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Impact of imaging biomarkers from body composition analysis on outcome of endovascularly treated acute ischemic stroke patients

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ABSTRACT

Background We investigate the association of imaging biomarkers extracted from fully automated body composition analysis (BCA) of computed tomography (CT) angiography images of endovascularly treated acute ischemic stroke (AIS) patients regarding angiographic and clinical outcome.

Methods Retrospective analysis of AIS patients treated with mechanical thrombectomy (MT) at three tertiary care-centers between March 2019–January 2022. Baseline demographics, angiographic outcome and clinical outcome evaluated by the modified Rankin Scale (mRS) at discharge were noted. Multiple tissues, such as muscle, bone, and adipose tissue were acquired with a deep-learning-based, fully automated BCA from CT images of the supra-aortic angiography.

Results A total of 290 stroke patients who underwent MT due to cerebral vessel occlusion in the anterior circulation were included in the study. In the univariate analyses, among all BCA markers, only the lower sarcopenia marker was associated with a poor outcome (P=0.007). It remained an independent predictor for an unfavorable outcome in a logistic regression analysis (OR 0.6, 95% CI 0.3 to 0.9, P=0.044). Fat index (total adipose tissue/bone) and myosteatosis index (inter- and intramuscular adipose tissue/total adipose tissue*100) did not affect clinical outcomes.

Conclusion Acute ischemic stroke patients with a lower sarcopenia marker are at risk for an unfavorable outcome. Imaging biomarkers extracted from BCA can be easily obtained from existing CT images, making it readily available at the beginning of treatment. However, further research is necessary to determine whether sarcopenia provides additional value beyond established outcome predictors. Understanding its role could lead to optimized, individualized treatment plans for post-stroke patients, potentially improving recovery outcomes.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Body composition analysis (BCA), which assesses fat, muscle, and bone mass, is a recognized biomarker with significant diagnostic and prognostic value in cardiovascular, oncological, and orthopedic diseases. A low skeletal muscle index (ie, sarcopenia), known to be a detrimental prognostic factor in patients with solid tumors, has recently been associated with unfavorable outcomes in patients with mild acute ischemic stroke and transient ischemic attack, including lower rates of discharge to home and poorer dysphagia status.

WHAT THIS STUDY ADDS

⇒ BCA can be easily obtained from CT angiography images and could be available right at the start of treatment. Among all BCA markers, only the lower sarcopenia marker was associated with a poor outcome (P=0.007) and remained an independent predictor for an unfavorable outcome in a logistic regression analysis (OR 0.6, 95% CI 0.3 to 0.9, P=0.044).

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Patients with a lower sarcopenia marker may require faster or better post-interventional care to ensure they are extubated quickly and receive therapeutic approaches for dysphagia, as they may have weakness of the swallowing-related muscles which may lead to impaired oral intake and aspiration pneumonia.

BACKGROUND

Mechanical thrombectomy (MT), in combination with intravenous thrombolysis, is the gold standard treatment for acute ischemic stroke (AIS) caused by proximal large vessel occlusion (LVO) in the anterior circulation.[1 2]

Stroke-related mortality is significant, with 7.08 million deaths recorded globally, of which 3.48 million were attributed to ischemic stroke. In 2020, the global prevalence of all stroke types was 89.13 million cases, with AIS alone affecting 68.16 million individuals.[3] Given the prevalence and severity of AIS, identifying prognostic biomarkers for both clinical and angiographic outcomes is crucial. Studies have identified prognostic markers in acute stroke patients, including the duration from symptom onset to endovascular reperfusion, transfer to a specialized stroke center, patient age, reperfusion rate measured by the modified treatment in cerebral infarction (mTICI) score, extent of

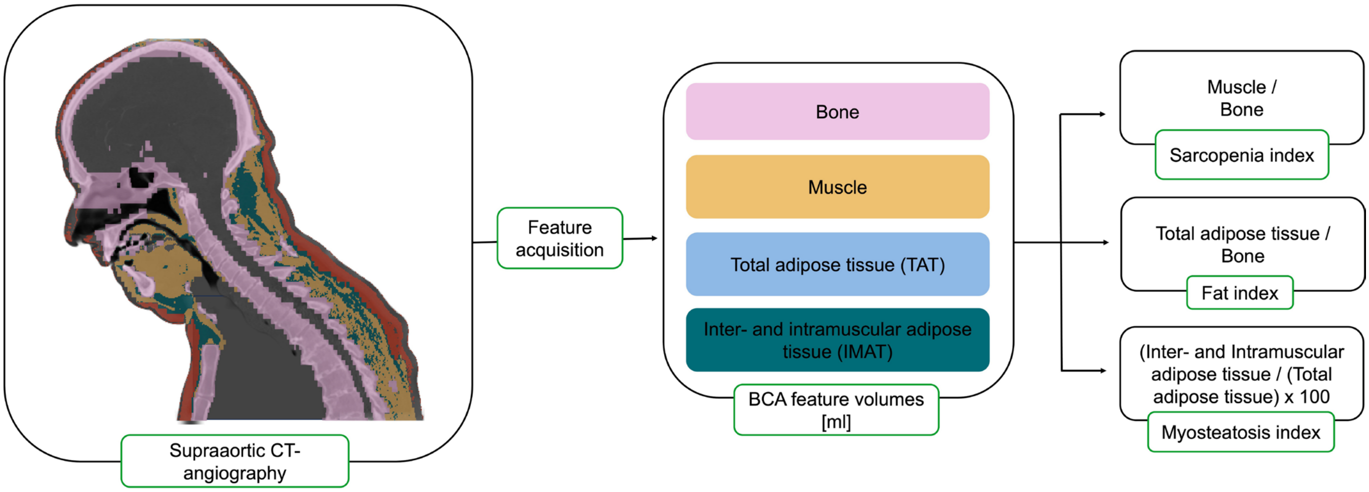

Figure 1 Feature extraction for body composition analysis.

infarction measured by the Alberta Stroke Program early CT score (ASPECTS) and the severity of neurological symptoms measured by the National Institutes of Health Stroke Scale (NIHSS), among others.[4] In addition, further studies have explored the correlation between body mass index (BMI) and mortality, revealing BMI's limitations in accurately assessing body composition due to physical anomalies and highlighting the need for alternative methods like body composition analysis (BCA).[5 6] BCA, which considers fat, muscle, and bone mass, is a recognized biomarker offering substantial diagnostic and prognostic value in cardiovascular, oncological, and orthopedic diseases.[6–8] Low skeletal muscle index, as a detrimental prognostic factor, has been studied in patients with solid tumors including bladder cancer and ovarian cancer.[8–10]

Sarcopenia, a progressive skeletal muscle disorder, is linked to higher risks of falls, fractures, physical disability, and mortality. Diagnosis involves identifying low muscle mass and strength with reduced physical performance using tools like grip strength tests, dual energy x-ray absorptiometry (DEXA) scans for imaging, and assessments such as gait speed tests.[11]

Moreover, recent studies found that sarcopenia is associated with unfavorable outcomes in patients with mild AIS and transient ischemic attack (TIA), including lower rates of discharge to home and poor dysphagia status.[12–15] Dysphagia following stroke is a prevalent complication that is often associated with conditions like pneumonia and malnutrition.[15] These findings highlight the need for further research on interventions targeting sarcopenia in stroke patients.

In the following, we assess biomarkers obtained from fully automated BCA and derived from existing image acquisition (computed tomography (CT) angiography images) unrelated to cerebral ischemia. We then analyze the relationship between these imaging biomarkers and angiographic and clinical outcomes of AIS patients undergoing endovascular treatment.

METHODS

Patient cohort

We conducted a retrospective study of AIS patients due to LVO or medium vessel occlusion in the anterior circulation who were treated with MT at three tertiary care centers in Germany between March 2019 and January 2022. All patients receiving MT due to vessel occlusions including distal internal cerebral artery (ICA), middle cerebral artery (M1, M2 and M3) and anterior cerebral artery (A1 and A2) were identified. Subsequently, only patients with a valid CT angiography and ultimately prior endovascular treatment were considered. In addition to the imaging data, baseline characteristics of MT including technical features, complications, angiographic, and clinical outcomes were noted. The etiology of the occlusion was based on the Trial of ORG 10172 in Acute Stroke Treatment (TOAST) classification. There were no limitations on procedural characteristics, including the use of different thrombectomy techniques and intra-arterial thrombolysis, which were left to the attending neuroradiologist's discretion. Endovascular treatment was performed with approved MT devices, using stent retrievers or large-bore aspiration catheters or a combination of both. Reperfusion was measured by the thrombolysis in cerebral infarction (TICI) scale score. The clinical efficacy outcome was the rate of functional independence as measured by the modified Rankin Scale (mRS) and defined as 0–2 at discharge. All NIHSS and mRS grades were assessed by a consultant neurologist. Postinterventional symptomatic intracranial hemorrhage (sICH) was graded according to the European Cooperative Acute Stroke Study criteria.[16] According to the guidelines of the respective local ethics committees, ethical approval was given when necessary for this anonymous retrospective study, which was conducted in accordance to the Declaration of Helsinki. Each patient's consent for treatment was obtained according to the individual institutional guidelines. Due to the retrospective nature of the study additional informed consent was deemed unnecessary.

Body composition analysis

In contrast to a previous publication, the pre-interventional CT head scans were not evaluated; instead, only CT scans of the supra-aortic angiography were utilized for a BCA.[17] In total, 290 CT scans of the supra-aortic angiography were extracted for BCA. A pre-trained network published by Koitka *et al*., which uses a multi-resolution 3D U-Net architectural variant enabling automatic tissue segmentation in CT images with high accuracy.[18] The body composition features were extracted by a combination of modern segmentation mechanisms and Hounsfield Unit (HU)-thresholding (eg, adipose tissue: −190–−30 HU).[18] The whole scan volume under the exclusion of the limbs was investigated and the following raw features were extracted as volumes (ml):

Table 1 Baseline characteristics and univariate analysis of unfavorable outcome in patients with anterior circulation stroke with available mRS at discharge

Parameter	Value (N=290)
Demographics	
Age (years)	78.0 (66.3–85.0)
Sex (male)	119 (41.0%)
Medical history	
Arterial hypertension	229 (79.0%)
Atrial fibrillation	138 (47.6%)
Diabetes	68 (23.4%)
Dyslipidemia	116 (40.0%)
Smoking	87 (30.0%)
Stroke characteristics	
Pre-stroke mRS (0–2)	270 (93.1%)
Baseline NIHSS	10 (10–19)
NIHSS discharge	7 (2-18)
mRS discharge	4 (2-5)
Baseline ASPECTS	10 (9–10)
ASPECTS 24 hours	8 (5-9)
Wake-up stroke	62 (21.4%)
Intravenous thrombolysis	160 (55.2%)
Onset to groin (min)	145 (111–207)
Groin to recanalization (min)	43.5 (27–69.5)
Site of occlusion	
Distal ICA	77 (26.6%)
MCA M1	124 (42.8%)
MCA M2	69 (23.8%)
MCA M3	9 (3.1%)
A1	3 (1.0%)
A2	2 (0.7%)
Multiple locations AC	6 (2.1%)
TOAST	
Large Artery Sclerosis	85 (29.3%)
Cardioembolic	140 (48.3%)
Small vessel occlusion	1 (0.3%)
Other/undetermined	64 (22.1%)
Tandem occlusion	25 (8.6%)
Final TICI	
2b-3	259 (89.3%)
2 c-3	186 (64.1%)
3	156 (53.8%)
Number of maneuvers	2 (1-3)
Number of stent retriever maneuvers	1 (1-2)
First-pass technique	
Aspiration	80 (27.6%)
Stent retriever+aspiration	202 (69.7%)
Missing data	8 (2.8%)
Overall hemorrhagic complications	39 (13.4%)
SAH	25 (8.6%)
sICH	14 (4.8%)

Continued

Table 1 Continued

Parameter	Value (N=290)
Outcome	
mRS discharge (0–2)	84/275 (30.5%)
mRS 6	82/275 (29.8%)
Missing data	15/290 (5.2%)
BCA Parameter	
Bone sum	940 (795–1130)
Muscle sum	1902 (1520–2454)
TAT sum	2065 (1395–3082)
IMAT sum	915 (633–1181)
Muscle/bone sum	2.1 (1.7–2.5)
TAT/bone sum	2.2 (1.6–3.0)
IMAT/TAT sum	43.3 (36.6–51.9)

	Favorable outcome, mRS 0–2 (N=84)	Unfavorable outcome, mRS 3–6 (N=191)	P value
Demographics			
Age (years)	71.0 (60.8–83.0)	79.0 (70.0–85.0)	0.006
Sex (male)	36 (42.9%)	74 (38.7%)	0.521
Medical history			
Arterial hypertension	61 (72.6%)	158 (82.7%)	0.055
Atrial fibrillation	38 (45.2%)	94 (49.2%)	0.543
Diabetes	16 (19.0%)	50 (26.2%)	0.202
Dyslipidemia	37 (44.0%)	77 (40.3%)	0.563
Smoking	26 (31.0%)	61 (31.9%)	0.872
Stroke characteristics			
mRS pre-treatment	0 (0–0)	1 (0–2)	<0.001
Baseline NIHSS	11 (6.8–15.3)	15 (12–20)	<0.001
NIHSS discharge	1 (0–2)	13.5 (7-42)	<0.001
mRS discharge	1 (0.8–2)	5 (4-6)	<0.001
Baseline ASPECTS	10 (9–10)	10 (8–10)	0.030
ASPECTS 24 hours	9 (8-10)	7 (4-8)	<0.001
Wake-up stroke	15 (17.9%)	44 (23.0%)	0.335
Intravenous thrombolysis	53 (63.1%)	100 (52.4%)	0.099
Onset to groin (min)	140 (115–230)	140 (107–203)	0.771
Groin to recanalization (min)	38.0 (25.5–49.5)	52 (32–87)	<0.001
Site of occlusion			
Distal ICA	14 (16.7%)	61 (31.9%)	0.009
MCA M1	39 (46.4%)	76 (39.8%)	0.304
MCA M2	26 (31.0%)	40 (20.9%)	0.073
MCA M3	4 (4.8%)	5 (2.6%)	0.462
A1	0 (0%)	3 (1.6%)	0.555
A2	1 (1.2%)	1 (0.5%)	0.518
Multiple locations	0 (0%)	5 (2.6%)	0.327
TOAST			
Large artery sclerosis	24 (28.6%)	54 (28.3%)	0.960
Cardioembolic	30 (35.7%)	94 (49.2%)	0.670
Small vessel occlusion	1 (1.2%)	0 (0%)	0.305
Other/undetermined	20 (23.8%)	43 (22.5%)	0.129
Tandem occlusion	11 (13.1%)	13 (6.8%)	0.089

Continued

Table 1 Continued

	Favorable outcome, mRS 0–2 (N=84)	Unfavorable outcome, mRS 3–6 (N=191)	P value
Final TICI			
2b-3	81 (96.4%)	164 (85.9%)	0.011
2 c-3	65 (77.4%)	109 (57.1%)	0.001
3	56 (66.7%)	89 (46.6%)	0.002
Number of maneuvers	1 (1-2)	2 (1-3)	<0.001
Number of stent retriever maneuvers	1 (0–2)	1 (1-2)	0.002
First-pass technique			0.358
Aspiration	26/81 (32.1%)	50/188 (26.6%)	
Stent retriever+aspiration	55/81 (67.9%)	138/188 (73.4%)	
Missing data	3/84 (3.6%)	3/191 (1.6%)	
Overall complications	6 (7.1%)	32 (16.8%)	0.033
SAH	6 (7.1%)	18 (9.4%)	0.537
sICH	0 (0%)	14 (7.3%)	0.007
BCA parameter			
Bone sum	940 (795–1104)	944 (807–1140)	0.681
Muscle sum	2061 (1628–2756)	188 (1528–2377)	0.169
TAT sum	2007 (1277–3176)	2166 (1471–3121)	0.699
IMAT sum	929 (604–1151)	903 (672–1212)	0.514
Muscle/bone sum	2.2 (1.8–2.5)	2.0 (1.7–2.4)	0.007
TAT/bone sum	2.2 (1.6–3.3)	2.2 (1.6–3.1)	0.726
IMAT/TAT sum	44.6 (36.4–52.1)	42.9 (36.7–51.4)	0.799

Data are presented as numbers and percentages or as medians with IQR.
AC, anterior circulation; ASPECTS, Alberta Stroke Program Early CT Score; h, hours; ICA, internal carotid artery; IMAT, intra-/intermuscular adipose tissue; MCA, middle cerebral artery; min, minutes; mRS, modified Rankin Scale; NIHSS, National Institutes of Health Stroke Scale; SAH, subarachnoid hemorrhage; sICH, symptomatic intracranial hemorrhage; TAT, total adipose tissue; TICI, thrombolysis in cerebral infarction; TOAST, Trial of ORG 10172 in Acute Stroke Treatment .

bone, muscle, subcutaneous adipose tissue (SAT), and intra-/intermuscular adipose tissue (IMAT). The addition of SAT and IMAT results in total adipose tissue (TAT). All investigated indices in this study are defined by dividing selected raw BCA features by the bone volume (sarcopenia index and fat index) or total adipose tissue volume x 100 (myosteatosis index, %) for normalization respectively. The various indices are shown in figure 1.

Statistical analysis

Categorical variables were presented as numbers and means and compared using Chi-squared and Fisher's exact tests where appropriate. Ordinal or continuous variables were presented as medians with interquartile ranges (IQRs) and compared using the Mann-Whitney U test. Pearson correlation was used to analyze the correlation between factors. Factors predictive of unfavorable outcome (mRS 3–6) or TICI 2 c-3 in the univariate analysis (P<0.05) were considered for inclusion in the multivariate analysis. Due to the high collinearity of certain factors with each other, factors were selected for inclusion in the multivariate analysis using the variance inflation factor. These preselected variables were entered into a binary logistic stepwise regression model to identify independent factors of the outcome measures. Receiver operating characteristic (ROC) curves were used to determine the sensitivity and specificity of the parameters for predicting each outcome measure. The Youden index was used to determine optimal cut-off values. All calculations were performed using SPSS software (version 25, IBM SPSS Statistics for Windows, Armonk, NY, USA). A P-value <0.05 was considered statistically significant.

RESULTS

Baseline characteristics and outcome

Patient baseline characteristics and univariate analysis of unfavorable outcome are detailed in table 1.

The median age was 78 years (IQR 66.3–85), with 119/290 patients (41.0%) being male. The most frequent site of vessel occlusion was the M1 segment (124/290 patients; 42.8%), followed by the distal ICA (77/290 patients; 26.6%) and the M2 segment (69/290 patients; 23.8%). Tandem occlusion was observed in 25/290 patients (8.6%). Intravenous thrombolysis (IVT) was administered to 160/290 patients (55.2%). Median baseline NIHSS and ASPECTS scores were 10 (IQR 10–19) and 10 (IQR 9–10), respectively. The median time from onset to groin puncture was 145 minutes (IQR 111–207), and the median time from groin puncture to final reperfusion was 43.5 minutes (IQR 27–69.5). Sixty-two patients (21.4%) presented with wake-up strokes. The rate of pretreatment functional independence (mRS 0–2) was 93.1% (270/290 patients). Cardioembolic causes were the most common etiology for vessel occlusion, found in 140/290 patients (48.3%), followed by large artery atherosclerosis (85/290 patients; 29.3%).

The most common first-pass technique was a combined approach using aspiration and stent-retriever thrombectomy,

Table 2 ROC analysis and bivariate logistic regression analysis of selected parameters to predict unfavorable outcome at discharge (mRS 3–6)

				Multivariate analysis excluding patient age		Multivariate analysis including patient age	
Parameter	AUC (95% CI)	Cut-off value	P	OR (95% CI)	P value	OR (95% CI)	P value
Age (years)	0.596 (0.521 to 0.672)	78	0.013			1.03 (1.0 to 1.06)	0.027
Baseline NIHSS	0.696 (0.626 to 0.766)	12	<0.001	1.10 (1.05 to 1.15)	<0.001	1.10 (1.05 to 1.15)	<0.001
Groin to recanalization (min)	0.647 (0.578 to 0.716)	35	<0.001	1.02 (1.01 to 1.03)	0.002	1.02 (1.01 to 1.03)	0.002
Distal ICA	0.576 (0.502 to 0.649)	–	0.052	1.4 (0.7 to 3.0)	0.344	1.5 (0.7 to 3.2)	0.297
TICI 0-2b	0.588 (0.515 to 0.661)	–	0.023	1.9 (0.9 to 3.7)	0.071	2.0 (1.1 to 4.1)	0.047
sICH	0.540 (0.466 to 0.614)	–	0.306	4.5 (0.7 to 34.7)	0.998	4.4 (0.6 to 31.5)	0.998
Muscle/bone sum	0.392 (0.317 to 0.467)	2.0	0.006	0.6 (0.3 to 0.9)	0.044	0.9 (0.5 to 1.5)	0.512

Goodness-of-fit of the regression analysis was assessed using the Hosmer-Lemeshow-Test, indicating a good model fit, $\chi^2(8) = 4.7$, P=0.788 and $\chi^2(8) = 5.9$, P=0.661, respectively.
AUC, area under the curve; ICA, internal carotid artery; min, minutes; NIHSS, National Institutes of Health Stroke Scale; OR, odds ratio; ROC, receiver operating characteristic; sICH, symptomatic intracranial hemorrhage; TICI, thrombolysis in cerebral infarction.

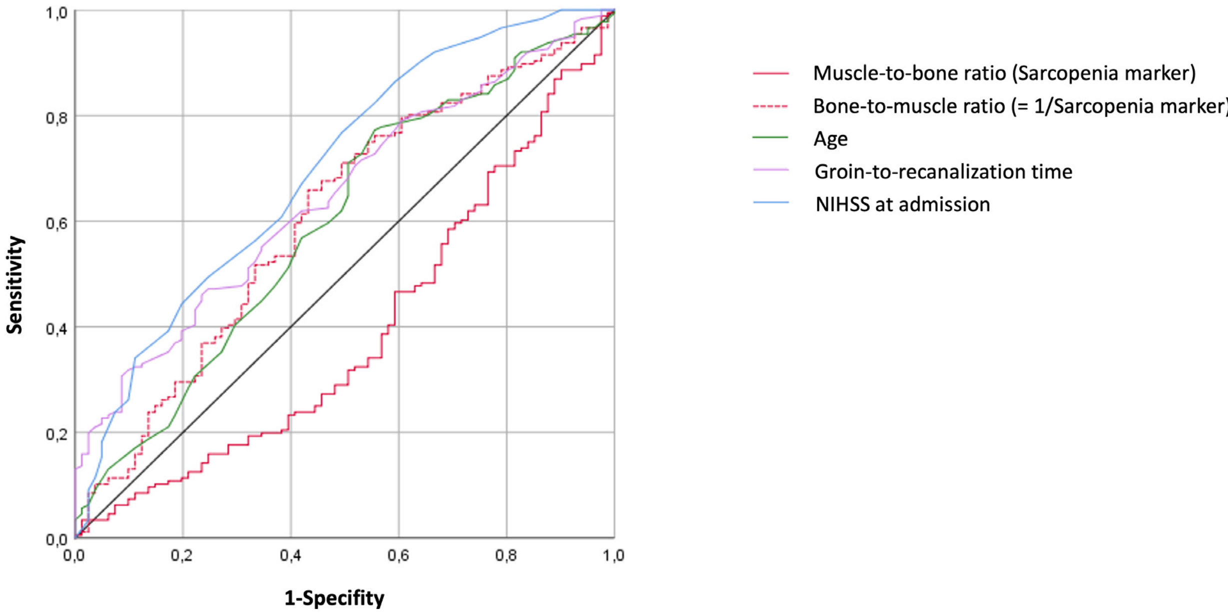

Figure 2 ROC (receiver operating characteristic) curves show the accuracy of selected parameters to predict unfavorable outcome.

applied in 69.7% of patients (202/290), followed by aspiration thrombectomy alone in 27.6% of patients (80/290). In eight patients, data regarding the first-pass technique was missing (2.8%). Successful reperfusion was achieved in 259/290 patients (89.3%), with 156/290 patients (53.8%) achieving complete reperfusion. The rate of procedure-related complications was 13.4% (39/290). Subarachnoid hemorrhage (SAH) occurred in 25/290 patients (8.6%), and symptomatic intracerebral hemorrhage (sICH) occurred in 14/290 patients (4.8%). Functional outcome data were available for 275 patients. Of these, functional independence (mRS 0–2) at discharge was achieved by 84 patients (30.5%). The mortality rate at discharge was 29.8% (82/275).

Univariate and multivariate analyses

For 275 patients with available outcome data, we performed univariate and multivariate analyses to identify predictors for an unfavorable outcome (mRS 3–6) at discharge.

In the univariate analysis, factors potentially associated with an unfavorable outcome were: higher age (P=0.006), higher pre-stroke mRS (0–2) (P<0.001), higher baseline NIHSS (P<0.001) or at discharge (P<0.001), higher mRS at discharge (P<0.001), lower baseline ASPECTS (P=0.030) or after 24 hours (P<0.001), higher interval time from groin to recanalization (P<0.001), occlusion site in the ICA (P=0.009), lower rates of final TICI 2b-3 (P=0.011), TICI 2c-3 (P=0.001), or TICI 3 (P=0.002), higher number of overall maneuvers (P<0.001) or stent retriever maneuvers (P=0.002), higher rates of overall complications (P=0.033) or sICH (P=0.007), and lower sarcopenia marker (P=0.007).

After multicollinearity testing, baseline NIHSS, interval from groin to recanalization, occlusion site in the ICA, TICI 0-2b, sICH and the sarcopenia marker muscle/bone were entered into a bivariate logistic regression analysis. Baseline NIHSS (OR 1.10, 95% CI 1.05 to 1.15; P<0.001), the interval from groin to recanalization (OR 1.02, 95% CI 1.01 to 1.03; P=0.002), and the sarcopenia marker muscle/bone (OR 0.6, 95% CI 0.3 to 0.9; P=0.044) remained as independent predictors for an unfavorable outcome. If patient age was additionally included in the multivariate analysis, the sarcopenia marker muscle/bone was no longer independently associated with outcome (OR 0.9, 95% CI 0.5 to 1.5; P=0.512). However, TICI 0-2b became independently associated with poor outcome (OR 2.0, 95% CI 1.1 to 4.1; P=0.047).

ROC analysis showed a high accuracy of the sarcopenia marker muscle/bone to predict unfavorable outcome with an AUC of 0.392 (95% CI 0.317 to 0.467, P=0.006), which translates to an AUC of 0.608 (95% CI 0.533 to 0.683) for the inverse value ratio of bone-to-muscle (table 2).

Baseline NIHSS had the highest accuracy to predict unfavorable outcome (AUC: 0.696, 95% CI 0.626 to 0.766; P<0.001), followed by the interval from groin to recanalization (AUC: 0.647, 95% CI 0.578 to 0.716; P<0.001), while age had a lower accuracy than the sarcopenia marker (AUC: 0.596, 95% CI 0.521 to 0.672; P=0.013) (figure 2).

Fat index (TAT/bone) and myosteatosis index (IMAT/TAT*100) did not affect clinical outcomes. Moreover, there were no associations between the BCA markers and angiographic outcomes (TICI 2c-3). The results are depicted in online supplemental tables 1 and 2.

DISCUSSION

Sarcopenia is a form of muscular degeneration defined by a loss of skeletal muscle mass, quality, and strength that is associated with an increased risk for death in elderly patients.[19 20] The causes of sarcopenia include reduced hormone levels, a decrease in neuromuscular junctions, heightened inflammation, lower levels of physical activity, and poor nutrition, factors which are also observed in patients post-stroke.[21]

The findings of this study underscore the significant impact of sarcopenia on the functional outcomes of stroke patients undergoing MT and are consistent with findings from existing studies.[14 22] In these studies, both the sarcopenia status before the stroke and sarcopenia caused by the stroke itself negatively affect clinical outcomes. The term "stroke-related sarcopenia" refers to the onset or worsening of sarcopenia due to stroke.[23] The prevalence of sarcopenia in stroke patients in acute hospitals is reported to be 8.5–33.8%.[14 24] Stroke patients are at higher risk of developing severe sarcopenia due to muscle atrophy linked to paralysis, disuse, spasticity, inflammation, denervation, reinnervation, and issues with feeding and intestinal absorption.[25] Nevertheless, it must be acknowledged that the sarcopenia marker is strongly correlated with age, as the most common cause of sarcopenia is the natural aging process, which indicates a potential confounding factor. It is unclear whether the poor outcome is due to age itself or because older patients have less muscle, making them more vulnerable. However, it is important to consider that the sarcopenia marker demonstrates higher accuracy than age in predicting outcomes (see ROC analysis), suggesting that this parameter can be considered as a complementary factor.

Ongoing studies emphasize the multifaceted nature of stroke recovery. Early and comprehensive management of acute ischemic stroke is crucial for improving outcomes.[1 2] In post-acute rehabilitation hospitals, approximately 50% of patients suffer from sarcopenia on admission.[26] Sarcopenia has been linked to decreased rehabilitation potential in stroke patients. Studies found that sarcopenia predicts lower activities of daily living capabilities, which could impede recovery efforts post-stroke.[12] Considering these findings, addressing sarcopenia through targeted interventions with emphasis on exercise and nutritional interventions could be a vital component of stroke rehabilitation protocols.

Typically, muscle mass is measured in specific areas such as the lumbar spine (eg, the psoas muscles or abdominal muscle mass at the third or fourth lumbar vertebra). Measuring muscle mass in the neck region is less common but has been used frequently in head and neck cancer patients as abdominal scans are not always available.[27] In our radiological system the BCA can be easily obtained from CT angiography images and could be available right at the start of treatment. Patients with lower sarcopenia markers may require faster or better post-interventional care to ensure they are extubated quickly and receive therapeutic approaches for dysphagia, as they may have weakness of the swallowing-related muscles which may lead to impaired oral intake and aspiration pneumonia.[28 29] Future research should focus on the development and implementation of strategies to improve muscle mass and function in stroke patients, potentially enhancing their overall recovery trajectory and reducing long-term disability. Moreover, the association between sarcopenia and adverse outcomes is consistent with findings in other medical conditions. Studies by Hosch *et al.*,[6] and Kroll *et al.*,[7] have shown that sarcopenia correlates with worse outcomes in COVID-19 and coronary artery disease patients, respectively. This broader applicability highlights the potential benefits of integrating BCA into routine clinical assessments for stroke patients without incurring extra time or resource costs.

Muscle fatty infiltration (myosteatosis) and body fat mass are known as key predictors of mortality risk in asymptomatic adults.[30 31] In our study, we found that sarcopenia, fat index, and myosteatosis index had no impact on the angiographic outcome. Theoretically, it is plausible that individuals with higher fat content or muscle fatty infiltration might have an increased risk of atherosclerosis, making it more challenging to navigate the vessels and potentially increasing the time from groin puncture to recanalization. However, our results suggest that these factors do not significantly affect the vascular status. Further research is needed to better understand these relationships and to rule out any subtle effects. Other potential markers that could provide a more comprehensive picture of the factors influencing outcomes related to sarcopenia include muscle density, inflammatory markers, bone mineral density, hormonal levels and nutritional status.

One limitation of the study is that the BCA analysis was performed from the entire volume of the CT angiography, which can also vary by a few millimeters from patient to patient. However, the CT angiography always included imaging of the aortic arch to the vertex as standard. An important limitation of our study is its retrospective and multicenter design, which includes inherent selection bias and the use of various thrombectomy equipment and techniques. However, it is noteworthy that the reperfusion rates were high and comparable to existing literature.[4]

CONCLUSION

Acute ischemic stroke patients with a lower sarcopenia marker are at risk for an unfavorable outcome. Imaging biomarkers extracted from BCA can be easily obtained from existing CT images, making them readily available at the beginning of treatment. However, further research is necessary to determine whether sarcopenia provides additional value beyond established outcome predictors. Understanding its role could lead to optimized, individualized treatment plans for post-stroke patients, potentially improving recovery outcomes.

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Patient consent for publication Not applicable.

Ethics approval This study involves human participants and was approved by University Hospital Essen, 19-9013-BOA. Each patient's consent for treatment was obtained according to the individual institutional guidelines. Due to the retrospective nature of the study additional informed consent was deemed unnecessary.

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	TICI 0-2b (N=104)	TICI 2c-3 (N=186)	P value
Demographics			
Age (years)	77.5 (63.0-84.0)	78.5 (68.0-86.0)	0.169
Sex (male)	33 (31.7%)	86 (46.2%)	**0.016**
Medical history			
Arterial Hypertension	77 (74.0%)	152 (81.7%)	0.124
Atrial Fibrillation	52 (50.0%)	86 (46.2%)	0.538
Diabetes	22 (21.2%)	46 (24.7%)	0.490
Dyslipidemia	43 (41.3%)	73 (39.2%)	0.726
Smoking	29 (27.9%)	58 (31.2%)	0.557
Stroke characteristics			
mRS pre-treatment	0 (0-2)	0 (0-2)	0.806
Baseline NIHSS	14 (11-19.5)	14 (9-18)	0.252
NIHSS discharge	13 (5-37)	5.5 (2-12.3)	**<0.001**
mRS discharge	5 (3-6)	3.5 (2-5)	**0.002**
Baseline ASPECTS	10 (8.8-10)	10 (9-10)	0.649
ASPECTS 24 h	7 (4.8)	8 (6-9)	**0.002**
Wake-up stroke	23 (22.1%)	39 (21.0%)	0.819
Intravenous thrombolysis	56 (53.8%)	104 (55.9%)	0.734
Onset to groin (min)	148 (111-233)	142 (113-200)	0.645
Groin to recanalization (min)	59 (36-89)	40 (25-57)	**<0.001**
Site of occlusion			
Distal ICA	33 (31.7%)	44 (23.7%)	0.135
MCA M1	39 (37.5%)	85 (45.7%)	0.176
MCA M2	28 (26.9%)	41 (22.0%)	0.349
MCA M3	3 (2.9%)	6 (3.2%)	0.872
A1	0 (0%)	3 (1.6%)	0.555
A2	1 (1.0%)	1 (0.5%)	1.0
Multiple locations	0 (0%)	6 (3.2%)	0.091
TOAST			
Large Artery Sclerosis	26 (25.0%)	59 (31.7%)	0.228
Cardioembolic	51 (49.0%)	89 (47.8%)	0.846
Small vessel occlusion	0 (0%)	1 (0.5%)	1.0
Other/undetermined	27 (26.0%)	37 (19.9%)	0.744
Tandem occlusion	8 (7.7%)	17 (9.1%)	0.674
Number of maneuvers	2 (1-4)	1 (1-2)	**<0.001**
Number of stent retriever maneuvers	2 (1-3)	1 (0-2)	**<0.001**
First-pass technique			0.393
Aspiration	25/99 (25.3%)	55/183 (30.1%)	
Stent retriever + aspiration	74/99 (74.7%)	128 (68.8%)	
Overall hemorrhagic complications	21 (20.2%)	18 (9.7%)	**0.012**
SAH	16 (15.4%)	9 (4.8%)	**0.002**
sICH	5 (4.8%)	9 (4.8%)	0.991
Parameter			
Bone sum	912 (799-1106)	951 (789-1145)	0.445
Muscle sum	1902 (1576-2489)	1925 (1432-2454)	0.828
TAT sum	2200 (1536-3074)	2048 (1333-3103)	0.613
IMAT sum	919 (668-1142)	915 (613-1210)	0.890
Muscle/bone sum	2.2 (1.8-2.4)	2.0 (1.7-2.5)	0.113
TAT/bone sum	2.4 (1.7-3.3)	2.2 (1.5-2.9)	0.266
IMAT/TAT sum	42.1 (35.1-50.6)	43.8 (37.1-53.8)	0.086

Supplement Table 1: Univariate analysis of TICI2c-3 in patients with anterior circulation stroke

ASPECTS: Alberta stroke program early CT score; h: hours; ICA: internal carotid artery; IMAT: intra-/intermuscular adipose tissue; min: minutes; MCA: middle cerebral artery; mRS: modified Rankin Scale; NIHSS: National Institutes of Health stroke scale; SAH: subarachnoid hemorrhage; sICH: symptomatic intracranial hemorrhage; TAT: total adipose tissue; TICI: thrombolysis in cerebral infarction

Parameter	AUC (95%CI)	P	OR (95%CI)	P value
Sex (male)	0.575 (0.503-0.646)	0.047	2.0 (1.1-3.4)	0.018
Groin to recanalization (min)	0.354 (0.281-0.426)	<0.001	0.98 (0.97-0.99)	<0.001

Supplement Table 2: ROC analysis and bivariate logistic regression analysis of selected parameters to predict TICI 2c-3. Goodness-of-fit of the regression analysis was assessed using the Hosmer-Lemeshow-Test, indicating a good model fit, $\chi^2(8) = 6.9$, $p = 0.548$.

AUC: area under the curve; min: minutes; OR: odds ratio