Neuroradiology (2023) 65:609–618
https://doi.org/10.1007/s00234-022-03078-6

INTERVENTIONAL NEURORADIOLOGY

Endovascular treatment in patients with middle cerebral artery occlusion of different aetiologies

Xiangjun Xu[1] · Ke Yang[1] · Junfeng Xu[1] · Qian Yang[1] · Yapeng Guo[1] · Youqing Xu[1] · Hao Wang[1] · Liang Ge[1] · Zhiming Zhou[1] · Xianjun Huang[1]

Received: 27 June 2022 / Accepted: 21 October 2022 / Published online: 5 November 2022

Abstract

Purpose The purpose of this study was to evaluate differences in endovascular treatment (EVT) outcomes in M1 segment middle cerebral artery occlusion (MCAO) patients with different pathologic subtypes.

Methods Patients with MCAO who received EVT from July 2014 to December 2020 were categorized into three groups: embolism without internal carotid artery steno-occlusion (MCAO-E), in situ atherosclerotic thrombosis (MCAO-AS) and embolism from tandem ICA steno-occlusion (MCAO-T). Baseline characteristics, EVT-related factors and clinical outcomes were compared between groups. Multivariable regression analyses were performed to evaluate the relationship between aetiologic classification and outcomes at 90 days after stroke.

Results Among eligible patients ($n=220$), MCAO-E ($n=129$, 58.6%) was the most common aetiology, followed by MCAO-AS ($n=47$, 21.4%) and MCAO-T ($n=44$, 20.0%). Patients with MCAO-E were significantly older but had a lower rate of dyslipidaemia and smoking history than those with MCAO-AS. Although patients with MCAO-AS and MCAO-T more often required rescue balloon angioplasty and stenting ($p<0.001$), no significant difference in the rate of final recanalization was found. Patients in the MCAO-AS group obtained better functional outcomes (90-day modified Rankin Scale score, 0–2) ($p=0.002$) and lower mortality than in the MCAO-E group ($p=0.009$). On multivariable logistic regression, we failed to find that stroke subtype was an independent predictor of functional outcomes and mortality.

Conclusions Patients with acute MCA M1 occlusion stroke due to different pathogeneses had comparable successful recanalization rates and functional independence at 90 days. The optimal management for MCAO patients with different aetiologies requires further research.

Keywords Endovascular thrombectomy · Middle cerebral artery occlusion · Balloon angioplasty · Stenting

Introduction

The efficacy of endovascular treatment (EVT) for acute ischaemic stroke in the anterior circulation has been established after several randomized controlled trials based on western populations were published [1, 2]. Nevertheless, the incidence of stroke due to atherosclerosis, especially intracranial atherosclerosis (ICAS), is much higher in Asian populations. A previous study indicated that among Chinese patients, the prevalence of ICAS was as high as 46.6% [3]. Moreover, patients with underlying ICAS tend to be refractory to thrombectomy therapy, resulting in a lower rate of recanalization and more frequent reocclusion [4–6]. Thus, the treatment strategy and outcomes of EVT for patients with emergent large vessel occlusion (ELVO) may differ according to different pathologic mechanisms [7–11].

Several studies have compared EVT outcomes between patients with intracranial arterial stenosis (ICAS-O) occlusion and patients with embolic occlusion [7–11]. However, no previous studies conducted a separate analysis specifically concentrating on patients with middle cerebral artery occlusion (MCAO) stroke due to different aetiologies. More importantly, few studies distinguished cardiac embolism

Xiangjun Xu, Ke Yang and Junfeng Xu contributed equally to this work.

✉ Zhiming Zhou
neuro_depar@hotmail.com

✉ Xianjun Huang
doctorhuangxj@hotmail.com

[1] Department of Neurology, Yijishan Hospital, Wannan Medical College, Wuhu, Anhui Province, China

from embolism from tandem ICA steno-occlusion in the 'embolic' group [12], the risk factors, collateral circulation, treatment methods and clinical outcomes of which may be obviously different [12–14]. We believe that a better understanding of these mechanisms may help establish therapeutic strategies and improve outcomes in these patients. Herein, we aimed to explore whether there were differences about the clinical characteristics and outcome features of MCAO patients resulting from different aetiologies.

Methods

Patient selection and data collection

We retrospectively analysed all consecutive patients with acute MCAO who underwent EVT at our centre between July 2015 and December 2020. The local Institutional Review Board approved the study and waived the requirement for written informed consent based on the retrospective study design.

Patients who met the following inclusion criteria were enrolled in this study: (a) occlusion of the M1 segment of the middle cerebral artery identified by digital subtraction angiography (DSA); (b) prestroke modified Rankin Scale (mRS) score < 2; (c) and time from stroke onset to puncture (OTP) ⩽ 24 h. Exclusion criteria included: (a) preoperational Alberta Stroke Program Early computed tomography (ASPECT) score < 6, (b) multiple vessel occlusion or occlusion in sites other than the M1 segments, (c) stroke caused by other determined causes and stroke of undetermined cause, and (d) no postoperative imaging. Figure 1 shows a flow chart for the study population.

Classification of the stroke mechanism

Echocardiography by continuous electrocardiographic monitoring or Holter monitoring and transesophageal echocardiography were used to determine the cause of stroke. The aetiology of stroke was agreed upon by stroke specialists at a weekly stroke conference.

Patients with MCAO were assigned to three groups based on the following angiographic characteristics: embolism without internal carotid artery (ICA) steno-occlusion (MCAO-E, Fig. 2), in situ atherosclerotic thrombosis in the MCA (MCAO-AS, Fig. 3), and embolism from tandem ICA steno-occlusion (MCAO-T, Fig. 4). MCAO-AS was defined more than 70% residual stenosis evidenced during EVT or in the final angiography at the target MCA site with or without a tendency for reocclusion. The severity of arterial stenosis was calculated according to warfarin aspirin symptomatic intracranial disease (WASID) criteria [15]. MCAO-T was the stroke mechanism defined as simultaneous extracranial ICA severe stenosis (or near-occlusion) or complete occlusion

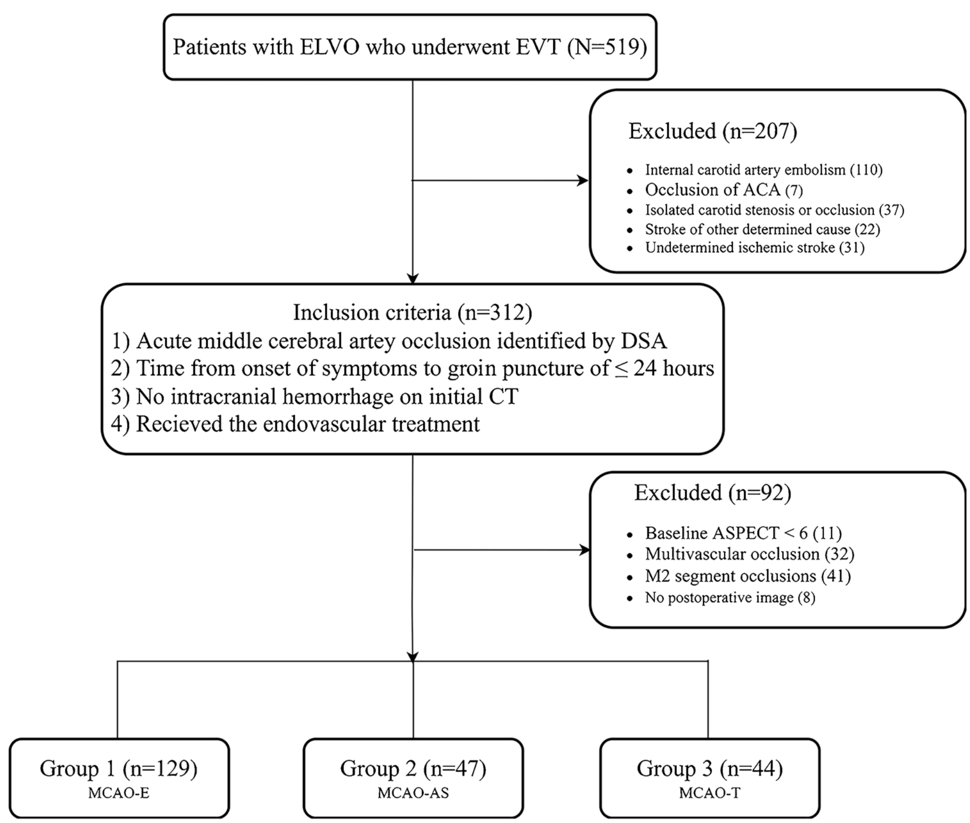

Fig. 1 The flow chart for inclusion

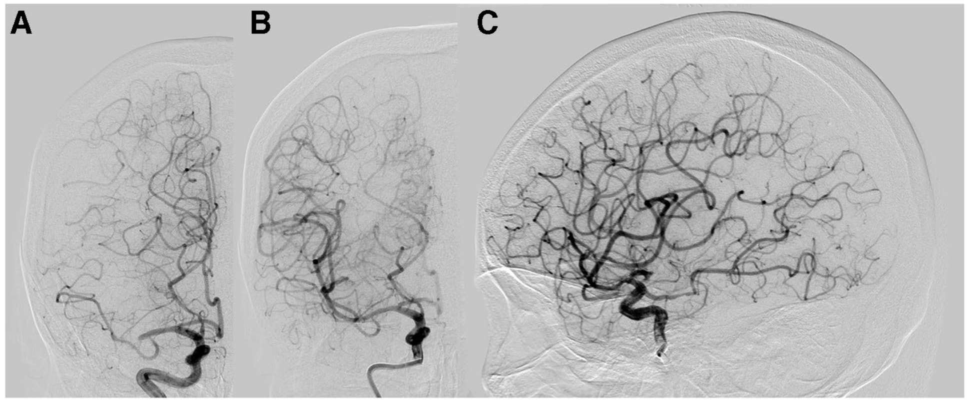

Fig. 2 Angiograms show right middle artery occlusion from embolism without ICA steno-occlusion (group 1) in 75-year-old man who presented with left side weakness and stare for 6 h. **A** Anteroposterior angiogram of right middle artery shows occlusion of M1segement. **B, C** After single attempt of stent retrieval, images show complete recanalization of middle artery without residual stenosis

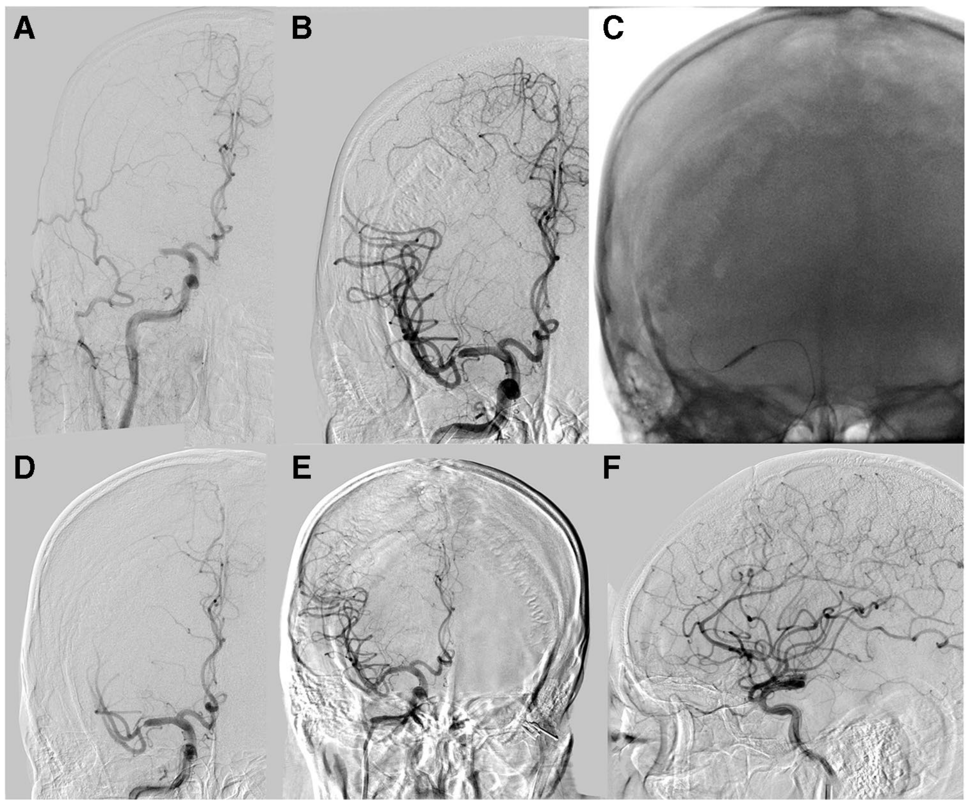

Fig. 3 Angiograms show right middle artery occlusion from in situ atherosclerotic thrombosis (group 2) in 63-year-old woman who presented with left-side weakness for 4 h. **A** Anteroposterior angiogram of right middle artery shows occlusion of M1segment of middle artery. **B** After single attempt of stent retrieval, image shows complete recanalization of middle artery with severe residual stenosis. **C**, **D** Rescue therapy failed, showing insufficient reperfusion after infusion with tirofiban, then a 2.0 × 20-mm Maverick balloon was used for expansion, but the MCA showed a tendency of re-occlusion. **E** A 2.5 × 8-mm Apollo stent was released. **F**, **G** Final angiogram shows recanalization with underlying atherosclerotic stenosis

plus MCAO determined by DSA or CTA [14]. When no evidence of MCAO-AS or MCAO-T was depicted, combined with a history of possible cardiogenic embolism, MCAO-E was considered to be the mechanism of stroke.

Endovascular treatment

The procedures were performed by experienced neurointerventionists. Different approved modalities were used during endovascular treatment, including aspiration thrombectomy (Penumbra, Alameda, CA, USA; Sofia), stent retrievers (Solitaire, Medtronic, Irvine, CA, USA), or combinations. Remedial action should be taken if reperfusion failed after the Solumbra or ADAPT technique. Intracranial angioplasty (Boston Scientific, Natick, MA, USA) with or without an Apollo balloon-mounted stent (MicroPort, Shanghai, China) or self-expanding stenting (Solitaire or Enterprise, Codman, Raynham, MA, USA) was performed when severe stenosis (more than 70%) or any degree of stenosis with insufficient reperfusion or reocclusion underlying ICAS of the MCA was observed on follow-up angiography after a mechanical thrombectomy procedure. Regarding the technical issue in the treatment of tandem lesions, proximal (extracranial) lesion- or distal (intracranial) lesion-first techniques were applied at the discretion of the operators. Intravenous administration of tirofiban (glycoprotein IIb/IIIa inhibitor) was

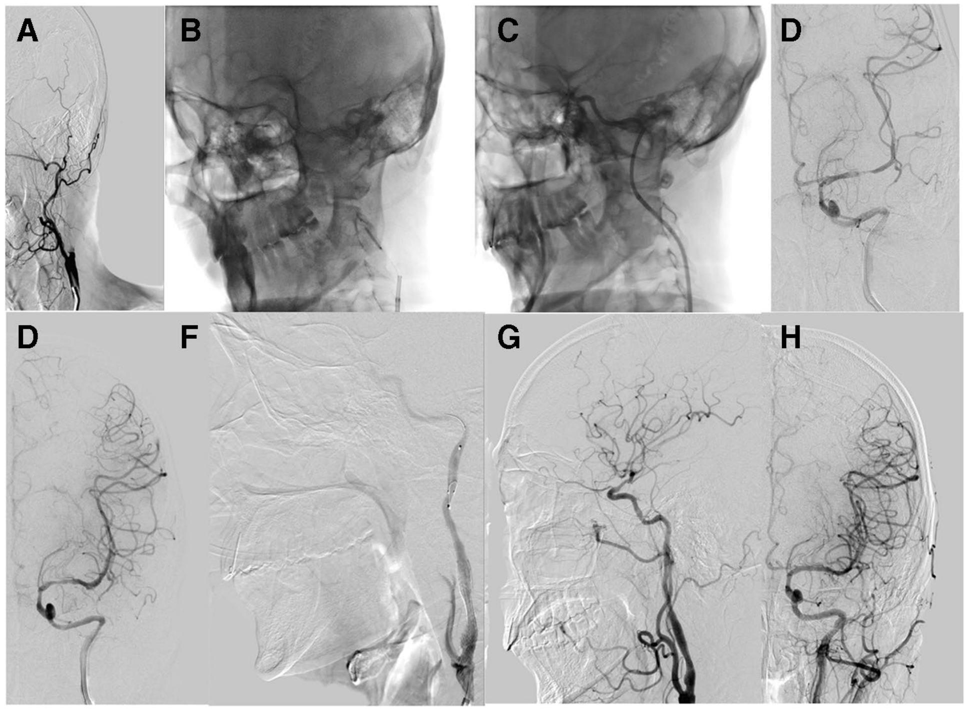

Fig. 4 A patient presented with right-side weakness and aphasia for 15 h was presented to the Emergency Room. NIHSS was 10 on presentation secondary to a left MCA syndrome. **A** DSA shows inclusion of left ICA with impaired antegrade flow. **B, C** Anteroposterior lateral image obtained after balloon angioplasty (Boston Scitific, Maverick; 2.0/20 mm) of left ICA shows tandem occlusion of left MCA. **D** After single attempt of stent retrieval, image shows complete recanalization of left MCA (**E**, **F**). A 6–8 × 40-mm Acculink stent was planted at the left ICA. **G**, **H** image shows complete recanalization of left ICA and MCA

used as antiplatelet therapy following rescue angioplasty with or without stenting, and then aspirin and clopidogrel were administered with tirofiban for 4 h, 24 h after the procedure, except when CT confirmed cerebral haemorrhage. Because of the emergency setting, we did not have access to test for the thromboelastography and clopidogrel gene polymorphisms. Part of the patients who undergo angioplasty or stent would receive the test of the thrombelastography and CYP2C19 polymorphisms postoperatively, once clopidogrel resistance was confirmed; aspirin combined with ticagrelor was established as the antiplatelet strategy. All strategies and devices for recanalization therapy were selected at the discretion of the operators.

Outcome measurement

The mRS score was used to assess 90-day clinical outcomes, which were divided into favourable (mRS score, 0–2 points) and poor (mRS score, 3–6 points). Recanalization status was assessed by the modified thrombolysis in cerebral infarction (mTICI) scale on the final angiogram, with scores of 0 to 2a defined as unsuccessful and scores of 2b to 3 defined as successful reperfusion. The safety outcomes included 90-day mortality and symptomatic intracerebral haemorrhage (sICH). sICH was regarded as any type of intracerebral haemorrhage on posttreatment imaging with at least a 4 point increase in NIHSS. Intracerebral haemorrhage (ICH) was diagnosed and classified, according to the European Cooperative Acute Stroke Study [16].

Collateral circulation was evaluated according to the DSA, adopting a 3-point scale score based on the following criteria: grade 0 (no filling or less than 1/3 filling of the occluded region), grade 1 (more than 1/3 but less than 2/3 filling of the occluded region) and grade 2 (more than 2/3 filling of the occluded region) [17, 18].

Statistical analysis

Patient baseline characteristics and outcome data were analysed and presented as the frequency, mean, SD, median and interquartile range. When comparing 3 groups, the Kruskal–Wallis test was applied for non-normally distributed continuous variables and the chi-square test for dichotomous variables, and then pairwise comparisons between the three groups were made three times (Group 1 vs. 2, Group 1 vs. 3, Group 2 vs. 3) Multivariable logistic regression controlling for potential confounders was performed to identify variables independently associated with clinical outcomes at 90 days for variables at the 0.1 level of significance on univariate analysis. IBM SPSS Statistics for Windows (version 25.0; IBM Corp, Armonk, NY) software was applied for all statistical analyses. A two-sided p value < 0.05 was regarded as statistically significant. In order to reduce the probability of type I error, we defined the p value threshold of < 0.016 with Bonferroni correction as statistically significant for multiple comparisons.

Results

Patient characteristics

A total of 220 patients were included for final analysis It is worth noting that stroke caused by other determined causes (arterial dissection, $n=19$, carotid artery web, $n=1$, carotid stent occlusion, $n=1$, lymphoma, $n=1$) was also excluded in the present study (Fig. 1). The baseline demographics are shown in Table 1. MCAO-E (129/220, 58.6%) was the most prevalent stroke mechanism, followed by MCAO-AS (47/220, 21.4%) and MCAO-T (44/220, 20.0%). Patients in the MCAO-E and MCAO-T groups were older and had more severe neurological deficits than those in the MCAO-AS group. As expected, atrial fibrillation was observed more frequently in the MCAO-E group (86.0% vs 4.3% in MCAO-AS and 4.5% in MCAO-T, $p<0.001$). Additionally, the frequencies of smoking and lipid levels were lower in the MCAO-E group than in the MCAO-AS and MCAO-T groups. However, no significant differences in the proportions of hypertension and diabetes mellitus were observed between three groups.

Procedural and clinical outcomes

The time from symptom onset to puncture (OTP) was longest in the MCAO-AS group (300 min; interquartile range [*IQR*], 240 to 434), followed by the MCAO-E group (280 min; *IQR*, 230 to 330) and MCAO-T group (270 min; *IQR*, 203 to 326) ($p=0.037$). The time from onset to recanalization (OTR) was also obviously longer in the MCAO-AS group ($p=0.034$). The procedure times were significantly longer in the MCAO-T group than in the MCAO-E group ($p=0.002$).

Balloon angioplasty and stenting for MCA were performed significantly more frequently in the MCAO-AS group than in the MCAO-E and MCAO-T groups. Balloon angioplasty and stenting for ICA were performed more frequently in the MCAO-T group than in the MCAO-E and MCAO-AS groups. Tirofiban was administered more frequently in MCAO-AS and MCAO-T groups ($p<0.001$). Unexpectedly, no significant differences were found regarding successful recanalization, with rates of 83.7%, 87.2% and 79.5% in the MCAO-E, MCAO-AS and MCAO-T groups, respectively.

The MCAO-E group showed a lower good clinical outcome rate than the MCAO-AS and MCAO-T groups (63/129, 48.8%; 35/47, 74.5%; 30/44, 68.2%; $p<0.05$). However, the difference between MCAO-E and MCAO-T did not reach statistical significance after adjusting the p value threshold to <0.0167 with Bonferroni correction for multiple comparisons. In addition, 90-day mortality was observed more often in the MCAO-E group than in the MCAO-AS group (31/129, 24.0%; 3/47, 6.4%; $p=0.009$). The distribution of mRS scores of 0–6 at 90 days is displayed in Fig. 5.

No significant difference in the sICH rate was found between the three groups, but the proportion of parenchymal haematoma 2 (PH2) was slightly higher in the MCAO-E

Table 1 Comparison of baseline characteristics among MCAO subtypes

Variables	MCAO-E	MCAO-AS	MCAO-T	p value			
	(Group 1, $n=129$)	(Group 2, $n=47$)	(Group 3, $n=44$)	Overall	Group 1 vs. 2	Group 1 vs. 3	Group 2 vs. 3
Age (years)	73 (67–78)	61 (54–70)	65 (53–74)	<0.001	<0.001	<0.001	0.237
NIHSS score, median (IQR)	14 (13–18)	13 (8–15)	15 (12–18)	<0.001	<0.001	0.764	0.004
ASPECT	8 (8–9)	9 (8–10)	9 (8–10)	0.040	0.314	0.012	0.204
Sex				0.001	0.083	<0.001	0.075
Male	69 (53.5)	32 (68.1)	37 (84.1)				
Female	60 (46.5)	15 (31.9)	7 (15.9)				
Hypertension	85 (65.9)	32 (68.1)	33 (75.0)	0.534	0.785	0.263	0.466
Diabetes mellitus	18 (14.0)	12 (25.5)	4 (9.1)	0.073	0.071	0.403	0.040
Atrial fibrillation	111 (86.0)	2 (4.3)	2 (4.5)	<0.001	<0.001	<0.001	1.000
Smoking	17 (13.2)	27 (57.4)	23 (52.3)	<0.001	<0.001	<0.001	0.620
Laboratory findings							
*Total cholesterol (mmol/l)	3.9 (1.0)	4.5 (0.9)	4.2 (1.0)	0.001	0.001	0.350	0.299
*Triglyceride (mmol/l)	0.9 (0.7–1.1)	1.4 (1.1–1.9)	1.2 (0.9–1.5)	<0.001	<0.001	<0.001	0.074
†LDL-C (mmol/l)	2.0 (1.5–2.5)	2.5 (2.2–2.9)	2.3 (1.8–2.9)	<0.001	<0.001	0.010	0.218

MCAO middle cerebral artery occlusion, *ICA* internal carotid artery, *NIHSS* National Institutes of Health Stroke Scale, *IQR* interquartile range, *ASPECT* Alberta Stroke Program Early CT, *LDL-C* low-density lipoprotein cholesterol

*Missing data in five patients

†Missing data in six patients

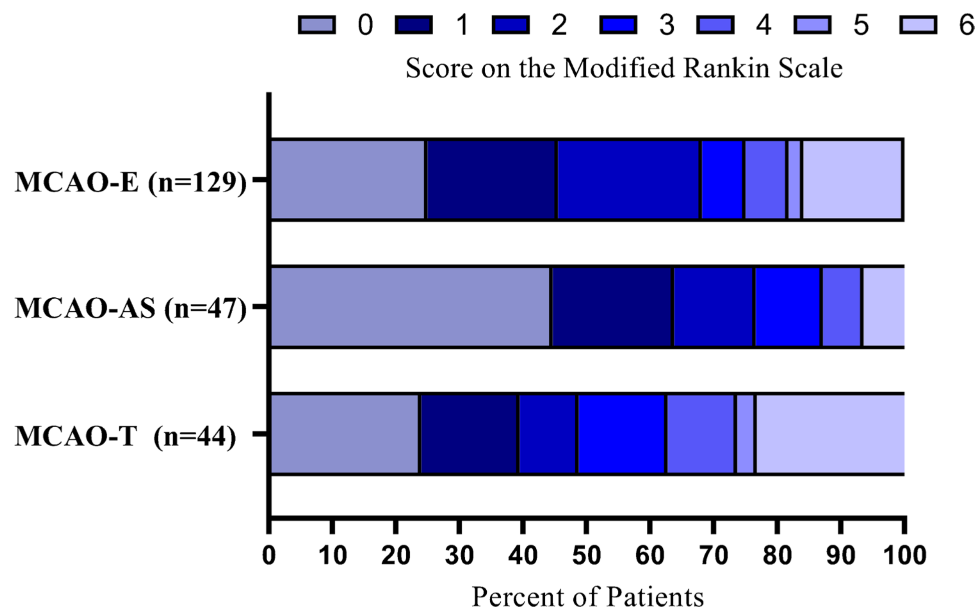

Fig. 5 Distribution of mRS scores at 90 days, according to different etiologies

group than in the MCAO-AS group (12.4% vs. 2.1%, $p = 0.045$) (Table 2).

Multivariate logistic regression analysis showed that age (*OR* = 1.054, 95% *CI* 1.015 to 1.094; $p = 0.006$), the NIHSS score at presentation (*OR* = 1.100, 95% *CI* 1.006 to 1.203; $p = 0.036$), admission ASPECT score (*OR* = 0.651, 95% *CI* 0.472 to 0.899; $p = 0.009$), diabetes mellitus (*OR* = 2.630, 95% *CI* 1.035 to 6.685; $p = 0.042$), collateral status (grade 2 versus grade 0: *OR* = 0.100, 95% *CI* 0.029 to 0.353; $p < 0.001$), mTICI after the procedure (*OR* = 0.365, 95% *CI* 0.144 to 0.924; $p = 0.033$) and sICH (*OR* = 23.27, 95% *CI* 2.528 to 214.19; $p = 0.005$) were independently associated with functional independence at 90 days (Table 3). Binary logistic regression analysis revealed that the following variables were independently associated with 90-day mortality: hypertension, atrial fibrillation, collateral status, revascularization status and sICH score (additional data are given in Supplemental Table 1). Unexpectedly, we failed to find that stroke subtype could independently predict functional outcomes and mortality.

Discussion

We examined the procedural and clinical outcomes of EVT for acute MCAO of different aetiologies in Chinese patients. First, we found that MCAO-E was the most frequent aetiology (58.6%), followed by MCAO-AS (21.4%) and MCAO-T (20%). The results were most similar to the findings of Lee, where the proportions of the above three subtypes were 57%, 24% and 19%, respectively [12].

Second, although we did not find differences in clinical outcomes among patients with different aetiologies of MCAO, a trend towards better outcomes for MCAO-AS was noted. Moreover, the 90-day mortality rate in patients with MCAO-AS was lower than in the other patients. Although several published studies assessed discrepancies among patients with ICAS-related occlusion with embolic occlusion, the conclusions were inconsistent. Kim et al. [4] and Lee et al. [9] showed worse clinical outcomes in patients with ICAS [9]. The Endovascular therapy for Acute Ischemic Stroke Trial (EAST) in China reported comparable 90-day functional independence between the embolic group and the ICAS group [10]. In contrast, Yoon et al. [11] suggested that patients with ICAS-O have a more favourable prognosis than those with embolism. We assumed that the inhomogeneous populations and occlusion sites led to the disparate results [19].

Several factors might explain the higher rate of favourable outcomes in patients with MCAO-AS in this study. First, the patients with MCAO-AS had lower baseline NIHSS scores at presentation and were younger than patients with MCAO-E. Second, the patients with MCAO-AS may have lower clot burden than patients with embolism. A lower clot burden was associated with a higher recanalization rate and a more favourable clinical outcome in the Multicentre Randomized Clinical Trial of Endovascular Treatment for Acute Ischemic Stroke in the Netherlands (MR-CLEAN) [20]. Third, the proportion of parenchymal haematoma was slightly higher in the MCAO-E group, although glycoprotein IIb/IIIa inhibitors were used more often in the other two groups. In the ACTUAL investigation (Endovascular Treatment for Acute Anterior Circulation Ischemic Stroke Registry) in China, patients with ischaemic stroke of cardioembolic origin had a higher risk of intracranial haemorrhage than patients with other stroke subtypes [21]. More

Table 2 Procedural characteristics and outcomes in patients with MCAO caused by three different etiologies

Variables	MCAO-E	MCAO-AS	MCAO-T	*p* value			
	(Group 1, *n* = 129)	(Group 2, *n* = 47)	(Group 3, *n* = 44)	Overall	Group 1 vs. 2	Group 1 vs. 3	Group 2 vs. 3
Time variables (min)							
OTP, media (*IQR*), min	280 (230–330)	300 (240–434)	270 (203–326)	0.037	0.022	0.607	0.022
Procedure time (*IQR*), min	50 (35–80)	60 (40–90)	68 (52.75–89.75)	0.002	0.219	0.001	0.059
OTR, media (*IQR*), min	344 (280–388.0)	364 (318–499)	332.5 (278.5–401.3)	0.034	0.015	0.816	0.030
Prior use of intravenous rt-PA	12 (9.3)	4 (8.5)	3 (6.8)	0.874	1.000	0.763	1.000
Angioplasty for MCA							
Balloon angioplasty	3 (2.3)	34 (72.3)	2 (4.5)	< 0.001	< 0.001	0.602	< 0.001
Stenting	6 (4.7)	18 (38.3)	5 (11.4)	< 0.001	< 0.001	0.150	0.003
Angioplasty for ICA							
Balloon angioplasty	0 (0)	0 (0)	40 (90.9)	< 0.001		< 0.001	< 0.001
Stenting	0 (0)	0 (0.0)	33 (75.0)	< 0.001		< 0.001	< 0.001
Infusion of Tirofiban	36 (27.9)	39 (83.0)	36 (81.8)	< 0.001	< 0.001	< 0.001	0.884
Collateral status				0.212	0.198	0.836	0.505
Grade 0	18 (14.0)	3 (6.4)	6 (13.6)				
Grade 1	41 (31.8)	12 (25.5)	12 (27.3)				
Grade 2	70 (54.3)	32 (68.1)	26 (59.1)				
mTICI grade 2b or 3	108 (83.7)	41 (87.2)	35 (79.5)	0.612	0.567	0.528	0.323
ICH							
Haemorrhagic infarction,1	19 (14.7)	6 (12.8)	12 (27.3)	0.111	0.741	0.061	0.083
Haemorrhagic infarction,2	7 (5.4)	2 (4.3)	6 (13.6)	0.159	1.000	0.097	0.149
Parenchymal haematoma, 1	2 (1.6)	1 (2.1)	0 (0)	1.000	1.000	1.000	1.000
Parenchymal haematoma, 2	16 (12.4)	1 (2.1)	2 (4.5)	0.063	0.045	0.165	0.608
sICH	15 (11.6)	1 (2.1)	3 (6.8)	0.121	0.073	0.568	0.350
mRS score at 90 d	3 (1–5)	1 (0–2)	2 (0–4)	0.002	< 0.001	0.227	0.059
mRS score 0–2 at 90 d	63 (48.8)	35 (74.5)	30 (68.2)	0.003	0.002	0.026	0.507
Mortality at 90 d	31 (24.0)	3 (6.4)	7 (15.9)	0.025	0.009	0.261	0.188

MCAO middle cerebral artery occlusion, *IQR* interquartile range, *OTP* symptom onset to groin puncture time, *OTR*, symptom onset to recanalization time; *rt-PA* recombinant tissue plasminogen activator, *MCA* middle cerebral artery, *ICA* internal carotid artery, *mTICI* modified thrombolysis in cerebral infarction, *ICH* intracerebral haemorrhage, *sICH* symptomatic intracerebral haemorrhage, *mRS* modified Rankin Scale score

recently, data from the Endovascular Treatment Key Technique and Emergency Work Flow Improvement of Acute Ischemic Stroke (ANGEL-ACT) also showed an increased risk of parenchymal haemorrhage in patients with cardiac embolism [22]. Cardioembolic stroke generally results in a larger core infarct and a smaller penumbra [23], which may increase the risk of ICH [24]. Thus, the greater severity at admission and higher occurrence of postoperative ICH may partly explain the higher proportion of 90-day mortality.

Unexpectedly, we did not find differences in favourable outcome, 90-day mortality and sICH rates between MCAO-AS and MCAO-T, presumably because both MCAO-AS and MCAO-T require a longer time for complete arterial occlusion, allowing the formation of adequate collateral flow prior to the onset of acute stroke, as reflected by the high proportion of grade 2 collateral circulation between the two groups, as shown in Table 2.

Of note, although significant differences in favourable outcomes and 90-day mortality were not detected in our study, time variables vary according to different aetiologies of MCAO. The MCAO-AS group seemed to have a longer OTR than the MCAO-E group. In addition, we observed that the procedure time was longer in patients in the tandem group than in patients with embolism. We speculated that reasonable optimization procedures may improve the prognosis of EVT patients with different aetiologies.

Table 3 Comparison of variables stratified by outcome in the overall cohort

Variables	Favorable outcome (*n* = 128)	Poor outcome (*n* = 92)	*p* value	Odds ratio (95% *CI*)	*p* value
Age (years)	67 (57–75)	73 (67–78)	< 0.001	1.054 (1.015–1.094)	0.006
NIHSS score, median (*IQR*)	14 (11–16)	15 (13–19)	< 0.001	1.100 (1.006–1.203)	0.036
ASPECT	9 (8–10)	8 (7–9)	< 0.001	0.651 (0.472–0.899)	0.009
Sex			0.629		
Male	82 (64.1)	56 (60.9)			
Female	46 (35.9)	36 (39.1)			
Hypertension	81 (63.3)	69 (75.0)	0.066		
Diabetes mellitus	15 (11.7)	19 (20.7)	0.071	2.630 (1.035–6.685)	0.042
Atrial fibrillation	54 (42.2)	61 (66.3)	< 0.001		
Smoking	47 (36.7)	20 (21.7)	0.017		
Laboratory findings					
*Total cholesterol (mmol/l)	4.12 (0.87)	4.07 (1.10)	0.743		
*Triglyceride (mmol/l)	1.1 (0.8–1.5)	0.9 (0.7–1.3)	0.058		
†LDL-C (mmol/l)	2.3 (1.8–2.7)	2.1 (1.5–2.6)	0.061		
Time variables (min)					
OTP, media (*IQR*), min	298 (240–347)	274 (230–330)	0.375		
Procedure time (*IQR*), min	55 (40–77)	63 (40–92)	0.119		
OTR, media (*IQR*), min	348 (280–405)	345 (288–399)	0.979		
Prior use of intravenous tPA	11 (8.6)	8 (8.7)	0.979		
Collateral status			< 0.001		< 0.001
Grade 0	4 (3.1)	23 (25.0)	Reference		
Grade 1	30 (23.4)	35 (38.0)		0.314 (0.087–1.136)	0.077
Grade 2	94 (73.4)	34 (37.0)		0.100 (0.029–0.353)	< 0.001
mTICI grade 2b or 3	114 (89.1)	70 (76.1)	0.010	0.365 (0.144–0.924)	0.033
sICH	1 (0.8)	18 (19.6)	< 0.001	23.27 (2.528–214.19)	0.005
Group 1	63 (49.2)	66 (71.7)	0.003		
Group 2	35 (27.3)	12 (13.0)			
Group 3	30 (23.4)	14 (15.2)			

NIHSS National Institutes of Health Stroke Scale, *ASPECT* Alberta Stroke Program Early CT, *IQR* interquartile range, *LDL-C* low-density lipoprotein cholesterol, *OTP* symptom onset to groin puncture time, *tPA* alteplase, *mTICI* modified thrombolysis in cerebral infarction, *OTR* symptom onset to recanalization time, *sICH* symptomatic intracerebral haemorrhage, *CI* confidence interval

*Missing data in five patients

†Missing data in six patients

Additionally, appropriate treatment strategies for different aetiologies may improve operational procedures. In our study, treatment plans varied according to different aetiologies of MCAO, which may be the reason for the lack of a significant difference in the time interval from puncture to final successful recanalization. However, this result differed from those in previous studies [9, 10, 12, 25]. Previous studies showed that the time from puncture to recanalization in MCAO-AS patients was always significantly longer than that in embolism patients. Additionally, the final recanalization status was comparable between groups through multiple endovascular management techniques, which may be one of the main reasons leading to no difference in the prognosis between the groups in this study. Therefore, achieving successful reperfusion as soon as possible is strongly associated with better clinical outcomes regardless of the aetiology of MCAO [26].

Similar to previous investigations, this study also showed that a favourable pretreatment collateral status was associated with a better functional outcome at 90 days after EVT [27]. However, clinical research on the association between stroke aetiology and collateral status yielded inconsistent results. Some previous studies suggested that patients with ICAS had better collateral flow than those with other stroke subtypes, which was significantly associated with better clinical outcomes [13, 28], while some other studies failed to demonstrate that stroke aetiology was a predictor of collateral status [29]. In the present study, no significant difference in collateral status was detected between the three different groups. The discrepant results between studies can be explained by different inclusion criteria, and most studies showed a higher rate of intracranial internal carotid artery and terminal internal carotid artery occlusions [13, 28], which may have been due to differences in collateral status between patients with cervical large-artery atherosclerosis and ICA embolization stroke. To eliminate the possible bias caused by different occlusion sites, we included only patients with MCA M1 occlusion and obtained a different result.

Our study had several limitations. First, this was a retrospective study conducted in a single stroke centre in China. Thus, the results of this study are not generalizable to the entire Chinese population or to other ethnic groups. Second, patients with ICAS are characterized by a high rate of reocclusion, which might be associated with poor outcomes. However, not all patients in our centre underwent follow-up CT angiography or MRA to confirm the maintenance of recanalization, and the lack of reocclusion data in the current study impedes further analysis of this factor. Third, some imbalances in baseline characteristics were noted between the groups.

However, our study differs notably from earlier studies, particularly with respect to the classification approach and patient selection criteria. First, we attempted to distinguish between embolism from tandem ICA steno-occlusion and cardiac embolism. Although previous studies assessed differences between ICAS-related occlusion and embolic occlusion, few studies have distinguished embolism due to tandem lesions from cardiogenic embolism. Second, to eliminate the influence of occlusion sites, we recruited only patients with MCA M1 occlusion. Third, the degree of collateral status was evaluated objectively. Although a previous study attributes the relatively mild neurological deficits in patients with ICAS to excellent collateral flow, the authors reached this conclusion based on the results of previous studies. We describe the results of the collateral circulation of MCAO, which showed no significant differences between different subtypes, despite the longer OTP and longer OTR in the MCAO-AS group. This indicated that patients with MCAO-AS in the condition of longer OTP, CT perfusion assessment may be helpful in identifying patients with excellent collateral circulation, who tend to benefit from EVT.

Conclusions

In conclusion, our study showed that patients with MCAO-AS were younger and less severe than patients with cardiogenic embolism. The recanalization rate and 90-day outcomes did not differ among the three groups, while the MCAO-AS group tended to show better functional outcomes and less mortality at 90 days.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00234-022-03078-6.

Authors' contributions XX, XH, and ZZ planned and conceived the study. WH and GL collected the data. QY and KY analyzed the image; YG and XY interpreted the data. XX, KY, WW, and JX wrote and critically revised the manuscript. All the authors have read and approved the final manuscript.

Funding This work was supported by the Anhui University Provincial Natural Science Research Project (No. KJ2021A0843) and the Scientific Research Project for middle-aged and young people of Wannan Medical College (No. WK2020F24).

Availability of data and materials The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Code availability Statistical code is available upon reasonable request.

Declarations

Conflict of interest We declare that we have no conflict of interest.

Ethics approval Subjects (or their parents or guardians) have given their written informed consent for being treated. The paper is exempt from ethical committee approval, since endovascular thrombectomy is considered the standard of care for treating acute ischemic stroke, and there has been no disclosure of the patients' information in this paper.

Consent to participate The need for individual patient consent has been waived.

Consent for publication The need for individual patient consent has been waived; therefore consent for publication is not required.

References

1. Jovin TG, Chamorro A, Cobo E, de Miquel MA, Molina CA, Rovira A et al (2015) Thrombectomy within 8 hours after symptom onset in ischemic stroke. N Engl J Med 372:2296–2306. https://doi.org/10.1056/NEJMoa1503780
2. Bracard S, Ducrocq X, Mas JL, Soudant M, Oppenheim C, Moulin T et al (2016) Mechanical thrombectomy after intravenous alteplase versus alteplase alone after stroke (THRACE): a randomised controlled trial. Lancet Neurol 15:1138–1147. https://doi.org/10.1016/S1474-4422(16)30177-6
3. Wang Y, Zhao X, Liu L, Soo YO, Pu Y, Pan Y et al (2014) Prevalence and outcomes of symptomatic intracranial large artery stenoses and occlusions in China: the Chinese Intracranial Atherosclerosis (CICAS) Study. Stroke 45:663–669. https://doi.org/10.1161/STROKEAHA.113.003508
4. Kim GE, Yoon W, Kim SK, Kim BC, Heo TW, Baek BH et al (2016) Incidence and clinical significance of acute reocclusion after emergent angioplasty or stenting for underlying intracranial stenosis in patients with acute stroke. AJNR Am J Neuroradiol 37:1690–1695. https://doi.org/10.3174/ajnr.A4770
5. Al Kasab S, Almadidy Z, Spiotta AM, Turk AS, Chaudry MI, Hungerford JP et al (2017) Endovascular treatment for AIS with underlying ICAD. J Neurointerv Surg 9:948–951. https://doi.org/10.1136/neurintsurg-2016-012529
6. Lee JS, Hong JM, Lee KS, Suh HI, Choi JW, Kim SY (2016) Primary stent retrieval for acute intracranial large artery occlusion

due to atherosclerotic disease. J Stroke 18:96–101. https://doi.org/10.5853/jos.2015.01347
7. Tsang ACO, Orru E, Klostranec JM, Yang IH, Lau KK, Tsang FCP et al (2019) Thrombectomy outcomes of intracranial atherosclerosis-related occlusions. Stroke 50:1460–1466. https://doi.org/10.1161/STROKEAHA.119.024889
8. Dobrocky T, Kaesmacher J, Bellwald S, Piechowiak E, Mosimann PJ, Zibold F et al (2019) Stent-retriever thrombectomy and rescue treatment of M1 occlusions due to underlying intracranial atherosclerotic stenosis: cohort analysis and review of the literature. Cardiovasc Intervent Radiol 42:863–872. https://doi.org/10.1007/s00270-019-02187-9
9. Lee JS, Lee SJ, Yoo JS, Hong JH, Kim CH, Kim YW et al (2018) Prognosis of acute intracranial atherosclerosis-related occlusion after endovascular treatment. J Stroke 20:394–403. https://doi.org/10.5853/jos.2018.01627
10. Jia B, Feng L, Liebeskind DS, Huo X, Gao F, Ma N et al (2018) Mechanical thrombectomy and rescue therapy for intracranial large artery occlusion with underlying atherosclerosis. J Neurointerv Surg 10:746–750. https://doi.org/10.1136/neurintsurg-2017-013489
11 Yoon W, Kim SK, Park MS, Kim BC, Kang HK (2015) Endovascular treatment and the outcomes of atherosclerotic intracranial stenosis in patients with hyperacute stroke. Neurosurgery 76(680):686. https://doi.org/10.1227/NEU.0000000000000694 discussion 686
12. Lee D, Lee DH, Suh DC, Kim BJ, Kwon SU, Kwon HS et al (2020) Endovascular treatment in patients with cerebral artery occlusion of three different etiologies. J Stroke 22:234–244. https://doi.org/10.5853/jos.2019.02404
13. Guglielmi V, LeCouffe NE, Zinkstok SM, Compagne KCJ, Eker R, Treurniet KM et al (2019) Collateral circulation and outcome in atherosclerotic versus cardioembolic cerebral large vessel occlusion. Stroke 50:3360–3368. https://doi.org/10.1161/STROKEAHA.119.026299
14. Assis Z, Menon BK, Goyal M, Demchuk AM, Shankar J, Rempel JL et al (2018) Acute ischemic stroke with tandem lesions: technical endovascular management and clinical outcomes from the ESCAPE trial. J Neurointerv Surg 10:429–433. https://doi.org/10.1136/neurintsurg-2017-013316
15. Samuels OB, Joseph GJ, Lynn MJ, Smith HA, Chimowitz MI (2000) A standardized method for measuring intracranial arterial stenosis. AJNR Am J Neuroradiol 21:643–646
16. Fiorelli M, Bastianello S, von Kummer R, del Zoppo GJ, Larrue V, Lesaffre E et al (1999) Hemorrhagic transformation within 36 hours of a cerebral infarct: relationships with early clinical deterioration and 3-month outcome in the European Cooperative Acute Stroke Study I (ECASS I) cohort. Stroke 30:2280–2284. https://doi.org/10.1161/01.str.30.11.2280
17. Tan IY, Demchuk AM, Hopyan J, Zhang L, Gladstone D, Wong K et al (2009) CT angiography clot burden score and collateral score: correlation with clinical and radiologic outcomes in acute middle cerebral artery infarct. AJNR Am J Neuroradiol 30:525–531. https://doi.org/10.3174/ajnr.A1408
18. Christoforidis GA, Mohammad Y, Kehagias D, Avutu B, Slivka AP (2005) Angiographic assessment of pial collaterals as a prognostic indicator following intra-arterial thrombolysis for acute ischemic stroke. AJNR Am J Neuroradiol 26:1789–1797
19. Yang W, Zhang Y, Li Z, Zhang L, Li H, Hua W et al (2021) Differences in safety and efficacy of endovascular treatment for acute ischemic stroke: a propensity score analysis of intracranial atherosclerosis-related occlusion versus embolism. Clin Neuroradiol 31:457–464. https://doi.org/10.1007/s00062-020-00899-x
20. Treurniet KM, Yoo AJ, Berkhemer OA, Lingsma HF, Boers AM, Fransen PS et al (2016) Clot burden score on baseline computerized tomographic angiography and intra-arterial treatment effect in acute ischemic stroke. Stroke 47:2972–2978. https://doi.org/10.1161/STROKEAHA.116.014565
21. Hao Y, Yang D, Wang H, Zi W, Zhang M, Geng Y et al (2017) Predictors for symptomatic intracranial hemorrhage after endovascular treatment of acute ischemic stroke. Stroke 48:1203–1209. https://doi.org/10.1161/STROKEAHA.116.016368
22. Huo X, Sun D, Raynald JB, Tong X, Wang A et al (2022) Endovascular treatment in acute ischemic stroke with large vessel occlusion according to different stroke subtypes: data from ANGEL-ACT registry. Neurol Ther 11:151–165. https://doi.org/10.1007/s40120-021-00301-z
23. Kim SJ, Seok JM, Bang OY, Kim GM, Kim KH, Jeon P et al (2009) MR mismatch profiles in patients with intracranial atherosclerotic stroke: a comprehensive approach comparing stroke subtypes. J Cereb Blood Flow Metab 29:1138–1145. https://doi.org/10.1038/jcbfm.2009.38
24. Albers GW, Thijs VN, Wechsler L, Kemp S, Schlaug G, Skalabrin E et al (2006) Magnetic resonance imaging profiles predict clinical response to early reperfusion: the diffusion and perfusion imaging evaluation for understanding stroke evolution (DEFUSE) study. Ann Neurol 60:508–517. https://doi.org/10.1002/ana.20976
25. Baek JH, Kim BM, Heo JH, Kim DJ, Nam HS, Kim YD (2018) Outcomes of endovascular treatment for acute intracranial atherosclerosis-related large vessel occlusion. Stroke 49:2699–2705. https://doi.org/10.1161/STROKEAHA.118.022327
26. Huang X, Cai Q, Xiao L, Gu M, Liu Y, Zhou Z et al (2019) Influence of procedure time on outcome and hemorrhagic transformation in stroke patients undergoing thrombectomy. J Neurol 266:2560–2570. https://doi.org/10.1007/s00415-019-09451-5
27. Anadani M, Finitsis S, Clarencon F, Richard S, Marnat G, Bourcier R et al (2022) Collateral status reperfusion and outcomes after endovascular therapy: insight from the endovascular treatment in ischemic stroke (ETIS) registry. J Neurointerv Surg 14:551–557. https://doi.org/10.1136/neurintsurg-2021-017553
28. Rebello LC, Bouslama M, Haussen DC, Grossberg JA, Dehkharghani S, Anderson A et al (2017) Stroke etiology and collaterals: atheroembolic strokes have greater collateral recruitment than cardioembolic strokes. Eur J Neurol 24:762–767. https://doi.org/10.1111/ene.13287
29. Timsit SG, Sacco RL, Mohr JP, Foulkes MA, Tatemichi TK, Wolf PA et al (1993) Brain infarction severity differs according to cardiac or arterial embolic source. Neurology 43:728–733. https://doi.org/10.1212/wnl.43.4.728