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Preoperative Frailty Risk in Cranioplasty Patients: Risk Analysis Index Predicts Adverse Outcomes

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Background: Cranioplasty is a common surgical procedure used to repair cranial defects, and it is associated with significant morbidity and mortality. Although frailty is a strong predictor of poor postoperative outcomes across surgical specialties, little is known about frailty's impact on cranioplasty outcomes. This study examined the association between frailty and cranioplasty by comparing the effect of the Risk Analysis Index-Administrative (RAI-A) and the Modified Frailty Index-5 (mFI-5) on cranioplasty outcomes.

Methods: The National Surgical Quality Improvement Program was queried for patients undergoing cranioplasty between 2012 and 2020. Receiver operating characteristics and multivariable analyses were used to assess the relationship of postoperative outcomes and the RAI-A, mFI-5, and increasing patient age.

Results: There were 2864 included study patients with a median age of 57 years (IQR, 44-67), and a higher proportion of patients were women (57.0%) and White (68.5%). The RAI-A had a more robust predictive ability for 30-day mortality (C-Statistic, 0.741; 95% confidence interval (CI), 0.678-0.804) compared with mFI-5 (C-Statistic, 0.574; 95% CI, 0.489-0.659) and increasing patient age (C-Statistic, 0.671; 95% CI, 0.610-0.732). On multivariable analyses, frailty was independently associated with mortality and other poor postoperative outcomes ($P < 0.05$).

Conclusions: The RAI-A demonstrated superior discrimination than the mFI-5 and increasing patient age in predicting mortality. Additionally, the RAI-A showed independent associations with nonhome discharge and postoperative complications (CDII, CDIIIb, and CDIV). The high rates of operative morbidity (5.0%–36.5%) and mortality (0.4%–3.2%) after cranioplasty highlight the importance of identifying independent risk factors for poor cranioplasty outcomes. *(Plast Reconstr Surg Glob Open 2023; 11:e5059; doi: 10.1097/GOX.0000000000005059; Published online 21 June 2023.)*

INTRODUCTION

Cranioplasty is a common surgical procedure shown to improve neurophysiologic functions by restoring the normal, closed, and fixed cranial vault.[1–5] The cranioplasty procedure is not completely risk-free, as it has a postoperative mortality between 0.4% and 3.2% and morbidity ranging between 15.0% and 36.5%.[5–8] Increasing patient age has traditionally been described as one of the key contributors to the emergence of postoperative complications following cranioplasty.[9]

Frailty is a decrease in physiologic reserve due to the impaired function of multiple organ systems and is characterized by a reduced ability to return to normal homeostasis.[10,11] In this context, patients identified as frail are more likely to experience postoperative complications than patients who are not frail.[12] Across the spectrum of surgical specialties, including a large number of studies involving neurosurgery, frailty has been shown to be an independent risk factor for mortality and poor postoperative outcomes.[11,13] A multitude of frailty scales attempt to quantify this decline in physiologic reserve and overall performance; however, there is a lack of consensus regarding the best frailty metric.

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There have been dozens of frailty scales utilized in the neurosurgical literature, most have utilized the 5-Factor Modified Frailty Index (mFI-5) or the mFI-11. The mFI-5 is a five-point frailty scoring tool, based on the Frailty Index Model, limited to scoring the presence of four key comorbidities and functional status.[11,14] The mFI-5 has demonstrated superior discrimination in predicting postoperative outcomes compared with increasing patient age alone in a variety of neurosurgery, otolaryngology, orthopedic, urology, and plastic surgery publications.[15–20] More recently, the Risk Analysis Index-Administrative (RAI-A), a 14-question frailty score instrument, has been validated and may possess superior discriminatory ability compared with other frailty scales such as the mFI-5.[21–23] The RAI-A can readily be applied in under 1 minute in administrative research, at the patient's bedside or in clinic at the point of care, and follows a frailty conceptual framework.[24] Our motivation to design this study resulted from a dearth of information regarding frailty's impact on cranioplasty outcomes.

We hypothesized that frailty will be an independent predictor of complications following cranioplasty outcomes and that the RAI-A will demonstrate superior discrimination to the mFI-5 and increasing patient age in predicting the primary outcome of 30-day mortality. Our secondary outcomes were complications, graded by the Clavien-Dindo (CD) I-IV classification system, and discharge disposition [nonhome discharge (NHD) versus home discharge].

Takeaways

Question: What is the relationship between the frailty indices, Modified Frailty Index-5 (mFI-5) and Risk Analysis Index-Administrative (RAI-A), and cranioplasty outcomes?

Findings: The study found that the RAI-A is a superior predictor of poor postoperative outcomes in cranioplasty patients compared to the mFI-5 and patient age.

Meaning: The RAI-A may be a valuable tool for frailty-based risk stratification in cranioplasty patients. Identifying independent risk factors for poor outcomes is crucial due to high rates of morbidity and mortality after the procedure. Using the RAI-A for frailty-based risk stratification could improve outcomes and aid in decision-making.

METHODS

Data Source

Patient cranioplasty data were obtained from the American College of Surgeons National Surgical Quality Improvement Program (NSQIP), a validated large national database, for years 2012–2020.[25] This study was conducted in accordance with the data user agreement between the American College of Surgeons and the University of New Mexico Hospital and was approved by the UNMH institutional review board as part of an application for frailty RAI-A studies.

Patient Population and Baseline Characteristics

We identified all patients greater than or equal to 18 years of age who had cranioplasty surgery, using Current Procedural Terminology (CPT) codes designated as primary or secondary procedures, between January 1, 2012, and December 31, 2020. The following CPT codes were used to characterize the population: CPT 62140 (cranioplasty for skull defect; up to 5 cm diameter), CPT 62141 (cranioplasty for skull defect; larger than 5 cm diameter), CPT 62146 (cranioplasty with autograft; up to 5 cm diameter), CPT 62147 (cranioplasty with autograft; greater than 5 cm diameter), 62143 (replacement of bone flap or prosthetic plate of skull), and 62145 (cranioplasty for skull defect with reparative brain surgery). Baseline demographic data included age, body mass index (BMI), sex, race, and ethnicity. Preoperative clinical data included diabetes mellitus (DM), hypertension (HTN), congestive heart failure (CHF), chronic obstructive pulmonary disease (COPD), dyspnea, renal failure, dialysis, disseminated cancer, weight loss, home origin, and functional status. Operative characteristics included indication by primary procedure, size of cranial defect, and type of material. There were 18.4% and 14.4% missing data in the categories of race and cranial defect size, respectively. For this reason, we categorized the missing information as "other."

Frailty Indices

Risk Analysis Index-Administrative

Hall et al[24] have previously described the creation and validation of the RAI-A as a screening tool for frailty. The RAI-A was specifically designed by Hall et al to be integrated easily into a surgeons' existing workflow without stressing resources.[24] The RAI-A takes less than a minute to administer and requires no additional training to score.[26] The RAI-A is contingent on 14 questions, including age, malignancy status, sex, weight loss, renal failure, heart failure, shortness of breath, prehospital nursing home residence, and degree of functional dependence. The RAI-A uses a numeric score ranging from 0 (not frail) to 81 (most frail). Previous studies have described four categories for defining the RAI-A frailty score thresholds: a score of 0–20 is robust, 21–30 is normal/prefrail, 31–40 is frail, and 41+ is severely frail (Table 1).[24]

Modified Frailty Index-5

The mFI-5 was described previously and has predicted poor postoperative outcomes in a variety of surgical specialties.[15,18,19,27] The total mFI-5 score is contingent on the presence of five comorbidities (DM, HTN, CHF, COPD, and functional dependence).[28] The mFI-5 is defined as 0 being robust, 1 being normal/pre-frail, 2 being frail, and 3 or greater being severely frail.[15,27]

Outcome Measures

The primary outcome was 30-day mortality defined as a patient's death within 30 days of the primary procedure. The secondary outcomes included discharge disposition defined as home discharge and NHD. NHD is

defined as discharge to a higher level of care: high-skilled facility, acute care, and outside emergency department. Additionally, complications graded using the standard CD I-IV classification system were reported. CD I consists of superficial site infection; CD II, postoperative bleeding or transfusion; CD IIIb, reoperation under anesthesia; and CD IV, sepsis, septic shock, pulmonary embolism, myocardial infarction, and ventilator status.[29]

Statistical Analysis

Continuous variables are presented as median with interquartile range (IQR). The discriminatory thresholds of RAI-A, mFI-5, and increasing patient age on 30-day mortality were evaluated using receiver operating characteristics (ROC) curve analysis. The area under the curve is represented as a C-statistic with a 95% confidence interval (CI). Multivariable analyses were conducted for RAI-A, mFI-5, and increasing patient age to assess the independent relationships between frailty and primary and secondary outcomes. Covariates controlled for included race, BMI, primary procedure, cranial defect size, and type of material [allograft, autograft, and other (unknown and missing)]. We excluded age from the model for RAI-A to prevent any collinearity, since age contributes to the total RAI-A score. We included age in the model for mFI-5. To address the issue of limited statistical power due to the small number of severely frail patients in the categorical version of the multivariable analysis, a dichotomous version of the multivariable model was also analyzed. In this dichotomous version, a threshold of less than or equal to 30 was used to define nonfrail patients and greater than 31 to define frail patients. Effect sizes are presented using odds ratio (OR) alongside their respective 95% CI. For all reported findings, a P value of less than 0.05 was considered statistically significant. All statistical analyses were performed on IBM SPSS Statistics version 28.0 (IBM Co., Armonk, N.Y.).

Table 1. RAI-A Scoring

Variable	Score	
Male sex	+3	
Weight loss	+8	
Renal failure/dialysis	+8	
CHF	+5	
Dyspnea	+3	
Patient origin	+1	
Functional status		
Independent	+0	
Partially dependent	+7	
Totally dependent	+14	
Age	**Score without Cancer History**	**Score with Cancer History**
<19 y	+0	+28
20–24 y	+1	+29
25–29 y	+4	
30–34 y	+6	+30
35–39 y	+8	
40–44 y	+10	+31
45–49 y	+12	
50–54 y	+14	+32
55–59 y	+16	
60–64 y	+18	+33
65–69 y	+20	+34
70–74 y	+22	
75–79 y	+24	+35
80–84 y	+26	
85–89 y	+28	+36
90–94 y	+30	
95–99 y	+32	+37
100+	+34	
Total RAI-A score range	0 to 81	

RESULTS

Study Population Characteristics

The NSQIP data query yielded 2864 patients, with a median age of 57 years (IQR, 44-67), female majority (57.0%), White majority (68.5%), and a median BMI of 28.0 kg/m^2 (IQR, 24.2-32.7) (Table 2). HTN was the most prevalent preoperative comorbidity (39.7%), followed by a history of disseminated cancer (13.8%) and DM (12.4%). Most of the patients were functionally independent (95.0%). Craniectomy was the most prevalent primary procedure (73.8%), and half of the patients had a cranial defect less than or equal to 5 cm (50.4%), while the vast majority of patients had synthetic materials used for their cranioplasty material (77.7%) (Table 2).

According to the RAI-A frailty distributions, 59.0% of the population was robust, 26.0% were normal/prefrail, 13.5% were frail, and 1.5% were severely frail, while the mFI-5 frailty distributions showed that 54.2% were robust, 32.2% were normal/prefrail, 12.2% were frail, and 1.5% were severely frail. When stratifying the incidence of mortality across age (binned), mFI-5, and RAI-A frailty scores, patients who were severely frail utilizing the RAI-A demonstrated the largest increase in incidence of mortality (Fig. 1).

ROC Analysis

ROC analysis was performed to enable comparison of the predictive thresholds of both frailty screening tools and increasing patient age for our primary outcome. The RAI-A had a higher discriminatory threshold for 30-day mortality (C-statistic, 0.741; 95% CI, 0.678–0.804; $P < 0.001$), than the mFI-5 (C-statistic, 0.574; 95% CI, 0.489–0.650; $P = 0.09$) and increasing patient age (C-statistic, 0.671; 95% CI, 0.610–0.732; $P < 0.001$) (Fig. 2).

Multivariable Analysis

RAI-A

On multivariable analysis, the independent relationship with postoperative outcomes and frailty status, as measured by RAI-A, was evaluated (Table 3). Patients who were normal/prefrail had an independent association with CD II (OR, 2.08; CI, 1.52–2.86; $P < 0.001$), CD IIIb (OR, 1.39; CI, 1.02–1.90; $P < 0.05$), CD IV (OR, 2.21; CI, 1.51–3.24; $P < 0.001$), 30-day mortality (OR, 5.10; CI, 2.20–11.86; $P < 0.001$), and NHD (OR, 3.77; CI, 2.68–5.31; $P < 0.001$). Frailty was independently associated with CD

Table 2. Demographic, Clinical, and Perioperative Characteristics of Adult Cranioplasty Patients Characterized by Frailty Screening Tool (Risk Analysis Index and Modified Frailty Index-5, n = 2890)

		RAI-A Categories				mFI-5 Categories			
Variables	**Total, n = 2864**	**Robust, n = 1691**	**Normal, n = 744**	**Frail, n = 386**	**Severely Frail, n = 43**	**Robust, n = 1552**	**Prefrail, n = 921**	**Frail, n = 349**	**Severely Frail, n = 42**
Demographics									
Age, median (IQR), years	57 (44–67)	49 (38–57)	70 (64–74)	63 (55–71)	65 (61–71)	50 (38–61)	62 (53–70)	65 (57–71)	65.5 (62–71)
Female, n (%)	1633 (57.0)	1113 (65.8)	295 (39.7)	205 (53.1)	20 (46.5)	917 (59.1)	519 (56.4)	180 (51.6)	17 (40.5)
Race, n (%)									
White	1961 (68.5)	1127 (66.6)	530 (71.2)	271 (70.2)	33 (76.7)	1071 (69.0)	638 (69.3)	229 (65.6)	23 (54.8)
Black	263 (9.2)	170 (10.1)	44 (5.9)	46 (11.9)	3 (7.0)	101 (6.5)	105 (11.4)	47 (13.5)	10 (23.8)
Asian	97 (3.4)	68 (4.0)	21 (2.8)	7 (1.8)	1 (2.3)	58 (3.7)	29 (3.1)	9 (2.6)	1 (2.4)
Other*	543 (19.0)	326 (19.3)	149 (20.0)	62 (16.1)	6 (14.0)	322 (20.7)	149 (16.2)	64 (18.3)	8 (19.0)
Hispanic ethnicity, n (%)	1961 (68.5)	1127 (66.6)	530 (71.2)	271 (70.2)	33 (76.7)	1071 (69.0)	638 (69.3)	229 (65.6)	23 (54.8)
BMI, median (IQR), kg/m2	28.0 (24.2–32.7)	28.3 (24.2–33.6)	28.2 (24.7–32.0)	26.5 (23.3–31.4)	25.9 (22.1–31.9)	26.9 (23.6–31.3)	29.0 (25.2–34.0)	30.1 (25.7–35.6)	28.7 (24.4–33.0)
Preoperative clinical status, n (%)									
DM	355 (12.4)	143 (8.5)	141 (19.0)	63 (16.3)	8 (18.6)	0 (0.0)	75 (8.1)	241 (69.1)	39 (92.9)
HTN	1137 (39.7)	486 (28.7)	436 (58.6)	191 (49.5)	24 (55.8)	0 (0.0)	756 (82.1)	340 (97.4)	41 (97.6)
CHF	11 (0.4)	0 (0.0)	7 (0.9)	3 (0.8)	1 (2.3)	0 (0.0)	1 (0.1)	5 (1.4)	5 (11.9)
COPD	102 (3.6)	24 (1.4)	29 (3.9)	43 (11.1)	6 (14.0)	0 (0.0)	30 (3.3)	54 (15.5)	18 (42.9)
Dyspnea	109 (3.8)	23 (1.4)	41 (5.5)	38 (9.8)	7 (16.3)	34 (2.2)	42 (4.6)	25 (7.2)	8 (19.0)
Renal failure	3 (0.1)	2 (0.1)	1 (0.1)	0 (0.0)	0 (0.0)	1 (0.1)	1 (0.1)	1 (0.3)	0 (0.0)
Dialysis	7 (0.2)	3 (0.2)	2 (0.3)	2 (0.5)	0 (0.0)	0 (0.0)	3 (0.3)	2 (0.6)	2 (4.8)
Disseminated cancer	394 (13.8)	0 (0.0)	12 (1.6)	341 (88.3)	41 (95.3)	176 (11.3)	143 (15.5)	68 (19.5)	7 (16.7)
Weight loss	50 (1.7)	3 (0.2)	9 (1.2)	11 (2.8)	27 (62.8)	19 (1.2)	17 (1.8)	10 (2.9)	4 (9.5)
Home origin	2510 (87.6)	1551 (54.2)	632 (22.1)	295 (10.3)	32 (1.1)	1387 (48.4)	809 (28.2)	285 (10.0)	29 (1.0)
Functional status									
Independent	2696 (95.0)	1646 (98.5)	676 (91.2)	350 (91.4)	24 (55.8)	1537 (100.0)	855 (93.5)	287 (83.2)	17 (40.5)
Partial dependence	115 (4.1)	25 (1.5)	52 (7.0)	21 (5.5)	17 (39.5)	0 (0.0)	50 (5.5)	50 (14.5)	15 (35.7)
Total dependence	27 (1.0)	0 (0.0)	13 (1.8)	12 (3.1)	2 (4.7)	0 (0.0)	9 (1.0)	8 (2.3)	10 (23.8)
Operative characteristics, n (%)									
Primary procedure									
Craniectomy	2113 (73.8)	1172 (69.3)	550 (73.9)	352 (91.2)	39 (90.7)	1167 (75.2)	661 (71.8)	259 (74.2)	26 (61.9)
Craniotomy	134 (4.7)	98 (5.8)	30 (4.0)	5 (1.3)	1 (2.3)	75 (4.8)	37 (4.0)	17 (4.9)	5 (11.9)
Other	617 (21.5)	421 (24.9)	164 (22.0)	29 (7.5)	3 (7.0)	310 (20.0)	223 (24.2)	73 (20.9)	11 (26.2)
Size of cranial defect†									
Less than/equal to 5 cm	1443 (50.4)	897 (53.0)	344 (46.2)	184 (47.7)	18 (41.9)	796 (51.3)	469 (50.9)	165 (47.3)	13 (31.0)
More than 5 cm	1008 (35.2)	570 (33.7)	289 (38.8)	134 (34.7)	15 (34.9)	535 (34.5)	323 (35.1)	128 (36.7)	22 (52.4)
Unknown	413 (14.4)	224 (13.2)	111 (14.9)	68 (17.6)	10 (23.3)	221 (14.2)	129 (14.0)	56 (16.0)	7 (16.7)

(*Continued*)

Table 2. *Continued*

Variables	Total, n = 2864	RAI-A Categories				mFI-5 Categories			
		Robust, n = 1691	Normal, n = 744	Frail, n = 386	Severely Frail, n = 43	Robust, n = 1552	Prefrail, n = 921	Frail, n = 349	Severely Frail, n = 42
Type of material, n (%)									
Allograft	2226 (77.7)	1311 (77.5)	580 (78.0)	303 (78.5)	32 (74.4)	1197 (77.1)	726 (78.8)	272 (77.9)	31 (73.8)
Autograft	89 (3.1)	54 (3.2)	26 (3.5)	8 (2.1)	1 (2.3)	50 (3.2)	31 (3.4)	5 (1.4)	3 (7.1)
Other	549 (19.2)	326 (19.3)	138 (18.5)	75 (19.4)	10 (23.3)	305 (19.7)	164 (17.8)	72 (20.6)	8 (19.0)
Postoperative outcomes, n (%)									
Clavien-Dindo I,	30 (1.0)	18 (1.1)	10 (1.3)	2 (0.5)	0 (0.0)	12 (0.8)	13 (1.4)	5 (1.4)	0 (0.0)
Clavien-Dindo II,	226 (7.9)	97 (5.7)	82 (11.0)	41 (10.6)	6 (14.0)	94 (6.1)	88 (9.6)	39 (11.2)	5 (11.9)
Clavien-Dindo IIIb,	229 (8.0)	121 (7.2)	73 (9.8)	35 (9.1)	0 (0.0)	105 (6.8)	91 (9.9)	28 (8.0)	5 (11.9)
Clavien-Dindo IV,	145 (5.1)	61 (3.6)	56 (7.5)	25 (6.5)	3 (7.0)	49 (3.2)	57 (6.2)	35 (10.0)	4 (9.5)
Mortality,	43 (1.5)	9 (0.5)	19 (2.6)	11 (2.8)	4 (9.3)	17 (1.1)	18 (2.0)	8 (2.3)	0 (0.0)
Nonhome discharge	213 (7.4)	63 (3.7)	97 (13.0)	44 (11.4)	9 (20.9)	71 (4.6)	79 (8.6)	50 (14.3)	13 (31.0)

Clavien-Dindo I: surgical site infection; Clavien-Dindo II: postoperative bleeding or transfusion(s); Clavien-Dindo IIIb: reoperation under anesthesia; Clavien-Dindo IV: sepsis, septic shock, pulmonary embolism, myocardial infraction, ventilator status.
*Other race—American Indian/Alaska Native, Native Hawaiian/Pacific Islander, and unknown
†Size of cranial defect had 15% missing data.

Fig. 1. Incidence of 30-day mortality stratified by age, RAI-A Score, and mFI-5 Score.

II (OR, 2.29; CI, 1.53–3.43; $P < 0.001$), CD IV (OR, 2.11; CI, 1.28–3.46; $P < 0.05$), 30-day mortality (OR, 5.65; CI, 2.21–14.43; $P < 0.001$), and NHD (OR, 3.46; CI, 2.26–5.28; $P < 0.001$). Severe frailty was independently predictive of CD II (OR, 2.86; CI, 1.15–7.09; $P < 0.05$), 30-day mortality (OR, 18.63; CI, 5.25–66.17; $P < 0.001$), and NHD (OR, 7.16; CI, 3.25–15.79; $P < 0.001$).

Frail patients had higher ORs for CD II (OR, 2.11; CI, 1.45–3.09; $P < 0.001$), CD IV (OR, 1.77; CI, 1.12–2.80; $P < 0.05$), 30-day mortality (OR, 2.90; CI, 1.39–6.08; $P < 0.05$), and NHD (OR, 2.27; CI, 1.56–3.31; $P < 0.001$) when compared with nonfrail counterparts (Table 3).

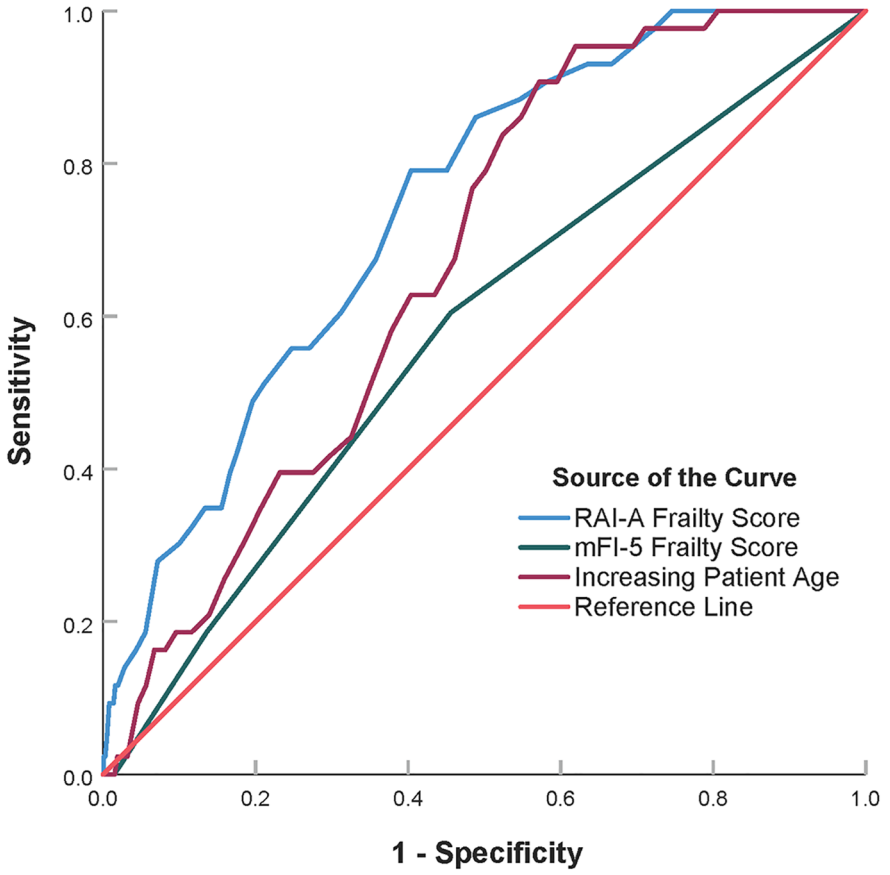
mFI-5

The independent relationship between frailty status, as measured by mFI-5, was also evaluated (Table 3). Normal/prefrail was independently associated with CD IV (OR, 1.60; CI, 1.05–2.44; $P < 0.05$). Frailty was independently predictive of CD IV (OR, 2.53; CI, 1.54–4.17; $P < 0.001$) and NHD (OR, 2.02; CI, 1.32–3.10; $P < 0.05$). Severe frailty was an independent risk factor for NHD (OR, 5.82; CI, 2.75–12.30; $P < 0.001$).

Frail patients had higher ORs for the secondary outcomes of CD IV (OR, 1.86; CI, 1.20–2.88; $P < 0.05$) and NHD (OR, 1.95; CI, 1.34–2.84; $P < 0.001$) when compared with nonfrail patients.

Increased Patient Age

The independent relationship with postoperative outcomes and increasing patient age was also evaluated (Table 3). Increasing patient age was independently associated with CD II (OR, 1.03; CI, 1.02–1.04; $P < 0.001$), CD IV (OR, 1.02; CI, 1.01–1.03; $P < 0.05$), 30-day mortality (OR, 1.04; CI, 1.02–1.07; $P < 0.05$), and NHD (OR, 1.06; CI, 1.04–1.07; $P < 0.001$) (Table 3). Similar results were observed for frail/nonfrail comparisons (Table 4).



Variable	AUC (95% CI)	p-value
RAI-A	0.741 (0.678 - 0.804)	<0.001
mFI-5	0.574 (0.489 - 0.659)	0.094
Increasing Patient Age	0.671 (0.610 - 0.732)	<0.001

Fig. 2. ROC curve assessing the predictive threshold for RAI-A, mFI-5, and age on 30-day mortality. A, ROC curve for assessing threshold probability for 30-day mortality. B, AUC represented by C-statistic for RAI-A, mFI-5, and increasing patient age for 30-day mortality. AUC indicates area under the curve.

DISCUSSION

The discriminative thresholds of the RAI-A and mFI-5 frailty assessment tools for predicting 30-day mortality were compared in this large NSQIP database study of 2864 NSQIP (2012–2020) cranioplasty patients. The independent relationship between the RAI-A and poor postoperative outcomes was significantly increased, ranging from 66% higher to an 18-fold increase. Our hypothesis that increased RAI-A scores would be an independent risk factor for poor cranioplasty outcomes was confirmed. To the best of our knowledge, this is a novel approach in understanding frailty's impact on cranioplasty outcomes and its role as an independent risk factor for mortality and poor outcomes after cranioplasty. Additionally, we demonstrate that the RAI-A frailty scale has superior discrimination than the mFI-5 frailty scale and increasing patient age for predicting 30-day mortality after cranioplasty.

Previously, an NSQIP study identified increasing patient age as an independent risk factor for adverse outcomes in patients undergoing cranioplasty. Although our results confirm that increased patient age is predictive of mortality, frailty measured by RAI-A and mFI-5 had larger effect sizes for the same outcome; furthermore, increasing RAI-A scores were independently predictive of increased mortality and demonstrated superior discrimination for mortality when compared with mFI-5 and increased patient age. This study demonstrates the inadequacies of the mFI-5 by establishing that it has inferior discrimination in predicting 30-day mortality when compared with RAI-A. Previous studies within neurosurgery have also displayed the RAI-A's superior discriminatory accuracy for predicting adverse outcomes when compared to mFI-5.[30,31] In addition, the mFI-5 is a unidimensional instrument that assesses frailty by using a limited subset of four comorbidities in conjunction with a measure of functional

Table 3. Multivariable Analyses Evaluating the Independent Association between Frailty Categories Determined by the Risk Analysis Index, Modified Frailty Index-5, and Age and Postoperative Outcomes

Variables	Clavien-Dindo I OR (95% CI)	Clavien-Dindo II OR (95% CI)	Clavien-Dindo IIIb OR (95% CI)	Clavien-Dindo IV OR (95% CI)	30-day Mortality OR (95% CI)	Nonhome Discharge OR (95% CI)
RAI-A*						
Prefrail	1.21 (0.55–2.65)	2.08 (1.52–2.86)†	1.39 (1.02–1.90)*	2.21 (1.51–3.24)†	5.10 (2.20–11.86)†	3.77 (2.68–5.31)†
Frail	0.48 (0.11–2.01)	2.29 (1.53–3.43)†	1.46 (0.97–2.19)	2.11 (1.28–3.46)‡	5.65 (2.21–14.43)†	3.46 (2.26–5.28)†
Severely frail	—	2.86 (1.15–7.09)‡	—	2.27 (0.68–7.62)	18.63 (5.25–66.17)†	7.16 (3.25–15.79)†
mFI-5§						
Prefrail	1.40 (0.59–3.30)	1.31 (0.94–1.82)	1.37 (0.99–1.90)	1.60 (1.05–2.44)*	1.53 (0.73–3.12)	1.25 (0.87–1.80)
Frail	1.40 (0.46–4.30)	1.46 (0.95–2.26)	1.09 (0.68–1.75)	2.53 (1.54–4.17)†	1.80 (0.71–4.56)	2.02 (1.32–3.10)‡
Severely frail	—	1.12 (0.41–3.06)	1.59 (0.60–4.24)	2.32 (0.77–6.95)	—	5.82 (2.75–12.30)†
Age*	1.04 (0.99–1.05)	1.03 (1.02–1.04)†	1.01 (0.99–1.02)	1.02 (1.01–1.03)‡	1.04 (1.02–1.07)‡	1.06 (1.04–1.07)†

Clavien-Dindo I: surgical site infection; Clavien-Dindo II: postoperative bleeding or transfusion(s); Clavien-Dindo IIIb: reoperation; Clavien-Dindo IV: sepsis, septic shock, pulmonary embolism, myocardial infraction, ventilator status.
*Covariates controlled for in this model include race, body mass index, primary procedure (craniectomy, craniotomy, and other), size of cranial defect (≤5 cm and >5 cm), and material (allograft, autograft, and other).
†$P < 0.001$, statistical significance.
‡$P < 0.05$.
§Also controlled for age in addition to the other covariates.

Table 4. Multivariable Analyses Evaluating the Independent Association between Frailty Status Determined by the Risk Analysis Index, Modified Frailty Index-5, and Age and Postoperative Outcomes

Variables	Clavien-Dindo I OR (95% CI)	Clavien-Dindo II OR (95% CI)	Clavien-Dindo IIIb OR (95% CI)	Clavien-Dindo IV OR (95% CI)	30-day Mortality OR (95% CI)	Non-Home Discharge OR (95% CI)
RAI-A*						
Nonfrail	Ref	Ref	Ref	Ref	Ref	Ref
Frail	0.44 (0.11–1.87)	2.11 (1.45–3.09)†	1.40 (0.94–2.08)	1.77 (1.12–2.80)‡	2.90 (1.39–6.08)‡	2.27 (1.56–3.31)†
mFI-5§						
Nonfrail	Ref	Ref	Ref	Ref	Ref	Ref
Frail	0.82 (0.28–2.45)	1.31 (0.88–1.96)	0.97 (0.63–1.49)	1.86 (1.20–2.88)‡	1.35 (0.57–3.22)	1.95 (1.34–2.84)†
Age*	1.03 (0.99–1.06)	1.03 (1.02–1.05)†	1.02 (1.01– 1.03)‡	1.03 (1.01–1.04)†	1.05 (1.01–1.08)‡	1.07 (1.05–1.08)†

Clavien-Dindo I: surgical site infection; Clavien-Dindo II: postoperative bleeding or transfusion(s); Clavien-Dindo IIIb: reoperation; Clavien-Dindo IV: sepsis, septic shock, pulmonary embolism, myocardial infraction, ventilator status.
*Covariates controlled for in this model include race, body mass index, primary procedure (craniectomy, craniotomy, and other), size of cranial defect (≤5 cm and >5 cm), and material (allograft, autograft, and other).
†$P < 0.001$, statistical significance.
‡$P < 0.05$.
§Also controlled for age in addition to the other covariates.

independence. The RAI-A, on the other hand, takes into account a total of five domains of frailty, including comorbidities, physical functionality, social variables, nutritional state, and a cognitive domain.[26] These findings corroborate the RAI-A as a superior frailty scale within surgical patients, including patients undergoing cranioplasty.

The high rate of poor cranioplasty outcomes demonstrates the need for accurate risk assessment to identify those patients at increased risk for adverse outcomes.[17] Frailty can assist in identifying patients who may benefit from additional preoperative planning, increased resource mobilization, and augmenting patient support systems.[32] Frail patients will likely benefit from a multidisciplinary approach to their care and/or closer postoperative observation.[32] Frailty's ability to allow hospitals to anticipate which patients may need extra postoperative attention and care allows hospitals to maximize their limited resources.[33,34] The preoperative diagnosis of frailty can facilitate conversations about prognosis; as a result, an improved decision-making conversation may be enabled between the clinician and the patient/family.[11,24]

The limitations of this study include its retrospective nature. Although we were not able to control all confounding variables, the NSQIP database is a validated resource. We used a robust methodology that followed statistical guidelines and recommendations for NSQIP research. Another limitation is the lack of separate coding that precludes us from identifying whether cranioplasties were primary cranioplasty procedures or if they were revision procedures. The number of cranial procedures before cranioplasty has been well-established as a significant risk factor for complications, with one study reporting a six-fold increase in complications.[35] Furthermore, this study also did not provide data on the time from the primary procedure to time of definitive cranioplasty. Evidence remains lacking as to whether any temporal variable (eg, early or late cranioplasty) is associated with worse postoperative outcomes.[7,36] Additionally, the NSQIP does not include etiology of original injury that created the need for cranioplasty, with this importance established by Belzberg et al, who reported that trauma had 80% higher chance of mortality and reoperation when compared with other etiologies (eg, stroke). It is worth noting that although we controlled for material type (allograft, autograft, and other) in our analysis, the lack of specific coding for the various types of materials used in cranioplasties

may have influenced the outcomes observed. Given the recent increase in the variety of materials implemented for cranioplasties, it is important to consider the potential impact of specific material types on outcomes in future studies.[19,37,38]

CONCLUSIONS

This large national database study on frailty's impact on cranioplasty outcomes demonstrates that the RAI-A was significantly associated with poor cranioplasty outcomes and had superior discrimination compared with the mFI-5 and increasing patient age in predicting mortality after cranioplasty. The high rates of operative morbidity (5.0%–36.5%) and mortality (0.4%–3.2%) are in contrast to the perception of many clinicians that cranioplasties carry minimal risk, and these outcomes highlight the importance of being able to predict which patients are at increased risk for poor cranioplasty outcomes. Predictive information will enable true shared decision-making with patients and their families, regarding the potential risk and benefits of operative intervention.

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DISCLOSURES

The authors have no financial interest to declare in relation to the content of this article.

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