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A Retrospective Study of Outcome Predictive Models for Anterior Circulation Stroke Post-Endovascular Thrombectomy: Are CT-Derived Morphomics Useful?

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Keywords

Anterior circulation stroke · Risk prediction · Endovascular thrombectomy · Morphomics

Abstract

Introduction: In acute ischaemic stroke secondary to a large vessel occlusion, endovascular thrombectomy (EVT) is the standard of care. However, prediction of functional outcomes following EVT remains challenging. We sought to determine whether CT-derived morphomic data on body composition can improve outcome prediction following EVT. **Methods:** A retrospective analysis of anterior circulation stroke patients who underwent EVT between 2021 and 2023 at a single centre was conducted. Demographic, clinical, and morphomic data including neck muscle and fat area and density were collected. Multivariate logistic regression was used to develop pre-procedure and 24-h post-EVT models for predicting 90-day outcomes. A positive outcome was defined as a modified Rankin Scale (mRS) score of ≤ 2 at 90 days post-EVT. These models were subsequently tested on 2 separate validation cohorts. **Results:** High pre-procedure ASPECTS scores, lower baseline NIHSS scores, absence of post-procedure

haemorrhage, younger age, and early neurological improvement were the strongest predictors of a positive outcome. None of the morphomic variables were significantly correlated with outcome. The 24-h model was highly accurate in predicting post-EVT outcomes in both validation cohorts. **Conclusion:** CT-derived morphomic variables did not significantly improve prediction of stroke outcomes post-EVT. Clinical and imaging variables (especially 24-h post-procedure data) showed high accuracy in predicting functional outcomes at 90 days.

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Introduction

Acute ischaemic stroke (AIS) remains one of the most devastating causes of morbidity and mortality worldwide [1]. Radiological imaging, most commonly in the form of computed tomography (CT) of the brain and cerebral vessels, is a cornerstone in the acute stroke clinical decision algorithm [2]. After the publication of multiple clinical trials in 2015, the American Heart Association recommended endovascular thrombectomy (EVT) as

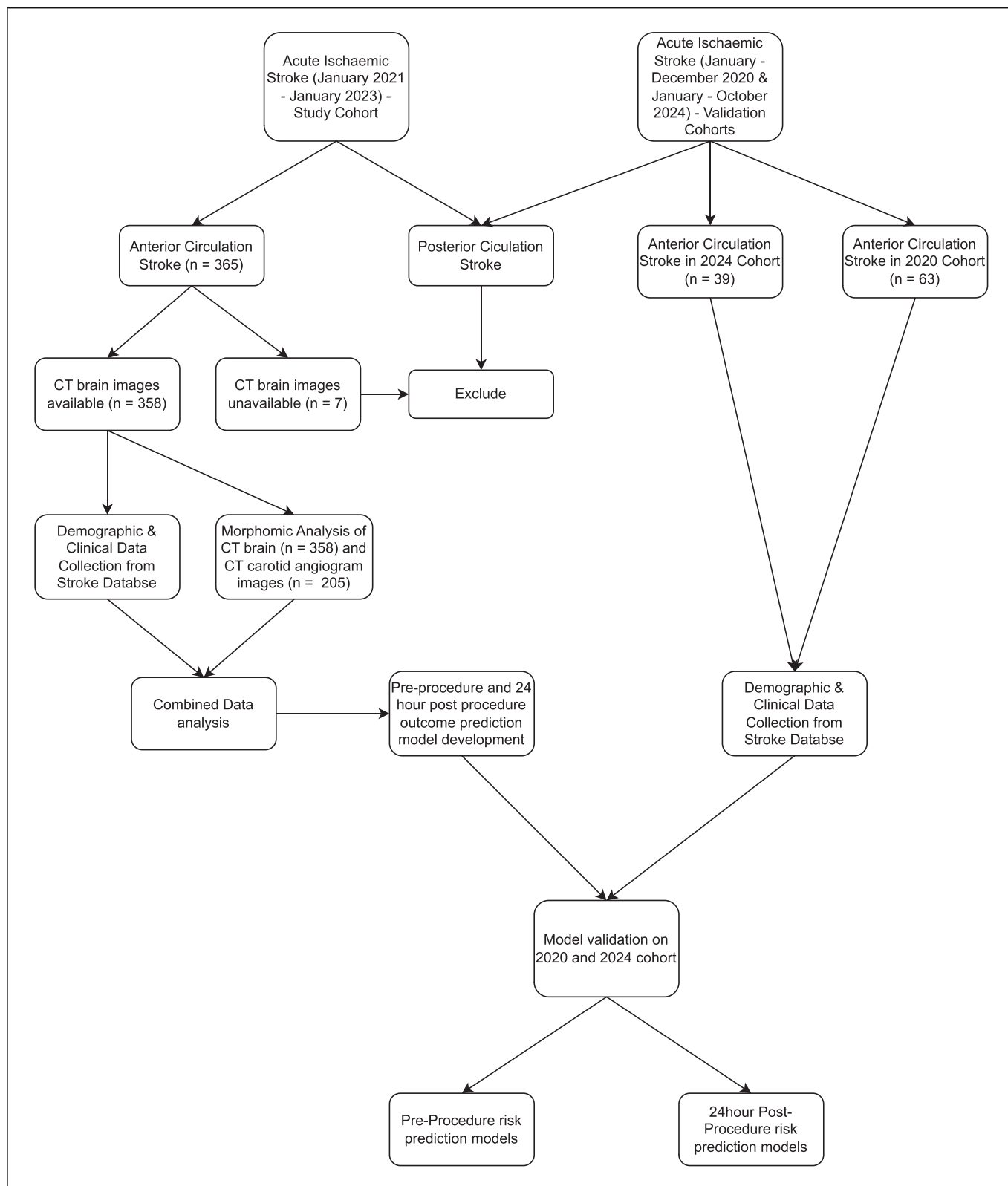


Fig. 1. Summary methods flow diagram. This diagram outlines patient selection, imaging availability, morphomic analysis, and development of pre-procedure and 24-h post-procedure prediction models, with external validation in 2020 and 2024 anterior circulation stroke cohorts.

Table 1. Patient demographics, clinical variables, and outcome variables

	All patients (n = 358)
Baseline characteristics	
Age, median (IQR), years	76 (16)
Male gender, n (%)	183 (51)
Baseline mRS ≤ 2 , n (%)	329 (91.6)
Average temporalis thickness, median (IQR), mm	5.45 (2.43)
PSM area (n = 205), mean $\pm$ SD, cm ²	39.03 $\pm$ 9.13
PSM area (normalized) (n = 205), mean $\pm$ SD	0.19 $\pm$ 0.04
PSM density (n = 205), mean $\pm$ SD, HU	45.3 $\pm$ 8.35
SCM muscle area (n = 205), median (IQR), cm ²	5.75 (2.87)
SCM muscle area (normalized) (n = 205), median (IQR)	0.03 (0.01)
SCM muscle density (n = 205), median (IQR), HU	48.76 (11.2)
SCF area (n = 205), median (IQR), cm ²	22.6 (12)
SCF density (n = 205), median (IQR), HU	-88.9 (14.3)
VF area (n = 205), median (IQR), cm ²	13.3 (15.1)
VF density (n = 205), median (IQR), HU	-78.5 (12.8)
Clinical and treatment factors	
External transfer, n (%)	192 (53.5)
NIHSS at presentation (n = 353), median (IQR)	14 (8)
ASPECTS pre-EVT (n = 330), median (IQR)	9 (3)
Received IV thrombolysis, n (%)	95 (26.5)
Onset to puncture (n = 323), median (IQR), min	325 (269)
Onset to reperfusion (n = 296), median (IQR), min	363.5 (271)
Optimal recanalization (TICI 2b-3), n (%)	304 (84.7)
Early neuro improvement (n = 303), n (%)	103 (28.7)
Symptomatic ICH (n = 291), n (%)	19 (5.3)
Any ICH, n (%)	39 (10.9)
Outcomes, n (%)	
90-Day favourable outcome (mRS ≤ 2) (n = 335)	156 (43.5)
90-Day mortality	50 (13.9)

Values are displayed as median and IQR for non-parametric data and mean and SD for parametric data. *N*, number of patients; %, the percentage of patients. mRS, modified Rankin Scale Score; PSM, paraspinal muscle; SCM, sternocleidomastoid; SCF, subcutaneous fat; VF, visceral fat; NIHSS, National Institute of Health Stroke Scale; ASPECTS, Alberta Stroke Program Early CT Score; EVT, endovascular thrombectomy; IV, intravenous; TICI, thrombolysis in cerebral infarction; ICH: intracranial haemorrhage; SD, standard deviation.

the standard of care in AIS with large vessel occlusion and Alberta Stroke Programme Early CT Score (ASPECTS) ≥ 6 [3]. The safety and efficacy of this therapeutic approach has been well established [4, 5]. Excitingly, recent level 1 data have also shown that even for patients with low ASPECTS/large core ischemic stroke, EVT resulted in better functional outcomes than medical care alone [6].

Despite the potential of EVT, optimal patient selection and outcome prediction following intervention remains challenging, especially in low ASPECTS cohorts. Robust validated predictive models are essential to help clinicians provide realistic outcome expectations to patients and families. Moreover, such a model would guide rehabilitation strategies, thereby enabling the

delivery of personalized medicine. Various imaging metrics such as size of core infarct, volume of occlusive thrombus, and degree of collateral arterial supply have been explored as potential predictors of patient outcome, with varying degrees of success [7, 8].

Sarcopaenia and frailty are overlapping entities with frailty defined as multi-system impairment associated with increased vulnerability to stressors and sarcopaenia as a generalized progressive loss of skeletal muscle mass and function [9]. Both entities, which become more prevalent with age, have been shown to affect stroke rehabilitation and outcomes [10]. An emerging approach in assessing sarcopaenia is analytical morphomics (AM). This is a novel and promising area in radiology that involves the measurement of different elements of body

Table 2. Patient demographics categorized by age groups

	Age <80 (<i>n</i> = 229)		Age ≥80 (<i>n</i> = 129)		SMD
	DA, %	result	DA, %	result	
Baseline characteristics					
Age, median (IQR), years	100	70 (13)	100	85 (6)	1.9624
Male gender, median (IQR), <i>n</i> (%)	100	138 (60)	100	45 (34.9)	
Baseline mRS ≤2, <i>n</i> (%)	100	222 (96)	100	107 (83)	
Average temporalis thickness, median (IQR), mm	92.58	5.85 (2.46)	95.35	4.85 (2.02)	−0.625
Clinical and treatment factors					
External transfer, <i>n</i> (%)	100	127 (55.2)	100	65 (50.4)	0.0499
NIHSS at presentation, median (IQR)	98.69	14 (8)	98.45	15 (8)	
ASPECTS pre-EVT, median (IQR)	99.13	9 (2)	99.22	9 (3)	
Received IV thrombolysis, <i>n</i> (%)	100	62 (27)	99.22	33 (25.6)	0.0977
Onset to puncture, median (IQR), min	87.78	319 (264)	93.8	334 (273)	
Onset to reperfusion, median (IQR), min	82.97	333 (251)	81.4	372 (310)	
Optimal recanalization (TICI 2b–3), <i>n</i> (%)	100	201 (87)	100	103 (79.8)	0.2075
Early neuro improvement, <i>n</i> (%)	87.33	71 (31)	80.62	32 (24.8)	
Symptomatic ICH, <i>n</i> (%)	79.91	13 (5.7)	82.95	6 (4.7)	
Any ICH, <i>n</i> (%)	100	28 (12.2)	99.22	11 (8.5)	
Outcomes, <i>n</i> (%)					
90-Day favourable outcome (mRS ≤2)	93.01	109 (47)	93.8	47 (36.4)	
90-Day mortality	99.56	21 (9.1)	100	29 (22.5)	

Data are displayed as median and IQR or *n* (%) as appropriate. Data availability (DA) is represented by %, whereby 100% indicates complete data were available for that variable for the respective subgroup (i.e., age <80 or age ≥80). Standardised mean difference (SMD), i.e., Cohen's *d* is displayed for the continuous variables. mRS, modified Rankin Scale Score; NIHSS, National Institute of Health stroke scale; ASPECTS, Alberta Stroke Program Early CT Score; EVT, endovascular thrombectomy; IV, intravenous; TICI, thrombolysis in cerebral infarction; ICH, intracranial haemorrhage.

Table 3. Vessel occlusion sites

Vessel occlusion sites	All patients (<i>n</i> = 358), <i>n</i> (%)	Age <80 (<i>n</i> = 229), <i>n</i> (%)	Age ≥80 (<i>n</i> = 129), <i>n</i> (%)
A1	4 (1.1)	1 (0.4)	3 (2.3)
A2	2 (0.6)	1 (0.4)	1 (0.8)
ICA	99 (27.7)	71 (31)	28 (21.7)
CCA	1 (0.3)	1 (0.4)	0 (0)
M1	196 (54.7)	127 (55.5)	69 (53.5)
M2	95 (26.5)	62 (27.1)	33 (25.6)
PCOM	1 (0.3)	0 (0)	1 (0.8)

Values are displayed as *n* (number of patients) and % (percentage of patients). A1, A1 segment of the anterior cerebral artery; A2, A2 segment of the anterior cerebral artery; ICA, internal carotid artery; CCA, common carotid artery; M1, M1 segment of the MCA; M2, M2 segment of the MCA; PCOM, posterior communicating artery.

composition at specific validated vertebral levels on cross-sectional diagnostic imaging that has already been acquired as part of the patient's routine care. AM aims to allow clinicians to gain additional information, which

would otherwise not be assessable by subjective visual analysis alone [11]. This technique has been used reliably to assess sarcopaenia without the need for any additional investigations [12]. In the head and neck region,

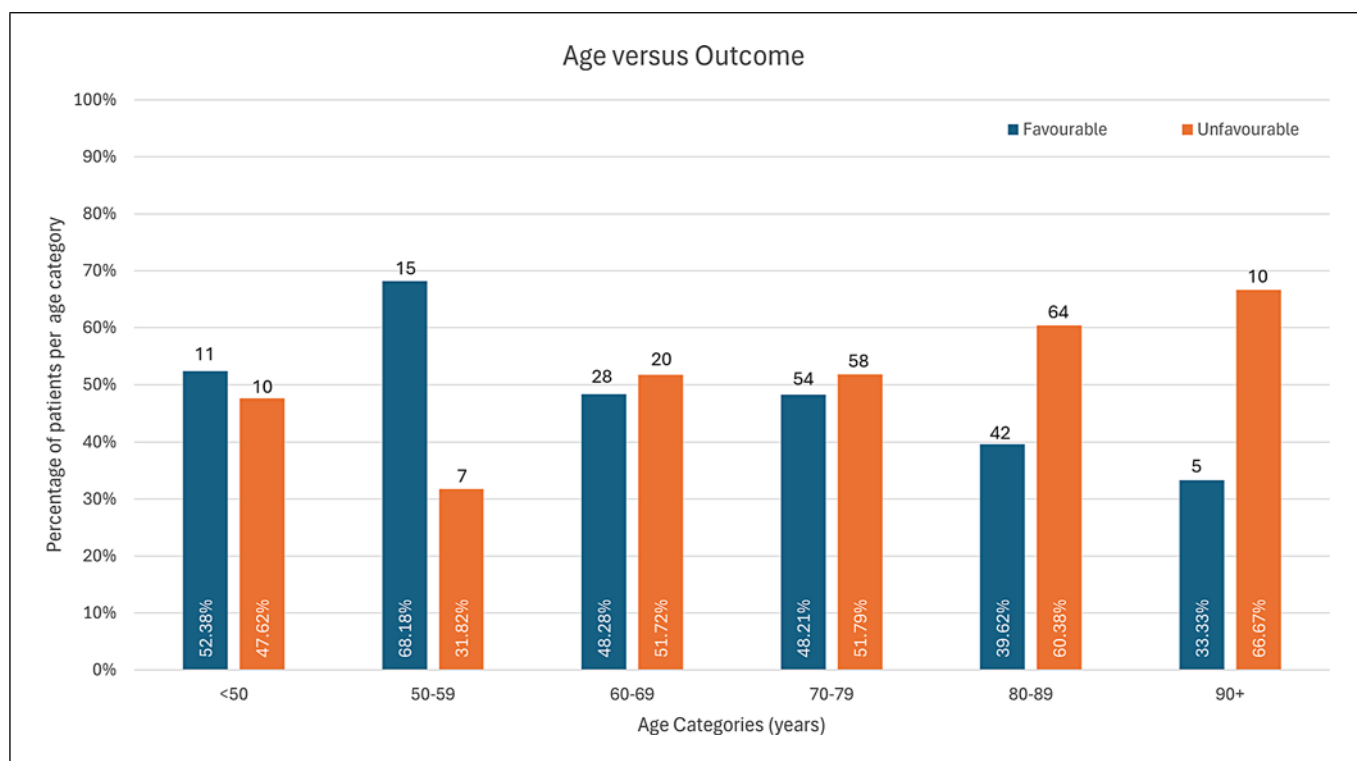


Fig. 2. Age versus outcome. Distribution of favourable and unfavourable outcomes across age categories. Bars show the percentage of patients per age group with each outcome, demonstrating a trend towards increasingly unfavourable outcomes in older age groups.

temporalis muscle thickness (TMT) has been identified as a reliable indicator of whole body skeletal muscle mass with some studies also suggesting a correlation between larger TMT and better post-thrombectomy functional outcomes [13]. Similarly, cervical paraspinal musculature at the level of the third cervical vertebra has also been shown to correlate well with total body skeletal muscle mass [14].

This study aimed to build a predictive model of post-EVT outcomes combining both AM and clinical pre- and post-procedure variables. TMT, sternocleidomastoid (SCM), paraspinal muscle (PSM), subcutaneous fat, and visceral fat (VF) cross-sectional areas (CSAs) and densities, along with other patient and clinical variables, were explored to determine their relationship with 90-day post-EVT outcome. Multivariate analysis, predictive model construction, and subsequent validation in small and large core stroke cohorts was performed. Two internal cohorts with varying demographics were used to validate the model and assess robustness. In contrast to recent studies which use complex machine learning and artificial intelligence to predict outcomes, the aim of this

paper was to develop a simple but accurate outcome prediction model that can be replicated in centres worldwide and would be applicable to both small and large core infarct cohorts [15, 16].

Methods

Study Design and Participants

A single-centre retrospective study was carried out in accordance with Institutional Review Board (Clinical Research Ethics Committee) ethical approval. All consecutive patients with anterior circulation AIS who underwent EVT in our institution between January 2021 and December 2023 were considered for inclusion. Any patients with occlusion in the posterior circulation were excluded.

Our imaging protocol comprised initial non-contrast CT head performed for all patients presenting with acute stroke symptoms. CT carotid and intracranial angiogram was performed in cases of suspected large vessel occlusion. CT perfusion was performed for late window

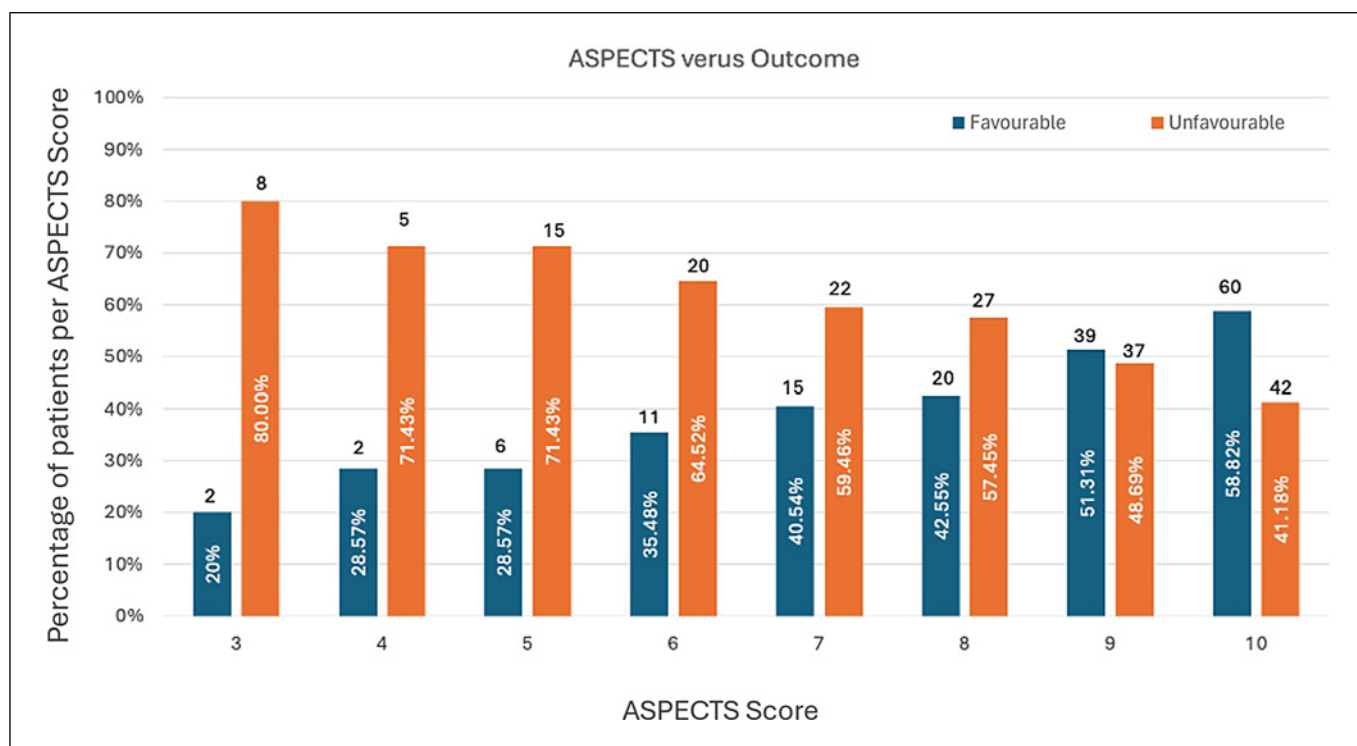


Fig. 3. ASPECTS score versus outcome. Distribution of favourable and unfavourable outcomes across ASPECTS scores. Bars show the percentage of patients per ASPECTS score with each outcome, demonstrating a trend towards increasingly unfavourable outcomes with lower ASPECTS scores.

and large core strokes. The National Institute of Health Stroke Scale (NIHSS) Score and baseline modified Rankin Score (mRS) were assessed by the stroke physician on duty at the time of patient presentation to the emergency department, or on patient arrival from an external referring hospital.

All treatment was performed according to the most recent version of international established stroke guidelines and our local departmental algorithm (online suppl. 1; for all online suppl. material, see <https://doi.org/10.1159/000550274>). Although a baseline mRS ≤ 2 was an eligibility cut-off in the algorithm, some patients with an mRS ≥ 2 were included when a consensus decision to offer treatment was made between the interventional neuroradiology and stroke medicine consultants. All endovascular procedures were performed by a consultant neuroradiologist using contact aspiration, stent retrieval, or a combination of both. Adequacy of recanalization was evaluated post-procedure using the modified Thrombolysis in Cerebral Infarction (mTICI) scale.

Similar data were collected for consecutive patients with anterior circulation AIS who underwent EVT be-

tween January to December 2020 and January to October 2024. These patients were not included in the main analysis but were instead used for validation of the developed prediction models. The 2020 cohort included patients eligible for EVT based on EXTEND-1A or DEFUSE-3 trial criteria [17, 18]. The 2024 cohort additionally included eligible low ASPECTS/large core infarcts based on ANGEL-ASPECTS and SELECT-2 trial criteria [6, 19]. The methodology is summarized in Figure 1.

Clinical Data

Patient identification and data collection was performed using the hospital stroke registry. Data collected included age, gender, NIHSS score, occlusion site, baseline mRS, administration of IV thrombolysis, time from symptom onset to groin puncture and re-perfusion, post-procedure TICI score (optimal recanalization was defined as a score of $\geq 2b$), presence of intracranial haemorrhage on follow-up imaging, symptomatic haemorrhage, early neurological improvement (defined as improvement of ≥ 8 points on the NIHSS scale at 24 h post-treatment or a NIHSS score of 0 at 24 h) [20], and

Table 4. Univariate and multivariate logistic regression analysis of variables and outcomes

Variable	90-Day mRS (0–6)		Favourable outcome (mRS ≤2)	
	univariate	multivariate	univariate	multivariate
Demographic				
Age	<0.001	<0.001	0.014	0.113
Male gender	0.461		0.525	
A. fib	0.755		0.945	
HTN	0.66		0.468	
Baseline mRS (0–6)	0.02	0.077	0.001	0.020
Clinical				
External transfer	0.075		0.006	0.012
NIHSS at presentation	<0.001	<0.001	<0.001	0.007
ASPECTS score	<0.001	<0.001	<0.001	0.009
Onset to puncture time	0.037	0.997	0.035	0.660
Onset to reperfusion time	0.052		0.055	
TICI 2b–3	<0.001	<0.001	0.002	0.008
Early neuro improvement	<0.001	<0.001	<0.001	<0.001
Symptomatic ICH	0.001	0.029	0.014	0.764
Any ICH	0.023	0.695	0.003	0.046
Morphomics				
Average TMT	0.219		0.862	
PSM area	0.462		0.265	
PSM area (normalized)	0.376		0.413	
PSM density	0.145		0.201	
SCM muscle area	0.063		0.113	
SCM muscle area (normalized)	0.062		0.221	
SCM muscle density	0.766		0.341	
VF area	0.846		0.484	
VF density	0.894		0.500	
SF area	0.835		0.995	
SF density	0.632		0.551	

The numbers above represent the *p* values generated from logistic regression analysis. Boldface values indicate statistical significance (i.e., *p* < 0.05). mRS, modified Rankin Scale Score; A. fib, atrial fibrillation; HTN, hypertension; PSM, paraspinal muscle; SCM, sternocleidomastoid; SCF, subcutaneous fat; VF, visceral fat; NIHSS, National Institute of Health stroke scale; ASPECTS, Alberta Stroke Program Early CT Score; EVT, endovascular thrombectomy; IV, intravenous; TICI, thrombolysis in cerebral infarction; ICH, intracranial haemorrhage.

90-day mRS [20]. All patients were treated according to a standardized post-EVT protocol established in our institution. As per protocol, patients undergo continuous cardiac monitoring, oxygen monitoring, temperature monitoring, and blood pressure monitoring every 15 min for the 1st hour post-EVT, every 30 min for 6 h, every hour for 17 h followed by observations as dictated by clinical need. A swallow assessment using a validated screening tool is carried out by a speech and language therapist within 4 h of arrival to the hospital. Bedside glucose monitoring is completed every 12 h from admission until a fasting glucose or HBA1C

result is obtained. Patients are screened for malnutrition on admission and weekly thereafter using the Malnutrition Screening Tool (MUST). Dietician referral for nutritional supplements is completed based on the MUST outcome. Patients are advised to rest for 24 h post-EVT following which a repeat CT brain is conducted and reviewed prior to physiotherapy review and mobilization. All anticoagulants and antiplatelets are held until the 24-h post-procedure repeat CT is clear. Medications are administered as per the National Clinical Guideline for Stroke for the UK and Ireland.

Table 5. Univariate and multivariate logistic regression analysis of variables and 90-day mortality

Variable	RIP	
	univariate	multivariate
Demographic		
Age	<0.001	0.035
Male gender	0.101	
A. fib	0.729	
HTN	0.132	
Baseline mRS (0–6)	0.295	
Clinical		
External transfer	0.245	
NIHSS at presentation	<0.001	<0.001
ASPECTS score	0.15	
Onset to puncture time	0.498	
Onset to reperfusion time	0.225	
TICI 2b–3	0.164	
Early neuro improvement	0.016	0.012
Symptomatic ICH	0.006	0.074
Any ICH	0.862	
Morphomics		
Average TMT	0.070	
PSM area	0.425	
PSM area (normalized)	0.96	
PSM density	0.949	
SCM muscle area	0.373	
SCM muscle area (normalized)	0.671	
SCM muscle density	0.938	
VF area	0.967	
VF density	0.458	
SCF area	0.273	
SCF density	0.938	

The numbers above represent the *p* values generated from logistic regression analysis. Boldface values indicate statistical significance (i.e., *p* < 0.05). mRS, modified Rankin Scale Score; A. fib, atrial fibrillation; HTN, hypertension; PSM, paraspinal muscle; SCM, sternocleidomastoid; SCF, subcutaneous fat; VF, visceral fat; NIHSS, National Institute of Health stroke scale; ASPECTS, Alberta Stroke Program Early CT Score; EVT, endovascular thrombectomy; IV, intravenous; TICI, thrombolysis in cerebral infarction; ICH, intracranial haemorrhage.

Morphomic Data

AM was performed on previously acquired CT imaging of the brain and CT angiography of the head and neck. All imaging data were accessible through the institutional picture archive communication system.

All scans were assessed by a consultant neuroradiologist in conjunction with a research fellow and a senior radiology resident. Images were analysed using CoreSlicer, a Web-based tool that enables semi-automated segmentation of muscle (–29 to +150 HU) and fat (–190

to –30 HU). This software has been previously validated against the commercially available cadaveric image analysis software “slice-O-matic” and required minimal manual correction following segmentation [21].

AM of the paraspinal and SCM muscles was performed at the C3 level as described by Swartz et al. [14]. However, in those patients with a flexed neck, imaging was analysed at a higher level to minimize inclusion of the mandible (online suppl. Material 2). Analysis of TMT was performed in the same fashion as previously described in literature [22]. Inter-rater reliability of TMT measurements was assessed using a 2-way random-effects model with absolute agreement. However, morphomic variables measured on CoreSlicer did not undergo intra-rater reliability assessment due to the automated nature of the obtaining the measurements.

In addition to the absolute values of SCM and PSM CSA, a “normalized” value was computed to account for variation in patient size. As body mass index data were unavailable, total CSA for each individual patient was used as the reference standard for normalization. Total CSA at the level of interest was derived using the manual segmentation tool in CoreSlicer by selecting all body tissues within the slice. Normalized morphomic values were calculated as ratios of the structure of interest to the total CSA (e.g., SCM ratio = SCM CSA/total CSA).

Statistical Analysis

Testing for normal distribution of continuous data was performed using the Kolmogorov-Smirnov test. Continuous variables were presented using mean and standard deviation if normally distributed, or median and interquartile range if non-parametric. Correlation between continuous variables such as TMT and age or baseline mRS was tested using Spearman’s correlation coefficient. The Mann-Whitney test was used to assess for differences in variables between groups. Univariate ordinal logistic regression was used to test for association between variables and outcomes at 90 days. Multivariate analysis was subsequently performed to assess for confounding factors. Missing data were handled by exclusion. Statistical analysis was performed using IBM® SPSS Statistics v.29, Jamovi (version 2.5), and R v 4.4.1.

Risk Prediction Model Development

Candidate variables included clinically relevant predictors and morphomic measures. Multiple multivariable model configurations, including models incorporating all morphomic variables irrespective of univariate significance, were evaluated. Morphomic variables did not improve model performance and therefore the final

Fig. 4. Logistic regression in the development of the 24-h model. The above is the result of the logistic regression analysis conducted to predict favourable (mRS score of ≤ 2 at 90 days) and unfavourable (mRS score of ≥ 3 at 90 days) outcomes. The entire cohort of 358 patients was used to create the model.

Model Coefficients - Favourable__outcome				
Predictor	Estimate	SE	Z	p
Intercept	2.5958	1.0164	2.55	0.011
Age	-0.0302	0.0118	-2.55	0.011
NIHSS_at_presentation	-0.1508	0.0330	-4.57	<.001
ASPECTS_category:				
1 - 0	0.8005	0.3516	2.28	0.023
Optimal_recanalization:				
1 - 0	1.2824	0.4674	2.74	0.006
Haemorrhage:				
1 - 0	-1.1301	0.5174	-2.18	0.029
Early_neuro_improvement:				
1 - 0	2.1893	0.3609	6.07	<.001
Hospital_Transfer:				
1 - 0	-0.8050	0.3036	-2.65	0.008
mRS_category:				
1 - 0	-0.9563	0.4797	-1.99	0.046

Note. Estimates represent the log odds of "Favourable__outcome = 1" vs. "Favourable__outcome = 0"

model included only predictors that demonstrated clinical relevance and statistically significant association with outcome in univariate analysis. A good functional outcome was defined as a 90-day mRS ≤ 2 . Two models were developed: one using both pre- and 24-h post-procedure variables (24-h model) and one using only pre-procedure variables (pre-model). Continuous variables displaying a nonlinear relationship with outcome were dichotomized into binary variables. The following categories were created: ASPECTS Score (≤ 7 and ≥ 8) and baseline mRS (≤ 1 , ≥ 2). Several ASPECTS thresholds in our training cohort were evaluated using univariate and multivariate analysis. A cut-off of ≤ 7 provided the best separation between favourable and unfavourable outcomes and was therefore selected as the optimal threshold in this dataset. The models were trained using the entire cohort of patients who underwent EVT during the study period (2021–2023) and subsequently tested on the 2020 and 2024 cohort of patients for validation. Multicollinearity among the predictor variables was assessed by calculating the variance inflation factors. Interaction analysis was conducted to explore the combined effects of the predictor variables. Age was included in the predictive model as a continuous variable. Categorization into elderly (age ≥ 80 years) and

non-elderly (age ≤ 80 years) was conducted for descriptive presentation of cohort characteristics, however was not used in model development. Although not used in the dichotomized predictive model, the 90-day mRS was additionally analysed using ordinal logistic regression (shift analysis) across the full 0–6 scale.

Results

Study Demographics

During the study period (2021–2023), a total of 365 patients underwent EVT for anterior circulation AIS. Seven patients were excluded due to unavailability of CT images or outcome data. A total of 358 patients were therefore included in the study; 183 males and 175 females, with a median age of 76 years. Overall, 92% of patients were functionally independent at baseline (mRS ≤ 2). Data regarding mRS after 90 days were available for 334 patients. Complete data on patient demographics, clinical variables, and outcomes are presented in Tables 1 and 2. Inter-rater reliability was not calculated for SCM, PSM, subcutaneous or visceral fat measurements as these were obtained via CoreSlicer with semi-automation. However, on a 2-way random-effects

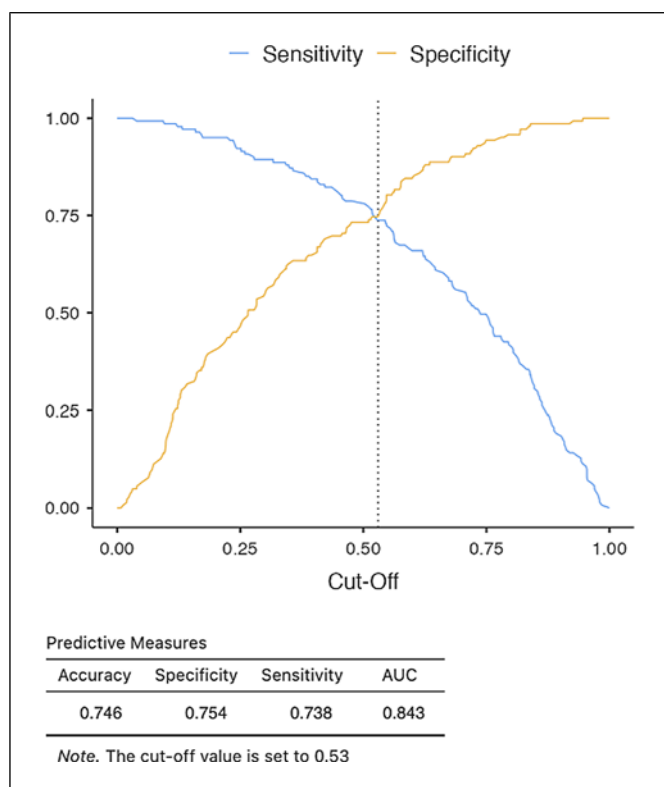


Fig. 5. Cut-off plot on the training set of patients using the 24-h model. The cut-off plot was generated based on the logistic regression model in Figure 4. A cut-off value of 0.53 (marked with a black vertical dotted line) found the best balance of sensitivity, specificity, and accuracy with values of 73.8%, 75.4%, and 74.6%, respectively.

model with absolute agreement, the intraclass correlation coefficient was 0.825 for TMT measurements showing good agreement between readers.

In our population cohort, the most common occlusion sites were the M1 segment of the middle cerebral artery (54.7%), the internal carotid artery (27.7%), and the M2 segment of the middle cerebral artery (26.5%). Occlusion sites were comparable between patients under the age of 80 and those above (Table 3).

Outcomes and Mortality Prediction

Unsurprisingly, patients above the age of 80 and those with lower ASPECTS scores had a greater proportion of negative outcomes (Fig. 2, 3). Univariate regression found that age, baseline mRS, NIHSS at presentation, ASPECTS, onset to groin puncture time, optimal recanalization, early neurological improvement, symptomatic haemorrhage post-procedure, and any haemorrhage post-procedure were significantly associated

with 90-day mRS score. On multivariate analysis, age, baseline mRS, NIHSS at presentation, ASPECTS, optimal recanalization, and early neurological improvement remained significant independent predictors. TMT was not significant on univariate analysis (Table 4).

Similarly, with a binary classification of good functional outcome (90-day mRS ≤ 2), univariate regression found that baseline mRS, NIHSS at presentation, ASPECTS score, onset to puncture time, optimal recanalization, early neurological improvement, symptomatic haemorrhage, any haemorrhage, and external hospital transfer were significantly associated (Table 4).

For 90-day mortality, age, NIHSS at presentation, early neurological improvement, and symptomatic haemorrhage were significantly associated on univariate regression analysis. Multivariate analysis showed that age, NIHSS at presentation, and early neurological improvement remained predictors of 90-day mortality. TMT again was not a statistically significant predictor (Table 5).

Overall, 205 patients had CT carotid angiograms performed in our centre, which were available for analysis of PSM and SCM metrics. On multivariate logistic regression, PSM, SCM, VF, and SFA CSA and density were not associated with functional outcome or mortality. Normalized PSM and SCM metrics were also not associated with functional outcome or mortality (Table 4).

Outcome Model Development and Validation

As described in the Methods, using the entire study cohort, 2 models were created: the 24-h model and the pre-model. Within the 24-h model, a cut-off threshold of 0.53 generated the best balance of sensitivity and specificity in the training cohort (Fig. 4, 5). Patient demographics for the test cohorts (2020 and 2024 groups) are available in online supplementary Material 3. Multicollinearity among predictor variables was assessed during model development using variance inflation factors. All factors were below 5 (highest VIF = 1.41) indicating multicollinearity was not a concern. Interaction analysis found the combined effects of predictor variables did not improve overall model quality and were thus excluded from the final model. The results of the interaction analysis and variance inflation factors are available in online supplementary Materials 4.1 and 4.2.

The 24-h model performed well with an accuracy of 82.5%, an area under the curve (AUC) of 0.901, and a sensitivity and specificity of 79.5% and 87.5%, respectively, when tested on the 2020 cohort. Within the 2024 cohort, the model displayed similar results with an

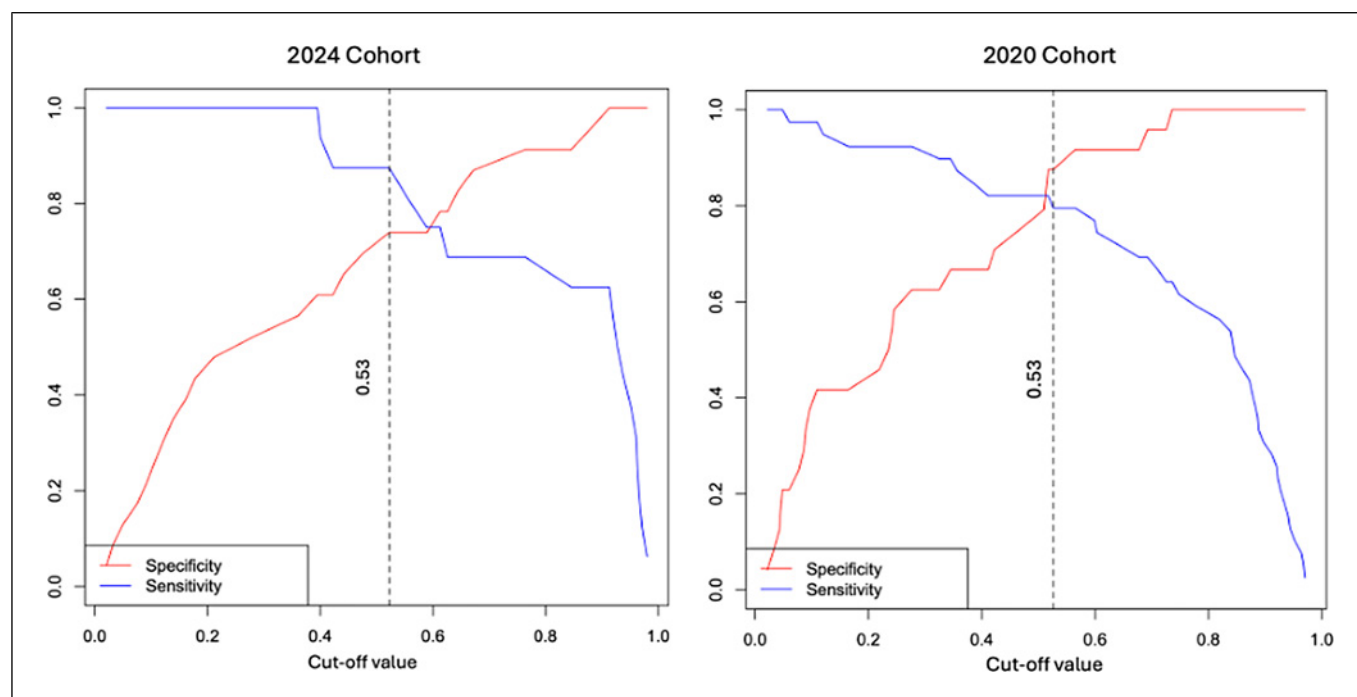


Fig. 6. Cut-off plot in predicting post-EVT outcomes in the test sets of patients using the 24-h model. The cut-off plots generated display the sensitivity curve in blue and specificity curve in red for the 2024 and 2020 test sets of patients. Cut-off values are displayed on the x-axis. The vertical dashed line indicates the cut-off value of 0.53 as

determined by the training set. The model performed well with an accuracy of 82.5% and a sensitivity and specificity of 79.5% and 87.5%, respectively, for the 2020 cohort. Within the 2024 cohort, the model displayed similar results with an accuracy of 79.5% and a sensitivity and specificity of 87.5% and 73.9%, respectively.

accuracy of 79.5%, an AUC of 0.899, and a sensitivity and specificity of 87.5% and 73.9%, respectively (Fig. 6, online suppl. Material 5). In the 2024 cohort, the model correctly predicted the 90-day outcome in 7/8 (87.5%) and 24/31 (77.4%) of the large and small core infarct groups, respectively (online suppl. Materials 6.1, 6.2).

However, when the pre-model was applied to both the 2020 and 2024 cohorts, it underperformed in comparison to the 24-h model. The pre-model displayed an accuracy of 68%, an AUC of 0.763, and a sensitivity and specificity of 82% and 46%, respectively, when tested on the 2020 cohort. When tested on the 2024 cohort, it showed an accuracy of 74.4%, an AUC of 0.88, and a sensitivity and specificity of 87.5% and 65.2%, respectively (online suppl. Materials 7.1–7.3).

Discussion

Evidence in the literature suggests frail patients with acute stroke have worse functional outcomes and higher rates of mortality at 90 days after EVT. However, the

factors associated with poorer outcomes in these patients are not fully clear [23]. Sarcopaenia is strongly associated with increased frailty, functional decline, and higher risk of mortality in a range of clinical settings [10]. It is therefore an important factor to consider in acute stroke [24]. The purpose of this study was to evaluate the prognostic utility of morphomic variables associated with sarcopaenia, such as TMT and neck muscle CSA, alongside other individual and clinical variables, to ultimately create a predictive model to support clinicians when discussing the expected level of recovery with patients and their relatives.

Although studies such as Lin et al. [13] have found that TMT is strongly associated with post-EVT functional outcomes at 90 days, we did not find TMT to be predictive of outcomes in our cohort. Similar conclusions were previously reached by Nozoe et al. [25] who agreed that although TMT is a valid and reliable measure of sarcopaenia risk, it does not correlate with functional 90-day outcomes. The reason why our findings align with Nozoe et al. [25], but do not align with Lin et al. [13], is uncertain. Differences in patient demographics

and analytical methods may have contributed, but further research is needed to explore these factors. Head and neck morphomic variables were also not found to have a statistically significant association with post-EVT outcomes in our cohort.

However, the 24-h model created without morphomic variables and instead using only clinical and imaging parameters was found to have excellent discriminatory power in predicting post-EVT outcomes. However, included variables, although easily acquired, are not fully available until 24 h after the procedure, thus limiting its use in patient selection in everyday practice. The authors acknowledge that biochemical markers of frailty such as albumin, haemoglobin, and glomerular filtration rate were not analysed. While inclusion of these variables and others would most probably increase the accuracy of the predictive model, it would likely be too complicated for use in daily practice. Additionally, the variables identified in this study including the NIHSS score, pre-stroke mRS, reperfusion grade, and symptomatic intracranial haemorrhage were also shown to be predictors of functional outcome in previous studies and used in other predictive models [26].

These models, however, were developed, tested, and validated using patient data from the original EVT trials, i.e., small core infarcts. Recent level 1 data have demonstrated that patients with large core infarcts may benefit from EVT, but accurate patient selection to prevent harm and predict functional outcome is challenging [6, 19]. We therefore sought to assess how our models performed in predicting 90-day outcome in a cohort including large core stroke (2024 cohort). The 24-h model using the same variables maintained excellent discrimination between positive and negative outcomes with an AUC of 0.899.

An ideal model would be able to predict outcome at presentation, thereby optimizing patient selection and preventing futile thrombectomies. To this end, using only pre-procedure variables, the pre-model was created. However, the pre-model underperformed in comparison to the 24-h model in both the 2020 and 2024 cohorts with accuracies of 68% and 74.4%, respectively. Although potentially a useful adjunct in the decision-making process, future work is required to identify additional baseline clinical and imaging variables to improve model performance. The availability of data on biomarkers such as vascular collateral status and data on co-morbidities such as diabetes mellitus, atrial fibrillation, and hypertension would likely have strengthened the pre-model as evidenced by previous studies [26–28].

This study has a number of limitations. Firstly, a comparably small patient cohort was included in the 3 year training set and external validation of the predictive model was not conducted. Although 2 separate internal cohorts were used for validation, an external set of patients is required to fully assess the robustness. Secondly, as previously mentioned, complete data on patient co-morbidities and clinical parameters were unavailable. Co-morbidities such as diabetes, ischaemic heart disease, and chronic kidney disease were incompletely recorded for a large proportion of patients. Body mass index was also unavailable prompting the use of normalized muscle and fat parameters, which may lead to variability and bias. Unavailability of these data was due to a combination of factors including external patient transfer, urgency of presentation, and the use of a paper-based system in our institution. Additionally, our patient cohort consisted mainly of older patients (median age 76) with a low baseline mRS with limited numbers of young patients with high baseline disability. Although this may lead to bias, this population cohort is not unexpected given the guidelines for EVT and is representative of stroke in an Irish population. Finally, our cohort had a very small proportion of patients who had had a prior stroke (<3%) and thus could not be analysed separately during model development.

Conclusion

Although AM did not improve the 90-day outcome prediction following EVT, the 24-h model presented herein shows high accuracy in outcome prediction, including in those presenting with large core strokes. Additionally, this model can be easily created and replicated by centres worldwide without the need for additional resources or expensive software. Therefore, the model, despite its limited ability in aiding patient selection, may be easily implemented in centres across the globe to support clinicians when discussing the expected level of recovery with patients and their relatives.

Statement of Ethics

This study protocol was reviewed and approved by the Clinical Research Ethics Committee (CREC), ECM 6 (c) 10/09/2024. Due to the retrospective and non-interventional nature of this study, the requirement of patient consent was waived by the Clinical Research Ethics Committee.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

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Author Contributions

C.M.: conceptualization, methodology, and writing – original draft; S.S.: methodology, formal analysis, and writing – review and editing; A.O.'B.: data curation and writing – original draft; E.K.:

visualization and writing – review and editing; P.O.'R.: investigation and data curation; M.M.M.: project administration; R.K.: resources and data curation; A.H.: resources and investigation; N.F.: resources, writing – review and editing, and validation; D.J.R.: conceptualization, supervision, writing – review and editing, and validation.

Data Availability Statement

All data generated or analysed during this study are included in this article and its online supplementary material files. Further enquiries can be directed to the corresponding author.

References

- 1 Saver JL, Goyal M, van der Lugt A, Menon BK, Majoie CBLM, Dippel DW, et al. Time to treatment with endovascular thrombectomy and outcomes from ischemic stroke: a meta-analysis. *JAMA*. 2016;316(12):1279–88. <https://doi.org/10.1001/jama.2016.13647>
- 2 Menon BK, Campbell BCV, Levi C, Goyal M. Role of imaging in current acute ischemic stroke workflow for endovascular therapy. *Stroke*. 2015;46(6):1453–61. <https://doi.org/10.1161/STROKEAHA.115.009160>
- 3 Powers WJ, Derdeyn CP, Biller J, Coffey CS, Hoh BL, Jauch EC, et al. American heart Association/American Stroke Association focused Update of the 2013 guidelines for the early management of patients with acute ischemic stroke regarding endovascular treatment. *Stroke*. 2015;46(10):3020–35. <https://doi.org/10.1161/STR.0000000000000074>
- 4 Berkhemer OA, Fransen PSS, Beumer D, van den Berg LA, Lingsma HF, Yoo AJ, et al. A randomized trial of intraarterial treatment for acute ischemic stroke. *N Engl J Med*. 2015;372(1):11–20. <https://doi.org/10.1056/NEJMoa1411587>
- 5 Bracard S, Ducrocq X, Mas JL, Soudant M, Oppenheim C, Moulin T, et al. Mechanical thrombectomy after intravenous alteplase versus alteplase alone after stroke (THRACE): a randomised controlled trial. *Lancet Neurol*. 2016;15(11):1138–47. [https://doi.org/10.1016/S1474-4422\(16\)30177-6](https://doi.org/10.1016/S1474-4422(16)30177-6)
- 6 Sarraj A, Hassan AE, Abraham MG, Ortega-Gutierrez S, Kasner SE, Hussain MS, et al. Trial of endovascular thrombectomy for large ischemic strokes. *N Engl J Med*. 2023;388(14):1259–71. <https://doi.org/10.1056/NEJMoa2214403>
- 7 Yoo AJ, Berkhemer OA, Fransen PSS, van den Berg LA, Beumer D, Lingsma HF, et al. Effect of baseline Alberta stroke Program Early CT Score on safety and efficacy of intra-arterial treatment: a subgroup analysis of a randomised phase 3 trial (MR CLEAN). *Lancet Neurol*. 2016;15(7):685–94. [https://doi.org/10.1016/S1474-4422\(16\)00124-1](https://doi.org/10.1016/S1474-4422(16)00124-1)
- 8 Berkhemer OA, Jansen IGH, Beumer D, Fransen PSS, Van Den Berg LA, Yoo AJ, et al. Collateral status on Baseline computed Tomographic angiography and intra-arterial treatment effect in patients with proximal anterior circulation stroke. *Stroke*. 2016;47(3):768–76. <https://doi.org/10.1161/STROKEAHA.115.011788>
- 9 Dodds R, Sayer AA. Sarcopenia and frailty: new challenges for clinical practice. *Clin Med*. 2016;16(5):455–8. <https://doi.org/10.7861/clinmedicine.16-5-455>
- 10 Matsushita T, Nishioka S, Taguchi S, Yamanouchi A, Okazaki Y, Oishi K, et al. Effect of improvement in sarcopenia on functional and discharge outcomes in stroke rehabilitation patients. *Nutrients*. 2021;13(7):2192. <https://doi.org/10.3390/nu13072192>
- 11 Derstine BA, Holcombe SA, Goulson RL, Ross BE, Wang NC, Sullivan JA, et al. Quantifying sarcopenia reference values using lumbar and thoracic muscle areas in a healthy population. *J Nutr Health Aging*. 2018;22(1):180–5. <https://doi.org/10.1007/s12603-017-0983-3>
- 12 O'Regan PW, O'Regan JA, Maher MM, Ryan DJ. The emerging role and clinical applications of morphomics in diagnostic imaging. *Can Assoc Radiol J*. 2024;75(4):793–804. <https://doi.org/10.1177/08465371241242763>
- 13 Lin Y-H, Chung C-T, Chen C-H, Cheng C-J, Chu H-J, Chen K-W, et al. Association of temporalis muscle thickness with functional outcomes in patients undergoing endovascular thrombectomy. *Eur J Radiol*. 2023;163:110808. <https://doi.org/10.1016/j.ejrad.2023.110808>
- 14 Swartz JE, Pothen AJ, Wegner I, Smid EJ, Swart KMA, de Bree R, et al. Feasibility of using head and neck CT imaging to assess skeletal muscle mass in head and neck cancer patients. *Oral Oncol*. 2016;62:28–33. <https://doi.org/10.1016/j.oraloncology.2016.09.006>
- 15 Brugnara G, Neuberger U, Mahmutoglu MA, Foltyn M, Herweh C, Nagel S, et al. Multimodal predictive modeling of endovascular treatment outcome for acute ischemic stroke using machine-learning. *Stroke*. 2020;51(12):3541–51. <https://doi.org/10.1161/STROKEAHA.120.030287>
- 16 Clement B, Aymeric R, Jean-Christophe G, Edouard B, Serge T, Frederic C, et al. Predictive models of clinical outcome of endovascular treatment for anterior circulation stroke using machine learning. *J Neurosci Methods*. 2025;416:110376. <https://doi.org/10.1016/j.jneumeth.2025.110376>
- 17 Campbell BCV, Mitchell PJ, Kleinig TJ, Dewey HM, Churilov L, Yassi N, et al. Endovascular therapy for ischemic stroke with perfusion-imaging selection. *N Engl J Med*. 2015;372(11):1009–18. <https://doi.org/10.1056/NEJMoa1414792>
- 18 Albers GW, Marks MP, Kemp S, Christensen S, Tsai JP, Ortega-Gutierrez S, et al. Thrombectomy for stroke at 6 to 16 hours with selection by perfusion imaging. *N Engl J Med*. 2018;378(8):708–18. <https://doi.org/10.1056/NEJMoa1713973>
- 19 Huo X, Ma G, Tong X, Zhang X, Pan Y, Nguyen TN, et al. Trial of endovascular therapy for acute ischemic stroke with large infarct. *N Engl J Med*. 2023;388(14):1272–83. <https://doi.org/10.1056/NEJMoa2213379>
- 20 Kobeissi H, Ghozy S, Bilgin C, Kadirvel R, Kallmes DF. Early neurological improvement as a predictor of outcomes after endovascular thrombectomy for stroke: a systematic review and meta-analysis. *J Neurointerv Surg*. 2023;15(6):547–51. <https://doi.org/10.1136/neurintsurg-2022-019008>
- 21 Mullie L, Afilalo J. CoreSlicer: a web toolkit for analytic morphomics. *BMC Med Imaging*. 2019;19(1):15. <https://doi.org/10.1186/S12880-019-0316-6>

- 22 Steindl A, Leitner J, Schwarz M, Nenning KH, Asenbaum U, Mayer S, et al. Sarcopenia in neurological patients: standard values for temporal muscle thickness and muscle strength evaluation. *J Clin Med*. 2020;9(5):1272. <https://doi.org/10.3390/jcm9051272>
- 23 Dabhi N, Kumar J, Kellogg RT, Park MS. Mechanical thrombectomy for treatment of acute ischemic stroke in frail patients: a systematic review of the literature. *J Neurointerv Surg*. 2024;16(8):788–93. <https://doi.org/10.1136/jnis-2023-020476>
- 24 Nozoe M, Kanai M, Kubo H, Yamamoto M, Shimada S, Mase K. Prestroke sarcopenia and functional outcomes in elderly patients who have had an acute stroke: a prospective cohort study. *Nutrition*. 2019;66:44–7. <https://doi.org/10.1016/j.nut.2019.04.011>
- 25 Nozoe M, Kubo H, Kanai M, Yamamoto M, Okakita M, Suzuki H, et al. Reliability and validity of measuring temporal muscle thickness as the evaluation of sarcopenia risk and the relationship with functional outcome in older patients with acute stroke. *Clin Neurol Neurosurg*. 2021;201:106444. <https://doi.org/10.1016/j.clineuro.2020.106444>
- 26 Chalos V, Venema E, Mulder MJHL, Roozenbeek B, Steyerberg EW, Wermer MJH, et al. Development and validation of a postprocedural model to predict outcome after endovascular treatment for ischemic stroke. *JAMA Neurol*. 2023;80(9):940–8. <https://doi.org/10.1001/jamaneurol.2023.2392>
- 27 Ravindran AV, Killingsworth MC, Bhaskar S. Cerebral collaterals in acute ischaemia: implications for acute ischaemic stroke patients receiving reperfusion therapy. *Eur J Neurosci*. 2021;53(4):1238–61. <https://doi.org/10.1111/ejn.14955>
- 28 Flint AC, Cullen SP, Faigeles BS, Rao VA. Predicting long-term outcome after endovascular stroke treatment: the totaled health risks in vascular events score. *AJNR Am J Neuroradiol*. 2010;31(7):1192–6. <https://doi.org/10.3174/ajnr.A2050>