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ORIGINAL RESEARCH

CBF Profile in Computed Tomography Perfusion-Based AutoMIStar Software Predicts Futile Recanalization After Basilar Artery Thrombectomy

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Background: Futile recanalization (FR) remains a significant challenge in patients with acute basilar artery occlusion (BAO) following successful endovascular treatment (EVT). This study aimed to investigate the predictive value of computed tomography perfusion (CTP)-based software (AutoMIStar; Apollo) for FR among BAO patients undergoing EVT.

Methods: We analyzed a prospectively maintained database to identify consecutive BAO patients who achieved successful recanalization (modified Thrombolysis in Cerebral Infarction grade ≥ 2b) after EVT between January 2020 and September 2022. Clinical characteristics and imaging parameters from non-contrast CT, CT angiography, and CTP-AutoMIStar were collected for analysis. FR was defined as an unfavorable outcome (modified Rankin Scale score > 3) at 90 days despite successful recanalization. Multivariable stepwise logistic regression analysis was performed to identify independent predictors of FR.

Results: Of the 54 patients included in this study, 24 (44.4%) experienced FR. In the univariate analysis, admission National Institutes of Health Stroke Scale score, posterior circulation Acute Stroke Prognosis Early CT Score, Basilar Artery on Computed Tomography Angiography (BATMAN) score, hypoperfusion intensity ratio, and perfusion deficit volume in delay time (DT) > 4 s, DT > 6 s, DT > 8 s, and all cerebral blood flow (CBF) thresholds were associated with FR (all $P < 0.05$). In the multivariate analysis, perfusion deficit volume in CBF < 35% (adjusted odds ratio [aOR] = 1.105, 95% confidence interval [CI]: 1.004–1.215; $P = 0.040$) and BATMAN score (aOR = 0.662, 95% CI: 0.455–0.964; $P = 0.031$) remained independent predictors of FR.

Conclusion: Perfusion deficit volume in CBF < 35% on CTP-AutoMIStar imaging maps and BATMAN score are independent predictors of FR after EVT in BAO patients. There is a significant positive correlation between perfusion deficit volume in CBF < 35% and the occurrence of FR.

Keywords: acute ischemic stroke, basilar artery occlusion, endovascular treatment, cerebral blood flow, computed tomography perfusion, futile recanalization

Introduction

Basilar artery occlusion (BAO) stroke is a devastating neurological disorder associated with significant disability and mortality.[1] Recent randomized controlled trials (RCTs) have demonstrated that endovascular treatment (EVT) offers superior functional outcomes in BAO patients presenting with moderate-to-severe neurological deficits within 24 hours of symptom onset, when compared to best medical management (BMM) alone.[2,3] However, real-world registry studies have revealed that despite achieving successful recanalization (modified Thrombolysis in Cerebral Infarction [mTICI] grade ≥ 2b), approximately 47.0–62.8% of BAO patients still exhibit unfavorable outcomes (modified Rankin Scale score [mRS] > 3) at 90 days after EVT.[4–7] The underlying mechanisms of this phenomenon known as futile recanalization (FR) remain incompletely clear. Therefore, the identification of risk factors or predictors for FR is crucial in assisting clinicians in selecting appropriate BAO patients for EVT and developing tailored patient management strategies.

Current guidelines recommend the use of whole-brain computed tomography perfusion (CTP) to select suitable patients with anterior circulation (AC) stroke for EVT and/or intravenous thrombolysis (IVT) within extended time windows.[8,9]

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However, the role of CTP in guiding clinical decision-making for EVT and/or IVT in posterior circulation (PC) stroke remains ambiguous. Recent studies have shown the prognostic significance of CTP parameters in BAO patients undergoing EVT.[10–14] For instance, the posterior circulation Acute Stroke Prognosis Early CT Score (pc-ASPECTS) derived from cerebral blood volume (CBV) maps, as well as visually quantified perfusion deficit volumes across all CTP maps can independently predict functional outcomes after EVT in BAO stroke.[10,11] Additionally, the RAPID software, widely used in AC stroke, has been piloted for the automatic analysis of perfusion imaging in BAO stroke, aiming to address the current lack of perfusion software solutions specific to PC stroke. Notably, several imaging parameters derived from the RAPID software, including CBV index, perfusion deficit volume in time to maximum (Tmax) > 6 s, and Critical Area Perfusion Score (CAPS), have emerged as potential predictors of clinical outcomes in BAO patients undergoing EVT.[12–14]

Despite these advancements, there is still a scarcity of specific data regarding the association between CTP imaging and FR following EVT in BAO stroke. Furthermore, the clinical utility of other commercially available CTP automated imaging analysis software remains unexplored in the context of BAO stroke. Hence, our study aimed to delve into the predictive value of quantitative CTP parameters generated by the AutoMIStar software, another American FDA-approved automated perfusion imaging software, in predicting FR after EVT in BAO patients.

Material and Methods

Patient Selection

We conducted a retrospective analysis on consecutive BAO patients retrieved from our comprehensive stroke center's prospectively maintained database (MEDICAL SYSTEM). This database serves as a repository for data pertaining to patients with acute ischemic stroke who have received reperfusion therapy, encompassing both EVT and IVT. For the purpose of this study, we specifically included BAO patients who underwent EVT between January 2020 and September 2022. Eligible patients had to fulfill the following inclusion criteria: (1) age ≥ 18 years; (2) baseline National Institutes of Health Stroke Scale (NIHSS) score ≥ 6; (3) complete non-contrast CT (NCCT), single-phase CT angiography (CTA), and whole-brain CTP imaging were acquired before EVT; (4) EVT was performed within 24 hours of symptom onset (or last known well) and successful recanalization, defined as an mTICI grade ≥ 2b, was achieved at the end of EVT. Patients were excluded if they had: (1) a premorbid mRS score > 2; (2) nondiagnostic or poor-quality CTP imaging; (3) concomitant anterior circulation infarction or anterior circulation large vessel occlusion; and (4) incomplete individual data. The study was approved by the Research Ethics Committee of the First Affiliated Hospital of Soochow University (No. 2023298). Given the retrospective nature of the study, the requirement for written informed consent was waived.

Imaging Acquisition and Analysis

Upon admission, patients underwent a standard multimodal CT protocol, including NCCT, single-phase CTA, and whole-brain CTP utilizing a 256-detector row GE Revolution CT scanner (GE Healthcare, Milwaukee, USA) with a z-axis coverage of 16 cm. The details of the acquisition protocol have been previously described.[15] To assess early ischemic changes in the posterior circulation territory, the pc-ASPECTS and pons-midbrain index (PMI) were evaluated on NCCT and CTA source images (CTA-SI).[16,17] The basilar artery was divided into 3 segments (distal, middle, and proximal segments) marked by the superior cerebellar artery and anterior inferior cerebellar artery. The thrombus burden and collateral circulation status were gauged using the posterior circulation CTA (pc-CTA) score and the Basilar Artery on Computed Tomography Angiography (BATMAN) score derived from CTA maps.[18,19] All CTP data were automatically post-processed using the AutoMIStar software (Apollo Medical Imaging Technology, Melbourne, Australia), which employed a delay and dispersion-corrected singular value deconvolution algorithm to generate maps of delay time (DT), cerebral blood flow (CBF), mean transit time (MTT), and CBV.[20] The AutoMIStar analysis provided quantitative measurements of the following imaging parameters: DT > 2 s, DT > 3 s, DT > 4 s, DT > 6 s, DT > 8 s, DT > 10 s, CBF < 40%, CBF < 35%, CBF < 30%, CBF < 25%, CBF < 20%, CBF < 15%, mismatch volume (DT > 3 s volume minus CBF < 30% volume), and hypoperfusion intensity ratio (HIR; DT > 6 s volume/DT > 2 s volume).[21] NCCT or magnetic resonance imaging (MRI) was performed immediately after EVT and at 36 hours (±12 hours) to evaluate intracranial hemorrhagic transformation and infarction sites. All imaging parameters were independently assessed by two

experienced neuroradiologists who were blinded to procedural data and clinical outcomes. Any disagreements were resolved through consensus.

Endovascular Treatment

All eligible patients received IVT with alteplase prior to EVT according to Chinese guidelines.[22] The EVT procedures were executed under ether general or non-general anesthesia. The frontline strategy for EVT included stent-retriever thrombectomy, contact aspiration, and a synergistic combination of both techniques. In cases where residual stenosis or re-occlusion was observed, balloon angioplasty and/or stent deployment were implemented as appropriate. The choice of procedural devices was at the discretion of board-certified neuro-interventionalists, but confined to devices approved for use in China during the study period. The degree of recanalization was assessed using the mTICI grade.[23] Successful recanalization and complete recanalization were defined as achieving mTICI grades of 2b-3 and 3 at the end of the procedure, respectively. First-pass effect was defined as achieving successful recanalization through a single pass of the thrombectomy device, without any rescue therapy during the course of the procedure.[24]

Clinical Data Collection and Outcome Measurement

Patient information was retrospectively retrieved from the database, including: (1) demographic characteristics (age and sex); (2) medical history (hypertension, diabetes mellitus, atrial fibrillation, hyperlipidemia, coronary artery disease, previous stroke, smoking, and drinking); (3) clinical characteristics (pre-stroke mRS score, wake-up stroke, admission NIHSS score, systolic blood pressure, diastolic blood pressure, temperature, blood glucose, and etiology of stroke based on the modified Trial of ORG 10172 in Acute Stroke Treatment classification[25]); (4) procedural-related parameters; (5) time metrics (onset-to-puncture time, puncture-to-recanalization time, and onset-to-recanalization time); and (6) follow-up data (90-day mRS score).

Symptomatic intracranial hemorrhage (sICH) was defined in accordance with the Safe Implementation of Thrombolysis in Stroke-Monitoring Study (SITS-MOST) criteria, which refers to local or remote parenchymal hematoma type 2 on follow-up imaging, along with a neurological deterioration of ≥ 4 points on the NIHSS score or death.[26] Functional outcomes were evaluated by experienced neurologists at 90 days after the index stroke event, either via telephone reviews or outpatient visits, utilizing the mRS score as a standardized metric. The primary outcome of this study was FR, defined as a 90-day mRS score > 3 despite successful recanalization (mTICI grade $\geq$ 2b) after EVT. Based on this criterion, patients were categorized into two distinct groups: the meaningful recanalization group and the FR group.

Statistical Analysis

Categorical variables were presented as frequencies and proportions, whereas continuous variables were expressed as means ± standard deviation (SD) or medians with interquartile ranges (IQR). To detect significant differences between patients in the meaningful recanalization group and the FR group, univariate analyses were conducted using the chi-squared or Fisher exact test for categorical variables, independent-sample *t*-test for continuous variables exhibiting a normal distribution, and Mann–Whitney *U*-test for continuous variables with a skewed distribution. Candidate variables with $P < 0.05$ in the univariate analysis were further tested for multicollinearity using the variance inflation factor (VIF). Only variables with a VIF < 5 were considered eligible for inclusion in the multivariable stepwise binary logistic regression model. The goodness-of-fit of the model was evaluated using the Hosmer-Lemeshow test, and a nomogram was constructed based on the results of the multivariable logistic regression analysis. Additionally, receiver operating characteristic (ROC) curve analysis with area under the curve (AUC) was performed to assess and compare the predictive performance of individual variables and the overall model. The optimal cutoff values for predicting FR were calculated using the Youden index, which is equal to sensitivity + specificity – 1. All statistical analyses were conducted using SPSS software (version 26.0; IBM Corp., Armonk, NY, USA), GraphPad Prism (version 9.0), and R software (version 4.2.1). The significance level was set at a P value < 0.05.

Results

Patient Characteristics

The flow chart depicting the patient selection process is presented in Figure 1. After excluding 15 patients, a total of 54 patients were included in the final analysis, with 30 patients in the meaningful recanalization group and 24 patients in the FR group. The characteristics of the included patients are summarized in Table 1. The mean age of the patients was 64.3 ± 11.1 years, and 66.7% of the participants were male. The median NIHSS score was 21 (IQR 14–26) on admission. The administration of IVT was performed before EVT in 20 patients (37.0%). Large artery atherosclerosis was the predominant etiology of stroke, accounting for 46.3% of cases, followed by cardio-embolism (38.9%) and other types (14.8%). The most commonly used frontline EVT strategy was stent retriever thrombectomy combined with contact aspiration, which was performed in 51.9% of all patients. Additionally, balloon angioplasty and/or stenting were performed in 10 patients (18.5%). Post-procedural intracranial hemorrhage occurred in 8 patients (14.8%), including 3 patients with sICH (5.6%). The 90-day all-cause mortality

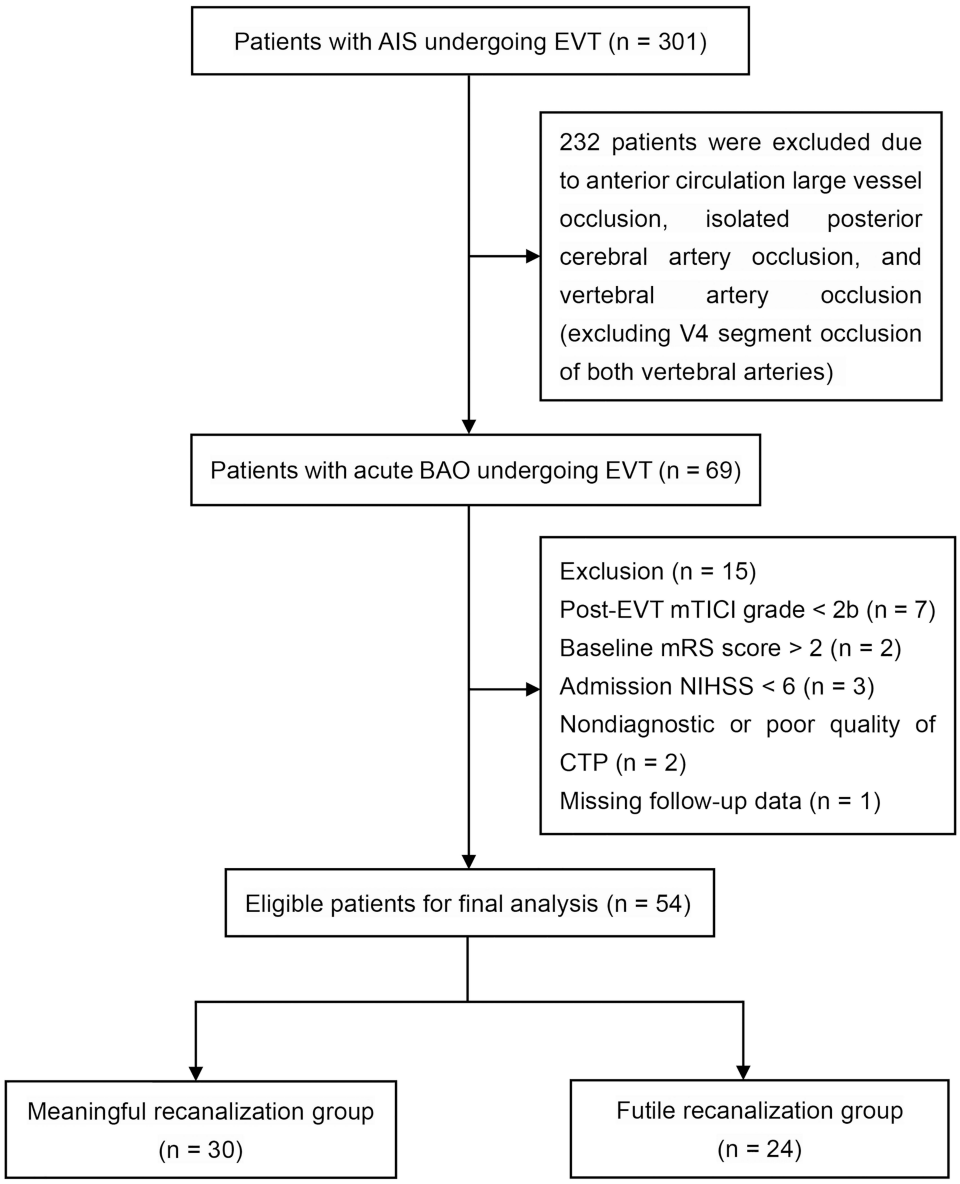

Figure 1 Flow chart presenting the process of patient inclusion and exclusion in this study.
Abbreviations: AIS, acute ischemic stroke; EVT, endovascular treatment; BAO, basilar artery occlusion; mTICI, modified Thrombolysis in Cerebral Infarction; mRS, modified Rankin Scale; NIHSS, National Institutes of Health Stroke Scale; CTP, computed tomography perfusion.

Table 1 Comparison of Characteristics Between the Meaningful Recanalization Group and the Futile Recanalization Group

Variables	Overall (n = 54)	Meaningful Recanalization (n = 30)	Futile Recanalization (n = 24)	*P* value
Baseline Characteristics				
Age, years, mean (SD)	64.3 (11.1)	63.2 (11.5)	65.8 (10.6)	0.400
Male, n (%)	36 (66.7)	22 (73.3)	14 (58.3)	0.245
Hypertension, n (%)	36 (66.7)	19 (63.3)	17 (70.8)	0.561
Diabetes mellitus, n (%)	17 (31.5)	8 (26.7)	9 (37.5)	0.394
Hyperlipidemia, n (%)	11 (20.4)	6 (20.0)	5 (20.8)	1.000
Atrial fibrillation, n (%)	19 (35.2)	8 (26.7)	11 (45.8)	0.143
Coronary artery disease, n (%)	8 (14.8)	4 (13.3)	4 (16.7)	1.000
Previous stroke, n (%)	7 (13.0)	3 (10.0)	4 (16.7)	0.687
Smoking, n (%)	23 (42.6)	12 (40.0)	11 (45.8)	0.667
Drinking, n (%)	17 (31.5)	10 (33.3)	7 (29.2)	0.743
Pre-stroke mRS, median (IQR)	0 (0–0)	0 (0–0)	0 (0–0)	0.693
NIHSS on admission, median (IQR)	21 (14–26)	18 (13–24)	23 (20–29)	0.023*
Wake-up stroke, n (%)	10 (18.5)	4 (13.3)	6 (25.0)	0.457
Baseline SBP, mmHg, median (IQR)	149 (138–166)	148 (135–166)	153 (141–169)	0.375
Baseline DBP, mmHg, median (IQR)	88 (76–99)	84 (72–99)	88 (78–99)	0.408
Temperature, °C, median (IQR)	36.5 (36.5–36.8)	36.5 (36.4–36.8)	36.6 (36.5–37.0)	0.289
Glucose, mmol/L, median (IQR)	7.9 (6.7–9.9)	7.6 (6.3–9.2)	8.4 (6.8–12.3)	0.098
Imaging data				
NCCT data, median (IQR)				
Pc-ASPECTS	9 (8–10)	9 (8–10)	9 (8–9)	0.225
PMI	1 (0–2)	0 (0–2)	1 (0–2)	0.543
CTA-SI data, median (IQR)				
Pc-ASPECTS	8 (7–8)	8 (7–8)	7 (6–8)	0.036*
PMI	2 (1–2)	2 (0–2)	2 (1–2)	0.124
Pc-CTA	2 (2–3)	2 (2–3)	3 (2–4)	0.305
BATMAN	5 (4–7)	6 (4–7)	4 (3–6)	0.004*
Vascular occlusion site, n (%)				0.732
Distal BA	27 (50.0)	16 (53.3)	11 (45.8)	
Middle BA	13 (24.1)	8 (26.7)	5 (20.8)	
Proximal BA	11 (20.4)	5 (16.7)	6 (25.0)	
Bilateral V4-VA	3 (5.6)	1 (3.3)	2 (8.3)	
CTP AutoMIStar data, mL, median (IQR)				
DT > 2 s	126.5 (73.3–164.5)	113.5 (57.0–165.3)	140.5 (104.8–173.5)	0.195
DT > 3 s	73.0 (26.8–112.5)	57.5 (19.8–104.5)	81.5 (62.5–113.5)	0.111
DT > 4 s	27.5 (9.0–61.3)	16.5 (8.3–55.8)	54.0 (24.5–68.8)	0.033*
DT > 6 s	5.5 (0.0–21.0)	0.0 (0.0–10.8)	13.5 (0.0–26.0)	0.040*
DT > 8 s	0.0 (0.0–4.0)	0.0 (0.0–0.0)	0.0 (0.0–8.8)	0.018*
DT > 10 s	0.0 (0.0–0.0)	0.0 (0.0–0.0)	0.0 (0.0–2.3)	0.059
CBF < 40%	4.0 (2.0–16.3)	2.5 (1.0–8.5)	9.5 (4.0–28.8)	0.006*
CBF < 35%	3.0 (1.0–10.3)	2.0 (0.0–6.3)	7.0 (2.0–22.5)	0.003*
CBF < 30%	2.0 (0.0–7.5)	1.0 (0.0–4.0)	5.0 (1.0–16.0)	0.005*
CBF < 25%	1.0 (0.0–5.3)	1.0 (0.0–3.0)	3.0 (0.5–9.3)	0.018*
CBF < 20%	1.0 (0.0–4.0)	0.0 (0.0–2.0)	2.0 (0.1–5.8)	0.017*
CBF < 15%	0.0 (0.0–2.0)	0.0 (0.0–1.0)	1.0 (0.0–3.8)	0.012*
Mismatch volume	65.0 (22.3–91.3)	52.0 (15.0–97.8)	71.5 (39.5–90.3)	0.226
HIR	0.0 (0.0–0.1)	0.0 (0.0–0.1)	0.1 (0.0–0.2)	0.035*

(*Continued*)

Table 1 (Continued).

Variables	Overall (n = 54)	Meaningful Recanalization (n = 30)	Futile Recanalization (n = 24)	*P* value
Toast, n (%)				0.700
Large artery atherosclerosis	25 (46.3)	15 (50.0)	10 (41.7)	
Cardioembolism	21 (38.9)	10 (33.3)	11 (45.8)	
Other types	8 (14.8)	5 (16.7)	3 (12.5)	
Treatment information				
Intravenous thrombolysis, n (%)	20 (37.0)	11 (36.7)	9 (37.5)	0.950
Frontline EVT strategy, n (%)				0.367
Stent retriever	23 (42.6)	12 (40.0)	11 (45.8)	
Contact aspiration	3 (5.6)	3 (10.0)	0 (0.0)	
Combined	28 (51.9)	15 (50.0)	13 (54.2)	
BD and/or stenting, n (%)	10 (18.5)	3 (10.0)	7 (29.2)	0.147
Number of passes	1 (1–1)	1 (1–1)	1 (1–2)	0.051
First-pass effect, n (%)	28 (51.9)	18 (60.0)	10 (41.7)	0.180
mTICI 3, n (%)	31 (57.4)	20 (66.7)	11 (45.8)	0.124
General anesthesia, n (%)	17 (31.5)	8 (26.7)	9 (37.5)	0.394
Time metrics, min, median (IQR)				
Onset to puncture	394 (272–569)	372 (271–593)	421 (271–559)	0.689
Puncture to recanalization	79 (62–97)	75 (54–93)	86 (66–103)	0.139
Onset to recanalization	456 (362–657)	438 (360–684)	545 (355–645)	0.548
Follow-up imaging data, n (%)				
Brainstem infarction	28 (51.9)	13 (43.3)	15 (62.5)	0.161
Cerebellar infarction	26 (48.1)	13 (43.3)	13 (54.2)	0.429
Thalamus infarction	11 (20.4)	4 (13.3)	7 (29.2)	0.273
PCA infarction	17 (31.5)	6 (20.0)	11 (45.8)	0.042*
ICH, n (%)	8 (14.8)	3 (10.0)	5 (20.8)	0.443
sICH, n (%)	3 (5.6)	0 (0.0)	3 (12.5)	0.082

Note: *Variables with *P* value < 0.05.

Abbreviations: mRS, modified Rankin Scale; NIHSS, National Institutes of Health Stroke Scale; SBP, systolic blood pressure; DBP, diastolic blood pressure; NCCT, non-contrast computed tomography; pc-ASPECTS, posterior circulation Acute Stroke Prognosis Early CT Score; PMI, pons-midbrain index; CTA-SI, CT angiography source images; pc-CTA, posterior circulation CTA; BATMAN, Basilar Artery on CTA; BA, basilar artery; VA, vertebral artery; CTP, CT perfusion; DT, delay time; CBF, cerebral blood flow; HIR, hypoperfusion intensity ratio; TOAST, Trial of Org 10,172 in Acute Stroke Treatment; EVT, endovascular treatment; BD, balloon dilation; PCA, posterior cerebral artery; ICH, intracranial hemorrhage; sICH, symptomatic ICH.

rate was 20.4%. Among the 11 patients who succumbed, eight passed away due to ischemic stroke, two due to cardiac arrest, and one due to severe systemic infections.

In the univariate analysis, significant differences were observed between the two groups in terms of the admission NIHSS score ($P = 0.023$), CTA-SI pc-ASPECTS ($P = 0.036$), BATMAN score ($P = 0.004$), HIR ($P = 0.035$), and perfusion deficit volumes in DT > 4 s ($P = 0.033$), DT > 6 s ($P = 0.040$), DT > 8 s ($P = 0.018$), and all CBF thresholds (all $P < 0.05$; Table 1). There were no significant differences in other baseline characteristics between the two groups (all $P > 0.05$). A higher proportion of posterior cerebral artery territory infarction was observed in the FR group on follow-up imaging. Taking into account the multicollinearity among candidate variables (DT > 4 s, DT > 6 s, and DT > 8 s; CBF < 40%, CBF < 35%, CBF < 30%, CBF < 25%, CBF < 20%, and CBF < 15%), we chose to include the perfusion deficit volumes in DT > 4 s and CBF < 35% in the multivariable logistic regression model due to their higher predictive power in the ROC curve analysis of DT and CBF threshold parameters (Supplemental Table 1).

Prognostic Value of Baseline Imaging Parameters

The candidate variables included in the multivariable analysis did not exhibit collinearity (all VIF < 5; Supplemental Table 2). In the multivariable stepwise binary logistic regression analysis adjusted for admission NIHSS, CTA-SI pc-

Table 2 Multivariable Stepwise Logistic Regression Analysis for Futile Recanalization After Endovascular Treatment

Variables	Adjusted OR	95% CI	β	χ^2	*P* value
BATMAN	0.662	0.455–0.964	−0.412	4.639	0.031*
CBF < 35%	1.105	1.004–1.215	0.099	4.213	0.040*

Note: *Variables with *P* value < 0.05.
Abbreviations: OR, odds ratio; CI, confidence interval; BATMAN, Basilar Artery on Computed Tomography Angiography; CBF, cerebral blood flow.

ASPECTS, perfusion deficit volume in DT > 4 s, and HIR, we found that a higher deficit volume in CBF < 35% (adjusted odds ratio [aOR] = 1.105, 95% confidence interval [CI]: 1.004–1.215; $P = 0.040$) and a lower BATMAN score (aOR = 0.662, 95% CI: 0.455–0.964; $P = 0.031$) remained independent predictors of FR (Table 2). The Hosmer-Lemeshow test displayed a good fit of the multivariable logistic regression model ($\chi^2 = 2.240$, $P = 0.815 > 0.05$). At a cutoff value of 0.347, the multivariable logistic regression model exhibited a sensitivity of 91.7%, specificity of 63.3%, positive predictive value of 66.7%, negative predictive value of 90.5%, and diagnostic accuracy of 75.9% in distinguishing FR. A nomogram was then constructed for ease of use (Figure 2). In the ROC curve analyses, the AUCs of the BATMAN score, perfusion deficit volume in CBF < 35%, and the multivariable logistic regression model were 0.724 (95% CI: 0.589–0.859), 0.734 (95% CI: 0.598–0.870), and 0.812 (95% CI: 0.696–0.927), respectively (Figure 3). The optimal cutoff values for predicting FR were a BATMAN score of 7 (sensitivity 87.5%; specificity 46.7%; accuracy 64.8%) and a perfusion deficit volume in CBF < 35% of 4.5 mL (sensitivity 62.5%; specificity 73.3%; accuracy 68.5%). Two representative case examples are presented in Figures 4 and 5.

Discussion

Our study evaluated the predictive performance of quantitative perfusion parameters generated by the AutoMIStar software for FR after EVT in BAO patients. The findings revealed that a larger perfusion deficit volume in CBF < 35% and a lower BATMAN score were independent predictors of FR. The optimal cutoff values for predicting FR were identified as 4.5 mL for perfusion deficit volume in CBF < 35% and a score of 7 for BATMAN. Notably, these two imaging biomarkers, especially the CBF profile, can be easily obtained and contribute to individualized prognostic assessment in routine clinical practice.

To date, four RCTs have been published on EVT in BAO stroke.[2,3,27,28] The BASICS (Basilar Artery International Cooperation Study)[27] and BEST (Basilar Artery Occlusion Endovascular Intervention versus Standard Medical Treatment)[28] trials did not prove a clinical benefit of EVT, yielding neutral outcomes. In contrast, the subsequent ATTENTION (Endovascular Treatment for Acute Basilar Artery Occlusion)[2] and BAOCHE (Basilar Artery Occlusion Chinese Endovascular Trial)[3] trials reported favorable outcomes in favor of EVT over BMM for BAO stroke. The

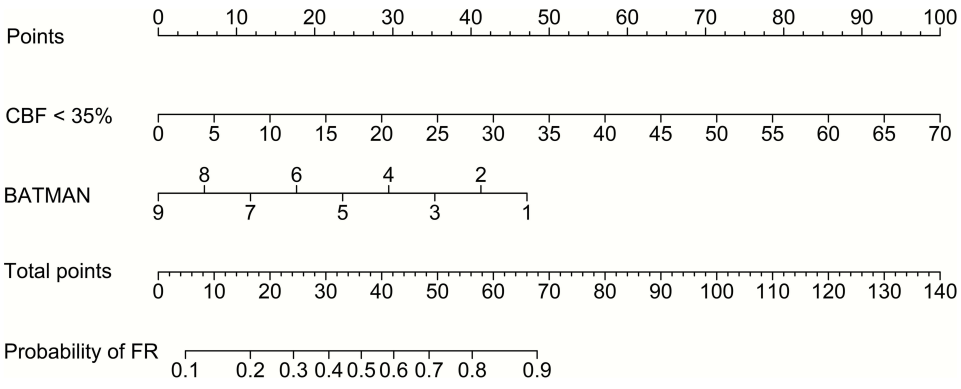

Figure 2 Development of a novel nomogram for predicting the individual risk of futile recanalization according to the results of multivariable logistic regression analysis.
Abbreviations: CBF, cerebral blood flow; BATMAN, Basilar Artery on Computed Tomography Angiography; FR, futile recanalization.

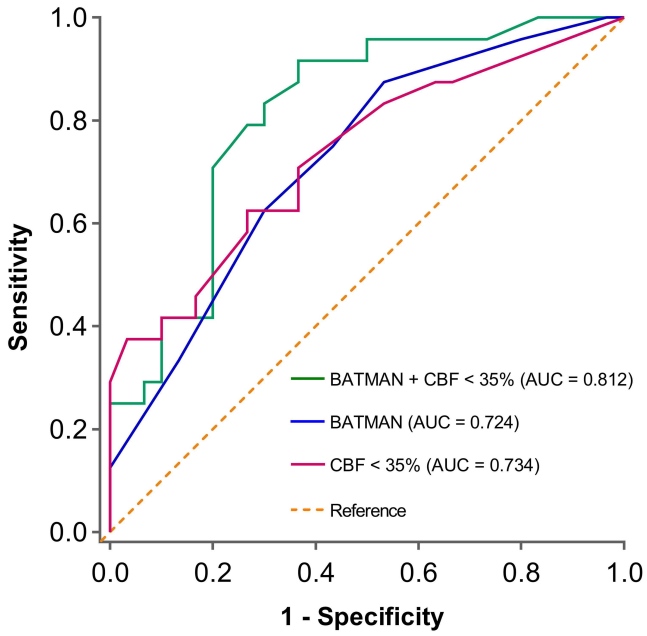

Figure 3 ROC curves of baseline BATMAN score, perfusion deficit volume in CBF < 35%, and combined model.
Abbreviations: ROC, receiver operating characteristic; BATMAN, Basilar Artery on Computed Tomography Angiography; CBF, cerebral blood flow; AUC, area under the curve.

positive results from the ATTENTION and BAOCHE trials may be partially attributed to the implementation of more rigorous imaging screening protocols, including the use of pc-ASPECTS and PMI to select patients with limited infarct cores prior to the procedure. Despite high rates of successful recanalization (nearly 90%) in these two trials, less than half of the BAO patients in the EVT group achieved independent ambulation at 90 days.[2,3] Furthermore, the ATTENTION and BAOCHE trials predominantly used NCCT or CTA-SI to assess early ischemic changes in the posterior circulation territory, which is challenging due to beam-hardening artifacts and the small size of critical brain structures.[29] Inter-observer consistency in evaluating pc-ASPECTS on NCCT and CTA-SI were also reported to be only slight, indicating a lack of reproducibility in clinical decision-making regarding EVT for BAO among clinicians.[30] Therefore, there is an urgent need to refine and optimize the current imaging evaluation paradigm for BAO patients.

Previous studies have suggested the potential utility of Tmax profile derived from the RAPID software in delineating salvageable penumbra and ischemic core in BAO stroke, as well as predicting prognosis following EVT.[13,14,31] Specifically, regions with Tmax > 10 s indicate the ischemic core, while regions with Tmax > 6 s may represent the penumbra.[13,31] In this study, we used the AutoMIStar software, which utilizes different deconvolution algorithms compared to the RAPID software, for the automatic post-processing of perfusion imaging in BAO stroke. Among the perfusion parameters obtained, we found that the perfusion deficit volume in CBF < 35% exhibited the best performance in distinguishing FR, with an AUC of 0.734 (95% CI: 0.598–0.870). Furthermore, this parameter independently predicted FR. Our findings not only corroborate and extend the results of a prior study that highlighted the superior predictive capability of manually segmented CBF deficit volume in the functional outcomes of BAO patients undergoing EVT,[11] but also introduce a more accessible parameter for evaluating FR in emergent clinical settings. Given the relatively small volume cut-off value of 4.5 mL, we speculate that the region with CBF < 35% may represent the ischemic core, as even a 0.5 mL injury in critical posterior circulation regions can lead to clinically significant damage.[14] In a recent imaging-based study, although DT and MTT parameters derived from AutoMIStar were identified to define the penumbra in PC stroke, no parameters were found to strongly correlate with the ischemic core volume.[32] However, it is noteworthy that 37% of patients in the complete recanalization group did not receive EVT, and thus the unknown time of recanalization might have confounded the correlation between initial perfusion imaging and the ischemic core volume on follow-up

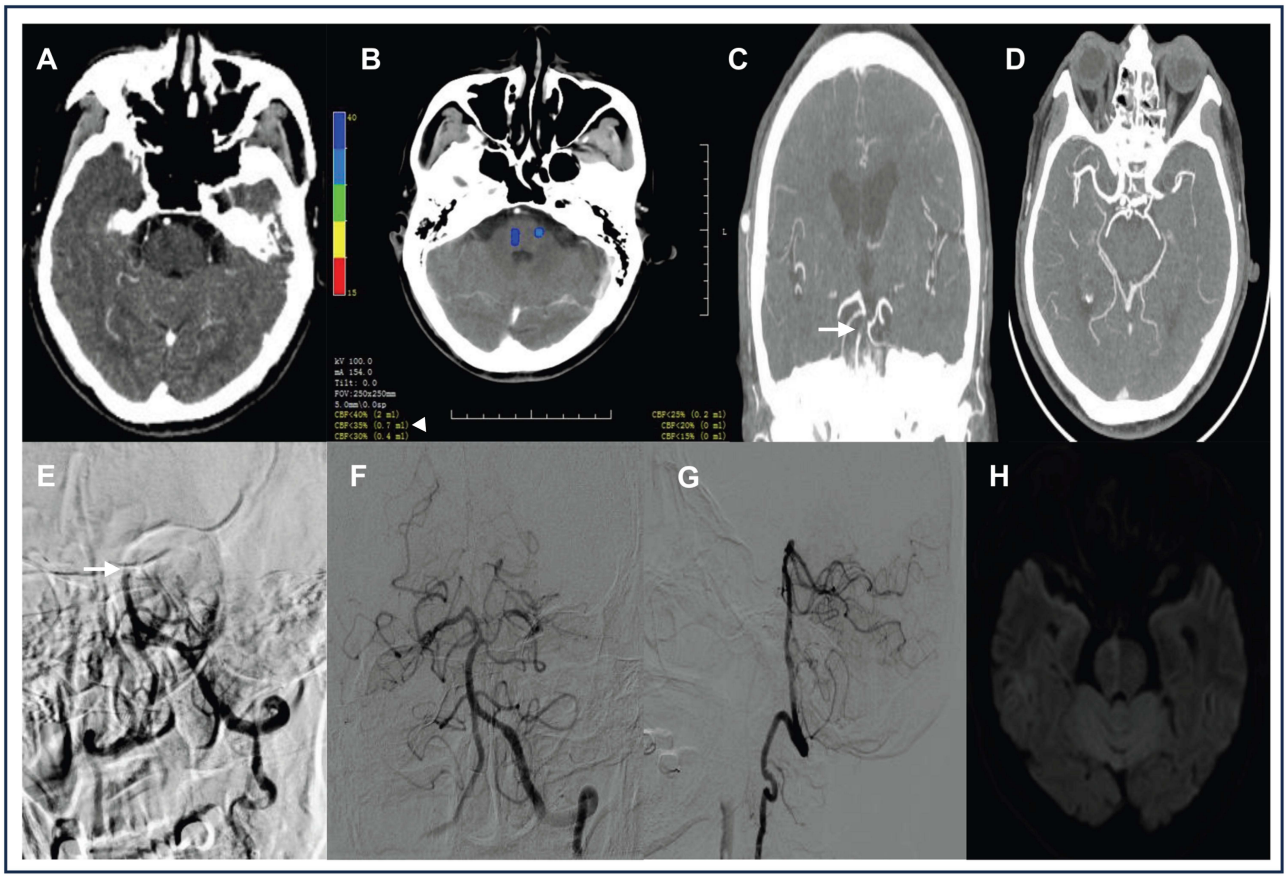

Figure 4 Representative case of meaningful recanalization after endovascular treatment. A 79-year-old man with known atrial fibrillation presented with compromised consciousness and dysarthria (National Institutes of Health Stroke Scales core of 10 on admission). At the 90-day follow-up, he had fully recovered from the acute ischemic stroke (modified Rankin Scale score of 0) after endovascular treatment. (**A**) CT angiography source images (CTA-SI) showed hypoattenuation in the right pons (< 50%). The posterior circulation Acute Stroke Prognosis Early CT Score was 8, and the pons-midbrain index was 1. (**B**) Baseline AutoMIStar analysis revealed hypoperfusion in the pons, with a cerebral blood flow (CBF) < 35% deficit volume of 0.7 mL (white arrowhead). (**C** and **D**) CTA images exhibited a distal basilar artery occlusion (white arrow), accompanied by the presence of bilateral posterior communicating arteries. The BATMAN score was 9. (**E–G**) Cerebral angiography confirmed the occlusion (white arrow), and successful recanalization was achieved following the first pass using a combination of stent-retriever thrombectomy and contact aspiration (onset-to-recanalization time: 442 min). (**H**) Follow-up diffusion-weighted magnetic resonance imaging showed an ischemic focus within the right pons.

imaging.[32] Future well-designed imaging studies are warranted to determine the optimal parameter and threshold in CTP-based AutoMIStar for accurately estimating ischemic cores in BAO stroke.

Collateral circulation plays a pivotal role in maintaining blood flow to the penumbra and shaping the progression of core infarct in acute ischemic stroke scenarios. A recent meta-analysis encompassing 16 real-world cohort studies demonstrated that the presence of robust pretreatment collaterals in BAO patients undergoing EVT was associated with a two-fold likelihood of favorable outcomes at 90 days, a higher probability of successful recanalization, and reduced odds of mortality compared to those with poor collaterals.[33] In our study, we further revealed that a low BATMAN score, which assesses thrombus burden and collateral status, could independently predict FR after EVT in BAO patients, with an AUC of 0.724 (95% CI: 0.589–0.859) and an optimal cut-off value of 7. However, a previous study proposed a BATMAN score of 3 as the optimal threshold for predicting FR following EVT in BAO stroke.[34] Moreover, a recent BASILAR sub-study showed that although patients with lower BATMAN scores (0–3 and 4–6) had worse functional outcomes than those with higher scores (7–9), they could still benefit from EVT compared to BMM.[35] These conflicting findings underscore the need for future research to determine the feasibility of using specific BATMAN score thresholds in identifying BAO patients amenable to EVT. Notably, another scoring scale called pc-CTA was not found to be associated with FR in the univariate analysis. This emphasizes the impact of collateral circulation on the functional outcomes of BAO patients with successful recanalization after EVT, as pc-CTA solely focuses on counting

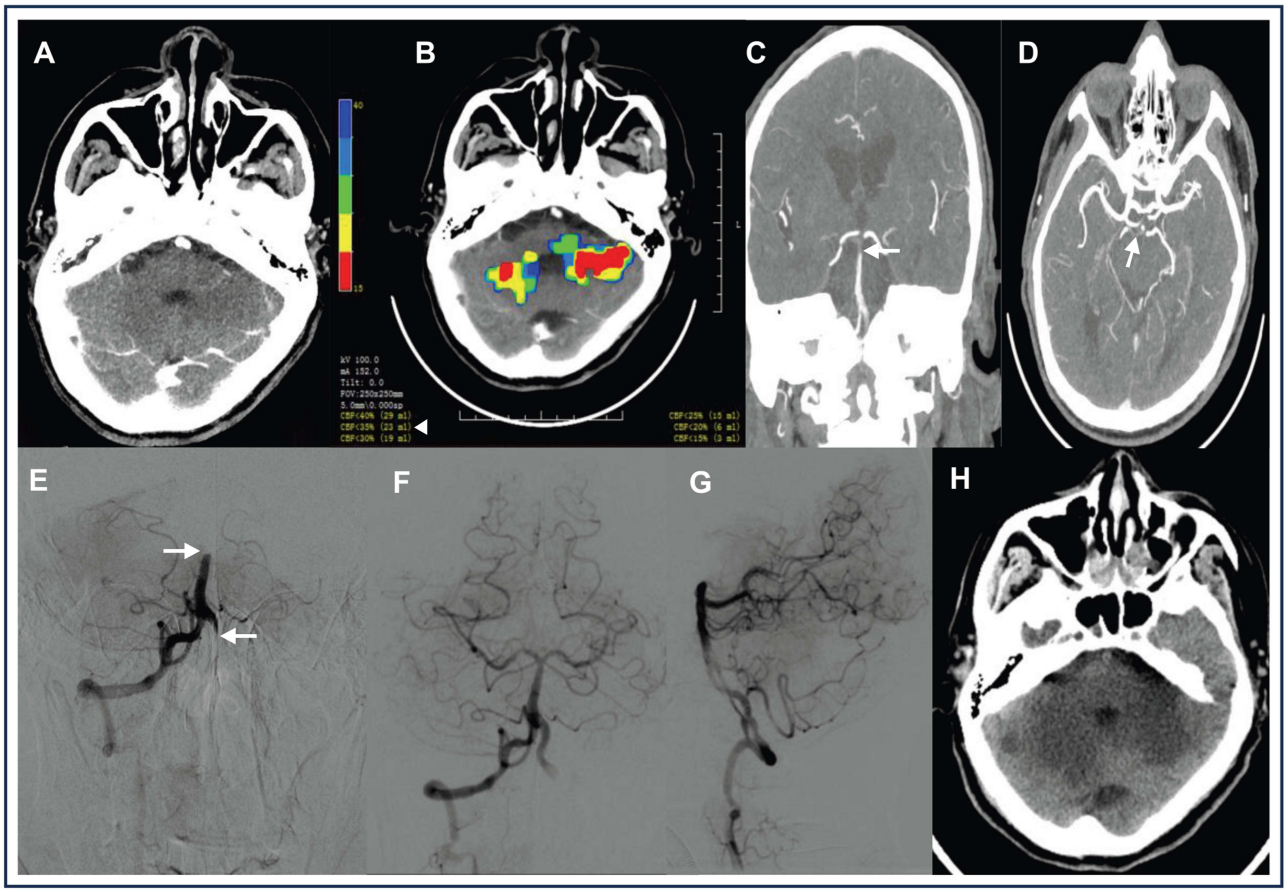

Figure 5 Representative case of futile recanalization after endovascular treatment. A 77-year-old man with known atrial fibrillation presented in a comatose state (National Institutes of Health Stroke Scales core of 32 on admission). Despite successful endovascular treatment, he passed away due to acute ischemic stroke during hospitalization (90-day modified Rankin Scale score of 6). (**A**) CT angiography source images (CTA-SI) did not show any hypoattenuation in the posterior circulation territory. The posterior circulation Acute Stroke Prognosis Early CT Score was 10, and the pons-midbrain index was 0. (**B**) Baseline AutoMIStar analysis revealed hypoperfusion in the pons and bilateral cerebellar hemispheres, with a cerebral blood flow (CBF) < 35% deficit volume of 23 mL (white arrowhead). (**C** and **D**) CTA images exhibited occlusions in the V4 segment of the left vertebral artery, the distal basilar artery, and the P1 segment of the right posterior cerebral artery (white arrows), along with a deficiency in the bilateral posterior communicating artery. The BATMAN score was 3. (**E–G**) Cerebral angiography confirmed these occlusions (white arrows), and successful recanalization was achieved following the first pass using a combination of stent-retriever thrombectomy and contact aspiration (onset-to-recanalization time: 351 min). (**H**) Follow-up non-contrast CT showed extensive infarction in the pons and bilateral cerebellar hemispheres.

occluded segments of the basilar artery and neglects the evaluation of the posterior communicating artery, which serves as the main collateral compensatory pathway in BAO stroke.[19,36]

The novelty of our study lies in the establishment of new and feasible imaging biomarkers for identifying BAO patients predisposed to experiencing FR following successful EVT. The imaging biomarkers include the extent of the ischemic core, as indicated by the perfusion deficit volume in CBF < 35%, and the extent of thrombus and collateral circulation assessed by the BATMAN score. These biomarkers have the potential to assist clinicians in early recognition of BAO patients who are more susceptible to FR after EVT, thereby facilitating the implementation of individualized intervention strategies to improve patient outcomes.

Artificial intelligence (AI) has gained increasing application in medical research, particularly in the field of stroke, cardiology, and various other diseases.[37–39] Recently, machine learning-based evaluation of NCCT pc-ASPECTS regions and diffusion-weighted imaging-derived radiomics both have shown promising preliminary results in predicting the functional outcomes of patients with PC stroke or BAO.[40,41] Moving forward, the application of AI algorithms in accurately interpreting perfusion imaging and predicting FR in BAO stroke may represent the next frontier in this field.

The present study has several limitations that should be acknowledged. First, our study was a single-center retrospective study with a relatively small sample size, which may introduce selection bias and limit the generalizability of our findings. Second, the AutoMIStar software, which was originally designed for assessing AC stroke, was used in our

study for PC stroke. This application requires further consideration. Nevertheless, no specific perfusion software solutions are currently available for PC stroke, and we did identify a significant AutoMIStar parameter for predicting FR, indicating the strong substitution effect of CBF < 35% volume as an ischemic core volume. Third, follow-up MRI was not performed in approximately half of the patients in our study. The NCCT evaluation of infarct volume in PC stroke is inaccurate due to artifacts and spatial resolution constraints. As a result, we were unable to analyze the correlation and agreement between AutoMIStar perfusion parameters on admission and the final infarct volume on follow-up imaging. Further imaging-based studies are needed to explore the association between AutoMIStar perfusion parameters and the final infarct volume on MRI. Finally, we did not set a separate validation group for the predictive model due to the limited sample size. Nonetheless, the data utilized in our study, particularly the AutoMIStar parameters, were easily obtainable and highly reproducible. Future prospective studies with a multicenter design are warranted to further validate our findings.

Conclusion

The CBF profile derived from the AutoMIStar software shows promise as a feasible and easily accessible imaging biomarker for predicting FR following EVT in BAO stroke. A larger perfusion deficit volume in CBF < 35% and a lower BATMAN score were independent predictors of FR in BAO patients who underwent successful EVT. Future multicenter prospective studies are necessary to validate the optimal threshold values of these two imaging parameters for predicting FR.

Data Sharing Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Ethics Approval and Informed Consent

This study protocol was reviewed and approved by the Research Ethics Committee (REC) of the First Affiliated Hospital of Soochow University (No. 2023298). The requirement for written informed consent from each participant was waived by the REC due to the retrospective nature of the review. Attentions were paid on keeping patient data confidential and the study was in compliance with the Declaration of Helsinki.

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Disclosure

The authors report no conflicts of interest in this work.

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