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Radiologic value of computerized tomography angiography (CTA) for assessment of carotid artery Tortuosity Index and its impact on stroke recovery

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► ***Original article***

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ABSTRACT

Background: This study investigated the relationship between extracranial internal carotid artery (EICA) and extracranial carotid artery (ECA) tortuosity and clinical prognosis in acute anterior circulation ischemic stroke (AIS). ***Materials and Methods:*** We retrospectively analyzed 201 patients with anterior circulation AIS who underwent head and neck CT angiography (CTA) between January–December 2023.CTA was performed using a Discovery CT750 HD scanner (GE Medical Systems), with scanning extending from the aortic arch to the skull vertex. Iopromide contrast agent (37g iodine/100ml) was administered intravenously. Images were reconstructed at 0.63-mm slice thickness using multiplanar reformation (MPR) and 3D volume rendering (VR). ***Results:*** Tortuosity Index (TI) of EICA and ECA were independent predictors of poor 90-day prognosis (modified Rankin Scale [mRS] ≥3) in multivariate regression (Model I: EICA OR=1.038, P=0.007.ECA OR=1.052, P=0.015). ROC analysis showed ECA-TI≥12.5 predicted poor prognosis with higher specificity (AUC=0.623,sensitivity 55.6%,specificity 68.3%) than EICA-TI ≥14.5 (AUC=0.601,sensitivity 61.9%,specificity60.7%). ***Conclusions:*** Increased EICA/ECA tortuosity independently correlates with poor AIS outcomes, with ECA-TI being a superior prognostic indicator.

INTRODUCTION

Imaging-based assessment of arterial tortuosity has emerged as a critical tool for evaluating cerebrovascular pathology. Computed tomography angiography (CTA) enables precise quantification of carotid tortuosity through metrics like the Tortuosity Index (TI), calculated as the ratio of vessel centerline length to straight-line distance between endpoints [1]. This imaging biomarker correlates with hemodynamic alterations; Kim *et al*. demonstrated that severe EICA tortuosity (>180°angulation) reduces cerebral blood flow by 15–22% using phase-contrast MRI [2]. The clinical relevance of tortuosity imaging is underscored by interventional studies. Chen *et al*. [3] established that CTA-measured TI≥14.5 predicts prolonged endovascular thrombectomy time (OR=3.2, p=0.01) due to microcatheter navigation difficulties [4]. Similarly, Krzyzewski *et al.* associated ICA tortuosity with higher procedural complications in carotid stenting (RR=2.7) [2].

Controversies persist regarding tortuosity's role in stroke pathogenesis. While earlier studies suggested developmental origins [5], recent CTA-based analyses by Kim *et al*. revealed correlations between carotid tortuosity and intracranial atherosclerosis (β=0.38, p<0.001) [6]. Crucially, Abhilash *et al.*'s computational fluid dynamics models confirmed that TI≥12.5 in ECA increases wall shear stress by 30%, potentially accelerating atherogenesis [7]. Despite these advances, the prognostic value of carotid tortuosity imaging in anterior circulation AIS remains unexplored. This study bridges this gap by investigating CTA-derived TI as a predictor of 90-day functional outcomes.

The prognosis of anterior circulation ischemic cerebral infarction is influenced by a multitude of factors, with its complexity manifesting in various dimensions [8]. Beyond carotid artery stenosis or occlusion, carotid artery tortuosity is frequently observed as a vascular morphological anomaly in clinical settings. Under normal anatomical conditions, the carotid artery exhibits natural curvature upon entering the cranial cavity [9]. Within the aortic arch, the degree of tortuosity in the extracranial segment of the internal carotid artery (EICA) or the extracranial segment of the carotid artery (ECA) varies considerably among individuals [10]. The etiology and underlying mechanisms of ECA tortuosity remain largely undefined. Previous research has suggested that carotid artery tortuosity may be associated with developmental abnormalities during the embryonic period, yet it appears not to be directly linked to risk factors for anterior circulation ischemic stroke (AIS) [11]. This view has been contested by some scholars who argue that carotid artery tortuosity is solely related to age and gender, and does not constitute a risk factor for carotid

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atherosclerotic stenosis or AIS [12]. Additionally, studies have indicated that arterial tortuosity may be associated with intracranial atherosclerosis [13].

Although the effect of carotid tortuosity is controversial, the degree of carotid tortuosity does have a significant impact on the recanalization time of occluded vessels during emergency endovascular thrombectomy in AIS. Studies have shown that with the aggravation of carotid artery tortuosity, the success rate of vascular recanalization may decline [14, 15]. This study provides the first evidence that CTA-quantified extracranial carotid tortuosity independently predicts 90-day functional outcomes in anterior circulation AIS. While prior research focused on tortuosity's technical impact during endovascular procedures [6, 14], we establish its prognostic value in medically managed patients-addressing a critical knowledge gap. Crucially, we demonstrate thatECA-TI outperforms EICA-TI in prognostic accuracy (AUC 0.623 vs.0.601), identifying ECA-TI≥12.5 as a novel imaging biomarker for poor prognosis. This advances vascular phenotyping beyond traditional stenosis assessment and offers a readily applicable CTA-derived metric for risk stratification.

MATERIALS AND METHODS

Study subjects

We retrospectively analyzed the clinical data of AIS patients who underwent head and neck CTA examination between January and December 2023.This study initially included 230 patients, 29 of whom were excluded due to lost follow-up and other reasons, so 201 patients were eventually included. There were 130 patients with good prognosis (mRS<3) as comparison and 71 patients with poor prognosis (mRS≥3) as observer. Clinicopathological data and follow-up information of all patients were complete. All research procedures involving human participants in this study complied with the ethical standards of the 1964 Helsinki Declaration and its subsequent amendments. This study was approved by the Ethics Committee of Jingxian Hospital (approval number: No.2022(06)).

Exclusion of inclusion criteria

Inclusion criteria: Adults (≥18 years) with anterior circulation acute ischemic stroke (AIS) confirmed by diffusion-weighted imaging (DWI). Underwent head and neck CTA within 72 hours of symptom onset. *Exclusion criteria*: Poor CTA image quality or bilateral carotid occlusion preventing tortuosity measurement. Pre-stroke modified Rankin Scale (mRS) score >1.

Measurement of carotid tortuosity

CTA scanning: Head and neck CT angiography (CTA) was performed on the Discovery CT750 HD Gemstone Spectrometer CT (GE Medical Systems, Milwaukee, WI) in all patients enrolled in the study. The scan extends horizontally from the aortic arch to the top of the skull. Contrast agent injection: During the CTA scan, ioproxamine is administered intravenously as a contrast agent with an iodine content of 37g/100ml (Trade name: Ultravist®, provided by Bayer Pharmaceuticals). Scanning parameter Settings: The main parameters of CTA scanning include tube voltage (80~120 kV) and tube current (250~450mA). The thickness of the scan layer used for image reconstruction is set to 0.63 mm to ensure clarity and detail of the image. Image reconstruction: The original CTA images of each patient were reconstructed using multi-plane recombination (MPR) and three-dimensional volume reconstruction (VR). These techniques help to observe the anatomy and tortuosity of the carotid artery from different angles. Image export and preservation: Reconstructed CTA images are exported through the Image Archiving and Communication System (PACS) and saved as DICOM (Digital Imaging and Communication Medicine) format files for subsequent analysis and processing (figure 1).

mRS Score during follow-up

This study meticulously gathered extensive clinical data from the enrolled patients, encompassing a range of variables including demographic characteristics, history of cerebral infarction or transient ischemic attack (TIA),risk factors for cerebral infarction, initial National Institutes of Health Stroke Scale (NIHSS) scores, and the location of the infarct within the cerebral hemisphere (noting whether it was on the dominant side). Additionally, the study recorded the specific site of cerebral artery occlusion, which included the main internal carotid artery (ICA), the M1 or M2 segments of the middle cerebral artery (MCA), the anterior cerebral artery (ACA), or other MCA branches. The time interval from symptom onset to computed tomography angiography (CTA) examination, the TOAST classification of cerebral infarction, the administration of intravenous thrombolytic therapy with recombinant tissue plasminogen activator (rt-PA), and post-discharge treatment strategies such as antiplatelet therapy, anticoagulant therapy, and statin use were also documented. Data collection was primarily conducted through patient hospital records, with supplementary information obtained via telephone interviews with patients or their family caregivers. Clinical outcomes were assessed using the modified Rankin Scale (mRS) at 90 days after the onset of precirculating AIS. The mRS Score was obtained through a telephone return visit by the researchers to the patients or their family caregivers. To ensure the convenience and accuracy of mRS Scores during telephone follow-up, scores of 0 to 5 were performed with reference to the simplified

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scoring scale used in the literature, except in cases where mRS Scores were 6 (representing death). According to existing studies, an mRS Score of less than 3 (0 to 2) is defined as a good prognosis for AIS, while an mRS Score of 3 or more (3 to 6) is defined as a poor prognosis.

Statistical Methods

All data were analyzed using SPSS software (version 20.0, IBM Corporation, Armonk, NY), ROC graphs are drawn by GraphPad Prism Software (version 6.01, GraphPad Software Inc, San Diego, CA). For continuous variables conforming to normal distribution, Mean (Mean) and standard deviation (SD) are used for statistical description. The normality test for continuous variables is performed by Kolmogorov-Smirnov test or Shapiro-Wilk test. Categorical variables were compared by chi-square (χ^2) test or Fisher's exact probability test. For the comparison of continuous variables between different groups, t test or Mann-Whitney U test were used respectively according to whether the data were normally distributed. For variables that showed statistical significance in univariate analyses (P-value<0.05), multivariate Logistic regression models were used to calculate odds ratios (OR) and 95% confidence intervals (CI) to assess the association between ECA or EICA curvature and poor outcomes in anterior circulation AIS. The receiver operating characteristic (ROC) curve was used to calculate the area under the curve (AUC) and determine the optimal critical point for TI values associated with poor prognosis.

RESULTS

Comparison of clinical baseline data between the two groups

The mean age was 66.8 years in the Observation group and 64.5 years in the Comparison group, with a statistical difference between the two groups (P_{-value}=0.018). There was no significant difference in sex ratio between the two groups (P_{-value}=0.938). The proportion of hypertensive patients in the Observation group and Comparison group was 31.7% and 10%,respectively,with no statistical difference between the two groups (P_{-value}=0.758). The proportion of patients with diabetes was 23.8% in the Observation group and 8.6% in the Comparison group, with no statistical difference between the two groups (P_{-value}=0.576). The proportion of patients was 26.9% in the Observation group and 6.4% in the Comparison group, with no statistical difference between the two groups (P_{-value}=0.360). There was no significant difference in the proportion of coronary heart disease between the two groups (P_{-value}=0.281). There was no significant difference in the proportion of patients with atrial fibrillation between the two groups (P_{-value}= 0.838). There was no significant difference in the proportion of smokers between the two groups (P=0.929). There was no significant difference in the proportion of alcohol consumption between the two groups (P_{-value}=0.472). There were no statistically significant differences in baseline NIHSS scores between the two groups (P_{-value}=0.206). There was no significant difference in the time from onset to CTA examination between the two groups (P=0.149). There was no significant difference in the proportion of left hemisphere cerebral infarction between the two groups (P_{-value}=0.932). There was no significant difference in the proportion of patients with large atherosclerosis between the two groups (P_{-value}=0.134). There was no significant difference in the proportion of patients with small artery occlusion between the two groups (P_{-value}=0.731). There was no significant difference in the proportion of patients with cardiac embolism between the two groups (P_{-value}=0.146). There was no significant difference in the proportion of patients with undetermined etiology between the two groups (P_{-value}=0.951). There was no significant difference in the proportion of arterial occlusion between the two groups (P_{-value}=0.472). There was no significant difference in the proportion of MCA M1 block between the two groups (P=0.885). There was no significant difference in the proportion of MCA M2 block between the two groups (P_{-value}=0.206). The proportion of patients was 36.5% in the Observation group and 10.7% in the Comparison group, with no statistical difference between the two groups (P_{-value}=0.119). The proportion of patients was 17.5% in the Observation group and 48.6% in the Comparison group, with no statistical difference between the two groups (P_{-value}=0.952) (table 1).

Risk factors for poor clinical prognosis of AIS

We used univariate Logistic regression analysis to screen out the risk factors of poor prognosis in patients with anterior circulation AIS. The results showed that the TI value of EICA (odds ratio OR=1.032; 95% CI is 1.010-1.054; P_{-value}=0.005) and the TI values of ECA (OR=1.049, 95%CI was 1.016-1.084; P_{-value}=0.003) were significantly associated with poor prognosis. Among the other variables analyzed, the ICA trunk was blocked (OR=8.200; 95%CI was 2.315-29.049; P_{-value}=0.001), section M1 of MCA was blocked (OR=10.25; 95%CI was 3.669-28.637; P_{-value}<0.001),M2 segment of MCA was blocked (OR=5.857; 95%CI was 2.060-16.656; P_{-value}=0.001), baseline NIHSS score (OR=1.410; 95%CI was 1.270-1.566; P_{-value}<0.001), dual antiplatelet therapy (aspirin + clopidogrel) (OR=0.047; 95%CI was 0.014-0.165. P_{-value}<0.001) and statin therapy (OR=0.103; 95%CI was 0.032-0.328. P_{-value}<0.001) and other factors had a significant impact on the prognosis of patients with anterior circulation AIS (table 2).

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Table 1. Comparison of clinical baseline data between the two groups [$\bar{x}$±SD, n].

	Observation group (71)	Comparison group (130)	t/x^2	P_{-value}
Age (years)	66.8±2.8	64.5±3.1	2.938	0.018
Gender (Male/female)	34/37	63/67	0.006	0.938
Hypertension	20(31.7)	34(10)	0.095	0.758
Diabetes mellitus	15(23.8)	32(8.6)	0.312	0.576
Hyperlipidemia	17(26.9)	49(6.4)	0.838	0.360
Coronary heart disease	16(9.5)	34(2.9)	1.164	0.281
Atrial fibrillation	15(7.9)	26(4.3)	0.042	0.838
Smoking	18(12.7)	17(5.0)	0.008	0.929
Alcohol consumption	15(23.8)	33(87.9)	0.517	0.472
Previous ischemic stroke or TIA	10(15.9)	18(12.9)	0.021	0.885
Baseline NIHSS score, median (IQR)	30(47.6)	50(35.7)	1.600	0.206
Time from onset to CTA in hours, median (IQR)	10(15.9)	23(16.4)	2.133	0.149
Stroke in left hemisphere	21(33.3)	53(37.9)	0.014	0.932
Large artery atherosclerosis	15(23.8)	16(4.3)	0.217	0.134
Small artery occlusion	5(7.9)	28(5.7)	0.322	0.731
Cardioembolism	6(9.5)	64.36 (11.62)	1.310	0.146
Other determined etiology	16(25.4)	90(64.3)	1.233	0.219
Undetermined etiology	68(12.80)	100(71.4)	0.214	0.951
Occlusion site of artery	34(54.0)	54(38.6)	0.541	0.472
M1 segment of MCA	50(79.4)	51(36.4)	0.121	0.885
M2 segment of MCA	28(44.4)	18(12.9)	1.102	0.206
Intravenous alteplase thrombolysis	23(36.5)	15(10.7)	2.413	0.119
Antithrombotic treatment	11(17.5)	68(48.6)	0.034	0.952
Aspirin	16(25.4)	37(26.4)	0.537	0.172
Clopidogrel	26(41.3)	18(12.9)	0.221	0.214
aspirin plus clopidogrel	16(25.4)	22(3)	1.019	0.226

TIA=transient ischemic attack; NIHSS=National Institutes of Health Stroke Scale; IQR=interquartile range; CTA=computed tomography angiography; MCA=middle cerebral artery.

Table 2. Risk factors for poor clinical prognosis in AIS were analyzed by univariate analysis.

	OR	95%CI	P_{-value}
Age	1.034	1.007-1.062	0.013
Atrial fibrillation	2.837	1.300-6.190	0.009
Baseline NIHSS score	1.410	1.270-1.566	0.003
Stroke in left hemisphere	2.044	1.113-3.755	0.021
Occlusion site of artery			
ICA main stem	8.200	2.315-29.049	0.001
M1 segment of MCA	10.25	3.669-28.637	0.006
M2 segment of MCA	5.857	2.060-16.656	0.001
Antithrombotic treatment			
Aspirin	0.210	0.078-0.565	0.002
Clopidogrel	0.326	0.112-0.950	0.040
Aspirin plus clopidogrel	0.047	0.014-0.165	0.002
Treatment with statins	0.103	0.032-0.328	0.002
Tortuosity Index (TI)			
EICA	1.032	1.010-1.054	0.005
ECA	1.049	1.016-1.084	0.003

AIS=acute ischemic stroke; OR=odds ratio; CI=confidence interval; ICA=internal carotid artery; TI=Tortuosity Index; EICA=extracranial internal carotid artery.

Multivariate Logistic regression Model I analysis

By multivariate Logistic regression analysis, we investigated whether EICA and ECATI values were independent risk factors for poor prognosis in patients with anterior circulation AIS. In order to ensure the stability and accuracy of the regression analysis and avoid analysis errors, we used two independent models to evaluate the EICA and ECATI values respectively. In Model I, all factors except the baseline NIHSS score were included in the analysis. Model II further corrected for baseline NIHSS scores, age, and sex. The analysis results showed that in model I, after adjusting for age, atrial fibrillation, infarct location, vascular occlusion site, antithrombotic therapy after cerebral infarction and statin therapy, the TI value of EICA (odds ratio OR=1.038,95% confidence interval CI: 1.010-1.067;P=0.007) and the TI value of ECA (OR=1.052,95%CI was 1.010-1.096; P_{-value}=0.015) is still considered to be an independent risk factor for poor prognosis of anterior circulation AIS (table 3).

Table 3. Independent risk factors for poor clinical prognosis in AIS.

	EICA		ECA	
	OR(95%CI)	P_{-value}	OR(95%CI)	P_{-value}
Age	1.045 (1.006-1.086)	0.022	1.041 (1.001-1.082)	0.043
Stroke in left hemisphere	2.571 (1.171-5.646)	0.387	2.682 (1.224-5.874)	0.014
Occlusion site of artery				
ICA main stem	22.748 (4.355-118.82)	0.019	19.412 (3.689-102.16)	0.003
M1 segment of MCA	20.872 (5.814-74.935)	0.001	17.421 (4.893-62.024)	0.006
M2 segment of MCA	5.502 (1.576-19.210)	0.002	No	0.009
Antithrombotic treatment				
Aspirin	No	0.008	5.395 (1.525-19.083)	0.009
	0.047 (0.010-0.220)	0.003	0.041 (0.008-0.203)	0.001
Tortuosity Index (TI)				
ECA	No	No	1.052 (1.010-1.096)	0.015

AIS=acute ischemic stroke; OR=odds ratio; CI=confidence interval; ICA=internal carotid artery; MCA=middle cerebral artery; TI=Tortuosity Index; ECA=extracranial carotid artery.

Multivariate Logistic regression model II analysis

In the multivariate Logistic regression analysis of model II, the TI value of EICA (odds ratio OR=1.038,95% confidence interval CI 1.008 -1.068; P_{-value}=0.012) and the TI value of ECA (OR=1.066,95%CI was 1.024-1.109; P_{-value}=0.002) continued to be an independent risk factor for poor prognosis in patients with anterior circulation AIS (table 4).

Prediction of poor prognosis of AIS with carotid artery tortuosity

By constructing ROC curves, this study

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analyzed the role of tortuous index (TI) values of EICA and ECA in predicting poor prognosis of patients with anterior circulation AIS. The AUC of the TI value of EICA is 0.601 (95% confidence interval 0.516-0.686; $P_{\text{-value}}$=0.021), the optimal critical value was determined to be 14.5, and the corresponding sensitivity and specificity were 61.9% and 60.7%,respectively (Yoden index was 0.223).The AUC of ECA's TI value is 0.623 (95% confidence interval is 0.538-0.708; $P_{\text{-valu}}$=0.005),the optimal cut-off value was 12.5,and the sensitivity and specificity were 55.6% and 68.3%,respectively (Yoden index was 0.239).In the group of patients with poor prognosis (mRS≥3),41.5% of patients with EICA TI value≥14.5 (n=39),and 22.1% of patients with TI value <14.5 (n=24), the distribution difference between the two was statistically significant ($P_{\text{-value}}$=0.003). Similarly,44.3% (n=35) of ECA patients had a TI value≥12.5, while 22.6% (n=28) of ECA patients had a TI value <12.5,and the distribution of ECA patients in the poor prognosis group also showed significant differences ($P_{\text{-value}}$=0.001).Based on the ROC curve and the analysis of the percentage distribution, it can be inferred that when the TI value of EICA is≥14.5 or the TI value of ECA is≥12.5,the risk of poor prognosis of patients may be increased (figure 2).

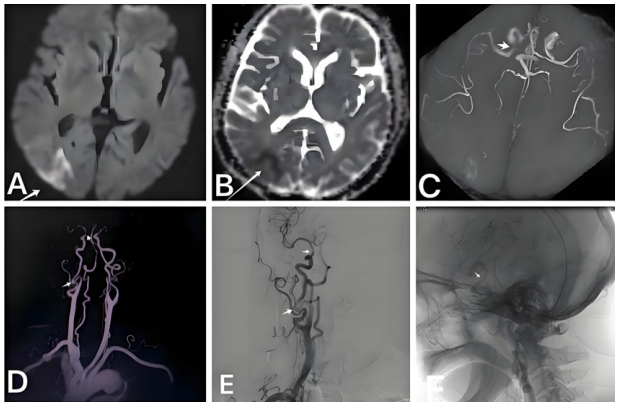


Figure 1. Tortuosity measured by head and neck imaging.(A) The patient showed acute cerebral infarction in the right occipital lobe on DWI imaging; B showed ADC image manifestations corresponding to cerebral infarction patients; C is the patient's head TOF-MRA showing severe stenosis in the C7 segment of the right internal carotid artery; CE-MRA showed that the right internal carotid artery was tortuosity in C1 and C2 segments, and severe stenosis in C7 segments. E is for cerebral angiography: positive image of the right carotid artery, showing obvious tortuosity in C1 and C2 segments and severe stenosis in C7 segments; F is for cerebral angiography: 3D imaging of the right carotid artery showed severe stenosis in the C7 segment of the right internal carotid artery, and the lumen stenosis was about 85%.)

Table 4. Independent risk factors for poor clinical prognosis in AIS were analyzed by multi-factor Logistic regression model II.

	EICA		ECA	
	OR(95%CI)	*P-value*	OR(95%CI)	*P-value*
Baseline NIHSS score	1.438 (1.287-1.606)	0.001	1.425 (1.278-1.589)	0.001
Tortuosity Index (TI)				
ECA	None	None	1.066 (1.024-1.109)	0.002

AIS=acute ischemic stroke; OR=odds ratio; CI=confidence interval; NIHSS=National Institutes of Health Stroke Scale; TI=Tortuosity Index.

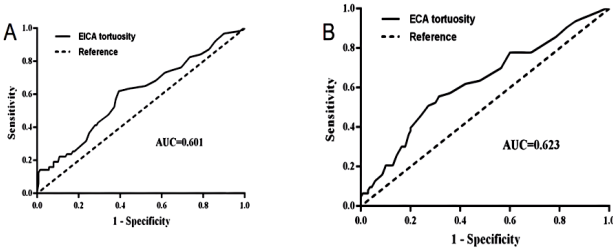


Figure 2. Prediction of poor clinical prognosis in AIS by carotid artery tortuosity. (Analysis of the ROC curve of **A;** ICA Tortuosity in predicting 90-day poor prognosis of precirculating acute ischemic cerebral infarction. ROC curve analysis of **B;** ECA tortuosity in predicting 90-day poor prognosis of acute ischemic cerebral infarction).

DISCUSSION

In this study, the analysis of the TI values of the ECA revealed that an increase in TI value was associated with a decreasing number of patients exhibiting a favorable prognosis, while the number of patients with an unfavorable prognosis increased [17]. Although, similar trends were observed in the TI quantile grouping of the EICA, the differences were not statistically significant. Previous literature has indicated that severe tortuosity or distortion of the carotid artery may impair cerebral blood flow, potentially leading to cerebral ischemia, which can be ameliorated through surgical intervention [18]. Vascular tortuosity may also be linked to established etiologies of AIS, such as carotid dissection and intracranial atherosclerosis. While there is some correlation between carotid artery tortuosity and AIS etiology, the relationship between vascular tortuosity and AIS prognosis remains unclear, necessitating further investigation [19]. The aim of this study was to examine the impact of ECA and EICA tortuosity on the clinical prognosis of patients with anterior circulation AIS, thereby providing a theoretical foundation for the study of vascular tortuosity and ischemic cerebrovascular disease. In patients with procirculatory acute ischemic stroke (AIS) who do not undergo emergency endovascular therapy upon admission, the degree of tortuosity in the EICA and the ECA serves as a crucial imaging parameter for predicting clinical outcomes at 90 days. The optimal threshold for the TI of the EICA is 14.5, while for the ECA, it is 12.5. Prognosis tends to be poor when

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vessel tortuosity surpasses these thresholds. There is a significant correlation between carotid artery tortuosity and factors such as procedural complexity, duration of the operation, vascular recirculation rate, and patient prognosis during endovascular therapy [20].

In a univariate analysis, it was observed that intravenous thrombolysis using recombinant tissue plasminogen activator (rt-PA) did not yield a statistically significant improvement in outcomes for patients with AIS. This finding was further examined in relation to the distribution of NIHSS scores. The analysis revealed that the majority of cerebral infarction patients included in this study presented with mild symptoms. Consequently, the therapeutic benefit of rt-PA intravenous thrombolysis in this subgroup was relatively limited, potentially obscuring differences in prognosis. Additionally, the time interval between symptom onset and CTA examination often exceeded the optimal window for intravenous thrombolysis by the time most patients were admitted to the hospital. This resulted in a reduced number of cases receiving intravenous thrombolysis and a small sample size, which may have introduced bias into the statistical analysis. In a univariate analysis, an unexpected finding emerged: intravenous thrombolysis with rt-PA did not significantly enhance outcomes in patients with AIS. Subsequent analysis revealed that the majority of patients exhibited relatively mild symptoms, as indicated by the distribution of NIHSS scores. It is well-documented that the therapeutic benefit of rt-PA intravenous thrombolysis is generally more pronounced in patients with moderate to severe ischemic cerebral infarction compared to those with mild cases [21]. In this study, the predominance of patients with mild cerebral infarction may have limited the observable efficacy of rt-PA intravenous thrombolysis, particularly in the context of the mRS scoring group. Additionally, it was observed that most patients were beyond the optimal time window for intravenous thrombolysis upon admission. This resulted in a limited number of patients receiving the treatment and consequently a small sample size, which may have affected the statistical analysis and introduced potential bias.

According to the results of multivariate Logistic regression analysis and ROC curve analysis, the TI value of ECA was more superior than EICA in predicting the poor prognosis of pre-circulation AIS, and the AUC, specificity and Yoden index were slightly higher than EICA. We consider that the tortuous indicator of ECA is more specific than EICA in predicting the poor prognosis of procirculatory AIS. Comparing with ECA, the influence of common carotid artery (CCA) tortuosity may be ignored by considering only the factors of EICA tortuosity. When CCA was added, the overall Tortuosity Index of ECA was significantly lower than that of EICA, suggesting that CCA was less tortuosity than EICA in general. As a direct continuation of CCA, EICA needs to take into account the influence of CCA tortuality on hemodynamics, so the tortuality index of ECA can be considered as the preferred predictor of prognosis of procirculatory AIS. Large artery occlusion was most significantly correlated with poor prognosis. Patients in this category are typically classified under the complete anterior circulation infarction subcategory of the Oxfordshire Community Stroke Project (OCSP), characterized by a reduced likelihood of vascular recanalization and an unfavorable prognosis in the absence of emergency endovascular intervention. When compared to monotherapy with either aspirin or clopidogrel, the combined use of these antiplatelet agents significantly enhanced clinical outcomes in a cohort predominantly experiencing mild cerebral infarction. These findings are largely consistent with previously published prospective multicenter clinical studies [22].

We conducted an in-depth analysis of the optimal cutoff value for the TI of the ECA to predict clinical outcomes in patients with anterior circulation AIS. Our findings indicate that an ECA TI value of ≥12.5 may be indicative of a poor prognosis in these patients. This conclusion is corroborated by the distribution of 90-day modified Rankin Scale (mRS) scores between groups with TI values of <12.5 and ≥12.5. Although, there is no significant correlation between ECA tortuosity and the onset of ischemic cerebrovascular disease, our study suggests a potential association between ECA tortuosity and adverse outcomes in anterior circulation AIS. The underlying mechanisms remain unclear, necessitating further investigation. While some literature posits that carotid artery tortuosity is unlikely to be an acute pathogenic factor in ischemic cerebral infarction, the aforementioned studies imply that it may contribute to inadequate blood supply and chronic cerebral ischemia [23]. Consequently, we propose that the unfavorable prognosis of procirculatory AIS associated with ECA tortuosity may be linked to persistent chronic cerebral hypoperfusion. However, this hypothesis requires validation through further research. The correlation between ECA tortuosity and the recurrence rate of anterior circulation AIS, as well as the conditions under which vascular tortuosity should be proactively addressed, warrant additional investigation. Clinically, ECA and vertebral artery tortuosity are often overlooked. A comprehensive understanding of the etiology and pathogenesis of cervical vascular tortuosity, along with its association with AIS, may significantly enhance the prevention and management of AIS.

This study has several limitations that should be acknowledged. First, as a retrospective single-center study, it is susceptible to selection bias, and the generalizability of findings may be limited by the specific patient population. Second, carotid tortuosity

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measurement relied on manual assessment of 2D reconstructed CTA images rather than automated software analysis, introducing potential interrater variability and measurement error. Finally, follow-up was limited to 90 days, and long-term outcomes remain unassessed.

CONCLUSIONS

Increased tortuosity of the EICA and ECA, quantified by CTA-derived TI, is an independent risk factor for poor 90-day outcomes in patients with anterior circulation acute ischemic stroke (AIS). Specifically, EICA-TI ≥14.5 and ECA-TI ≥12.5 are associated with unfavorable prognosis, with ECA-TI demonstrating superior predictive value as a prognostic indicator.

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