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Prediction of Futile Recanalization Following Mechanical Thrombectomy for Acute Ischemic Stroke Using Quantitative Electroencephalography: Temporal Delta/Alpha Power Ratio as an Independent Predictor

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Abstract: *Objective*: Previous studies have reported associations between quantitative electroencephalography (QEEG) parameters and acute ischemic stroke (AIS). However, the relationship between QEEG parameters and clinical outcomes in AIS patients with complete intracranial recanalization post-thrombectomy has been rarely explored. This study aims to evaluate the relationship between the QEEG parameter, specifically the regional delta/alpha power ratio (DAR), and futile recanalization (FR) in AIS patients with anterior circulation large vessel occlusion undergoing mechanical thrombectomy. *Methods*: A retrospective study was conducted on AIS patients with anterior circulation large artery occlusion who underwent mechanical thrombectomy and achieved complete vessel recanalization (mTICI 2b or 3) between May 2020 and October 2021. Patients with complete recanalization were categorized into effective recanalization and FR groups based on their modified Rankin scale (mRS) scores at three months. The FR group was defined as having an mRS score of 3–6 at three months, while the effective recanalization group had an mRS score of 0–2. Univariate analysis was performed to identify factors associated with FR, and factors with $P < 0.05$ were further analyzed using binary logistic regression to determine independent predictors of FR. Receiver operating characteristic (ROC) curve analysis was employed to assess the predictive ability of identified factors for FR. *Results*: Among 152 patients, 81 had effective recanalization, while 71 had FR, resulting in an FR rate of 46.7%. Univariate analysis revealed that baseline characteristics such as admission NIH stroke scale (NIHSS) score, neutrophil ratio, hemorrhagic transformation rate, number of thrombectomy passes, and time to recanalization were higher, whereas ASPECTS score was lower in the FR group compared to the effective recanalization group, all with statistical significance ($P < 0.05$). Electrophysiologically, DAR values in the affected frontal and temporal regions were significantly higher in the FR group compared to the effective recanalization group ($P < 0.05$). After adjusting for potential confounders, multivariable adjusted regression analysis demonstrated that regional DAR (odds ratio [OR] 1.205 [95% CI 1.041–1.396], $P = 0.013$), neutrophil ratio (OR 1.040 [95% CI 1.040–1.081], $P = 0.042$), ASPECTS score (OR 0.556 [95% CI 0.397–0.780], $P = 0.001$), and admission NIHSS score (OR 1.209 [95% CI 1.064–1.373], $P = 0.004$) were independent predictors of FR. ROC analysis indicated that combining regional DAR, especially temporal DAR, with other clinical factors could effectively predict adverse outcomes. *Conclusion*: Baseline characteristics including NIHSS score, ASPECTS score, and neutrophil ratio are independent predictors of FR, while electrophysiological characteristics, particularly temporal DAR of regional DAR, are closely associated with adverse outcomes at three months post-mechanical thrombectomy in AIS patients with anterior circulation large vessel occlusion. This shows that models incorporating temporal DAR can effectively predict FR.

Keywords: Acute ischemic stroke; Quantitative electroencephalography; Delta/alpha power ratio; Mechanical thrombectomy; Futile recanalization

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1. Introduction

Acute ischemic stroke (AIS) is one of the leading causes of death and disability in China. More than one-third of patients suffer from large vessel occlusion, which represents a severe subtype of AIS with a poor prognosis and imposes significant societal and economic burdens [1]. The primary treatment modality for large vessel occlusive AIS involves intravascular therapy within the time window (<6 h) or beyond the extended time window (6-24 h) using perfusion imaging to re-establish blood flow through the occluded vessel, thus salvaging the ischemic penumbra [2–4]. However, multiple studies have indicated that 46% to 55% of patients undergoing intravascular therapy within the time window and 41% to 43% of patients undergoing intravascular therapy beyond the time window fail to achieve functional independence at 90 days post-recanalization (mRS 3–6), termed as futile recanalization (FR) [2–3, 5]. Clinical outcomes of completely recanalized patients with similar characteristics may vary. Current research suggests that predictive factors for FR may include the patient's clinical characteristics, time to initiation and intraoperative management of intravascular therapy, collateral circulation and hemodynamics, core infarct volume, cerebral edema, and baseline brain white matter hyperintensity, yet other predictors of adverse outcomes remain unclear [5–16].

For patients with poor prognosis due to extensive cerebral infarction, there is a significant enlargement of the ischemic core area, accompanied by decreased cerebral blood flow perfusion and more severe irreversible neuronal damage. Electroencephalography (EEG) can reflect changes in cortical neuronal metabolism and electrical activity. When cerebral blood flow (CBF) is impaired, faster frequency waves on EEG gradually decrease, while slower frequency waves increase. As cerebral blood flow perfusion continues to decline to the ischemic threshold, neurons undergo irreversible damage, resulting in an electrically silent EEG. By analyzing EEG frequency, rhythm, amplitude, waveform, and other variables, through frequency domain or time domain analysis, specific quantitative parameters are derived using particular function models, termed Quantitative Electroencephalogram (QEEG) [17–18]. Subsequently, direct observation of the distribution and changes in alpha, beta, theta, delta, and gamma frequency bands of EEG waves is conducted [18]. A review emphasizes that specific QEEG indices can assist clinicians in making clinical decisions regarding stroke. Continuous monitoring informs the efficacy of acute endovascular reperfusion therapy. Brief recording aids in prognosis prediction, clinical diagnosis, and treatment assistance [19]. QEEG can reveal neuronal activity in the ischemic penumbra of AIS, providing potential information for salvaging hypoperfused brain tissue of the penumbra [19–23]. Currently, most studies have identified the delta-alpha power ratio (DAR) as the QEEG-related index that shows the greatest value in AIS monitoring [19, 21, 24–25].

QEEG exhibits superior detection and localization capabilities compared to EEG. Delta lesions identified by QEEG have been demonstrated to correlate with lesion locations in neuroimaging studies, including MRI [19, 26]. Early studies suggested that in patients with ischemic stroke (IS) due to occlusion of the middle cerebral artery (MCA) and internal carotid artery (ICA), delta activity in EEG is most prominent at the ipsilateral frontotemporal central electrode as shown in **Figure 1** [19, 27]. Subsequent observations in MCA-AIS revealed maximal delta power at electrodes overlying the anterior hemisphere, with a few studies reporting the significance of ipsilateral single frontal area delta activity reduction (DAR) in AIS patients with anterior circulation large vessel occlusion [20, 25]. However, there is no clear data regarding the prognostic value of DAR in the anterior-temporal single electrode for AIS prognosis. Therefore, this study assesses the relationship between regional DAR (frontal DAR and temporal DAR) and clinical outcomes in AIS patients with complete reperfusion after endovascular thrombectomy of anterior circulation large vessel occlusion and utilizes ROC curves to evaluate the optimal regional quantitative EEG parameters combined with other factors for predicting FR after thrombectomy.

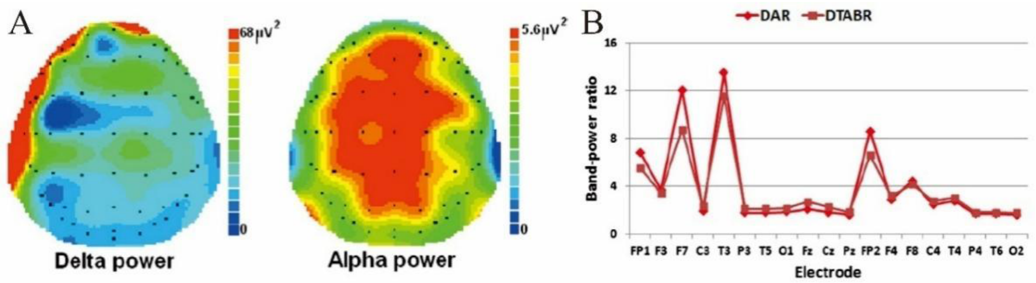

Figure 1. EEG data was obtained from a 7-hour post-stroke AIS (left middle cerebral artery) female patient with an NIHSS score of 7. Panel A: Topographic maps of average delta (left) power and alpha (right) power distribution. Panel B: Shows DAR (delta activity reduction) and (Delta+theta)/(alpha+beta) power ratio (DTABR) for each electrode. Values are highest at ipsilateral frontal and anterior temporal electrodes

2. Clinical data and methods

2.1. Study population

AIS patients with anterior circulation large vessel occlusion who underwent mechanical thrombectomy treatment either within or outside the time window after perfusion imaging assessment between January 2020 and October 2021 at the affiliated Three Gorges Hospital of Chongqing University were included, with signed informed consent.

2.1.1. Inclusion criteria

The inclusion criteria include the following. All patients diagnosed clinically according to the Diagnostic Criteria for Cerebral Infarction revised at the 2019 National Conference on Cerebrovascular Diseases and confirmed by head CT and/or MRI; age between 18 and 80 years; deficit symptoms consistent with occluded vessels; anterior circulation large vessel occlusion confirmed by cervical CTA or DSA (middle cerebral artery M1 or internal carotid artery); first-time stroke with no history of previous cerebral infarction; able to undergo EEG examination; emergency mechanical thrombectomy performed within or outside the time window after perfusion imaging assessment, achieving mTICI 2b or 3 reperfusion grade.

2.1.2. Exclusion criteria

The exclusion criteria include the following. CTA or DSA indicating concomitant contralateral large vessel stenosis or occlusion; concurrent ischemic lesions outside the territory of the ipsilateral or contralateral internal carotid artery or middle cerebral artery, such as brainstem infarction, occipital lobe infarction, cerebellar infarction, or multiple infarctions in both cerebral hemispheres; hemorrhagic diseases of the brain, cerebrovascular malformations, intracranial space-occupying lesions, arterial aneurysms, etc.; patients with unstable vital signs; history of previous stroke, epilepsy, or other neurological disorders such as encephalitis or drug poisoning; use of sedatives or psychotropic drugs before EEG monitoring, which may affect EEG results.

2.2. Research methods

Data collection was based on previous studies and experience, gathering general patient information, as detailed below.

2.2.1. Demographic data

Demographic data includes gender, age, history of alcohol consumption, history of smoking, and so on. The definitions are as follows.

History of alcohol consumption: Drinking frequency of ≥ 3 times per week, or alcohol intake exceeding 100 mg of alcohol concentration (50° or above), or consuming one can of beer (500 ml) per occasion.

History of smoking: Having smoked for more than 6 months cumulatively in the past, with a daily smoking habit of ≥ 1 cigarette, and a personal history of smoking within one month before the onset of the current stroke.

2.2.2. Clinical data

Collection of medical history (hypertension, diabetes, atrial fibrillation, history of previous stroke), admission clinical characteristics (National Institutes of Health Stroke Scale (NIHSS) score, pre-stroke modified Rankin Scale (mRS) score), site and etiology of infarction, Alberta Stroke Program Early CT Score (ASPECTS), blood glucose level, neutrophil ratio, and treatment details (treatment methods, number of thrombectomy procedures, hemorrhagic transformation) were included as baseline information. The relevant assessment criteria are as follows.

History of hypertension: Previously diagnosed with hypertension or currently taking antihypertensive medication; under resting conditions, systolic blood pressure ≥ 140 mmHg and/or diastolic blood pressure ≥ 90 mmHg measured on three separate occasions.

History of diabetes: Previously diagnosed with diabetes or currently taking antidiabetic medication; fasting blood glucose ≥ 7.0 mmol/L; glycated hemoglobin (HbA1c) ≥ 6.5%; oral glucose tolerance test: 2-hour postprandial blood glucose ≥ 11.1 mmol/L.

2.2.3. EEG data

Digital video EEG recordings were performed using equipment from Beijing Taiyang Company within 6–24 hours after mechanical thrombectomy. Electrodes were placed according to the international 10/20 system at FP1, FP2, F3, F4, F7, F8, T3, T4, T5, T6, O1, O2, P3, P4, C3, C4, Fz, Cz, and Pz locations. The referenced electrode was used as the baseline. After degreasing the skin, electrodes were attached using conductive gel and secured with medical-grade net caps. The paper speed was set at 3 cm/s, with a high-frequency filter of 35 Hz and a low-frequency filter of 0.5 Hz. EEG data were recorded for 30 minutes, with a stable and artifact-free baseline of 1800 ms selected. Through the fast Fourier transform (FFT), absolute power values in the delta, theta, alpha, and beta frequency bands were calculated based on the power spectrum generated by each electrode. Regional delta and alpha absolute power ratios were then calculated to determine hemisphere-specific DAR, including F-DAR and T-DAR, in the frontal and temporal regions.

2.3. Statistical methods

Data processing and analysis were performed using statistical product and service solutions (SPSS) 25.0 software. Continuous variables for two groups of patients (effective reperfusion group, mRS 0–2; FR group, mRS 3–6) were expressed as mean ± standard deviation (x ± s), while categorical variables were expressed as percentages (%). Normality tests for quantitative EEG parameters were conducted using Q-Q and P-P probability plots, indicating that DAR values in each hemisphere region were normally distributed. For single-factor analysis, independent *t*-tests were used for continuous data, and rank-sum tests and chi-square tests (χ^2) were used for categorical data comparison between the two groups. Factors with $P < 0.05$ in single-factor analysis were determined as independent risk factors for FR using binary logistic regression analysis. The predictive ability of these risk factors for FR was evaluated using ROC curves and the area under the curve of ROC (AUC).

3. Results

3.1. Univariate analysis

Data from a total of 152 AIS patients who underwent mechanical thrombectomy for complete recanalization of anterior circulation large vessel occlusion were collected, among which the FR rate was 46.7%. Among them, 81 cases were classified into the effective recanalization group with a mean age of 66.1 ± 12.2 years, and 71 cases were classified into the FR group with a mean age of 69.7 ± 11.5 years based on the mRS score at 3 months post-treatment. **Table 1** summarizes the descriptive analysis of baseline data for both groups of patients. The FR group showed significantly higher admission NIHSS score ($P < 0.001$), neutrophil ratio ($P = 0.011$), hemorrhagic transformation rate ($P < 0.001$), number of thrombectomy passes ($P < 0.001$), and time to recanalization ($P = 0.01$) compared to the effective recanalization group, while ASPECTS score ($P < 0.001$) was lower in the FR group than the effective recanalization group, all with statistical significance. **Table 2** displays the regional DAR descriptive analysis of the two groups of patients, showing the baseline values of F-DAR and T-DAR on the affected side and ipsilateral side in the FR group were higher than those in the effective recanalization group, with statistically significant differences observed in the affected side F-DAR ($P = 0.04$) and T-DAR ($P = 0.02$) baseline values compared to the effective recanalization group ($P < 0.05$).

Table 1. Univariate analysis of effective recanalization and FR groups after endovascular treatment for acute ischemic stroke

Variables	Effective recanalization group (*n* = 81)	Variables (*n* = 71)	*P* < 0.05
Demographics			
Age (x ± s)[a]	66.1 ± 12.243	69.7 ± 11.523	0.068
Gender (*n*, %)[b]			
Male	44 (54.3)	36 (50.7)	
Female	37 (45.7)	35 (49.3)	
Medical history			
History of hypertension (*n*, %)[b]	39 (48.1)	38 (53.5)	0.509
History of diabetes (*n*, %)[b]	15 (18.5)	15 (21.1)	0.687

Table 1 (Continued)

Variables	Effective recanalization group (*n* = 81)	Variables (*n* = 71)	*P* < 0.05
Atrial fibrillation (*n*, %)[b]	40 (49.4)	36 (50.7)	0.871
History of stroke (*n*, %)[b]	4 (4.9)	9 (12.7)	0.089
Admission evaluation			
NIHSS Score [c] (median)[b]	11 (9,15)	15 (14,16)	< 0.000
Pre-stroke mRS Score (*n*, %)[b]			0.797
0	78 (96.3)	65 (91.5)	
Others	3 (3.7)	6(8.4)	
Blood glucose (x±s)[a]	7.5 ± 2.4	8.2 ± 2.8	0.132
Neutrophil ratio (x±s)[a]	76.6 ± 12.2	81.2 ± 9.9	0.011
Imaging			
ASPECTS score (median)[c]	7 (5.5,8)	5 (5,6)	< 0.000
Infarcted vessels (*n*, %)[b]			0.191
ICA	17 (21)	23 (32.4)	
MCA-M1	54 (66.7)	40 (56.3)	
MCA-M2	7 (8.6)	5 (7)	
ICA+MCA	3 (3.7)	3 (4.2)	
Disease characteristics			
Onset time (x ± s)[a]	5.8 ± 4.3	6.8 ± 4.8	0.193
TOAST classification (*n*, %)[b]			
Large artery atherosclerosis	39 (48.1)	30 (42.3)	0.722
Cardioembolism	36 (44.4)	35 (49.3)	
Others	6 (7.4)	6 (8.5)	
Treatment (*n*, %)[b]			0.577
Thrombolysis & Thrombectomy	19 (23.5)	14 (19.7)	
Thrombectomy alone	62 (76.5)	57 (80.3)	
Number of thrombectomy passes (median)[c]	2 (1,2)	2 (2,3)	< 0.000
Time to recanalization (x ± s) [a]	115.8 ± 42.5	143. 3 ± 58.8	0.01
Hemorrhagic transformation (*n*, %) [b]	15 (18.5)	38 (53.5)	< 0.000

Note: x ± s: mean ± standard deviation; a: *t*-test; b: chi-square test (χ^2); c: Mann-Whitney *U* test; *n*: frequency

Table 2. Electrophysiological analysis of effective recanalization and FR groups after endovascular treatment for acute ischemic stroke

Electrophysiological factors	Effective recanalization group (*n* = 81)	FR group (*n* = 71)	*t*	*P* < 0.05
IH-F	1.947 ± 1.746	3.219 ± 3.288	2.919	0.04
IH-T	2.818 ± 2.452	4.528 ± 3.997	3.221	0.02
CH-F	1.710 ± 1.639	2.655 ± 2.886	2.434	0.17

CH-T	2.218 ± 2.147	3.185 ± 3.178	2.165	0.32

Note: IH-F: Ipsilateral hemisphere frontal area; IH-T: Ipsilateral hemisphere temporal area; CH-F: Contralateral hemisphere frontal area; CH-T: Contralateral hemisphere temporal area.

3.2. Multivariate analysis of factors associated with FR after endovascular treatment for acute ischemic stroke

The baseline data with **P** < 0.05 from the univariate analysis were subjected to binary logistic regression analysis. The chi-square value was 62.05, with a significance level of less than 0.01, indicating statistical significance at the 1% level. This suggests that the model has statistical significance. The log(-2)-likelihood value was 148.008, Cox-Snell *R* square was 0.335, and Nagelkerke *R* square was 0.448, indicating a high level of model fit. Therefore, the model provides a relatively ideal interpretation of the original data. The Hosmer-Lemeshow test yielded a chi-square value of 3.673, with a *P*-value of 0.878, indicating a good fit for the predicted model. Furthermore, the regional DAR (F-DAR, T-DAR) with *P* < 0.05 was combined with clinical baseline data for binary logistic analysis as shown in **Table 3**. The results showed that each group's model had statistical significance (*P* < 0.00), and their predictive fit was good (*P* > 0.05).

Table 3. Multivariate analysis of baseline information and electrophysiological characteristics after endovascular treatment for acute ischemic stroke

	Baseline information *n*[d]	**Baseline information [d] +IH-F**	**Baseline information [d] +IH-T**
Chi-square (model summary)	62.050	66.747	69.077
Sig	< 0.00	< 0.00	< 0.00
log(-2)-likelihood value	148.008	143.311	140.981
Cox-Snell *R* square	0.335	0.355	0.365
Nagelkerke *R* Square	0.448	0.475	0.488
Chi-Square (Hosmer-Lemeshow Test)	3.767	5.106	10.749
Sig (Hosmer-Lemeshow Test)	0.878	0.746	0.216

3.3. ROC analysis

Through ROC analysis, the predictive performance of baseline data in multivariate analysis for FR was evaluated, yielding an AUC of 0.848, with a sensitivity of 77.5% and specificity of 79%. Upon incorporating electrophysiological data of regional DAR, the optimal predictive performance was observed when combining ipsilateral T-DAR with baseline data of AUC = 0.859, sensitivity = 88.9%, and specificity = 88.9%. Subsequently, combining ipsilateral F-DAR with baseline data also showed good performance of AUC = 0.855, sensitivity = 86.4%, and specificity = 86.4%. However, all these performances were superior to baseline data alone as shown in **Figure 2** and **Table 4**.

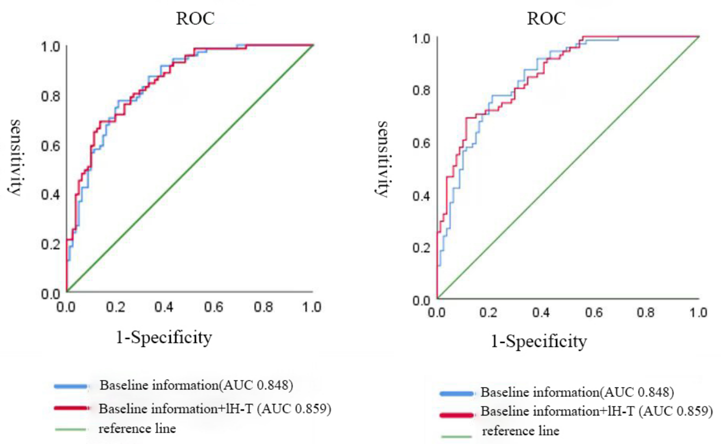

Figure 2. ROC Curve analysis of baseline information and electrophysiological characteristics following endovascular treatment for acute ischemic stroke; IH-F: Ipsilateral hemisphere-frontal DAR; IH-T: Ipsilateral hemisphere temporal DAR; CH-F: Contralateral hemisphere- frontal DAR; CH-T: Contralateral hemisphere temporal DAR

Table 4. Multifactor analysis of baseline information and electrophysiological characteristics following endovascular treatment for acute ischemic stroke

Factors	Baseline information [d]	Baseline information [d] +IH-F	Baseline information [d] +IH-T
Correct percentage (%)	75.7	74.6	75.0
AUC (95%CI)	0.848 (0.788, 0.908)	0.855 (0.797, 0.913)	0.859 (0.802, 0.915)
Threshold (%)	42.9	58.7	54.5
Sensitivity (%)	77.5	86.4	88.9
Specificity (%)	79	86.4	88.9
Sig	< 0.00	< 0.00	< 0.00

Note: IH-F: Ipsilateral hemisphere- frontal DAR; IH-T: Ipsilateral hemisphere temporal DAR; CH-F: Contralateral hemisphere- frontal DAR; CH-T: Contralateral hemisphere temporal DAR.

The ROC curve confirmed that the combination of baseline data with DAR in the affected temporal region was the optimal model. Binary logistic regression analysis revealed that regional DAR IH-T (odds ratio, 1.205 [95% CI: 1.041–1.396], $P = 0.013$), neutrophil ratio (odds ratio, 1.040 [95% CI: 1.040–1.081], $P = 0.042$), ASPECTS score (odds ratio, 0.556 [95% CI: 0.397–0.780], $P = 0.001$), and NIHSS score (odds ratio, 1.209 [95% CI: 1.064–1.373], $P = 0.004$) were independent predictive factors for FR (**Figure 3**).

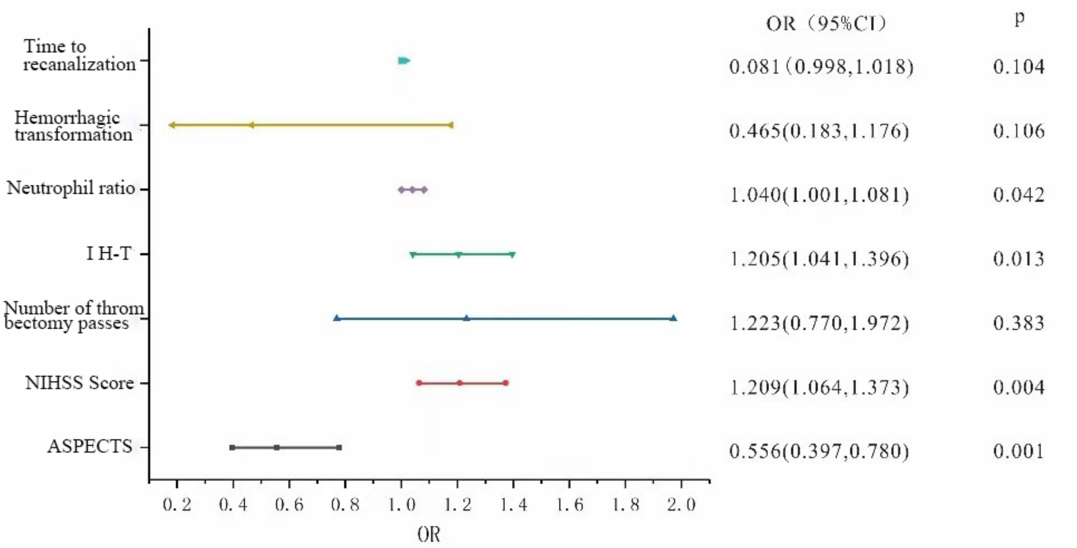

Figure 3. Multifactor analysis of baseline information and electrophysiological characteristics following endovascular treatment for acute ischemic stroke; OR: odds ratio; IH-T: Ipsilateral hemisphere temporal

4. Discussion

Mechanical thrombectomy is the standard treatment for anterior circulation large vessel occlusion AIS [28]. With advancements in thrombectomy devices, the rate of successful reperfusion can reach 71%–84%. However, vascular reperfusion as demonstrated by angiography does not necessarily indicate complete cerebral tissue reperfusion [5]. In this study, data from 152 patients with anterior circulation large vessel occlusion AIS was collected, showing the effective reperfusion rate after mechanical thrombectomy was 53.3%. Nearly half of the patients ultimately failed to achieve functional independence at 90 days. Therefore, predicting FR is crucial for making rational decisions regarding subsequent treatment for AIS patients.

Consistent with prior studies, this study concludes that NIHSS score, ASPECTS score, and neutrophil ratio are associated with poor outcomes. As clinical indicators reflecting the severity of neurological impairment and assessing prognosis, patients with NIHSS scores > 15 and ASPECTS scores ≤ 5 after successful reperfusion often indicate a poor prognosis. Biologically, experimental studies have found that in the pathological examination of proximal large vessel occlusion, early accumulation of platelets, fibrinogen, and neutrophils mostly occurs in the downstream microcirculation of the venous compartment. This phenomenon is referred to as downstream microvascular thromboinflammation (DMT). DMT can exacerbate cerebral ischemic injury, promote blood-brain barrier disruption, and facilitate hemorrhagic transformation [29–30]. This partially explains why neutrophil count is correlated with adverse clinical outcomes in these studies. This research also suggests that in patients with elevated neutrophil levels, irreversible cerebral infarction progresses rapidly after vessel occlusion, rendering reperfusion procedures often ineffective.

This study combined brain functional values to jointly evaluate the prognosis of patients with large-area cerebral infarction. In the QEEG, the regional DAR baseline in the FR group was higher than that in the successful reperfusion group ($P < 0.05$). Among them, DAR in the temporal region was identified as the optimal predictor for poor prognosis in patients with anterior circulation acute ischemic stroke before successful reperfusion. Combining baseline DAR in the temporal region with the affected side effectively predicts FR.

DAR is the relative ratio between slow and faster frequencies. Research has demonstrated the strongest negative correlation between δ power (1–3 Hz) and regional cerebral blood flow (rCBF), while α power (8–13 Hz) exhibits a relatively strong positive correlation with rCBF [19, 25]. The ratio between slow and fast frequencies essentially quantifies abnormalities, increasing the overall signal strength of slow activities, thus better reflecting the distribution, proportion, and amplitude changes of frequency bands. As cerebral perfusion decreases, brain cell metabolism also declines, cortical function deteriorates, and slow waves (delta or theta waves) increase in EEG recordings. Moreover, as perfusion decreases, cortical function declines and brain wave frequency slows down. Therefore, a higher slow wave index indicates more significant local brain tissue ischemia, indicating less local cerebral perfusion [17, 22, 27, 31]. In 1983, DAR was reported as the most reliable QEEG index for assessing poor prognosis in ischemic stroke from EEG recordings obtained from 11 electrodes [32]. In animal experiments, a close relationship between SEEG parameter alpha/delta power ratio and motor function recovery was observed following occlusion of the middle cerebral artery, monitored via EEG [33]. Some scholars have proposed that QEEG within the first 72 hours of stroke onset may be a powerful tool for predicting short-term and long-term prognosis in patients with acute ischemic stroke, with the highest prediction accuracy observed within 24 hours [23, 34]. Bentes et al. suggested that alpha, beta relative power, and DAR are optimal QEEG prediction indices [19, 34–35]. This study retrospectively analyzed QEEG within 24 hours postoperatively and concluded that DAR is an independent prognostic factor for FR, where a higher slow wave index indicates a poorer prognosis for patients.

In 2006, delta activity observed in patients with middle cerebral artery (MCA) infarction confirmed by MRI was found to originate from cortical regions within the blood supply area of the brain, particularly the anterior or lateral temporal lobe and lateral frontal lobe, with the highest DAR values observed in the temporal region [19, 36]. Subsequent studies reported that in patients with large vessel AIS, significant delta wave oscillations were observed in the ipsilateral hemisphere, particularly in the fronto-central and fronto-temporal electrodes, several hours after stroke onset, with the frontal region exhibiting the most pronounced average power [19, 37]. Although recent studies have utilized single-channel frontal DAR to assess AIS, the results have shown that frontal DAR can distinguish between AIS and non-AIS patients. Additionally, dynamic changes in frontal DAR during AIS treatment can evaluate treatment efficacy [20, 25, 37]. However, there is currently no clear data on the prognostic value of quantitative EEG parameters in the frontal and temporal regions for anterior circulation large vessel AIS. This study compared the average power of T-DAR in the ipsilateral hemisphere between the FR group and the successful reperfusion group post-thrombectomy and found that it had the greatest predictive ability for FR. It was demonstrated that for regional QEEG indices, ipsilateral hemisphere T-DAR had the optimal predictive efficiency, with a 20% increase in FR occurrence rate for every doubling of DAR value. Moreover, the combination of baseline data, NIHSS score, ASPECTS score, and neutrophil ratio, plays an important role in AIS prognosis and clinical management decisions. Furthermore, it was suggested in 2013 that the presence of delta activity in the contralateral hemisphere, as measured by EEG and magnetoencephalography, is an important prognostic factor after stroke, indicating a significant deterioration in cerebral pathophysiology [38]. A study in 2021 by Ferreira et al. reported significant delta activity in the contralateral frontal region in rats after middle cerebral artery occlusion [39]. However, this study did not observe differences in contralateral regional DAR between the two groups, and further research and analysis are needed to elucidate the role and specific mechanisms of contralateral slow waves.

A limitation of this study is its single-center design. The study focused on patients with occlusion of the M1 segment of the middle cerebral artery and/or internal carotid artery, but due to variations in the time of onset, the location and size of infarction differed among patients. The study did not conduct a comparative analysis after stabilization of the condition post-treatment, which may reduce its representativeness. Furthermore, similar to other QEEG studies, effectively identifying and excluding EEG artifacts may pose a challenge. Artifacts such as muscle interference affecting faster activities or eye movement interference affecting delta activities may be present. The difficulty in removing artifacts may limit the utility of QEEG.

5. Conclusion

Current research suggests that factors influencing FR may include patients' clinical characteristics, the initiation time and intraoperative procedures of endovascular treatment, collateral circulation and hemodynamics, core infarct volume, brain edema, and baseline cerebral white matter hyperintensities. This study indicates that admission NIHSS score, ASPECTS score, and neutrophil ratio are independent predictors of FR. Additionally, among electrophysiological features, temporal single-channel Delta/Alpha Ratio (DAR) is an independent predictor of poor prognosis after mechanical thrombectomy in patients with anterior circulation large vessel occlusion ischemic stroke. The predictive model combining quantitative EEG data can enhance the prediction ability of FR. Therefore, the relevant information from EEG should be considered in the assessment of FR. Further investigation into electrophysiological predictors of FR after endovascular treatment can help formulate effective interventions to reduce FR occurrence and improve the post-treatment prognosis of AIS patients. More extensive multicenter prospective studies are warranted to validate these findings and develop a reliable FR risk prediction model.

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Disclosure statement

The authors declare no conflict of interest.

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