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Distinction between acute and chronic carotid disease based on computed tomography angiography in acute ischemic stroke patients with carotid artery occlusion

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Abstract

Background Prompt endovascular thrombectomy is crucial for patients with acute ischemic stroke due to internal carotid artery (ICA) occlusion. However, distinguishing acute from chronic carotid disease can be challenging. This study investigates the utility of initial CT angiography (CTA) findings in differentiating acute and chronic ICA disease among acute cerebral infarction patients with ICA occlusion.

Methods We conducted a retrospective analysis of CTA data from acute stroke patients with apparent ICA occlusion at a single stroke center. Patients were categorized into acute and chronic groups based on clinical information, mechanical thrombectomy outcomes, and infarct patterns. We compared CTA findings between the groups, focusing on occlusion site and carotid atherosclerosis burden.

Results Between January 2016 and June 2021, 42 patients were included in the study (28 acute; 14 chronic). The acute group had a significantly higher proportion of tapering patterned proximal occlusion compared to the chronic group. Patients with chronic ICA disease were more likely to have stump patterned proximal occlusion and advanced atherosclerotic burden in the contralateral proximal ICA. The carotid occlusion imaging score, comprising occlusion pattern and atherosclerosis burden, demonstrated good performance in discriminating chronic carotid disease from acute carotid occlusion (area under the receiver operating curve = 0.94, 95% confidence interval = 0.87–1.00, $p < 0.001$).

Conclusions The occlusion shape of the ipsilateral ICA and the atherosclerotic burden of the contralateral ICA can aid in differentiating chronic carotid disease from acute ICA occlusion among acute stroke patients with ICA occlusion.

Keywords Cerebral infarction, Carotid occlusion, Computed tomography angiography, Chronic occlusion

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Background

Mechanical thrombectomy has become a standard treatment for acute ischemic stroke patients with large artery occlusion [1–3]. Prompt and accurate evaluation of vascular status is crucial for determining the appropriate revascularization strategy; however, distinguishing between chronic and acute occlusion can be challenging [4–7]. This distinction is especially relevant in patients with an unclear time of stroke onset, in whom imaging findings frequently serve as the primary basis for acute therapeutic decision making. Acute interval carotid artery (ICA) occlusion and ICA occlusion associated with chronic carotid disease differ in their underlying hemodynamic characteristics and pathophysiological mechanisms. Acute occlusions are often related to embolism or recently formed thrombus, leading to an abrupt interruption of antegrade flow and limited opportunity for compensatory collateral circulation to develop. As a result, these occlusions often present with sudden hemodynamic compromise, and stroke patients with acute ICA occlusion could be associated with markedly poor prognosis if recanalization is not achieved. In contrast, ICA occlusion associated with chronic carotid disease is characterized by long-standing atherosclerotic plaque formation, progressive luminal narrowing, and vascular remodeling. These chronic processes allow gradual adaptation of cerebral perfusion through the development of collateral pathways, including the circle of Willis and leptomeningeal collaterals [8, 9]. Consequently, stroke with ICA occlusion in the setting of chronic carotid disease

often manifests with relatively milder neurological deficits due to established collateral flow and may require a different therapeutic approach, as bypass surgery or carotid stenting is frequently considered. In such cases, recanalization can be technically challenging or even unfeasible [8, 9]. However, distinguishing the location and etiology of ICA occlusion can be unreliable even for specialized radiologists in emergency settings [4]. While digital subtraction angiography (DSA) provides the most accurate evaluation of cerebral vasculature, its invasive nature limits its use in emergency settings [10]. Magnetic resonance angiography (MRA) is noninvasive but may be constrained by longer acquisition times and flow-related artifacts. Computed tomography angiographic (CTA), in contrast, enables rapid and practical assessment of both extracranial and intracranial vessels, and is therefore most widely used in acute ischemic stroke. However, CTA may overestimate ICA occlusion in the presence of slow flow or poor collateral circulation [5]. The aim of this study was to identify CTA markers that can effectively differentiate between acute and chronic carotid disease in acute stroke patients with ICA occlusion.

Methods

Patient selection

With approval of the institutional review board (IRB number: 1009-062-332), in this retrospective study, we examined consecutive stroke patients eligible for endovascular thrombectomy (EVT) at Seoul National University Hospital between January 2016 and June 2021. Demographic, clinical, and imaging data were obtained from electronic medical records. This study was conducted ethically in accordance with the guidelines of the Declaration of Helsinki. The need to obtain informed consent was waived by the IRB of Seoul National University Hospital because of the retrospective design and minimal risk.

As illustrated in Fig. 1, the inclusion criteria were as follows: (1) acute ischemic stroke patients eligible for EVT, and (2) presence of symptomatic ICA occlusion on the initial single-phase CTA. The exclusion criteria were as follows: (1) inadequate initial CTA image, and (2) carotid dissection.

Tandem ICA–MCA occlusion identified on the initial CTA was not used as an exclusion criterion, given the known limitations of single-phase CTA in accurately detecting distal occlusions in the setting of ICA occlusion. ICA occlusion on CTA was defined as the absence of contrast opacification along the expected course of the ICA extending from the extracranial segment toward the intracranial ICA. Importantly, in all included cases, the presence of ICA occlusion was subsequently confirmed on DSA performed during EVT.

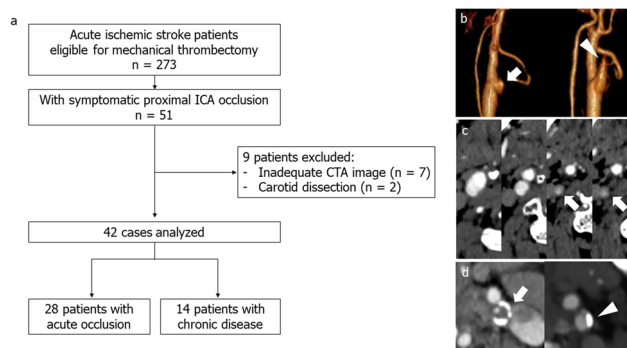


Fig. 1 Patient selection flow and examples of carotid occlusion imaging score parameters. **a** Out of 273 patients who underwent EVT, ICA occlusion was detected in 51 patients using CTA. After excluding 9 patients due to insufficient extracranial vessel coverage on CTA ($n = 7$) and cervical ICA dissection ($n = 2$), 42 cases were included. **b** Proximal ICA occlusion appearing as a flat interruption at the carotid bifurcation is defined as a stump (arrow), whereas tapering was defined as a gradual disappearance with some distal flow, showing contrast enhancement extending more than 1 cm from the carotid bifurcation (arrowhead). **c** Intermediate-pattern occlusion included cases that did not meet the criteria for stump or tapering patterns, including tapering-like patterns that contrast enhancement extending less than 1 cm from bifurcation or have irregular margins. **d** Calcification covering 180 degrees or more of the carotid wall is classified as linear (arrow), while lesser calcification is classified as spotty

Imaging protocol

The stroke CT imaging protocol comprised (1) non-contrast CT to exclude hemorrhage and (2) contrast-enhanced CT of the head and neck during the arterial phase, accompanied by perfusion mapping. All CT scans were performed using a 320-detector row scanner (Aquilion ONE; Toshiba Medical System) with an imaging protocol that included scanning from the vertex to the aortic arch with 1.0 mm slice thickness. Nonionic contrast media (Iomeron 400 ml) were administered into the antecubital vein at a rate of 5 ml/sec using a power injector. CT perfusion maps were processed with the singular value decomposition plus algorithm in VITREA software (Vital Images, MN, USA). The infarct core criteria were defined as a 41% reduction in relative cerebral blood volume (rCBV), while a 6.8-second increase in time to peak without CBV reduction indicated penumbra [11]. Perfusion map variables, including penumbra volume, core volume, penumbra-to-core volume ratio, and the sum of penumbra and core volumes, were analyzed. Conventional angiographic images with DSA were acquired during EVT using a biplane angiography suite system (Innova IGS 630 biplane system; GE Healthcare, Chalfont St Giles, UK).

Carotid artery imaging analysis

Initial brain images were reviewed by two neurologists (Bae J, Kim JM), who classified all cases as either acute ICA occlusion or ICA occlusion with chronic carotid

disease based on clinical data, mechanical thrombectomy outcomes, and infarct patterns. Chronic carotid disease is defined as those with over 70% residual stenosis observed in conventional angiography, as this degree of stenosis more reliably reflects advanced atherosclerotic involvement with potential hemodynamic significance, which was central to the objective of the present study. Baseline CTA scans were evaluated to determine occlusion patterns and atherosclerotic burden (Fig. 2). The occlusion site assessment focused on two key aspects: occlusion pattern and presence of carotid T occlusion. (1) Occlusion pattern was categorized into three patterns: tapering, stump and intermediate. [4–5] Tapering-pattern was defined as smooth, gradual disappearance with some distal flow, showing contrast enhancement extending more than 1 cm from the carotid bifurcation. Stump-pattern was defined as a flat, sharply demarcated cutoff immediately distal to the carotid bifurcation. Intermediate-pattern included cases not meeting either definition, such as tapering-like contrast enhancement extending less than 1 cm from bifurcation or residual contrast filling with an ill-defined, non-tapering luminal contour along the proximal ICA. (2) Carotid T occlusion was determined by the absence of contrast in the carotid terminus [6]. Atherosclerotic burden was assessed in both proximal ICAs with respect to (1) degree of stenosis, classified as none, mild (< 50%), or moderate (> 50%); and (2) presence of calcification burden, categorized as none, spotty, or linear (encompassing over 180 degrees of the carotid wall).

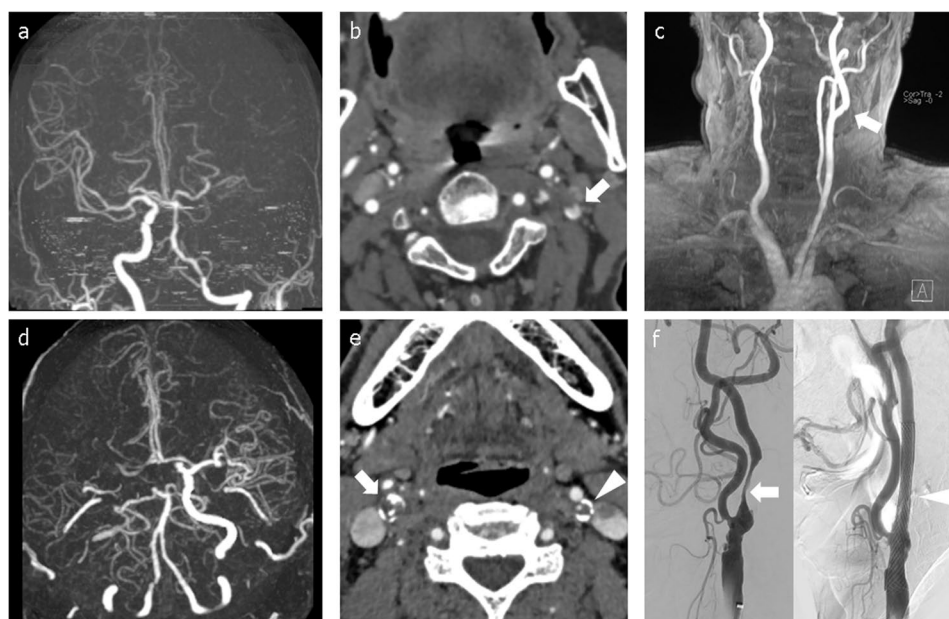


Fig. 2 Representative images of ICA occlusion. A 75-year-old female with right hemiplegia and global aphasia had a left ICA occlusion on CTA (**a**). Axial contrast CT image showed no significant calcification or stenosis in both proximal ICAs (**b**). Post-thrombectomy angiography revealed an intact left ICA, suggesting acute occlusion (arrow, **c**). A 76-year-old male with left-sided mild weakness had a right ICA occlusion extending to MCA on CTA (**d**). Axial contrast CT image showed moderate calcification in the right proximal ICA (arrow) and severe stenosis and calcification in the contralateral ICA (arrowhead) (**e**). Post-thrombectomy angiography revealed severe residual ICA stenosis (arrow), necessitating balloon angioplasty and stenting (arrowhead, **f**)

A carotid occlusion imaging score was developed based on significant factors identified through multivariable ordinal logistic regression.

Statistical analysis

Statistical analyses were conducted using R version 4.5.2 (R Foundation for Statistical Computing, Vienna, Austria). Univariable analyses compared demographic, clinical, and imaging variables between the two groups using independent sample t-tests or Mann-Whitney U tests for continuous variables, and χ^2 tests or Fisher's exact tests for categorical variables. To address potential confounding due to baseline clinical differences between groups, a multivariable logistic regression analysis was performed. Variables that differed between groups in univariable analyses ($P < 0.10$) and clinically relevant factors were included in the model. The multivariable analysis included age, sex, smoking status, and atrial fibrillation, with occlusion type (acute vs. chronic) as the dependent variable.

CTA imaging features were first evaluated with univariable analysis, and variable with $p < 0.10$ were further analyzed using multivariable ordinal logistic regression with backward stepwise selection. Two independent predictors (occlusion pattern and contralateral proximal ICA stenosis) were retained in the final model. Based on their regression coefficients and clinical relevance, we additionally included contralateral proximal ICA calcification (linear vs. other) and developed a carotid occlusion imaging score. The receiver operating characteristic (ROC) curve analysis and the area under the curve (AUC) were employed to predict chronic carotid disease using the carotid occlusion imaging score. To explore potential

overfitting of the proposed score, we performed an exploratory bootstrap-based internal validation using resampling techniques.

Results

Of the 273 eligible stroke patients who underwent EVT, we identified 51 patients with symptomatic extracranial ICA occlusion (Fig. 1). After excluding nine patients (seven with inadequate extracranial vessel imaging and two with cervical ICA dissection), 42 patients were included in the analysis. Of these, 28 patients (66.7%) were categorized as acute group, and 14 patients (33.3%) as chronic group (Table 1). The chronic group had a higher proportion of males and a greater smoking history, while atrial fibrillation was more prevalent in the acute group. In multivariable logistic regression adjusting for age, sex, smoking status, and atrial fibrillation, atrial fibrillation was independently associated with acute ICA occlusion (adjusted odds ratio [OR] 0.04, 95% confidence interval [CI] 0.003–0.25; $p = 0.003$). Other baseline clinical characteristics, including sex and smoking status, were not independently associated with occlusion type after adjustment. Initial neurological severity and clinical outcomes at discharge were numerically worse in the acute occlusion group, although the differences were not statistically significant. The acute occlusion group exhibited significantly larger penumbra and infarct core volumes, although the penumbra-to-core ratio did not significantly differ. Tandem ICA–MCA occlusion on the initial CTA was observed in 4 patients in the acute group and 2 patients in the acute-on-chronic group. And one patient in the chronic group had bilateral ICA occlusion. For this case, the contralateral carotid status was handled

Table 1 Baseline characteristics

	Acute (n = 28)	Chronic (n = 14)	p value
Age, years, median (IQR)	75 (63–80.75)	75 (58.5–78)	0.45
Sex, male, n (%)	13 (46.4%)	12 (85.7%)	0.02
Coronary artery disease, n (%)	6 (21.4%)	4 (28.6%)	0.71
Hypertension, n (%)	22 (78.6%)	10 (71.4%)	0.71
Diabetes, n (%)	14 (50.0%)	10 (71.4%)	0.32
Dyslipidemia, n (%)	17 (60.7%)	7 (50.0%)	0.51
Smoking, n (%)	3 (10.7%)	6 (42.9%)	0.04
Atrial fibrillation, n (%)	21 (75.0%)	2 (14.3%)	0.001
Intravenous thrombolysis, n (%)	10 (35.7%)	4 (28.6%)	0.74
Good reperfusion, n (%)	24 (88.9%)	12 (85.7%)	> 0.99
Initial NIHSS, median (IQR)	15.5 (9.5–19)	12.5 (6–15.5)	0.35
Discharge NIHSS, median (IQR)	6 (1–14.5)	2.5 (1–9.25)	0.83
mRS at 3 months, median (IQR)	3 (1–5)	1 (0.25–3.75)	0.34
Perfusion findings, median (IQR)			
Penumbra, mL	108.3 (53.2–131.6)	43.0 (26.3–70.4)	0.006
Core, mL	41.4 (7.1–59.9)	7.9 (2.5–15.7)	0.009
Penumbra/core ratio	2.53 (1.56–8.55)	4.27 (3.33–9.32)	0.52

IQR interquartile range, NIHSS National Institutes of Health Stroke Scale, mRS modified Rankin scale

Table 2 Comparison of the occlusion pattern and atherosclerotic burden between acute and chronic group

			Acute (n = 28)	Chronic (n = 14)	p value
Occlusion pattern					
Proximal ICA	Tapering		20 (71.4%)	1 (7.1%)	< 0.01
	Intermediate		7 (25.0%)	4 (28.6%)	
	Stump		1 (3.6%)	9 (64.3%)	
Distal ICA	Carotid T-occlusion		15 (53.6%)	4 (28.6%)	0.12
Atherosclerotic burden					
Ipsilateral	calcification	Degree			0.08
		None	11 (39.3%)	1 (7.1%)	
		Spotty	5 (17.9%)	5 (35.7%)	
Contralateral	calcification	Linear	12 (42.9%)	8 (57.1%)	0.03
		None	12 (42.9%)	2 (14.3%)	
		Spotty	11 (39.3%)	4 (28.6%)	
	stenosis	Linear	5 (17.9%)	8 (57.1%)	< 0.01
		None	16 (57.1%)	1 (7.1%)	
		Mild	10 (35.7%)	7 (50.0%)	
		Moderate	2 (7.1%)	6 (42.9%)	

ICA internal carotid artery

Table 3 Multivariable logistic regression and carotid occlusion imaging score for chronic carotid disease detection**A. Multivariable ordinal logistic regression**

Predictor	coefficient	OR(95% CI)	p-value
Occlusion pattern	3.07	21.48(2.62-175.93)	<0.01
Contralateral pICA stenosis	2.58	13.14(1.47-117.37)	0.02

B. Carotid occlusion imaging score

	Definition	Points
Occlusion pattern	Tapering=0, Intermediate=1, Stump=2	0-2
Contralateral pICA stenosis	None=0, Mild=1, Moderate=2	0-2
Contralateral pICA calcification	None or spotty =0, Linear=1	0-1
Total score	Sum of all components	0-5

C. Diagnostic performance of the score

Cut-off (≥)	Sensitivity	Specificity	PPV	NPV
1	1.00	0.39	0.45	1.00
2	0.93	0.71	0.62	0.95
3	0.86	0.89	0.80	0.93
4	0.64	1.00	1.00	0.85

OR odds ratio, CI confidence interval

ICA internal carotid artery, pICA proximal internal carotid artery

according to the prespecified grading scheme and was categorized as moderate stenosis for the contralateral proximal ICA stenosis variable.

Comparing occlusion patterns and atherosclerotic burden between the two groups, the acute group predominantly exhibited a tapering pattern (71.4%), while the chronic group tended to show a stump pattern (64.3%, Table 2). But the proportion of carotid T occlusion did not significantly differ between the groups. Atherosclerotic stenosis and calcification burden in the contralateral ICA were more significantly associated with chronic carotid disease, whereas atherosclerotic calcification in the ipsilateral ICA did not significantly differ. The extent of distal ICA calcification was similar between the groups. The carotid occlusion imaging score, constructed

using the ipsilateral ICA occlusion pattern and contralateral ICA atherosclerosis burden (stenosis and calcification, Table 3), demonstrated reasonable diagnostic accuracy (area under the ROC curve=0.94, 95% confidence interval: 0.87–1.00, $p<0.001$, Fig. 3) with the optimal cutoff value greater than three (sensitivity: 0.86, specificity: 0.89).

After demonstrating good discriminative performance of the carotid occlusion imaging score on receiver operating characteristic analysis, we further evaluated whether the score provided information independent of baseline clinical characteristics. In a multivariable logistic regression model incorporating the dichotomized carotid occlusion imaging score (≥ 3 vs. < 3) along with age, sex, smoking status, and atrial fibrillation, a score ≥ 3

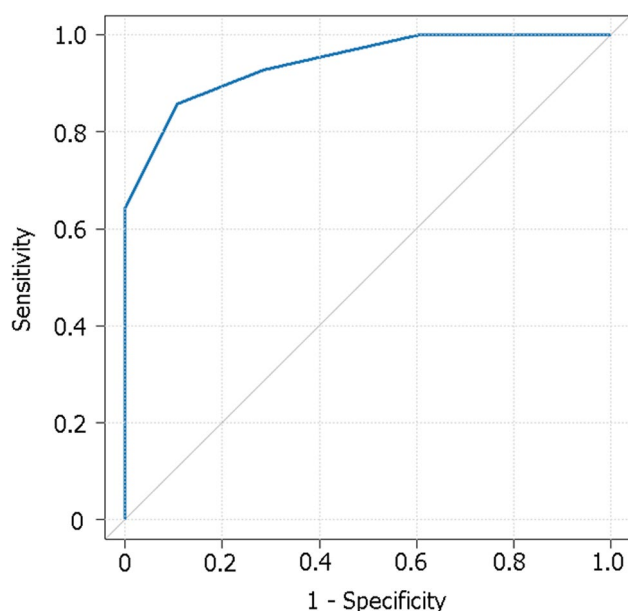


Fig. 3 Receiver operating characteristics curve for detecting chronic carotid disease using the carotid occlusion imaging score. The area under the curve was 0.94 (95% CI: 0.87–1.00, $p < 0.001$), with an optimal cutoff value of 3(≥) for predicting chronic carotid disease (sensitivity 0.86, specificity 0.89)

remained independently associated with chronic carotid disease (adjusted OR 56.9, 95% CI 5.36–2475, $p = 0.005$), Supplementary Table S1). In this model, atrial fibrillation was independently associated with the acute occlusion group (adjusted OR 0.05, 95% CI 0.001–0.62, $p = 0.04$), whereas age, sex, and smoking status were not independently associated after adjustment.

Discussion

In acute ischemic stroke patients with ICA occlusion, rapid endovascular treatment is often central to management; however, when the occlusion is associated with underlying chronic carotid disease, thrombectomy alone may be insufficient or technically challenging, and additional or alternative revascularization strategies may be required [8, 9]. Our study revealed that patients with acute ICA occlusion were more likely to exhibit a tapering occlusion pattern and relatively normal contralateral ICA vasculature. In contrast, patients with chronic carotid disease were associated with a stump pattern occlusion and a significant atherosclerotic burden in the contralateral ICA. Interestingly, there was no significant difference in ipsilateral proximal ICA calcification or distal ICA calcification between the two groups. Unlike luminal stenosis, calcification primarily reflects chronic plaque burden rather than hemodynamic significance or plaque vulnerability, it may have limited discriminatory value in this setting. In addition, carotid calcification grading is not yet standardized; therefore, we applied a

simplified, pragmatic classification for rapid assessment on emergency CTA [12–14]. The observed trend toward greater ipsilateral proximal calcification in the chronic group did not reach statistical significance, which may partly reflect the limited sample size.

Although sex, smoking status, and atrial fibrillation differed between acute and chronic groups in univariable analyses, only atrial fibrillation remained independently associated with the acute occlusion group after multivariable adjustment. This finding is consistent with the established role of atrial fibrillation as a major contributor to acute embolic stroke mechanisms. From a pathophysiological perspective, embolic occlusion related to atrial fibrillation may occur in the absence of advanced underlying carotid atherosclerosis, which could partly explain the lower contralateral atherosclerotic burden and the predominance of tapering-type occlusion patterns observed on CTA in the acute group. In contrast, occlusions associated with chronic carotid disease are more likely to reflect long-standing atherosclerotic remodeling, resulting in different imaging appearances. Notably, when incorporated into a multivariable model adjusting for major baseline clinical characteristics, the carotid occlusion imaging score remained independently associated with chronic carotid disease. However, the magnitude of the odds ratio and the wide confidence interval likely reflect the limited sample size and the small number of outcome events. Accordingly, the discriminative performance of the score should be interpreted as hypothesis-generating rather than definitive, pending external validation.

While previous studies have attempted to differentiate acute from chronic ICA occlusion based on CTA findings, their conclusions have been heterogeneous due to varying inclusion criteria and imaging modalities analyzed [4–5]. The definition of chronic ICA occlusion remains heterogeneous in the literature [15–17]. Many previous studies have defined chronic occlusion based on comparison with prior vascular imaging, often requiring documentation of persistent ICA occlusion over a predefined time interval; however, the specific imaging criteria and temporal thresholds vary across reports. Furthermore, data focusing on the imaging characteristics of chronic ICA occlusion in the acute stroke setting remain limited. In the present study, prior vascular imaging was not available, and partial recanalization was achieved during endovascular treatment in all included cases. Accordingly, lesions classified as chronic should not be interpreted as definitive chronic total ICA occlusions in a strict pathological sense. Rather, this group represents ICA occlusions associated with advanced underlying carotid disease, which may overlap with cases that are clinically regarded as chronic occlusion in routine practice.

Chronic ICA disease is most commonly caused by atherosclerosis, which, being a systemic disease, usually affects both ICAs [18–19]. Therefore, the finding in this study that patients in chronic group exhibited a greater atherosclerotic burden in the contralateral proximal ICA is consistent with this pathophysiologic mechanism. By leveraging the pathophysiological understanding and previously reported CTA findings, we developed a scoring system to identify chronic carotid disease that may require alternative endovascular or surgical revascularization strategies rather than conventional thrombectomy for acute occlusion. Our observations of the predominant tapering pattern in the acute occlusion group and the stump pattern in the chronic group align with earlier studies [4–5]. Although the carotid T occlusion pattern was previously reported to be prevalent in pseudo-occlusion (82%)—referring to an isolated intracranial thrombus impeding ascending blood flow with normal proximal ICA—versus atherosclerotic cases (15%) [6], our study found no significant difference between acute and chronic groups, likely due to the small number of included patients.

Our study has several limitations. First, it was conducted at a single center with a small patient sample, necessitating further research to externally validate the derived scoring system and to confirm its generalizability in independent cohorts. Although we performed an exploratory bootstrap-based internal validation to assess potential overfitting, given the small sample size, these results were not emphasized and should be interpreted with caution. Second, an unavoidable time gap exists between initial CTA and DSA for thrombectomy, during which clots may have migrated, potentially leading to discrepancies between the initial CTA and subsequent angiographic findings. Third, selection bias may be present, as we only included symptomatic ICA occlusion patients who underwent EVT. In addition, longitudinal clinical and imaging information prior to the index stroke was largely unavailable. Specifically, prior vascular imaging documenting pre-existing carotid stenosis and well-characterized ipsilateral TIA or stroke history were not consistently available, which limited our ability to incorporate such factors into the proposed imaging-based scoring system. Future studies integrating longitudinal clinical data and prior vascular imaging may further refine risk stratification and improve classification.

Conclusions

Distinguishing between acute and chronic carotid disease using limited imaging information poses a diagnostic challenge in acute stroke management. Carotid occlusion patterns and atherosclerosis burden may serve as useful indicators to help clinicians detect chronic ICA disease.

Abbreviations

ICA	Internal carotid artery
CTA	Computed tomography angiographic
DSA	Digital subtraction angiography
MRA	Magnetic resonance angiography
EVT	Endovascular thrombectomy
rCBV	Relative cerebral blood volume
ROC	Receiver operating characteristic
AUC	Area under the curve
OR	Odds ratio
CI	Confidence interval

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12883-026-04768-x>.

Supplementary Material 1.

Supplementary Material 2.

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Not applicable.

Authors' contributions

B.J., K.J.M., K.D.W., Y.W., J.H.Y., L.E.J., L.S.H., and J.K.H. contributed to the conception and design of the study. B.J., K.J.M., C.K.S., and J.K.H. contributed to acquisition, post-processing and analysis of the data. B.J. and K.J.M. drafted the text and prepared the figures.

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Data availability

The study data are available from the corresponding author upon reasonable request and with the permission of all contributing authors.

Declarations

Ethics approval and consent to participate

This study was conducted ethically in accordance with the guidelines of the Declaration of Helsinki. The Institutional Review Board of Seoul National University Hospital approved this study (IRB number: 1009-062-332), and informed consent was waived due to the retrospective design and minimal risk.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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