used to characterize continuous variables. Frequencies and percentages were used for dichotomous/categorical variables. The $\chi^2$, Fisher exact test (for dichotomous/categorical), Student *t*-test, and nonparametric Mann Whitney *U* test (continuous) were performed. Receiver operating characteristic (ROC) curve analyses were used to compare the sensitivity and specificity of RAI, mFI-5, and increasing patient age for predicting 30-day mortality, eLOS, and pLOS. The resulting C-statistic and 95% CI depicting the area under the curve are reported. Subgroup ROC analyses for surgery classification (elective and emergency) and surgery type (spine, cranial, and other [functional, peripheral, and vascular]) were also performed. Multivariable regression estimates for primary and secondary outcomes are presented as OR and 95% CI. Our models were chosen based on parsimony, control of variance inflation, and maximum likelihood to ensure the best statistical fit and accuracy. Statistical significance was established when the two-tailed *P*-value was less than or equal to .05. All statistical analyses were performed using STATA 17 (StataCorp, LLP, College Station, TX).

## RESULTS

### Study Participants

We included 20 710 octogenarians who underwent a neurosurgery procedure between 2012 and 2020 in ACS-NSQIP. The mean age was 83 years (SD, 2.5), with a men (52.7%) and White (79.8%) majority and a high BMI of 27.2 kg/m2 (IQR, 24.2-30.3) (Tables 1 and 2). The most prevalent comorbidities included hypertension (76.4%), diabetes (21.6%), and a preexisting cancer diagnosis (9.7%). The median operative time was 116 minutes (IQR, 76.0, 172.0), 4.4% died within a 30-day period, 26.1% of patients had an eLOS, and 0.8% had a pLOS. In addition, 31.0% were discharged to a SNF, and 8.5% of patients were readmitted (Tables 1 and 2).

### ROC Analyses

ROC curves compared the predictive threshold of RAI, mFI-5, and increasing patient age. The RAI had a higher predictive threshold for 30-day mortality, with a C-statistic of 0.743 (95% CI: 0.726-0.760), compared with mFI-5 C-statistic of 0.574 (95% CI: 0.556-0.591) and increasing patient age C-statistic of 0.577 (95% CI: 0.558-0.596), overall DeLong, $P < .001$ (Figure 1a). For eLOS, RAI had a higher predictive threshold C-statistic of 0.692 (95% CI: 0.683-0.700) than mFI-5 C-statistic of 0.556 (95% CI: 0.548-0.564) and increasing patient age C-statistic of 0.546 (95% CI: 0.537-0.555), overall DeLong, $P < .001$ (Figure 1b). For pLOS, RAI had a higher predictive threshold C-statistic of 0.697 (95% CI: 0.660-0.733) than mFI-5 C-statistic of 0.550 (95% CI: 0.509-0.590) and increasing patient age C-statistic of 0.504 (95% CI: 0.464-0.544), overall DeLong, $P < .001$ (Figure 1c).

In a subgroup by surgery classification, 74.1% of patients underwent an elective procedure while 25.9% underwent an emergency procedure (Tables 1 and 2). Figure 2a-2c presents ROC comparisons for elective procedures and shows that RAI consistently had a higher predictive threshold DeLong *P* value of ≤.01. Similar outcomes were observed for emergency procedures, as depicted in Figure 3a-3c.

In subgroup analyses by procedure type, 76.9% of patients underwent spine procedures, 20.5% underwent cranial procedures, and 2.7% underwent other neurosurgery procedures (Tables 1 and 2). In comparisons for spine procedures, RAI had higher predictive threshold than mFI-5 and increasing patient age overall DeLong *P* value of ≤.001 (Figure 4a-4c). In comparisons for cranial procedures, we observed mixed results with DeLong *P* value ranging between ≤.001–.44 (Figure 5a-5c). In other procedures RAI consistently had a higher predictive threshold, and overall DeLong *P* value ranged from ≤.001–.51 (Figure 6a-6c).

### Multivariable Analyses

#### *RAI*

Risk stratification using RAI yielded all 4 risk strata ie, robust 88.8%, normal 10.0%, frail 1.0%, and severely frail 0.1% (Table 1). Evaluating the independent relationship with 30-day mortality, patients identified as normal had a 5-fold increased risk compared with patients identified as robust (OR: 4.76, 95% CI: 4.08-5.55), frail patients had a 13-fold increased risk (OR: 13.00, 95% CI: 9.52-17.73), and severely frail patients had a 10-fold increased risk (OR: 10.04, 95% CI: 4.41-22.82) (Table 3). A similar trend was observed for eLOS; patients identified as normal had a 5-fold increased risk (OR: 4.50, 95% CI: 4.08-4.96), frail patients had a 10-fold increased risk (OR: 9.50, 95% CI: 6.92-13.06), and severely frail patients had an 8-fold increased risk (OR: 8.33, 95% CI: 3.73-18.60) (Table 3). For pLOS, normal had a 68% increased risk (OR: 1.68, 95% CI: 1.13-2.48). Frail patients had a 44% increased risk but not statistically significant. In addition, all 30 severely frail patients had pLOS and therefore unable to yield an OR (Table 3). There were decreased risk of SNF discharges across severity of frailty strata $P < .05$, and readmissions showed increased risk across severity of frailty strata $P < .05$ (Table 3).

#### *mFI-5*

Risk stratification using mFI-5 also yielded all 4 risk strata ie, robust 18.4%, normal 52.9%, frail 24.3%, and severely frail 4.4% (Table 2). The normal stratum had no significant differences for all 3 primary outcomes (Table 3). When evaluating the independent relationship with 30-day mortality, patients identified as frail had a 73% increased risk compared with patients identified as robust (OR: 1.73, 95% CI: 1.40-2.15), and severely frail patients had a 5-fold increased risk (OR: 4.47, 95% CI: 3.42-5.84) (Table 3). For eLOS, patients identified as frail had a 64% increased risk (OR: 1.64, 95% CI: 1.48-1.81), and severely frail patients had a 4-fold increased risk (OR: 3.62, 95% CI: 3.09-4.25) (Table 3). While for pLOS, patients identified as frail had a 15% increased risk (OR: 1.15, 95% CI: 0.75-1.78), and severely frail patients had a 46% increased risk (OR: 1.46, 95% CI: 0.74-2.86); however, these were not statistically significant (Table 3). SNF discharges and readmissions showed increased risks across severity of frailty strata $P < .05$ (Table 3).

**TABLE 1. Demographics and Clinical Characteristics of Octogenarian Patients Undergoing Neurosurgery Procedures Delineated by the RAI Screening Tool**

| | | RAI[e] | | | | |
|---|---|---|---|---|---|---|
| Variable | Total N = 20 710 | Robust N = 18 397 | Normal N = 2069 | Frail N = 214 | Severely frail N = 30 | *P* value |
| Age, mean (SD), y | 83.0 (2.5) | 83.0 (2.5) | 83.2 (2.6) | 83.3 (2.7) | 82.5 (2.6) | <.001 |
| Sex, n (%) | | | | | | |
| Male | 10 917 (52.7) | 9303 (50.6) | 1439 (69.6) | 156 (72.9) | 19 (63.3) | <.001 |
| Female | 9793 (47.3) | 9094 (49.4) | 630 (30.4) | 58 (27.1) | 11 (36.7) | |
| Race, n (%) | | | | | | |
| White | 16 523 (79.8) | 14 878 (80.9) | 1462 (70.7) | 158 (73.8) | 25 (83.3) | <.001 |
| Black | 903 (4.4) | 779 (4.2) | 109 (5.3) | 13 (6.1) | 2 (6.7) | |
| Asian | 600 (2.9) | 537 (2.9) | 57 (2.8) | 5 (2.3) | 1 (3.3) | |
| Others[a] | 2684 (13.0) | 2203 (12.0) | 441 (21.3) | 38 (17.8) | 2 (6.7) | |
| Ethnicity, n (%) | | | | | | |
| Hispanic | 917 (4.4) | 813 (4.4) | 90 (4.3) | 11 (5.1) | 3 (10.0) | <.001 |
| BMI, median (IQR), kg/m$^2$ | 27.2 (24.2, 30.3) | 27.2 (24.3, 30.4) | 26.9 (23.9, 29.9) | 26.6 (23.4, 30.0) | 23.1 (19.9, 26.3) | <.001 |
| ASA score, n (%) | | | | | | |
| I | 95 (0.5) | 90 (0.5) | 5 (0.2) | 0 (0.0) | 0 (0.0) | <.001 |
| II | 4318 (20.9) | 4207 (22.9) | 109 (5.3) | 2 (0.9) | 0 (0.0) | |
| III | 13 393 (64.7) | 11 936 (64.9) | 1330 (64.3) | 110 (51.4) | 17 (56.7) | |
| IV | 2766 (13.4) | 2045 (11.1) | 609 (29.4) | 100 (46.7) | 12 (40.0) | |
| V | 138 (0.7) | 119 (0.6) | 16 (0.8) | 2 (0.9) | 1 (3.3) | |
| HTN, n (%) | 15 826 (76.4) | 14 096 (76.6) | 1549 (74.9) | 157 (73.4) | 24 (80.0) | <.001 |
| Diabetes, n (%) | 4468 (21.6) | 3916 (21.3) | 483 (23.3) | 61 (28.5) | 8 (26.7) | <.001 |
| COPD, n (%) | 1315 (6.4) | 1039 (5.6) | 204 (9.9) | 63 (29.4) | 9 (30.0) | <.001 |
| CHF, n (%) | 341 (1.7) | 179 (1.0) | 121 (5.8) | 37 (17.3) | 4 (13.3) | <.001 |
| Functional status, n (%) | | | | | | |
| Dependent | 1860 (9.0) | 1009 (5.5) | 696 (33.6) | 127 (59.3) | 28 (93.3) | <.001 |
| Cancer diagnosis, n (%) | 2004 (9.7) | 498 (2.7) | 1331 (64.3) | 152 (71.0) | 23 (76.7) | <.001 |
| Dialysis, n (%) | 146 (0.7) | 79 (0.4) | 49 (2.4) | 15 (7.0) | 3 (10.0) | <.001 |
| Surgery classification, n (%) | | | | | | |
| Emergent | 5371 (25.9) | 4054 (22.0) | 1154 (55.8) | 143 (66.8) | 20 (66.7) | <.001 |
| Elective | 15 339 (74.1) | 14 343 (78.0) | 915 (44.2) | 71 (33.2) | 10 (33.3) | |
| Operative time, median (IQR), mins | 116.0 (76.0, 172.0) | 114.0 (75.0, 170.0) | 130.0 (85.0, 185.0) | 139.0 (91.0, 196.0) | 132.0 (88.0, 208.0) | <.001 |

**TABLE 1. Continued.**

| Variable | Total N = 20 710 | RAI[e] Robust N = 18 397 | Normal N = 2069 | Frail N = 214 | Severely frail N = 30 | *P* value |
|---|---|---|---|---|---|---|
| Procedure type, n (%) | | | | | | |
| Spine | 15 915 (76.9) | 15 123 (82.2) | 694 (33.5) | 84 (39.3) | 14 (46.7) | <.001 |
| Cranial | 4247 (20.5) | 2759 (15.0) | 1343 (64.9) | 129 (60.3) | 16 (53.3) | |
| Others[b] | 548 (2.7) | 515 (2.8) | 32 (1.5) | 1 (0.5) | 0 (0) | |
| Complications, n (%)[c] | | | | | | |
| CD 0-I | 17 564 (84.8) | 15 864 (86.2) | 1549 (74.9) | 129 (60.3) | 22 (73.3) | <.001 |
| CD II-IV | 3146 (15.2) | 2533 (13.8) | 520 (25.1) | 85 (39.7) | 8 (26.7) | |
| LOS, median (IQR), days | 3.0 (1.0, 7.0) | 3.0 (1.0, 6.0) | 7.0 (4.0, 12.0) | 9.0 (6.0, 16.0) | 9.0 (6.0, 16.0) | <.001 |
| Extended LOS, n (%)[d] | 5410 (26.1) | 4039 (22.0) | 1192 (57.6) | 158 (73.8) | 21 (70.0) | <.001 |
| LOS >30 d, n (%) | 165 (0.8) | 127 (0.7) | 35 (1.7) | 3 (1.4) | 0 (0.0) | <.001 |
| SNF, n (%) | 6410 (31.0) | 5789 (31.5) | 578 (27.9) | 40 (18.7) | 3 (10.0) | <.001 |
| 30-d readmission, n (%) | 1761 (8.5) | 1429 (7.8) | 290 (14.0) | 36 (16.8) | 6 (20.0) | <.001 |
| Mortality, n (%) | 919 (4.4) | 572 (3.1) | 276 (13.3) | 63 (29.4) | 8 (26.7) | <.001 |

ASA, American Society of Anesthesiologists; BMI, body mass index; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; HTN, hypertension; LOS, length of hospital stay; RAI, Risk Analysis Index; SNF, skilled nursing facility.
[a]Other: American Indian/Alaska Native, Native Hawaiian/Pacific Islander, and unknown.
[b]Other: functional, peripheral, and vascular.
[c]Complications comprises all postoperative occurrences stratified by the Clavein-Dindo classification; grades range from 0: no complication to IV: life-threatening complications.
[d]Extended LOS is defined as LOS ≥75 percentile.
[e]P-value computed using the Fisher exact test and $\chi^2$ tests for proportions; Student *t*-tests for means; and nonparametric tests for medians.

### *Increasing Patient Age*

When we evaluated the relationship between increasing patient age and postoperative outcomes, we found that there were only point increases ≤10% (Table 3).

## DISCUSSION

### Key Results

We analyzed the discriminative thresholds of 2 frailty risk assessment tools and increasing patient age in 20 710 octogenarian neurosurgery patients in the ACS-NSQIP database. Overall, the RAI frailty scale possessed superior discriminative threshold compared with mFI-5 and increasing patient age for predicting 30-day mortality, eLOS, and pLOS. Furthermore, RAI exhibited a much higher predictive threshold in most paired analyses ie, RAI vs mFI-5 and RAI vs increasing patient age. In addition, higher preoperative RAI scores were independently predictive of worse postoperative outcomes. Interestingly, when SNF discharges were examined, in this subset of patients, RAI's mortality rate was higher than mFI-5's, explaining the negative relationship which we observed.

### Limitations

This study's findings should be interpreted with the following limitations in mind. First, the database only accounts for 30-day postoperative outcomes. Although RAI was developed to predict mortality up to 12 months,[14] our study does not reflect the full spectrum of its predictive ability in a clinical setting beyond 30 days. We suggest that long-term tracking of mortality beyond 30 days become a standard data collection metric in national databases. In addition, prospective studies should be conducted across hospital systems to record long-term mortality outcomes to better evaluate the accuracy of RAI. Although studies of this nature may be limited by their sample sizes, they can more accurately track a patient's long-term postoperative outcomes. We are applying for research funding to fund the expansion of RAI-specific data collection through a multicenter neurosurgical research network.

Second, as with any retrospective study, there are inherent biases that occur when selecting patients to include in the national database. In addition, these patients are representative of contributing facilities which are limited to primarily large teaching hospitals. Although bias can never be fully eliminated, the improvement of statistical analyses for data harmonization,[36] the inclusion of patient-reported data, and

**TABLE 2. Demographics and Clinical Characteristics of Octogenarian Patients Undergoing Neurosurgery Procedures Delineated by the mFI-5 Screening Tool**

| Variables | Total N = 20 710 | mFI-5[e] Robust N = 3817 | Normal N = 10 960 | Frail N = 5030 | Severely frail N = 903 | *P* value |
|---|---|---|---|---|---|---|
| Age, mean (SD), y | 83.0 (2.5) | 82.9 (2.5) | 83.0 (2.5) | 83.0 (2.5) | 83.2 (2.6) | <.001 |
| Sex, n (%) | | | | | | |
| Male | 10 917 (52.7) | 2066 (54.1) | 5529 (50.4) | 2825 (56.2) | 497 (55.0) | <.001 |
| Female | 9793 (47.3) | 1751 (45.9) | 5431 (49.6) | 2205 (43.8) | 406 (45.0) | |
| Race, n (%) | | | | | | |
| White | 16 523 (79.8) | 3053 (80.0) | 8872 (80.9) | 3938 (78.3) | 660 (73.1) | <.001 |
| Black | 903 (4.4) | 82 (2.1) | 442 (4.0) | 293 (5.8) | 86 (9.5) | |
| Asian | 600 (2.9) | 86 (2.3) | 303 (2.8) | 177 (3.5) | 34 (3.8) | |
| Others[a] | 2684 (13.0) | 596 (15.6) | 1343 (12.3) | 622 (12.4) | 123 (13.6) | |
| Ethnicity, n (%) | | | | | | |
| Hispanic | 917 (4.4) | 112 (2.9) | 411 (3.8) | 317 (6.3) | 77 (8.5) | <.001 |
| BMI, median (IQR), kg/m$^2$ | 27.2 (24.2, 30.3) | 25.9 (23.2, 28.8) | 27.1 (24.4, 30.2) | 28.0 (25.0, 31.5) | 28.1 (24.9, 32.5) | <.001 |
| ASA score, n (%) | | | | | | |
| I | 95 (0.5) | 49 (1.3) | 28 (0.3) | 17 (0.3) | 1 (0.1) | <.001 |
| II | 4318 (20.9) | 1324 (34.7) | 2436 (22.2) | 523 (10.4) | 35 (3.9) | |
| III | 13 393 (64.7) | 2070 (54.2) | 7169 (65.4) | 3570 (71.0) | 584 (64.7) | |
| IV | 2766 (13.4) | 353 (9.2) | 1259 (11.5) | 882 (17.5) | 272 (30.1) | |
| V | 138 (0.7) | 21 (0.6) | 68 (0.6) | 38 (0.8) | 11 (1.2) | |
| HTN, n (%) | 15 826 (76.4) | 0 (0.0) | 10 027 (91.5) | 4904 (97.5) | 895 (99.1) | <.001 |
| Diabetes, n (%) | 4468 (21.6) | 0 (0.0) | 431 (3.9) | 3318 (66.0) | 719 (79.6) | <.001 |
| COPD, n (%) | 1315 (6.4) | 0 (0.0) | 185 (1.7) | 745 (14.8) | 385 (42.6) | <.001 |
| CHF, n (%) | 341 (1.7) | 0 (0.0) | 13 (0.1) | 152 (3.0) | 176 (19.5) | <.001 |
| Functional status, n (%) | | | | | | |
| Dependent | 1860 (9.0) | 0 (0.0) | 304 (2.8) | 941 (18.7) | 615 (68.1) | <.001 |
| Cancer diagnosis, n (%) | 2004 (9.7) | 424 (11.1) | 1022 (9.3) | 467 (9.3) | 91 (10.1) | .01 |
| Dialysis, n (%) | 146 (0.7) | 18 (0.5) | 52 (0.5) | 56 (1.1) | 20 (2.2) | <.001 |
| Surgery classification, n (%) | | | | | | |
| Emergent | 5371 (25.9) | 896 (23.5) | 2579 (23.5) | 1511 (30.0) | 385 (42.6) | <.001 |
| Elective | 15 339 (74.1) | 2921 (76.5) | 8381 (76.5) | 3519 (70.0) | 518 (57.4) | |
| Operative time, median (IQR), mins | 116.0 (76.0, 172.0) | 112.0 (74.0, 170.0) | 116.0 (76.0, 172.0) | 118.0 (77.0, 171.0) | 117.0 (75.0, 177.0) | .23 |

**TABLE 2. Continued.**

| Variables | Total N = 20 710 | mFI-5[e] Robust N = 3817 | Normal N = 10 960 | Frail N = 5030 | Severely frail N = 903 | *P* value |
|---|---|---|---|---|---|---|
| Procedure type, n (%) | | | | | | |
| Spine | 15 915 (76.9) | 2830 (74.1) | 8572 (78.2) | 3865 (76.8) | 648 (71.8) | <.001 |
| Cranial | 4247 (20.5) | 889 (23.3) | 2100 (19.2) | 1022 (20.3) | 236 (26.1) | |
| Others[b] | 548 (2.7) | 98 (2.6) | 288 (2.6) | 143 (2.8) | 19 (2.1) | |
| Complications, n (%)[c] | | | | | | |
| CD 0-I | 17 564 (84.8) | 3302 (86.5) | 9490 (86.6) | 4119 (81.9) | 653 (72.3) | <.001 |
| CD II-IV | 3146 (15.2) | 515 (13.5) | 1470 (13.4) | 911 (18.1) | 250 (27.7) | |
| LOS, median (IQR), d | 3.0 (1.0, 7.0) | 3.0 (1.0, 6.0) | 3.0 (1.0, 6.0) | 4.0 (2.0, 8.0) | 6.0 (3.0, 11.0) | <.001 |
| Extended LOS, n (%)[d] | 5410 (26.1) | 867 (22.7) | 2552 (23.3) | 1549 (30.8) | 442 (49.0) | <.001 |
| LOS >30 d, n (%) | 165 (0.8) | 37 (1.0) | 67 (0.6) | 49 (1.0) | 12 (1.3) | <.001 |
| SNF, n (%) | 6410 (31.0) | 1042 (27.3) | 3213 (29.3) | 1789 (35.6) | 366 (40.5) | <.001 |
| 30-d readmission, n (%) | 1761 (8.5) | 266 (7.0) | 857 (7.8) | 500 (9.9) | 138 (15.3) | <.001 |
| Mortality, n (%) | 919 (4.4) | 132 (3.5) | 410 (3.7) | 265 (5.3) | 112 (12.4) | <.001 |

ASA, American Society of Anesthesiologists; BMI, body mass index; HTN, hypertension; COPD, chronic obstructive pulmonary disease; CHF, congestive heart failure; LOS, length of hospital stay; mFI-5, modified Frailty Index-5; SNF, skilled nursing facility.
[a]Other: American Indian/Alaska Native, Native Hawaiian/Pacific Islander, and unknown.
[b]Other: functional, peripheral, and vascular.
[c]Complications, comprises all postoperative occurrences stratified by the Clavein-Dindo classification; grades range from 0: no complication to IV: life-threatening complications.
[d]Extended LOS is defined as LOS ≥75 percentile.
[e]*P*-value computed using the Fishers exact test and $\chi^2$ tests for proportions; Student *t*-tests for means; and nonparametric tests for medians.

diverse population represented in our data sets may help to mitigate these limitations and make our findings more generalizable.

## Interpretation

Our findings highlight the need for accurate frailty risk assessment tools in the geriatric neurosurgical patient population and specifically in octogenarians. In the past, frailty assessment tools have generally been cumbersome and difficult to administer. However, newer frailty indices, such as mFI-5 and RAI, allow physicians to assess surgical risk in real time. In particular, RAI is known for its ease of use, taking less than 2 minutes to administer at bedside.[26] Furthermore, RAI is more comprehensive than mFI-5 as it covers 5 domains of frailty, as opposed to the 2 frailty domains of mFI-5.[37,38] These elements of RAI allow for rapid point-of-care frailty assessment and precise risk stratification to guide preoperative risk conversations with patients and their families. Furthermore, preoperative risk assessment, combined with preoperative "prehabilitation" or preoperative interventions, could aid in optimizing perioperative care and enhancing postoperative outcomes.[28,29,39]

Although frailty has become an integral part of geriatric surgical care, a lack of consensus on how to effectively measure and define it exists across surgical specialties. Even without standardized approach to screening or risk definitions, mortality in emergency and elective procedures has gradually decreased because of the development of specialized pathways targeted at defect prone areas along the perioperative continuum.[7,27] For example, Whitehouse et al[27] found that over a 4-year period, 55% emergency vs 20% elective neurosurgical patients died. Their study also demonstrated that the mortality rate was highest in the first 6 months after surgery, reaffirming the need for accurate and validated preoperative risk assessment tools, and why the 30-day databases, such as ACS-NSQIP, cannot fully account for the harm caused by mortality as only 30-day data are reported.[27] Our findings demonstrate that RAI was helpful in predicting worse patient outcomes for both elective and emergency procedures. This is especially important in emergency procedures, where quick and accurate decision making is critical. The availability of vital information on a patient's frailty status in the emergency setting can help health care professionals make informed decisions, leading to improved patient care and ultimately better outcomes. Furthermore, these results underscore RAI's versatility and potential utility in preoperative frailty risk assessment. A better understanding of how to use frailty screening tools in emergency

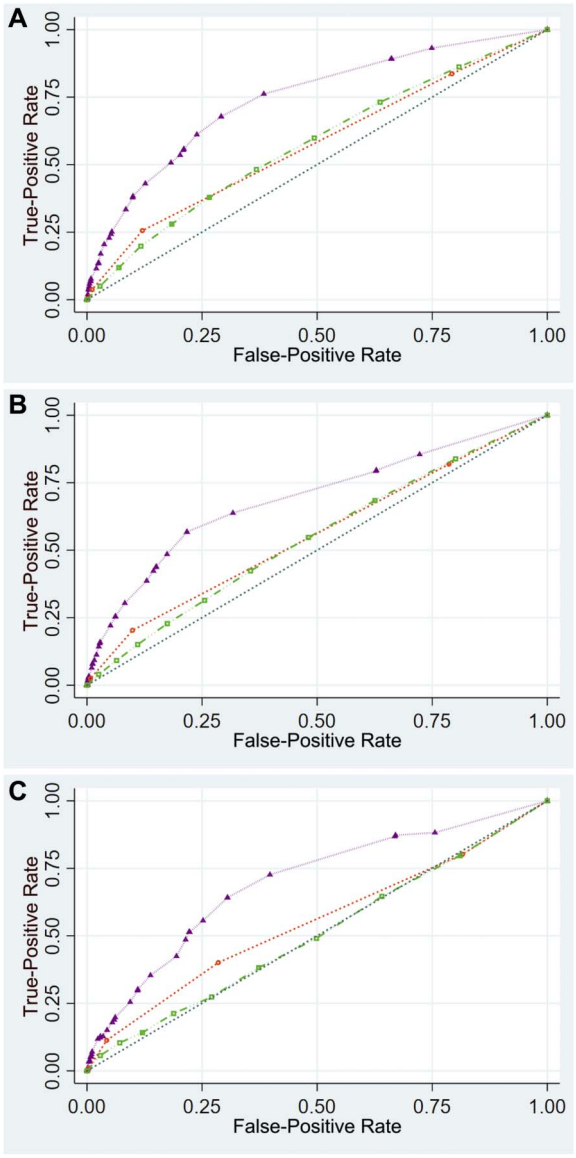


**FIGURE 1.** *Assessing the predictive thresholds of frailty screening tools and age for all octogenarian neurosurgery patients (N = 20,710) using receiver operating characteristics analysis outlined by* **A**, *30-day mortality,* **B**, *extended length of hospital stay, and* **C**, *LOS >30 days.* **A**, *30-day mortality C-statistics (95% CI): RAI 0.743 (0.726-0.760) vs mFI-5 0.574 (0.556-0.591) vs age 0.577 (0.558-0.596). Delong P-value: RAI vs mFI-5 vs age <0.001; RAI vs mFI-5 < 0.001; RAI vs age <0.001; mFI-5 vs age = 0.99.* **B**, *Extended LOS C-statistics (95% CI): RAI 0.692 (0.683-0.700) vs mFI-5 0.556 (0.548-0.564) vs age 0.546 (0.537-0.555). Delong P-value: RAI vs mFI-5 vs age <0.001; RAI vs mFI-5 < 0.001; RAI vs age <0.001; mFI-5 vs age = 0.01.* **C**, *LOS >30 days C-statistics (95% CI): RAI 0.697 (0.660-0.733) vs mFI-5 0.550 (0.509-0.590) vs age 0.504 (0.464-0.544). Delong P-value: RAI vs mFI-5 vs age <0.001; RAI vs mFI-5 < 0.001; RAI vs age <0.001; mFI-5 vs age = 0.14. LOS, length of hospital stay; mFI-5, modified Frailty Index-5; RAI, Risk Analysis Index.*

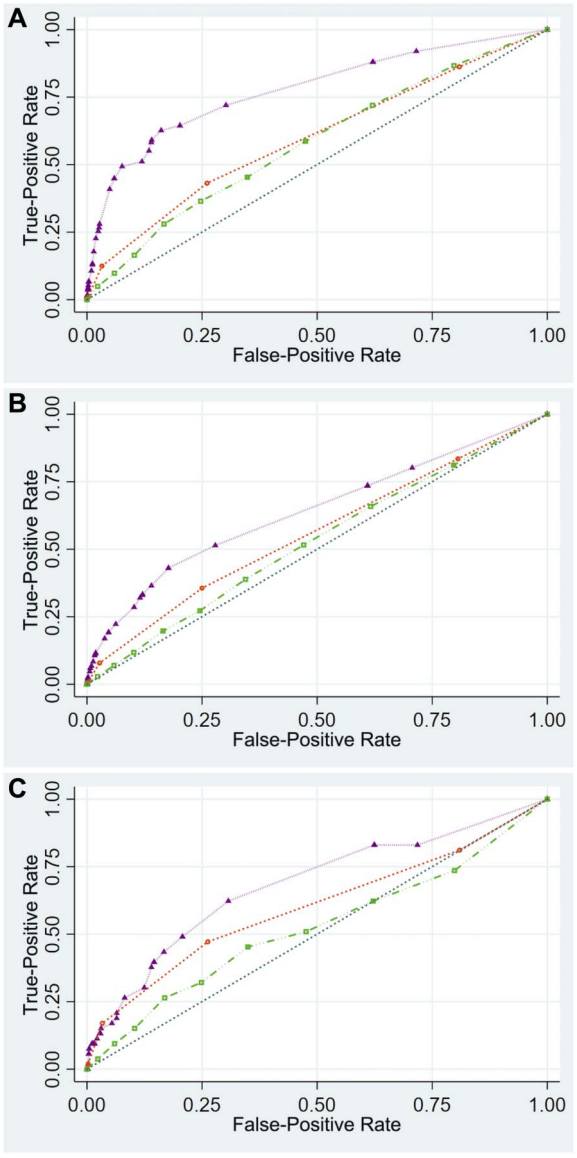


**FIGURE 2.** *Assessing the predictive thresholds of frailty screening tools and age for elective octogenarian neurosurgery patients (N = 15,339) using receiver operating characteristics analysis outlined by* **A**, *30-day mortality,* **B**, *extended LOS, and* **C**, *LOS >30 days.* **A**, *30-day mortality C-statistics (95% CI): RAI 0.777 (0.743-0.812) vs mFI-5 0.598 (0.560-0.635) vs age 0.581 (0.543-0.619). Delong P-value: RAI vs mFI-5 vs age <0.001; RAI vs mFI-5 < 0.001; RAI vs age <0.001; mFI-5 vs age = 0.52.* **B**, *Extended LOS C-statistics (95% CI): RAI 0.640 (0.625-0.654) vs mFI-5 0.559 (0.545-0.572) vs age 0.527 (0.513-0.541). Delong P-value: RAI vs mFI-5 vs age <0.001; RAI vs mFI-5 < 0.001; RAI vs age <0.001; mFI-5 vs age = 0.001.* **C**, *LOS >30 days C-statistics (95% CI): RAI 0.681 (0.603-0.760) vs mFI-5 0.600 (0.514-0.685) vs age 0.522 (0.435-0.610). Delong P-value: RAI vs mFI-5 vs age = 0.01; RAI vs mFI-5 = 0.12; RAI vs age = 0.001; mFI-5 vs age = 0.20. LOS, length of hospital stay; mFI-5, modified Frailty Index-5; RAI, Risk Analysis Index.*

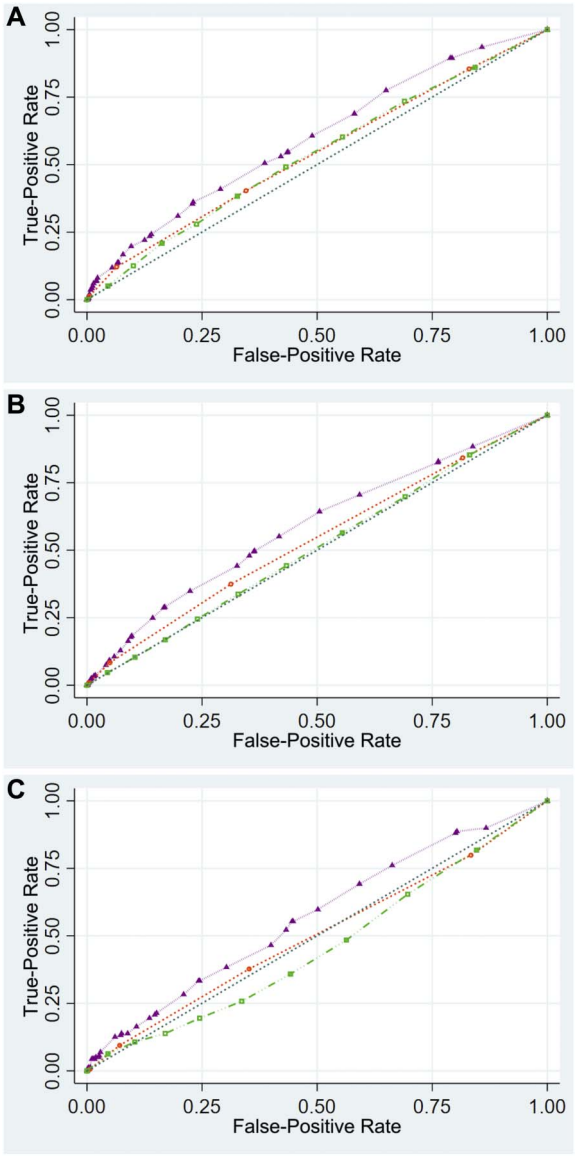


**FIGURE 3.** *Assessing the predictive thresholds of frailty screening tools and age for emergency octogenarian neurosurgery patients (N = 5, 371) using receiver operating characteristics analysis outlined by* **A**, *30-day mortality,* **B**, *extended LOS, and* **C**, *LOS >30 days.* **A**, *30-day mortality C-statistics (95% CI): RAI 0.597 (0.575-0.620) vs mFI-5 0.540 (0.518-0.562) vs age 0.534 (0.513-0.559). Delong P-value: RAI vs mFI-5 vs age <0.001; RAI vs mFI-5 < 0.001; RAI vs age <0.001; mFI-5 vs age = 0.79.* **B**, *Extended LOS C-statistics (95% CI): RAI 0.588 (0.572-0.604) vs mFI-5 0.538 (0.523-0.553) vs age 0.508 (0.492-0.524). Delong P-value: RAI vs mFI-5 vs age <0.001; RAI vs mFI-5 < 0.001; RAI vs age <0.001; mFI-5 vs age = 0.01.* **C**, *LOS >30 days C-statistics (95% CI): RAI 0.570 (0.525-0.615) vs mFI-5 0.502 (0.457-0.547) vs age 0.457 (0.412-0.502). Delong P-value: RAI vs mFI-5 vs age = 0.002; RAI vs mFI-5 = 0.02; RAI vs age = 0.001; mFI-5 vs age = 0.20. LOS, length of hospital stay; mFI-5, modified Frailty Index-5; RAI, Risk Analysis Index.*

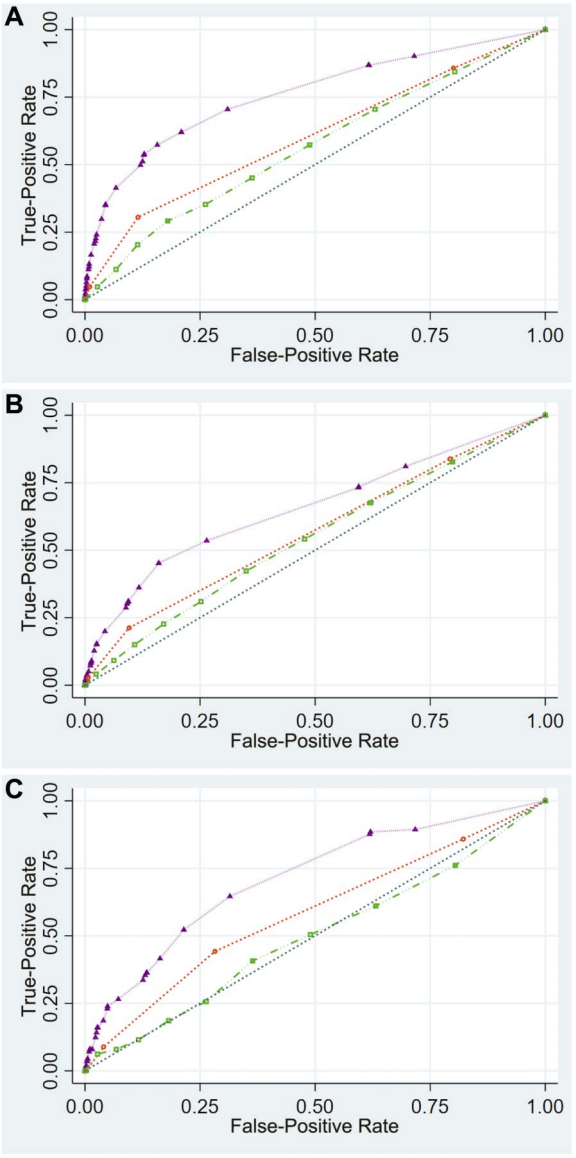


**FIGURE 4.** *Assessing the predictive thresholds of frailty screening tools and age for spine octogenarian neurosurgery patients (N = 15, 915) using receiver operating characteristics analysis outlined by* **A**, *30-day mortality,* **B**, *extended LOS, and* **C**, *LOS >30 days.* **A**, *30-day mortality C-statistics (95% CI): RAI 0.760 (0.728-0.791) vs mFI-5 0.603 (0.571-0.634) vs age 0.565 (0.531-0.599). Delong P-value: RAI vs mFI-5 vs age <0.001; RAI vs mFI-5 < 0.001; RAI vs age <0.001; mFI-5 vs age = 0.10.* **B**, *Extended LOS C-statistics (95% CI): RAI 0.657 (0.646-0.669) vs mFI-5 0.567 (0.557-0.577) vs age 0.545 (0.533-0.556). Delong P-value: RAI vs mFI-5 vs age <0.001; RAI vs mFI-5 < 0.001; RAI vs age <0.001; mFI-5 vs age = 0.001. C) LOS >30 days C-statistics (95% CI): RAI 0.712 (0.663-0.760) vs mFI-5 0.582 (0.530-0.635) vs age 0.497 (0.441-0.553). Delong P-value: RAI vs mFI-5 vs age <0.001; RAI vs mFI-5 < 0.001; RAI vs age <0.001; mFI-5 vs age = 0.05. LOS, length of hospital stay; mFI-5, modified Frailty Index-5; RAI, Risk Analysis Index.*

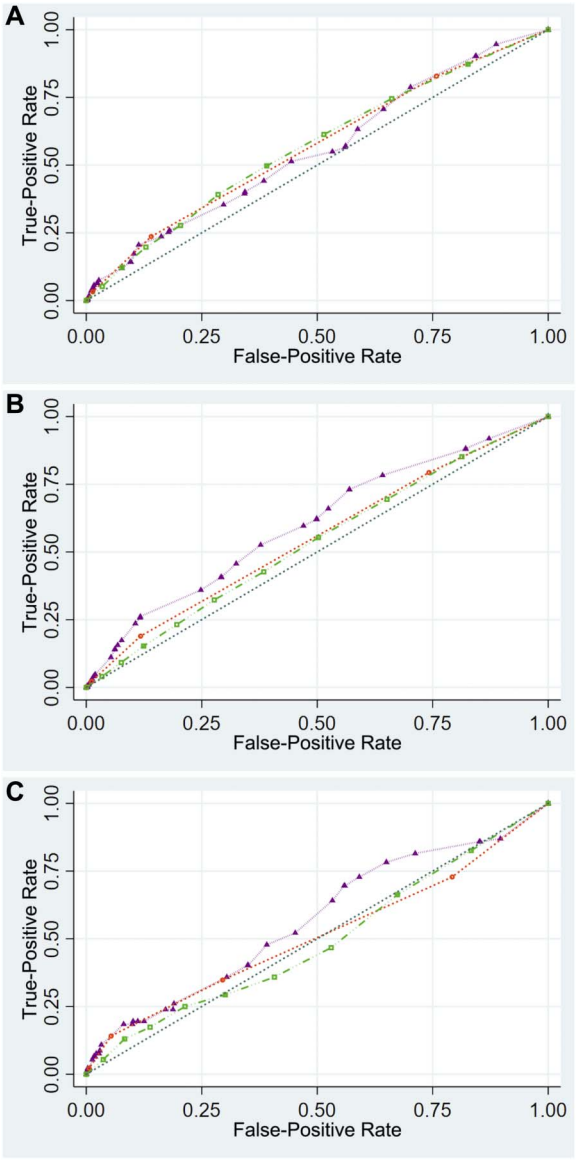


**FIGURE 5.** *Assessing the predictive thresholds of frailty screening tools and age for cranial octogenarian neurosurgery patients (N = 4, 247) using receiver operating characteristics analysis outlined by* **A**, *30-day mortality,* **B**, *extended LOS, and* **C**, *LOS >30 days.* **A**, *30-day mortality C-statistics (95% CI): RAI 0.556 (0.531-0.580) vs mFI-5 0.567 (0.546-0.589) vs age 0.569 (0.545-0.594). Delong P-value: RAI vs mFI-5 vs age = 0.44; RAI vs mFI-5 = 0.21; RAI vs age = 0.44; mFI-5 vs age = 0.77.* **B**, *Extended LOS C-statistics (95% CI): RAI 0.603 (0.586-0.619) vs mFI-5 0.550 (0.535-0.565) vs age 0.535 (0.518-0.552). Delong P-value: RAI vs mFI-5 vs age <0.001; RAI vs mFI-5 < 0.001; RAI vs age <0.001; mFI-5 vs age = 0.02.* **C**, *LOS >30 days C-statistics (95% CI): RAI 0.567 (0.506-0.628) vs mFI-5 0.510 (0.446-0.574) vs age 0.491 (0.429-0.553). Delong P-value: RAI vs mFI-5 vs age = 0.16; RAI vs mFI-5 = 0.14; RAI vs age = 0.08; mFI-5 vs age = 0.67. LOS, length of hospital stay; mFI-5, modified Frailty Index-5; RAI, Risk Analysis Index.*

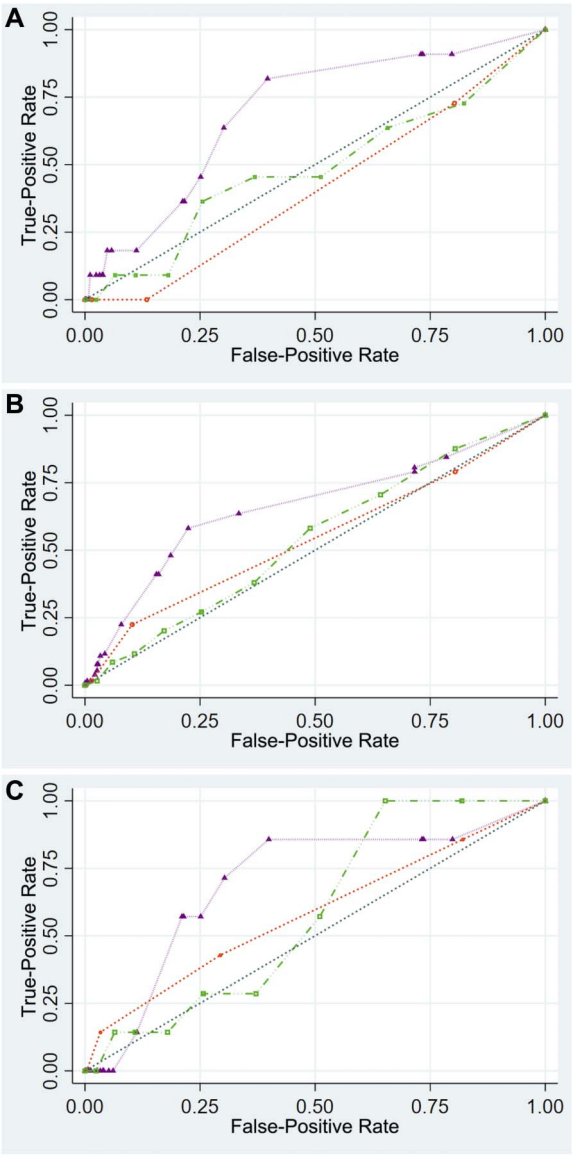


**FIGURE 6.** *Assessing the predictive thresholds of frailty screening tools and age for other octogenarian neurosurgery patients (N = 548) using receiver operating characteristics analysis outlined by* **A**, *30-day mortality,* **B**, *extended LOS, and* **C**, *LOS >30 days.* **A**, *30-day mortality C-statistics (95% CI): RAI 0.698 (0.548-0.848) vs mFI-5 0.414 (0.292-0.535) vs age 0.486 (0.292-0.680). Delong P-value: RAI vs mFI-5 vs age = 0.01; RAI vs mFI-5 = 0.005; RAI vs age = 0.07; mFI-5 vs age = 0.59.* **B**, *Extended LOS C-statistics (95% CI): RAI 0.661 (0.603-0.719) vs mFI-5 0.542 (0.490-0595) vs age 0.542 (0.487-0.597). Delong P-value: RAI vs mFI-5 vs age <0.001; RAI vs mFI-5 = 0.003; RAI vs age = 0.001; mFI-5 vs age = 0.81.* **C**, *LOS >30 days C-statistics (95% CI): RAI 0.700 (0.492-0.908) vs mFI-5 0.582 (0.349-0.815) vs age 0.587 (0.430-0.745). Delong P-value: RAI vs mFI-5 vs age = 0.51; RAI vs mFI-5 = 0.41; RAI vs age = 0.29; mFI-5 vs age = 0.97. LOS, length of hospital stay; mFI-5, modified Frailty Index-5; RAI, Risk Analysis Index.*

**TABLE 3. Independent Relationships Between the RAI, the mFI-5, Age, and Postoperative Outcomes in Octogenarian Neurosurgery Patients**

| Variables | Mortality OR (95% CI) | Extended LOS OR (95% CI) | LOS >30 days OR (95% CI) | SNF discharge OR (95%CI) | Readmissions OR (95% CI) |
|---|---|---|---|---|---|
| RAI | | | | | |
| Robust (RAI = 0-20) | [REF] | [REF] | [REF] | [REF] | [REF] |
| Normal (RAI = 21-30) | 4.76 (4.08, 5.55)[a] | 4.50 (4.08, 4.96)[a] | 1.68 (1.13, 2.48)[a] | 0.78 (0.70, 0.87)[a] | 1.92 (1.69, 2.23)[a] |
| Frail (RAI = 31-40) | 13.00 (9.52, 17.73)[a] | 9.50 (6.92, 13.06)[a] | 1.44 (0.45, 4.64) | 0.40 (0.27, 0.59)[a] | 2.35 (1.63,3.38)[a] |
| Severely frail (RAI ≥41) | 10.04 (4.41, 22.82)[a] | 8.33 (3.73, 18.60)[a] | — | 0.18 (0.05, 0.69)[b] | 2.80 (1.13, 6.90)[b] |
| mFI-5 | | | | | |
| Robust (mFI-5 = 0) | [REF] | [REF] | [REF] | [REF] | [REF] |
| Normal (mFI-5 = 1) | 1.16 (0.95, 1.42) | 1.08 (0.99, 1.18) | 0.71 (0.47, 1.06) | 1.09 (1.00, 1.19)[b] | 1.14 (0.99, 1.32) |
| Frail (mFI-5 = 2) | 1.73 (1.40, 2.15)[a] | 1.64 (1.48, 1.81)[a] | 1.15 (0.75, 1.78) | 1.49 (1.35, 1.63)[a] | 1.51 (1.29, 1.77)[a] |
| Severely frail (mFI-5 ≥3) | 4.47 (3.42, 5.84)[a] | 3.62 (3.09, 4.25)[a] | 1.46 (0.74, 2.86) | 1.86 (1.59, 2.18)[a] | 2.49 (2.00, 3.11)[a] |
| Age | 1.10 (1.08, 1.13)[a] | 1.08 (1.06, 1.09)[a] | 1.03 (0.96, 1.09) | 1.04 (1.03, 1.05)[a] | 1.02 (1.00, 1.04)[b] |

OR odds ratio; LOS, length of stay; mFI-5, modified Frailty Index-5, RAI, Risk Analysis Index; SNF, skilled nursing facility.
[a]*P*-value <.001.
[b]*P*-value <.05.
— Indicates 30 patients in severely frail group that had LOS >30 days.
Regression models were adjusted for race, BMI, and operative time and multivariable models for RAI, mFI-5, and age.
We followed strict variable selection to ensure no collinearity between variables.

neurosurgical situations with specific neurosurgical diseases (taking into consideration the disease specific prognosis as well) is an important next area of frailty research. Such results will aid the surgeon in not overextrapolating and underextrapolating scores when frank discussion need to occur quickly, given that delays in emergency neurosurgery would add to the poor outcome.

The mFI-5[17,18,21,31,32,40-42] and RAI[14,22-24,37,43] are effective tools depending on the population.[37,44] Nonetheless, our findings demonstrate that RAI, as opposed to mFI-5 or increasing patient age, may be a more accurate method of evaluating frailty in the older population. Generally, frailty indices have been developed to include some of the most pertinent factors that affect patients' surgical outcomes. However, there are currently no time-efficient indices that can feasibly account for all possible components of frailty.[45] Although these validated tools may accurately predict outcomes, they do not account for all possible contributing factors. In addition, although there are discussions about frailty and resource planning, surgeons may overly rely on these risk assessment tools to solely determine the eligibility of patients for high-risk procedures.[46,47] However, risk frameworks vary, and frailty scores should be used in tandem with other clinically relevant indicators for decision making and surgical planning to deploy resources in the perioperative period. Each individual patient requires careful consideration of the risks associated with frailty vs the advantages and quality of life associated with successful surgery when major complications are avoided.

## Generalizability

A recent study which featured RAI's predictive threshold in patients who underwent deep brain stimulation procedures found that frail patients had worse postoperative outcomes than their nonfrail counterparts, despite the common belief that these procedures are "low risk" and less demanding than other neurosurgery procedures.[34,35] Although our study effectively shows that RAI is an accurate predictor of worse outcomes in octogenarians undergoing both low-risk and high-risk procedures, validating this instrument and gaining a greater grasp of its potential clinical application will require additional research. Moreover, RAI provides a wide range of scores that allow for cutoffs to be adjusted for surgical specialties.[37] In the future, RAI score cutoffs can be adjusted and calibrated specifically for elective or emergency procedures and specific neurosurgical populations stratified by their perceived operative risk. This would provide a robust framework for health care teams to use when caring for vulnerable patient populations. In addition, RAI should be studied prospectively in neurosurgical settings to assess the applicability and effectiveness of its use in clinic. In fact, we have over 2 years of prospective RAI data collected for all neurosurgical patients at our institution, and these outcomes will be shared in publication soon. Ideally, RAI scores are a key component used across an entire healthcare system, to foster an interdisciplinary and individualized approach to patient care regarding the best treatment recommendations.

## CONCLUSION

In a critical review of 20 710 ACS-NSQIP database, we found that RAI was a more accurate predictor of 30-day mortality, eLOS, and pLOS than mFI-5 or increasing patient age in octogenarian neurosurgery patients. More research is needed to discover how RAI performs across different specialized neurosurgical populations. As the field of geriatric neurosurgery is rapidly developing into a distinct surgical subdiscipline, it is increasingly clear that comprehensive risk assessment strategies tailored to optimize perioperative care are essential for health care teams to optimally support this at-risk patient population and potentially improve postoperative outcomes.

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**Supplemental Digital Content 1**. Scoring for the National Surgical Quality Improvement Program Database Variables by Frailty Indices. mFI-5 score (total = 5): 0—"robust," 1—"prefrail," 2—"frail," and > = 3—"severely frail." RAI score (total = 81): < = 20—"robust," 21–30—"prefrail," 31–40—"frail," and ≥41—"severely frail."
**Supplemental Digital Content 2**. Screening Cutoffs for Postoperative Outcomes Based on the Risk Analysis Index Scores.
**Supplemental Digital Content 3**. Screening Cutoffs for Postoperative Outcomes Based on the Modified Frailty Index-5 Scores.
**Supplemental Digital Content 4**. Screening Cutoffs for Postoperative Outcomes Based on Age.