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Precision in Stroke Care: Novel Model for Predicting Functional Independence in Urgent Carotid Intervention Patients

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BACKGROUND: Stroke requires timely intervention, with carotid endarterectomy (CEA) and carotid artery stenting (CAS) increasingly used in select acute carotid-related stroke patients. We aimed to build a model to predict neurologic functional independence (modified Rankin scale [mRS] ≤ 2) in this high-risk group.

STUDY DESIGN: We analyzed data from 302 stroke patients undergoing urgent CEA or CAS between 2015 and 2023 at a tertiary comprehensive stroke center. Predictors included (1) stroke severity (NIH Stroke Scale), (2) time to intervention (≤48 hours), (3) thrombolysis use, and (4) frailty risk score. Two-way interactions were included to enhance generalizability without overfitting. Multiple models were constructed and selected based on the area under the receiver operating characteristic curve. The primary endpoint was discharge neurological functional independence (mRS ≤ 2).

RESULTS: Presenting clinical factors and neurological outcomes data from 302 patients undergoing urgent CEA and CAS during the index hospitalization from 2015 to 2023 at a tertiary comprehensive stroke center formed the model's foundation. Most patients (72.8%, 220 of 302) were discharged functionally independent (mRS ≤ 2). The combined 30-day rate of stroke, death, and MI was 8.3% (25 of 302), 6.5% (14 of 214) for CEA alone, and 12.5% (11 of 88) for CAS. The model, incorporating thrombolysis, time to intervention, stroke severity (NIH Stroke Scale), and frailty risk, correctly predicted 93% of functional independence outcomes (area under the receiver operating characteristic curve 0.808).

CONCLUSIONS: We present a novel model using 4 clinical factors—stroke severity, time to intervention, thrombolysis use, and frailty risk—to predict functional neurologic independence with 93% accuracy in patients undergoing urgent carotid interventions for acute stroke. This high predictive capability can enhance clinical decision-making and improve patient outcomes by identifying those most likely to benefit from timely carotid revascularization.

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Abbreviations and Acronyms

AIC	=	Akaike Information Criteria
ASE	=	average squared error
AUC	=	area under the curve
CAS	=	carotid artery stenting
CEA	=	carotid endarterectomy
EMR	=	electronic medical record
GLM	=	generalized linear model
HFRS	=	Hospital Frailty Risk Score
IQR	=	interquartile range
MCR	=	misclassification rate
mRS	=	modified Rankin Scale
NIHSS	=	NIH Stroke Scale
ROC	=	receiver operating characteristic

Stroke remains a leading cause of mortality and disability worldwide, necessitating timely intervention to prevent neurological deterioration. Carotid artery disease accounts for up to 20% of all ischemic strokes.[1] Carotid endarterectomy (CEA) and carotid artery stenting (CAS) are widely used interventions for select patients presenting with acute carotid-related stroke, aiming to prevent recurrent ischemic events due to carotid atherosclerotic plaque vulnerability.[2,3] Current US[4] and European[1] guidelines recommend revascularization within 14 days of symptom onset for neurologically stable patients. With the establishment of regional stroke centers, "urgent" carotid interventions are increasingly performed during the initial hospitalization after an acute ischemic stroke.[5-11] However, accurately predicting neurological functional outcomes in this high-risk group remains a significant clinical challenge.

The NIH Stroke Scale (NIHSS) score provides objective criteria for assessing stroke severity.[12] At the same time, the modified Rankin Scale (mRS) is frequently used as a primary outcome measure for poststroke functional independence, with scores 0 to 2 indicating minimal disability and independence, and scores 3 to 5 reflecting greater neurological dependence.[13]

Although thrombolysis and mechanical thrombectomy are effective in improving neurological recovery and functional outcomes in elderly stroke patients, the role of frailty is critical in influencing prognosis.[14] Frailty, characterized by a decline in physiological reserve across multiple organ systems, affects up to 15% of Americans older than 65 years of age, with an additional 4 % being "prefrail."[15] Frailty is increasingly recognized as an independent predictor of poor functional outcomes and higher mortality after ischemic stroke,[5,16] mainly among elderly patients.[15-18] Despite its importance, frailty is often underassessed in acute stroke settings due to the limitations of traditional assessment tools, which require manual input and are impractical in the acute care setting.[19]

The Hospital Frailty Risk Score (HFRS) addresses this gap by assessing frailty risk based solely on ICD-10 codes from the electronic medical record (EMR), facilitating rapid, objective evaluation in acute settings.[20] Developed and validated on a cohort of more than 1 million patients, the HFRS has demonstrated strong predictive accuracy in various in-patient populations, offering a nuanced understanding of patient risk profiles. The HFRS has proven effective in other patient populations[21-23] and shows potential generalizability to patients presenting with acute carotid-related stroke.[5,24]

Several factors influence neurological functional outcomes postintervention, including stroke severity (NIHSS),[1,4,6,11] thrombolysis use,[4,6,7,11] time to intervention,[1,4,25] and frailty.[5,24] However, these variables are often evaluated independently in stroke centers, and no single model currently integrates them to create a unified predictive tool. Determining which patients fit the "high-risk" profile remains complex, and guidelines from the Society for Vascular Surgery suggest selecting patients for urgent CAS or CEA based on anatomy and comorbidities but lack precise criteria for symptom-based risk assessment.[26]

To address this gap, we developed a novel predictive model that integrates NIHSS, thrombolysis use, time to intervention, and patient's frailty using the HFRS. Our objective was to assess whether this model could improve the predictive accuracy of neurological functional independence in patients with acute carotid-related stroke.

METHODS

Study design and outcomes measure

This was a retrospective cohort study that included patients who underwent urgent CEA or CAS for stroke at a tertiary comprehensive stroke center from 2015 to 2023. The aim was to develop and validate a model to predict neurological functional independence at discharge, as defined by a modified Rankin Scale (mRS) score of ≤2. A total of 302 patients were included, with clinical, procedural, and outcome data collected from the institutional EMR and verified by chart review. The study's primary outcome was functional independence, defined as a discharge mRS score ≤2, indicating that the patient was either independent or required minimal assistance for daily activities. Secondary outcomes included composite 30-day events of stroke, death, and MI.

Building and integration of a novel in-patient a carotid frailty risk index into the electronic medical record

A custom rule was designed in our EMR (Epic Systems Corporation, Verona, WI) to automatically calculate the Carotid Frailty Risk score based on a patient's active problem list and recent diagnosis.[5] Each ICD-10 code was entered into the rule twice, once to search the patient's active problem list and once to search the current visit's diagnosis, then assigned each item found the corresponding weight to produce a single score. This rule incorporates 218 individual line items to search for the 109 distinct ICD-10 codes with a frailty weight.[20]

Once the rule was validated in retrospective data, then by targeted clinicians in live patient data, a new scoring system was configured to display the calculated score and associated risk level based on the previous results of this study. Next, to enhance the user experience in the EMR, a color-coded system was implemented to visually represent the risk levels (green represents "low," yellow represents "intermediate," and red represents "high"), aligning with the thresholds identified for this population in our recent work.[5] The scoring system also stored the values in flowsheets to allow retrieval of historical scores to allow for trending over time.

To save the historical scores, Epic functionality "batch jobs" needed to be configured to tell the system how often to file the patient's score. This batch job was configured to file the patient's current score daily and set up to run overnight to ensure that it did not cause system performance degradation during peak usage hours. To ensure easy access and understanding of the score, a new report was created to display the score, reference information, and historical scores. This report was integrated into hover bubbles for relevant columns and included as a patient snapshot report, enhancing clinicians' visibility.

Predictor variables and model selection

To construct the predictive model for functional and clinical outcomes in patients with stroke undergoing urgent carotid interventions, 4 key clinical variables were used (1) stroke severity: measured at presentation using the NIHSS, stroke severity was categorized as no symptoms (0), minor (1 to 4), moderate (5 to 15), or severe (>15); (2) time to intervention: defined as the time from hospital admission to the carotid intervention, this variable was dichotomized at 48 hours (≤48 or >48 hours); (3) thrombolysis use: it was captured as a binary variable (yes or no); and (4) frailty risk score: frailty was assessed using a novel frailty risk score, represented as both a numeric value and categorical variables: low risk (≤10), intermediate risk (10 to 30), and high risk (>30).

The primary endpoint was neurological functional independence, defined as an mRS score ≤2 on hospital discharge. Several variations of the clinical predictors were incorporated into candidate models to optimize predictive performance. The model-building process followed a generalized linear model (GLM) approach with a logit link function. Interactions between the clinical variables were explored to improve the model's predictive accuracy while ensuring simplicity and avoiding overfitting.

The model-building and selection strategy followed a stepwise approach:

1. Defining the dependent variable: The dependent variable Y is an n-dimensional vector of Bernoulli-distributed random variables Y_i, where each observed value y_i of Y_i represents the function l status of patient i. For $i = 1,\ 2, \ldots, n$:

$$y_i = \begin{cases} 1 & \text{if functionally independent } (\text{mRS} \leq 2) \\ 0 & \text{if functionally independent } (\text{mRS} > 2) \end{cases} \tag{1}$$

$$P\left(Y_i = y | x_i\right) = \begin{cases} \pi_i\left(x_i\right) & if\ y = 1 \\ 1 - \pi_i\left(x_i\right), & if\ y = 0 \end{cases} \tag{2}$$

$$E\left(Y_i | x_i\right) = \pi_i\left(x_i\right), \tag{3}$$

where ***xi*** is a p-dimensional vector of predictors, and $\pi_i\left(x_i\right)$ is the probability of functional independence conditional on the predictors.

2. Model structure: A GLM with l git link function $g\left(\cdot\right)$ is used to model the conditional probability of functional independence.

$$P\left(Y_i = 1 \left| x_i \right.\right) = \pi_i\left(x_i\right) \tag{4}$$

$$logit\left(\pi_i\left(x_i\right)\right) = ln\left(\frac{\pi_i\left(x_i\right)}{1 - \pi_i\left(x_i\right)}\right) \tag{5}$$

Using equations (4) and (5), the GLM has form

$$g\left(\pi_i\left(x_i\right)\right) = ln\left(\frac{\pi_i\left(x_i\right)}{1 - \pi_i\left(x_i\right)}\right) = x_i'\beta, \tag{6}$$

where $\boldsymbol{\beta}$ is a p-vector of fixed effects parameters for predictors x_i. The inverse logit function $g^{-1}\left(\cdot\right)$ is used to obtain a solution for the conditional probability of functional i dependence. Plugging maximum likelihood estimates $\hat{\beta}$ into the solution for $\pi_i\left(x_i\right)$ gives the predicted probability

$$\hat{\pi}_i\left(x_i\right) = g^{-1}\left(x_i'\hat{\beta}\right) = exp\left(x_i'\hat{\beta}\right) / \left[1 + exp\left(x_i'\hat{\beta}\right)\right]. \tag{7}$$

3. Candidate models: Various configurations of predictors are incorporated into (6), leading to M candidate models for predicting functional independence, each with form:

$$ln\left(\frac{\pi_i\left(x_i\right)}{1-\pi_i\left(x_i\right)}\right)=\alpha+x_{i,1}\beta_1+x_{i,2}\beta_2+\cdots+x_{i,p_j}\beta_{p_j}, \quad (8)$$

where $\boldsymbol{\alpha}$ is the intercept, $\boldsymbol{pj}$ is the number of predictors in model j, and $1, 2, \ldots, M$. The corresponding predicted probability from model j is

$$\hat{\pi}_i\left(x_i\right)=exp\left(\hat{\alpha}+\sum_{k=1}^{p_j}x_{i,k}\hat{\beta}_k\right)/\left[1+exp\left(\hat{\alpha}+\sum_{k=1}^{p_j}x_{i,k}\hat{\beta}_k\right)\right] \quad (9)$$

4. Model fitting: Each model is fit to sample data and the area under the curve (AUC) for the receiver operating characteristic (ROC) curve is estimated. The area under the ROC curve is equivalent to the concordance index *c* for models with binary response.[14] An a priori cut point of 0.5 is used such that functional independence is predicted for predicted probabilities ≥ 0.5. The candidate model with the highest AUC is selected for further examination.

Model performance

There were 63 different models, each with a unique configuration of fixed effects (main effects and interactions). There were 56 sets of predictors, each comprised a unique combination of the various forms of the four clinical factors. Incorporating each set of predictors into every model results in 63 × 56 = 3,528 potential candidates. A total of 1,088 potential candidates did not converge, leaving 2,440 candidate models. The model selected had the highest AUC among those 2,440 models.

Hence, using the model selection algorithm mentioned earlier, the model chosen based on AUC incorporates the main effects for the 4 clinical factors, all 2-way interactions with a frailty risk score (HFRS), and the interaction between stroke severity and time to intervention. Akaike Information Criteria (AIC), average squared error (ASE), misclassification rate (MCR), and several analogs to the coefficient of determination (R^2) for GLMs were used in addition to AUC to compare candidate models. When comparing candidate models, larger R^2 and smaller AIC, ASE, and MCR indicate a better fit to the data. The model selected by AUC also had the highest R^2 (all versions) and lowest ASE, ranked in the top 5% of all candidate models by AIC and the top 2% by MCR. Patients were sorted by predicted probability along the x-axis. Bubbles represent probability ranges 0.025, sized by the number of patients within each range, and are colored by observed outcome (blue: mRS ≤ 2; yellow: mRS > 2). The green-shaded region indicates where the model correctly classified 93% of functionally independent patients (mRS ≤ 2), with predicted probabilities exceeding 0.5. ROC curves for the selected model with and without interaction terms are presented in Panel B of Figure 2, demonstrating improved performance when interactions were included (AUC = 0.808 vs 0.769).

Composite outcome

A composite clinical endpoint consisting of 30-day stroke, death, or MI was also investigated but was not pursued further due to insufficient sample size and response rate. The overall response rate was 8.3% (25 of 302), with a rate of 6.2% (16 of 260) among patients without thrombectomy. For patients who underwent CEA, the rate was 6.5% (14 of 214), whereas for patients who underwent CAS, the response rate was 12.5% (11 of 88).

Statistical methods

The demographic and clinical characteristics of patients in the sample are summarized in Table 1; frailty risk score and stroke severity; and clinical and neurologic outcomes are summarized in Tables 2–6. All summaries are presented by functional status at discharge and for the combined cohort of 302 patients. Continuous measures are presented as mean and SD or median and interquartile range (IQR), and categorical measures as frequency and percentage. Associations between continuous measures and discharge functional status are assessed via 2-sample *t*-tests (age and BMI) and Wilcoxon rank-sum tests (days to intervention, length of stay, frailty risk score [HFRS], stroke severity [NHISS], and mRS). Associations of functional status with individual 30-day clinical outcomes (postprocedure stroke, hemorrhagic conversion, death, and MI) are evaluated with Fisher's exact tests. Chi-square tests assess associations with all other categorical measures. The p values from post hoc pairwise comparisons of individual levels of frailty risk score and stroke severity are adjusted for multiple comparisons via Hommel's method.

Percentages of patients discharged functionally independent and dependent in the overall cohort and stratified by carotid intervention are shown in Tables 4, 5, respectively, and are categorized by components of the intervention, risk levels by HFRS score, stroke severity by NIHSS, and clinical outcomes within 30 days of intervention. Categories are organized in rows and percentages within each row sum to 100%. Associations between categories and functional status are assessed via chi-square tests, whereas within-row comparisons of functional status percentages are carried out by *z*-tests for equality of

Table 1. Demographic and Clinical Characteristics in the Patient Cohort and Stratification by Neurological Functional Independence (mRS ≤ 2) and Dependence (mRS > 2)

Patient characteristic	Cohort (n = 302)	Functionally independent, mRS ≤ 2 (n = 220)	Functionally dependent, mRS > 2, (n = 82)	p Value
Age, y, mean (SD)	65.8 (11.3)	65.1 (11.4)	67.7 (11.0)	0.071
Age ≥ 60 y, n (%)	225 (74.5)	158 (71.8)	67 (81.7)	0.080
Sex, f, n (%)	113 (37.4)	87 (39.5)	26 (31.7)	0.211
Race, n (%)				0.250
Black	72 (23.8)	49 (22.3)	23 (28.0)	
White	221 (73.2)	166 (75.5)	55 (67.1)	
Other/unknown	9 (3.0)	5 (2.3)	4 (4.9)	
BMI, kg/m^2, mean (SD)	28.8 (6.5)	28.8 (6.4)	28.7 (6.9)	0.841
Smoker (current/former), n (%)	204 (67.5)	148 (67.3)	56 (68.3)	0.798
Diabetes, n (%)	103 (34.1)	74 (33.6)	29 (35.4)	0.778
Coronary artery disease, n (%)	80 (26.5)	57 (25.9)	23 (28.0)	0.708
Peripheral artery disease, n (%)	43 (14.2)	28 (12.7)	15 (18.3)	0.218
Hypertension, n (%)	269 (89.1)	194 (88.2)	75 (91.5)	0.416
Hyperlipidemia, n (%)	231 (76.5)	172 (78.2)	59 (72.0)	0.256
Previous stroke, n (%)	79 (26.2)	62 (28.2)	17 (20.7)	0.190

mRS, modified Rankin scale.

Table 2. Patients Discharged with Neurological Functional Independence (mRS ≤ 2), Stratified by Carotid Intervention Type, Presence of Additional Interventions, Time to Intervention, Hospital Frailty Risk Score Level, and Stroke Severity at Admission (NIHSS Score)

Variable	N	Functionally independent, mRS ≤ 2, n (%)	Functionally dependent, mRS > 2, n (%)	p Value
All patients	302	220 (72.8)	82 (27.2)	<0.001*
Intervention				
Carotid intervention				0.021*
CEA	214	164 (76.6)	50 (23.4)	<0.001*
CAS	88	56 (63.6)	32 (36.4)	0.011*
Thrombolysis	65	42 (64.6)	23 (35.4)	0.031*
Thrombectomy	42	28 (66.7)	14 (33.3)	0.031*
Time to intervention				0.173
≤48 h	150	104 (69.3)	46 (30.7)	<0.001*
>48 h	152	116 (76.3)	36 (23.7)	<0.001*
Hospital Frailty Risk Score				
Risk level				<0.001*
Low (score ≤10)	24	21 (87.5)	3 (12.5)	<0.001*
Intermediate (score >10 to ≤30)	152	126 (82.9)	26 (17.1)	<0.001*
High (score >30)	126	73 (57.9)	53 (42.1)	0.075
NIHSS				
Stroke severity				<0.001*
No symptoms (0)	71	65 (91.5)	6 (8.5)	<0.001*
Minor (1–4)	104	81 (77.9)	23 (22.1)	<0.001*
Moderate (5–15)	95	62 (65.3)	33 (34.7)	0.006*
Moderate to severe (16–20)	18	9 (50.0)	9 (50.0)	1.000
Severe (21–42)	14	3 (21.4)	11 (78.6)	0.033*

*Statistically significant.
CAS, carotid artery stenting; CEA, carotid endarterectomy; NIHSS, NIH Stroke Scale.

Table 3. Patients Discharged with Neurological Functional Independence (mRS ≤ 2), Stratified by Type of Carotid Intervention (Carotid Endarterectomy and Carotid Artery Stenting), and Categorized by Additional Intervention, Time to Intervention, Hospital Frailty Risk Score Level, and Stroke Severity at Admission (NIHSS Scores)

	Carotid endarterectomy				Carotid artery stenting			
Variable	N	mRS ≤ 2	mRS > 2	p Value	N	mRS ≤ 2	mRS > 2	p Value
Intervention								
Additional intervention								
Thrombolysis only	37	28 (75.7)	9 (24.3)	0.004*	13	5 (38.5)	8 (61.5)	0.593
Thrombectomy only	6	4 (66.7)	2 (33.3)	0.414	21	15 (71.4)	6 (28.6)	0.149
Thrombolysis + thrombectomy	1	1 (100)	0 (0)	-	14	8 (57.1)	6 (42.9)	0.593
None	170	131 (77.1)	39 (22.9)	<0.001*	40	28 (70.0)	12 (30.0)	0.046*
Time to intervention								
≤48 h	83	65 (78.3)	18 (21.7)	<0.001*	67	39 (58.2)	28 (41.8)	0.179
>48 h	131	99 (75.6)	32 (24.4)	<0.001*	21	17 (81.0)	4 (19.0)	0.009*
Hospital frailty risk score								
Risk level								
Low (score ≤ 10)	18	17 (94.4)	1 (5.6)	<0.001*	6	4 (66.7)	2 (33.3)	0.414
Intermediate (score > 10 to ≤ 30)	112	95 (84.8)	17 (15.2)	<0.001*	40	31 (77.5)	9 (22.5)	0.001*
High (score >30)	84	52 (61.9)	32 (38.1)	0.029*	42	21 (50.0)	21 (50.0)	1.000
NIHSS								
Stroke severity								
No symptoms (0)	63	59 (93.7)	4 (6.3)	<0.001*	8	6 (75.0)	2 (25.0)	0.315
Minor (1–4)	82	63 (76.8)	19 (23.2)	<0.001*	22	18 (81.8)	4 (18.2)	0.014*
Moderate (5–15)	60	37 (61.7)	23 (38.3)	0.141	35	25 (71.4)	10 (28.6)	0.045*
Moderate to severe (16–20)	8	5 (62.5)	3 (37.5)	0.480	10	4 (40.0)	6 (60.0)	0.527
Severe (21–42)	1	0 (0)	1 (100)	-	13	3 (23.1)	10 (76.9)	0.157

*Statistically significant.
mRs, modified Rankin scale; NIHSS, NIH Stroke Scale

proportions. p values are adjusted for multiple comparisons via Hommel's method as needed. Functional status is further examined by carotid intervention in categories made up of combinations of additional interventions with frailty risk, stroke severity, and 30-day clinical outcomes. Percentages of patients with discharge mRS ≤2 and >2 within these composite categories can be found in **Supplemental Digital Content 1**, Table 1 (http://links.lww.com/JACS/A438).

To predict functional independence, candidate models were assessed using several fit statistics in addition to the AUC. These fit statistics included the AIC, ASE, MCR, Cox and Snell's Generalized R^2,[15] Nagelkerke's Max-Rescaled R^2,[16] McFadden's Deviance R^2 or Likelihood Ratio Index,[17] Estrella's Scaled R^2,[18] Aldrich and Nelson's Pseudo R^2,[19] Veall and Zimmermann's Adjusted Pseudo R^2,[20] and Lave and Efron's Ordinary Least Squares.[21,22] These fit statistics provided comprehensive measures of model fit and predictive performance, enabling a robust evaluation of each model's ability to predict functional independence.

RESULTS

A total of 302 patients underwent urgent carotid interventions, CEA or CAS, between 2015 and 2023 at a tertiary comprehensive stroke center are included in the study. "Urgent" signifies a carotid intervention during the index hospitalization[5-11] for an established stroke. The mean time from acute stroke to a carotid intervention was 3.0 days in the entire cohort—3.8 days for CEA and 1.3 days for CAS. The primary goal was to predict neurologic functional independence at discharge, defined as an mRS score ≤2, by using a novel predictive model incorporating 4 key clinical variables: stroke severity (NIHSS), time to intervention, thrombolysis use, and the HFRS recently validated in patients with stroke.[5] Of 302 patients, 220 (72.8%) were discharged functionally independently (mRS score ≤ 2).

Patient characteristics and baseline data

The baseline demographics and clinical characteristics of the cohort are presented in Table 1. The mean age of the cohort was 65.8 years (SD 11.3), with 37.4% women.

Table 4. Complication or AE (Stroke, Death, or MI) Within 30 Days of Intervention, Stratified by Carotid Intervention (CAS and CEA) and in Subgroups Defined by Additional Interventions, Time to Intervention, Hospital Frailty Risk Score Levels and NIH Stroke Scale at Admission

	Cohort		CEA		CAS		
Variable	**n**	**AE (%)**	**n**	**AE (%)**	**n**	**AE (%)**	**p Value**
All patients	302		214		88		
Complication		25 (8.3)		14 (6.5)		11 (12.5)	0.088
Intervention							
Additional intervention							
Thrombolysis	65	9 (13.8)	38	3 (7.9)	27	6 (22.2)	0.294
Thrombectomy	42	9 (21.4)	7	2 (28.6)	35	7 (20.0)	0.631
Multimodal intervention							
Carotid + thrombolysis	50	6 (12.0)	37	3 (8.1)	13	3 (23.1)	0.519
Carotid + thrombectomy	27	6 (22.2)	6	2 (33.3)	21	4 (19.0)	0.691
Carotid + thrombolysis + thrombectomy	15	3 (20.0)	1	0 (0)	14	3 (21.4)	-
Carotid only	210	10 (4.8)	170	9 (5.3)	40	1 (2.5)	0.691
Time to intervention							
≤48 h	150	17 (11.3)	83	6 (7.2)	67	11 (16.4)	0.155
>48 h	152	8 (5.3)	131	8 (6.1)	21	0 (0)	0.600
Hospital frailty risk score							
Risk level							
Low: score ≤10	24	2 (8.3)	18	2 (11.1)	6	0 (0)	1.000
Intermediate: score >10 to ≤30	152	8 (5.3)	112	3 (2.7)	40	5 (12.5)	0.090
High: score >30	126	15 (11.9)	84	9 (10.7)	42	6 (14.3)	1.000
NIH Stroke Scale							
Stroke severity							
No symptoms (0)	71	0 (0)	63	0 (0)	8	0 (0)	-
Minor (1–4)	104	4 (3.8)	82	4 (4.9)	22	0 (0)	1.000
Moderate (5–15)	95	13 (13.7)	60	8 (13.3)	35	5 (14.3)	1.000
Moderate to severe (16–20)	18	4 (22.2)	8	1 (12.5)	10	3 (30.0)	1.000
Severe (21–42)	14	4 (28.6)	1	1 (100)	13	3 (23.1)	-

AE, adverse event; CAS, carotid artery stenting; CEA, carotid endarterectomy.

Cardiovascular comorbidities, including hypertension (89.1%), hyperlipidemia (76.5%), current or former tobacco use (67.5%), diabetes (34.1%), and coronary artery disease (26.5%), were prevalent, and 26.2% of patients had a history of previous stroke before presenting with the index carotid-related cerebral ischemic event. The racial breakdown of the cohort included 73.2% White and 23.8% Black patients. There was no significant difference in most baseline characteristics between functionally independent and dependent patients, except for a trend toward older age and higher prevalence of previous stroke in the functionally dependent group ($p = 0.071$ and $p = 0.190$, respectively).

Procedural characteristics and clinical outcomes

Of the 302 patients, 214 (70.9%) underwent CEA, and 88 (29.1%) underwent CAS. Functional independence (mRS ≤ 2) on hospital discharge was achieved in 164 of 214 (76.6%) of patients who underwent CEA and 56 of 88 (63.6%) of CAS (Table 2). The lowest observed rates of functional independence (mRS score ≤ 2) were in patients who underwent CAS also treated with thrombolysis (38.5% with CAS + thrombolysis and 57.1% with CAS + thrombolysis and thrombectomy; Table 3). Higher rates of functional independence were seen in those who underwent CAS only (70%) or CAS and thrombectomy (71.4%). Patients who underwent CEA for whom thrombolysis was used had a similar rate of functional independence on discharge to CEA with no additional interventions (75.7% with thrombolysis and 77.1% with CEA only). The combined 30-day adverse event rate, consisting of stroke, MI, or death, was 8.3%, with a lower rate observed in patients who underwent CEA (6.5%) than in patients who underwent CAS (12.5%; Table 4). This increased rate

Table 5. Complications Within 30 Days of Discharge and mRS on Discharge Stratified by Stroke Severity (NIHSS) Scores Between Functionally Independent (mRS ≤ 2) and Functionally Dependent (mRS > 2) Patients

Variable	Cohort (n = 302)	Functionally independent, mRS ≤ 2 (n = 220)	Functionally dependent, mRS > 2 (n=82)	p Value
Clinical outcomes ≤30 d from intervention, n (%)				
Stroke or hemorrhagic conversion	22 (7.3)	7 (3.2)	15 (18.3)	<0.001*
Postprocedure stroke	11 (3.6)	5 (2.3)	6 (7.3)	0.076
Hemorrhagic conversion	11 (3.6)	2 (0.9)	9 (11.0)	<0.001*
Death	6 (2.0)	1 (0.5)	5 (6.1)	0.006*
MI	2 (0.7)	1 (0.5)	1 (1.2)	0.470
Stroke, death, or MI	25 (8.3)	9 (4.1)	16 (19.5)	<0.001*
mRS score by NIHSS, median (IQR)				
All strokes (0–42)	1 (0–3)	1 (0–1)	3 (3–4)	<0.001*
No symptoms (0)	0 (0–1)	0 (0–1)	4 (3–4)	<0.001*
Minor (1–4)	1 (1–2)	1 (0–1)	3 (3–4)	<0.001*
Moderate (5–15)	2 (0–3)	1 (0–2)	3 (3–4)	<0.001*
Moderate to severe (16–20)	3 (1–4)	1 (1–2)	4 (4–4)	0.004*
Severe (21–42)	4 (3–5)	0 (0–1)	4 (3–5)	0.025*

*Statistically significant.
IQR, interquartile range; mRS, modified Rankin scale; NIHSS, NIH Stroke Severity.

Table 6. Hospital Stay, Frailty Risk and Stroke Severity at Hospital Admission Stratified by Neurological Functional Independence (mRS ≤ 2) on Hospital Discharge

Variable	Cohort (n = 302)	Functionally independent, mRS ≤ 2 (n = 220)	Functionally dependent, mRS > 2 (n=82)	p Value
Hospital stay, n (%)				
Time to intervention ≤48 h	150 (49.7)	104 (47.3)	46 (56.1)	0.173
Days to intervention, median (IQR)	3 (1–4)	3 (1–4)	2 (0–4)	0.122
Length of stay, d, median (IQR)	6 (5–10)	6 (4–8)	10 (6–15)	<0.001*
Hospital frailty risk score, n (%)				
Risk level				
Low (score ≤ 10)	24 (7.9)	21 (9.5)	3 (3.7)	0.093
Intermediate (10 < score ≤ 30)	152 (50.3)	126 (57.3)	26 (31.7)	<0.001*
High (score > 30)	126 (41.7)	73 (33.2)	53 (64.6)	<0.001*
Score, median (IQR)	26.9 (16.8–39.9)	24.7 (14.3–35.3)	37.2 (24.4–48.7)	<0.001*
NIH Stroke Scale, n (%)				
Stroke severity				<0.001*
No symptoms (0)	71 (23.5)	65 (29.5)	6 (7.3)	<0.001*
Minor (1–4)	104 (34.4)	81 (36.8)	23 (28.0)	0.154
Moderate (5–15)	95 (31.5)	62 (28.2)	33 (40.2)	0.089
Moderate to severe (16–20)	18 (6.0)	9 (4.1)	9 (11.0)	0.102
Severe (21–42)	14 (4.6)	3 (1.4)	11 (13.4)	<0.001*
NIH Stroke Scale score, median (IQR)	3 (1–8)	2 (0–6)	7 (3–15)	<0.001*

*Statistically significant.
IQR, interquartile range; mRS, modified Rankin Scale.

in the CAS group may be attributed to a higher proportion of patients presenting with severe strokes, as indicated by higher NIHSS scores. Of note, an adverse event rate of only 2.5% was seen in patients who underwent CAS with no additional interventions, whereas rates among patients receiving additional interventions were much higher (22% with thrombolysis and 20% with thrombectomy). Patients who underwent CEA had similar rates with and without thrombolysis. Although 33.3% of those treated via CEA and thrombectomy experienced the composite outcome, the sample size for this subgroup was small at 7 (Table 4).

Postprocedure stroke or hemorrhagic conversion occurred in 7.3% of the total cohort, and this was significantly more common in the functionally dependent group (18.3%) compared with the independent group (3.2%, $p < 0.001$, Table 5). As expected, hemorrhagic conversion specifically was a significant driver of poor outcomes, with an 11% incidence in functionally dependent patients compared with only 0.9% in those who were functionally independent ($p < 0.001$). Mortality at 30 days was 2%, with significantly higher mortality in the neurologically dependent group (6.1%) compared with the independent group (0.5%, $p = 0.006$).

Frailty risk and stroke severity

Frailty risk, calculated using the HFRS, was a significant predictor of neurological functional independence. Patients discharged functionally independent were admitted with lower frailty risk (median score 24.7, IQR 14.3 to 35.3) compared with those discharged functionally dependent (median 37.2, IQR 24.4 to 48.7; $p < 0.001$, Table 6). Frailty scores were categorized into low-, intermediate-, and high-risk groups, using the frailty risk categories recently reported by our group.[5] Frailty low risk constituted 7.9% of patients, 50.3% as intermediate risk, and 41.7% as high risk (Table 6). Patients in the high-risk category (greater than 30 points) experienced the worst outcomes, with higher rates of functional dependence (mRS > 2) at discharge (42.1%) compared with 17.1% in the intermediate group and 12.5% in the low-risk group (Table 2). Similar trends were observed for both CEA and CAS, with 32 of 84 (38.1%) of patients who underwent high-risk CEA and 21 of 42 (50%) of patients who underwent high-risk CAS discharged functionally dependent. In patients who underwent CEA, functional dependence decreased to 15.2% (17 of 112) and 5.6% (1 of 18) in intermediate- and low-risk groups, respectively, and to 22.5% (9 of 40) and 33.3% (2 of 6) for the same groups in patients who underwent CAS. Although the percentage of functionally dependent low frailty risk CAS patients exceeds that of the intermediate-risk patients, this anomaly can be attributed to small sample size (6) and one of the functionally dependent patients being admitted with a severe stroke (NIHSS = 29).

Stroke severity (NIHSS) also played a significant role in predicting outcomes. Patients with no symptoms (NIHSS 0) and minor strokes (NIHSS 1 to 4) had the highest rates of functional independence (91.5% and 77.9%, respectively), whereas only 21.4% of patients with severe strokes (NIHSS > 20) achieved functional independence ($p < 0.001$, Table 2). Similar associations between stroke severity and functional independence can again be seen in patients who underwent CEA and CAS (Table 3). The median NIHSS score for functionally independent patients was 2 (IQR 0 to 6), significantly lower than the median score of 7 (IQR 3 to 15) for functionally dependent patients ($p < 0.001$, Table 6). Finally, similar trends across frailty risk and stroke severity were seen in the composite clinical outcome with stroke, death, or MI occurring in higher frequencies with increasing score on HFRS or NIHSS (Table 5).

Time to intervention and length of stay

Time to intervention, defined as the time from admission to carotid intervention, was a factor in the model but did not differ significantly between the functionally independent and dependent groups. The median time to intervention was 3 days (IQR 1 to 4 days) in both groups, with 49.7% of the cohort receiving treatment within 48 hours ($p = 0.173$). In patients who underwent CAS, however, 81% of those whose carotid intervention was deferred beyond 48 hours were discharged functionally independent compared with 58.2% of those who underwent CAS within 48 hours of being admitted. This disparity was not observed for CEA, with functional independence achieved in 78.3% of patients with delayed intervention and 75.6% of patients who underwent the procedure within the first 2 days. This difference is likely attributed to the fact that more CAS patients were admitted with more severe strokes and intracranial thrombi requiring intervention within 48 hours. Length of hospital stay was significantly longer in functionally dependent patients, with a median stay of 10 days (IQR 6 to 15 days) compared with 6 days (IQR 4 to 8 days) for independent patients ($p < 0.001$, Table 6).

Predictive model performance

The predictive model for neurological functional independence was constructed using 4 key clinical variables: frailty risk, stroke severity (NIHSS), time to intervention, and thrombolysis use. Interaction terms were included to improve predictive accuracy, particularly interactions between frailty risk and stroke severity and between time to intervention and stroke severity. The final model achieved an AUC of 0.808, correctly classifying 93% of functionally independent patients (Fig. 1). When the interaction terms were excluded, the AUC dropped to 0.768, underscoring the importance of these interactions in enhancing the model's predictive ability (Fig. 2).

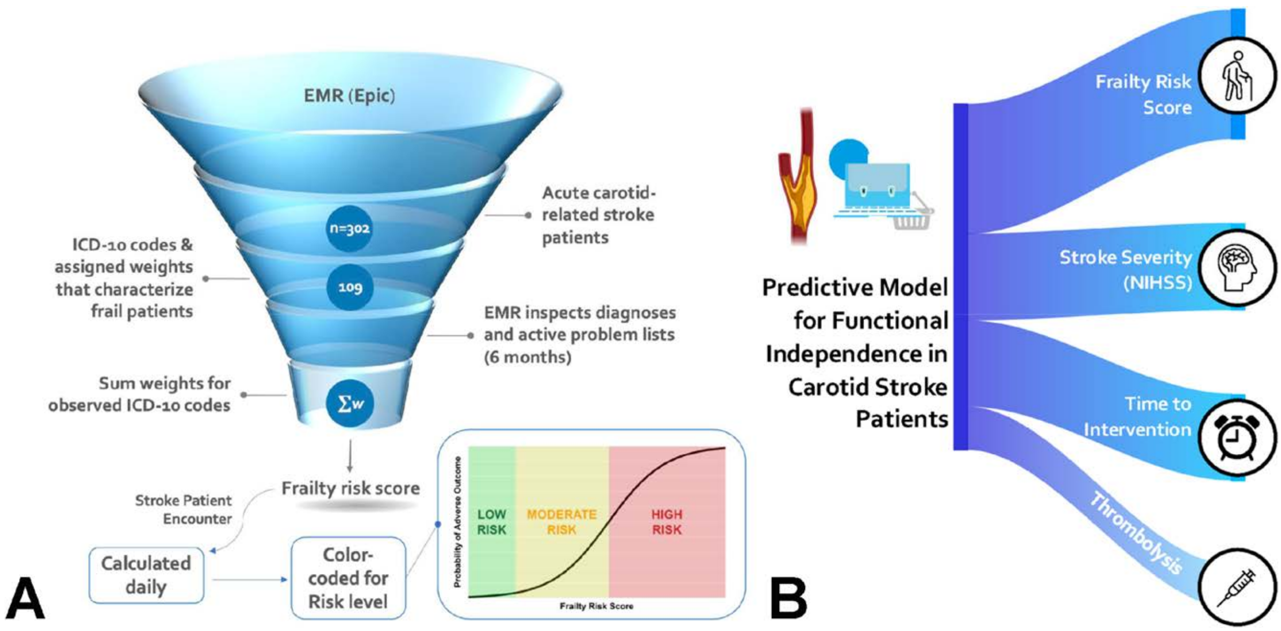

Figure 1. Novel model overview. (A) Visualization of process for calculation and utilization of hospital frailty risk score in acute carotid-related stroke patients. (B) Clinical factors incorporated into predictive model displayed by strength of point-biserial correlation with functional independence. EMR, electronic medical record; NIHSS, NIH Stroke Severity.

The distribution of predicted probabilities of functional independence evidences the model's strong performance in predicting neurological functional outcomes. Patients were categorized by predicted probability, and the green-shaded area in Figure 1 highlights the model's 93% accuracy in predicting functional independence for patients with predicted probabilities exceeding 0.5.

Composite clinical outcomes

The composite outcome of stroke, death, or MI within 30 days postprocedure occurred in 8.3% of the cohort. This composite outcome was significantly higher in neurological functionally dependent (mRS > 2) patients (19.5%) compared with those who were functionally independent (mRS ≤ 2; 4.1%, $p < 0.001$, Table 5). Additionally, functionally dependent patients had higher rates of postprocedure stroke (7.3% vs 2.3%, $p = 0.076$), though this did not reach statistical significance. Hemorrhagic conversion and death were significantly higher in the functionally dependent group ($p < 0.001$ and $p = 0.006$, respectively).

Time to intervention appears to be a factor associated with the composite outcome. Stroke, death, or MI occurred in 11.3% (17 of 150) of patients for whom the intervention was carried out within 48 hours of admission and in 5.3% (8 of 152) of those for whom intervention was delayed beyond the 48-hour mark. This trend is more pronounced among patients who underwent CAS. A rate of 16.4% (11 of 67) was observed in patients who underwent the procedure within 2 days of admission vs 0% (0 of 21) when treatment was administered after the initial 48 hours. For patients who underwent CEA, rates of the composite outcome were similar regardless of time to intervention (Table 4).

DISCUSSION

We present a novel predictive model that accurately forecasts neurological functional independence (mRS ≤ 2) in patients undergoing urgent carotid interventions for acute stroke. By integrating 4 critical clinical variables—stroke severity (NIHSS), frailty (measured by the HFRS), time to intervention, and thrombolysis use—the model achieves high predictive accuracy for functional independence of 93%, supported by an AUC of 0.808. This tool provides clinicians with an accessible, data-driven approach to identifying patients most likely to benefit from timely carotid revascularization, enhancing decision-making in acute stroke care.

Clinical outcomes: carotid endarterectomy and carotid artery stenting

Although our findings reveal significant differences in outcomes between CEA and CAS, this is likely due to patients undergoing CAS presenting with more severe strokes and

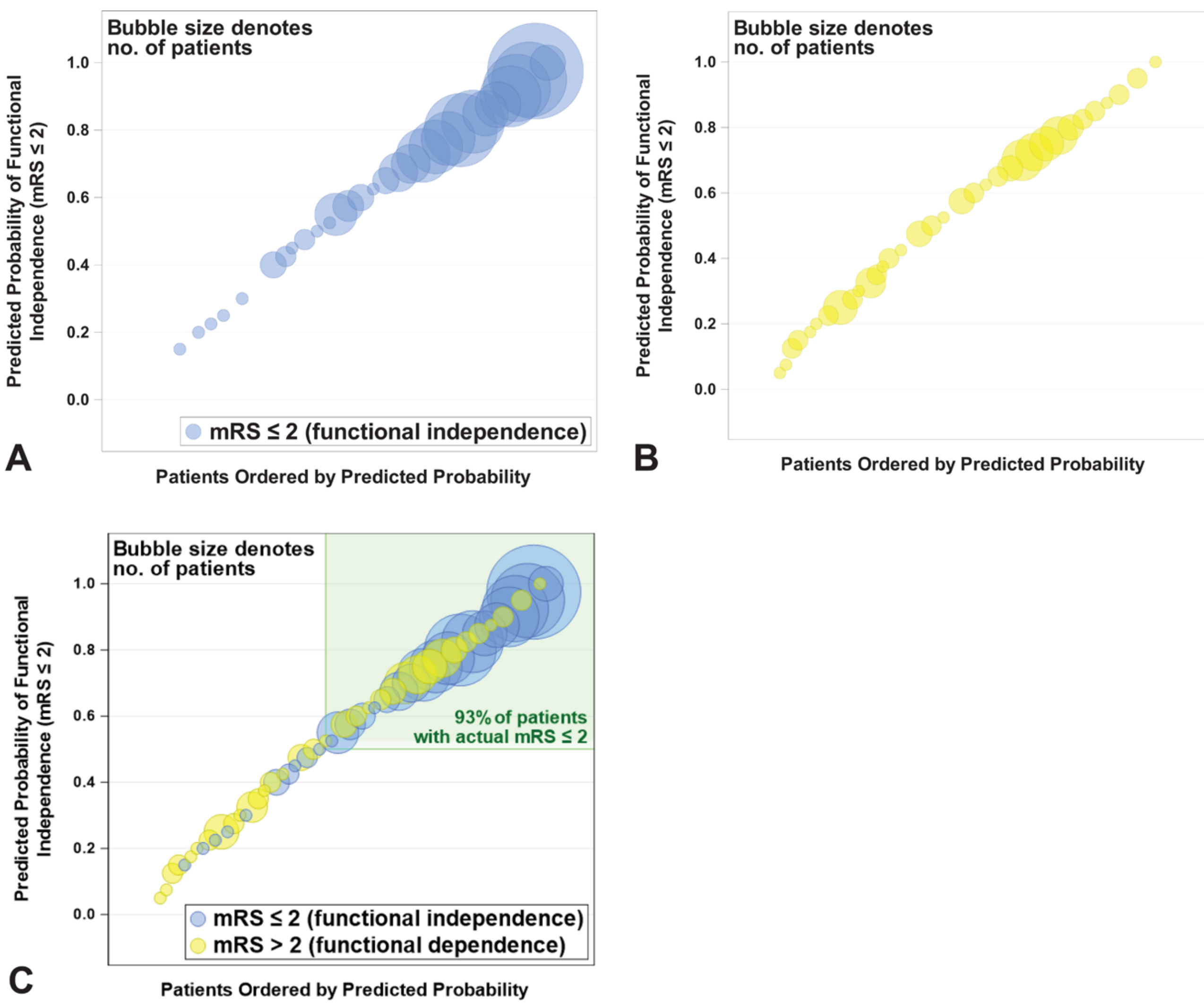

Figure 2. Functional independence is plotted as a measure of the predicted probability. Bubble size denotes the number of patients within each probability range. The green-shaded area shows where the model correctly identifies 93% of functionally independent patients (modified Rankin scale [mRS] ≤ 2). (A) Plot for patients with discharge mRS ≤ 2 showing that the predictive model functions as intended and correctly classifies the majority as functionally independent. (B) Plot for patients with discharge mRS > 2 showing a uniform distribution of predicted probabilities of functional independence and confirming that the model is not intended to predict functional dependence. (C) Plot for all patients emphasizing the model's discriminatory power for predicting functional independence.

requiring interventions within 48 hours. As shown in Table 2, patients undergoing CEA had a higher rate of functional independence at discharge (76.6%) compared with those undergoing CAS (63.6%), a significant difference ($p = 0.021$). When treatment also included thrombolysis, only 48.1% of patients who underwent CAS achieved functional independence vs 76.3% of patients who underwent CEA. Additionally, the combined 30-day adverse event rate—including stroke, MI, or death—was lower among CEA (6.5%) than in patients who underwent CAS (12.5%). Use of additional intervention (thrombolysis or thrombectomy) seems to play a role in the disparate rates between CAS and CEA. Thrombolysis in particular was associated with a higher adverse event rate in patients who underwent CAS but not in those treated with CEA. Among patients receiving no additional interventions, the composite outcome rate for CAS was actually lower than for CEA (2.5% and 5.3%, respectively; Table 4). Again, these disparities may be attributed to the higher stroke severity in CAS patients, who presented with greater NIHSS scores and were more likely to require thrombolysis and mechanical thrombectomy (Table 3). These factors

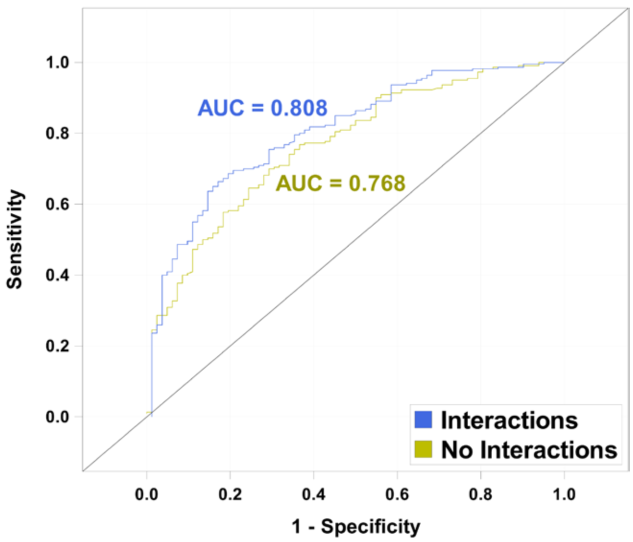

Figure 3. Receiver operating characteristic curve showing improved model performance when including interaction terms among 4 clinical factors (stroke severity [NIH Stroke Severity], frailty risk [Hospital Frailty Risk Score], time to intervention, and use of thrombolysis). Area under the curve (AUC) increases to 0.808 with interactions, compared with 0.768 without, indicating enhanced predictive capability.

suggest that although CAS is essential for certain high-risk patients, it carries a higher procedural risk, especially in those with severe strokes, and may not independently predict functional independence.

Frailty as a key predictor of outcomes

Frailty, assessed via the HFRS, emerged as a crucial predictor of postintervention outcomes. In our cohort, 41.7% of patients were classified as high-risk based on their frailty score (Table 6). High-risk patients had markedly worse outcomes, with 42.1% being functionally dependent at discharge, compared with 17.1% in the intermediate-risk group and only 12.5% in the low-risk group ($p < 0.001$, Table 2). The median frailty score among functionally dependent patients was significantly higher (37.2) than that of independent patients (24.7; $p < 0.001$). The high-risk group also had a higher rate of the 30-day composite clinical outcome (stroke, death, or MI) at 11.9% compared with 5.3% in intermediate-risk patients and 8.3% in low-risk patients (Table 4). These findings reinforce the value of integrating frailty assessments into preoperative planning, as frailty substantially impacts recovery potential in acute stroke settings.

We successfully integrated the HFRS[20] into our EMR system), enabling automatic calculation and display of frailty scores based on ICD-10 codes. By developing a custom Carotid Frailty Risk score tailored for patients with stroke due to carotid disease, clinicians and other providers can now access real-time frailty assessments to support risk stratification and clinical decision-making. This integration demonstrates the model's feasibility and practicality in acute care settings.

Utility of the Hospital Frailty Risk Score in the acute stroke setting

Although alternative frailty assessments such as the Risk Analysis Index[27] may be more straightforward in ambulatory care, we found that the HFRS, which relies solely on ICD-10 codes, is well suited for acute stroke populations.[5] Its dependence on preexisting clinical data streamlines the frailty assessment process and facilitates integration into EMRs without requiring additional patient input, making it particularly valuable for urgent decision-making.

Other predictive factors: stroke severity, time to intervention, and thrombolysis

Stroke severity, measured by NIHSS, showed a strong correlation with functional outcomes. Patients with minor strokes (NIHSS 1–4) had the highest rates of functional independence among symptomatic patients (77.9%), whereas only 21.4% of patients with severe strokes (NIHSS > 20) achieved independence (Table 2, $p < 0.001$). The median NIHSS score was significantly lower in functionally independent patients (NISS = 2) than in dependent patients (NIHSS = 7; $p < 0.001$, Table 6).

Time to intervention also played a critical role. Evidence suggests delaying CEA or CAS by 48 hours in cases of stable ischemic stroke symptoms. In patients who underwent CAS, however, 41.8% of those treated within the first 48 hours of admission were discharged functionally dependent vs only 19% for whom CAS was delayed (Table 3). Timing of CAS was also associated with elevated risk of 30-day composite clinical outcome of stroke, death, or MI (Table 4). This difference is likely attributed to the fact that CAS patients undergoing interventions within 48 hours had worse admitting stroke severity, requiring intracranial thrombectomy. This timing effect was not observed in the CEA group. Although the median time to intervention in our cohort did not differ significantly by discharge functional status, our results underscore that early intervention, within the recommended timeframe of under 14 days and ideally waiting 48 hours in neurologically stable patients,[1,4] is associated with favorable outcomes, especially for high-risk patients.

Thrombolysis use was observed more frequently among functionally dependent patients (28.0%) compared with independent patients (19.1%), though this difference was not statistically significant ($p = 0.092$). This trend may reflect the more severe initial stroke presentation in these patients, necessitating more aggressive intervention.

Model performance and interaction terms

This model demonstrates robust performance, with an AUC of 0.808. Incorporating interaction terms between frailty risk and stroke severity, and between time to intervention and stroke severity, enhanced predictive accuracy. Excluding these interactions reduced the AUC to 0.768, underscoring their importance (Fig. 3). Cross-validation confirmed that the model accurately classified 93% of functionally independent patients (Fig. 1), suggesting strong potential for clinical application.

Implications for clinical practice and electronic medical record integration

Integration of our model into an EMR system can facilitate seamless clinical workflow implementation using standards such as Fast Healthcare Interoperability Resources and Substitutable Medical Applications and Reusable Technologies on Fast Healthcare Interoperability Resources.[28] This enables real-time risk stratification and individualized patient management, potentially improving outcomes by guiding intervention decisions. By leveraging Substitutable Medical Applications and Reusable Technologies on Fast Healthcare Interoperability Resources' interoperability capabilities, models such as the one described here can be easily adapted across various healthcare systems, allowing for broader application and scalability. Additionally, integrating our predictive model into the EMR system aligns closely with the Centers for Medicare & Medicaid Services' Age-Friendly Health Systems initiative,[29] which emphasizes personalized, evidence-based care for older adults through its "4Ms" framework: "What Matters, Medication, Mentation, and Mobility." By automating frailty assessments using the HFRS based on existing ICD-10 codes, this model facilitates real-time risk stratification without additional burden on clinicians or patients, directly supporting the "Mobility" and "What Matters" components. This seamless integration enables healthcare providers to tailor interventions according to individual frailty status, optimize clinical decision-making, and enhance communication regarding prognosis and treatment options. Consequently, it aids in meeting Centers for Medicare & Medicaid Services' quality metrics for frailty assessment and intervention, promoting widespread adoption of age-friendly practices across healthcare systems and potentially improving outcomes for older adults undergoing acute stroke interventions.

Limitations and future directions

This study's retrospective, single-center design may limit its generalizability. Future research should validate the model prospectively across multiple centers. Additionally, although our model includes key clinical variables, other factors—such as socioeconomic status and access to rehabilitation services—may also impact outcomes and warrant further investigation.

CONCLUSIONS

We present a highly accurate predictive model for forecasting functional independence (mRS ≤ 2) in patients undergoing urgent carotid interventions for acute stroke. By integrating stroke severity (NIHSS), frailty risk (HFRS), time to intervention, and thrombolysis use, the model provides a comprehensive assessment of recovery potential, enhancing clinical decision-making and patient counseling in acute carotid-related stroke management. Incorporating frailty—a crucial predictor of postoperative outcomes—offers a more holistic understanding of patients' physiological reserve and vulnerability. The successful integration of frailty assessments into the EMR system underscores the model's practicality and potential for widespread adoption. Ultimately, this personalized, data-driven approach aims to improve patient outcomes by enabling clinicians to make more informed decisions in acute stroke care.

Author Contributions

Data curation: Bazan, Fort, Burton
Formal analysis: Bazan, Fort, Burton
Funding acquisition: Bazan
Investigation: Bazan
Methodology: Bazan, Fort, Burton
Project administration: Bazan
Resources: Bazan
Software: Bazan, Fort, Snyder
Supervision: Bazan
Validation: Bazan
Visualization: Bazan, Fort, Burton
Writing – original draft: Bazan, Fort
Writing – review & editing: Bazan
Conceptualization: Opelka, Money, Sternbergh

REFERENCES

1. Naylor R, Rantner B, Ancetti S, et al. Editor's choice—European Society for Vascular Surgery (ESVS) 2023 clinical practice guidelines on the management of atherosclerotic carotid and vertebral artery disease. Eur J Vasc Endovasc Surg 2023;65:7–111.
2. Bazan HA, Brooks AJ, Vongbunyong K, et al. A pro-inflammatory and fibrous cap thinning transcriptome profile

accompanies carotid plaque rupture leading to stroke. Sci Rep 2022;12:13499.
3. Miceli G, Basso MG, Pintus C, et al. Molecular pathways of vulnerable carotid plaques at risk of ischemic stroke: a narrative review. Int J Mol Sci 2024;25:4351.
4. AbuRahma AF, Avgerinos ED, Chang RW, et al. Society for vascular surgery clinical practice guidelines for management of extracranial cerebrovascular disease. J Vasc Surg 2022;75:4S–22S.
5. St Hilaire C, Burton J, Lunkkadi K, et al. Frailty scores impact the outcomes of urgent carotid interventions in acute stroke patients: a comprehensive analysis of risk and prognosis. J Vasc Surg 2024;79:e14–e16.
6. Rivera PA, Burton J, Hayson A, et al. Neurologic outcomes of carotid and other emergent interventions for ischemic stroke over 6 years with dataset enhanced by machine learning. J Vasc Surg 2022;76:1280–1288.e2.
7. Bazan HA, Zea N, Jennings B, et al. Urgent carotid intervention is safe after thrombolysis for minor to moderate acute ischemic stroke. J Vasc Surg 2015;62:1529–1538.
8. Bazan HA, Caton G, Talebinejad S, et al. A stroke/vascular neurology service increases the volume of urgent carotid endarterectomies performed in a tertiary referral center. Ann Vasc Surg 2014;28:1172–1177.
9. Loftus IM, Paraskevas KI, Naylor AR. Urgent carotid endarterectomy does not increase risk and will prevent more strokes. Angiology 2017;68:469–471.
10. Taurino M, Dezi T, Aloisi F, et al. Factors affecting the outcome of symptomatic carotid stenosis surgical treatment in a single center series. Ann Vasc Surg 2022;83:258–264.
11. Hayson A, Burton J, Allen J, et al. Impact of presenting stroke severity and thrombolysis on outcomes following urgent carotid interventions. J Vasc Surg 2023;78:702–710.
12. Hinkle JL. Reliability and validity of the national institutes of health stroke scale for neuroscience nurses. Stroke 2014;45:e32–e34.
13. Saver JL, Chaisinanunkul N, Campbell BCV, et al. Standardized nomenclature for modified Rankin scale global disability outcomes: consensus recommendations from stroke therapy academic industry roundtable XI. Stroke 2021;52:3054–3062.
14. Michelard M, Detante O, Heck O, et al. Thrombolysis and thrombectomy for stroke in octogenarians and nonagenarians: a regional observational study. Rev Neurol (Paris) 2023;179:1068–1073.
15. Bandeen-Roche K, Seplaki CL, Huang J, et al. Frailty in older adults: a nationally representative profile in the United States. J Gerontol A Biol Sci Med Sci 2015;70:1427–1434.
16. Cai H, Zhang H, Liang J, et al. Genetic liability to frailty in relation to functional outcome after ischemic stroke. Int J Stroke. 2024;19:50–57.
17. Leff B, Ritchie C, Ornstein KA. Frailty in older adults. N Engl J Med 2024;391:1759.
18. Yang F, Li N, Yang L, et al. Association of pre-stroke frailty with prognosis of elderly patients with acute cerebral infarction: a cohort study. Front Neurol 2022;13:855532.
19. Welsh SA, Pearson RC, Hussey K, et al. A systematic review of frailty assessment tools used in vascular surgery research. J Vasc Surg 2023;78:1567–1579.e14.
20. Gilbert T, Neuburger J, Kraindler J, et al. Development and validation of a hospital frailty risk score focusing on older people in acute care settings using electronic hospital records: an observational study. Lancet 2018;391:1775–1782.
21. Gouda P, Wang X, Youngson E, et al. Beyond the revised cardiac risk index: validation of the hospital frailty risk score in noncardiac surgery. PLoS One 2022;17:e0262322.
22. Shimizu A, Tsuguma Y, Sakata S, et al. The hospital frailty risk score predicts poor prognoses in middle-aged and older patients with acute pancreatitis: a nationwide retrospective cohort study in Japan. Pancreas 2023;52:e249–e255.
23. Koo AB, Elsamadicy AA, Renedo D, et al. Higher hospital frailty risk score is associated with increased complications and healthcare resource utilization after endovascular treatment of ruptured intracranial aneurysms. J Neurointerv Surg. 2023;15:255–261.
24. Kilkenny MF, Phan HT, Lindley RI, et al. Utility of the hospital frailty risk score derived from administrative data and the association with stroke outcomes. Stroke 2021;52:2874–2881.
25. Mihindu E, Mohammed A, Smith T, et al. Patients with moderate to severe strokes (NIHSS score >10) undergoing urgent carotid interventions within 48 hours have worse functional outcomes. J Vasc Surg 2019;69:1471–1481.
26. Ricotta JJ, Aburahma A, Ascher E, et al. Updated society for vascular surgery guidelines for management of extracranial carotid disease. J Vasc Surg 2011;54:e1–31.
27. Covell MM, Roy JM, Gupta N, et al. Frailty in intracranial meningioma resection: the risk analysis index demonstrates strong discrimination for predicting non-home discharge and in-hospital mortality. J Neurooncol 2024;169:85–93.
28. Wesley DB, Blumenthal J, Shah S, et al. A novel application of SMART on FHIR architecture for interoperable and scalable integration of patient-reported outcome data with electronic health records. J Am Med Inform Assoc 2021;28:2220–2225.
29. Surgeons ACo. CMS Age Friendly Hospital Measure. Available at: https://www.facs.org/quality-programs/accreditation-and-verification/geriatric-surgery-verification/cms-age-friendly-hospital-measure/#:~:text=The%20CMS%20Age%20Friendly%20Hospital%20Measure%20will%20evaluate%20hospitals'%20progress,operating%20rooms%2C%20and%20emergency%20departments. Accessed December 2, 2024.

Discussion

DR ALI ABURAHMA (Charleston, WV): I need first to thank Dr Bazan and his group for their contribution to the care of acute stroke patients over the past several years. Caring for stroke patients is extremely critical both in the US and worldwide, as stroke constitutes the fifth most common cause of mortality in the US and the second in Europe. The current carotid guidelines of the Society for Vascular Surgery (SVS) and the European Society for Vascular Surgery (ESVS) recommend revascularization within 14