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Carotid plaque morphology on computed tomography angiography associated with cervical recanalization strategy in acute ischemic stroke with anterior circulation tandem lesions

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Abstract

PURPOSE

To determine whether carotid plaque morphology on preprocedural computed tomography angiography (CTA) is associated with the cervical recanalization strategy used during endovascular treatment (EVT) of acute ischemic stroke caused by anterior circulation tandem atherosclerotic lesions.

METHODS

We retrospectively analyzed a prospective single-center database of consecutive adults treated with mechanical thrombectomy within 24 h of last known well between January 2022 and February 2025. CTA features of the extracranial internal carotid artery lesion included plaque composition, occlusion-cap morphology, string sign, and calcification pattern (none, eggshell, or dystrophic). Patients were categorized according to cervical recanalization strategy: aspiration alone or percutaneous transluminal angioplasty with or without stenting (PTA±stent). Multivariable logistic regression was used to identify factors independently associated with PTA±stent.

RESULTS

Seventy-nine patients were included (median age, 68 years). Cervical recanalization was achieved with aspiration alone in 40 patients (50.6%) and with PTA±stent in 39 (49.4%); stents were implanted in 14 patients. Dystrophic calcification was more frequent in the PTA±stent group (38.5% vs. 17.5%; p = 0.038). Dystrophic calcification (adjusted odds ratio [OR], 4.84; 95% confidence interval [CI], 1.37–17.06; p = 0.014) and male sex (adjusted OR, 4.97; 95% CI, 1.43–17.31; p = 0.012) were independently associated with PTA±stent. Successful intracranial reperfusion was more frequent in the PTA±stent group (92.3% vs. 70.0%; p = 0.012), with no significant differences in symptomatic intracranial hemorrhage or 90-day functional outcome.

CONCLUSION

Dystrophic carotid calcification on CTA was independently associated with the use of cervical angioplasty with or without stenting. This preprocedural imaging feature may facilitate technical and antithrombotic planning during thrombectomy for tandem occlusions.

INTRODUCTION

Tandem lesions, defined as intracranial occlusions associated with high-grade stenosis (> 70%) or occlusions of the extracranial internal carotid artery (ICA), constitute a clinically relevant group of acute ischemic stroke (AIS) patients due to large vessel occlusion [1]. Their prevalence is approximately 15–

30% of all patients who are candidates for endovascular treatment (EVT) in the anterior circulation. EVT of tandem lesions is characterized by complex procedures with an unfavorable prognosis in cases of suboptimal management [2, 3].

In tandem occlusions, the optimal EVT strategy remains undefined, and both retrograde and antegrade approaches are currently used [1, 4]. In cervical ICA stenosis or occlusion, treatment options range from aspiration alone to percutaneous transluminal angioplasty (PTA) with or without stent implantation. Compared with balloon angioplasty alone, acute carotid stenting has been associated with higher rates of successful reperfusion and functional independence [1, 5]. Similar findings have been reported in comparisons of stenting and non-stenting strategies [6, 7]. More recently, an individual participant data meta-analysis from the IRIS collaboration showed that acute carotid stenting during EVT was associated with better 90-day functional outcomes, without a statistically significant increase in symptomatic intracranial hemorrhage, regardless of prior intravenous thrombolysis [8]. However, treatment selection remained largely dependent on operator judgment, highlighting the absence of standardized criteria for cervical treatment selection.

In addition to clinical and technical variables, CTA plaque morphology may provide information on whether an aspiration-only strategy is likely to be sufficient or whether PTA with or without stenting may be required during the acute procedure [8]. The traditional imaging markers of carotid plaque vulnerability, such as lipid core, intraplaque hemorrhage, or ulceration, were developed primarily for chronic or subacute risk stratification and were not designed to guide immediate decisions in patients with AIS due to tandem atherosclerotic lesions [9].

Despite the available literature, there is a lack of imaging biomarkers capable of identifying cervical lesions more likely to undergo PTA with or without stenting during EVT. Whether the morphological phenotype of extracranial carotid plaque on preprocedural CTA is associated with the cervical recanalization strategy remains uncertain. Because this decision is usually made during the procedure, a reliable preprocedural imaging marker could have implications for device and antithrombotic planning.

This study aimed to determine whether CTA-defined morphological characteristics of extracranial carotid plaque were associated with the cervical recanalization strategy used during EVT, specifically aspiration alone versus PTA±stent.

METHODS

Study Design/Ethics and Consent

We conducted a retrospective analysis of a prospective database of consecutive patients with AIS due to tandem atherosclerotic lesions treated with mechanical thrombectomy (MT) within 24 h of last known well at a comprehensive stroke center between January 2022 and February 2025. The study was approved by the local research ethics committee (approval number blinded for review), which waived study-specific informed consent, and was conducted in accordance with the Declaration of Helsinki and

applicable data-protection legislation. Procedural informed consent was obtained according to standard clinical practice. Data were coded to protect patient confidentiality. Given the exploratory nature of the study, no formal sample size calculation was performed. All consecutive eligible patients treated during the prespecified study period were included.

Inclusion Criteria

Inclusion criteria were age ≥ 18 years, acute anterior circulation tandem atherosclerotic lesion confirmed by digital subtraction angiography (DSA), EVT within 24 h of last known well, and baseline National Institutes of Health Stroke Scale (NIHSS) score ≥ 5. Patients with common carotid artery occlusion, bilateral carotid occlusions, non-evaluable CTA plaque morphology because of severe imaging artifacts, occlusion of a pre-existing carotid stent, or unavailable source images were excluded.

Patient Characteristics

The following demographic, clinical, and imaging variables were recorded: age; sex; cardiovascular risk factors, including hypertension, dyslipidemia, diabetes, atrial fibrillation, and current smoking; history of stroke or transient ischemic attack; ischemic heart disease; heart failure; peripheral arterial disease; chronic kidney disease; baseline modified Rankin Scale (mRS); admission NIHSS score; baseline ASPECTS on non-contrast CT; and intravenous thrombolysis.

CTA Imaging Protocol and Assessment

CTA Imaging Protocol and Assessment
All patients underwent multidetector CTA before EVT per institutional protocol. Acquisition extended helically from the aortic arch to the cranial vertex in a single pass, with breath-hold whenever feasible. Acquisition parameters included collimation of 0.5–0.6 mm, rotation time of 0.28–0.5 s, pitch of 0.8–1.2, and tube voltage of 100–120 kVp with automatic mA modulation. Field of view was tailored to the neck and head. For arterial opacification, we injected 70–80 mL of 350–400 mgI/mL iodinated contrast at 4 mL/s via an antecubital vein, followed by a 20 mL saline chaser. Bolus-tracking used a ROI positioned in the ascending aorta with a 120–150 HU threshold; scanning began 3–5 s after the threshold was reached to optimize arterial phase and minimize venous contamination. Axial images were reconstructed at a slice thickness of 0.5 mm.

An interventional neuroradiologist with more than 15 years of experience and a senior radiology resident with 4 years of experience in emergency stroke CTA interpretation assessed the images in consensus using predefined imaging criteria. Both readers were blinded to clinical and procedural information. Laterality, extracranial internal carotid artery occlusion, occlusion-cap morphology (tapered vs. blunt), string sign [10], and intracranial occlusion site (ICA terminus, MCA-M1, or MCA-M2) were assessed on cervical and intracranial CTA. Plaque composition was qualitatively classified by consensus according to

the visually predominant component across axial images and vessel-axis multiplanar reconstructions, as either soft-predominant or calcified-predominant. Eggshell calcification was defined as thin peripheral calcification < 2 mm in thickness, whereas dystrophic calcification was defined as calcified thickening ≥ 2 mm with bulky, irregular, and/or nodular morphology. Calcium thickness was measured perpendicular to the vessel wall at the site of greatest thickness. CTA lesion and plaque characteristics are illustrated in Fig. 1.

Endovascular Procedure

All procedures were performed by experienced neurointerventionalists at a tertiary stroke referral center. The treatment sequence was decided at the operator's discretion, using a retrograde approach (intracranial thrombectomy first) or an antegrade approach (treatment of the cervical lesion first), depending on the anatomy, ease of access, and clinical stability. At the extracranial ICA level, the recanalization strategy was recorded as aspiration alone or percutaneous transluminal angioplasty (PTA) with or without stent implantation (PTA ± stent). When an acute cervical thrombotic component was suspected, aspiration was initially attempted. PTA was performed when post-aspiration residual stenosis did not allow passage of a guide catheter distal to the lesion. A self-expanding carotid stent was used as a rescue strategy when stable patency of the ICA could not be achieved with aspiration/PTA, especially in cases of intraprocedural reocclusion or high-grade residual stenosis. Post-stent angioplasty was performed based on the final angiographic result.

Intracranial thrombectomy was performed using aspiration, stent retriever, or combined techniques, depending on the operator's preference and vascular characteristics. Final angiographic results (including mTICI reperfusion and cervical patency) and periprocedural complications were recorded as safety and efficacy variables of the procedure. In patients requiring carotid stenting, intravenous tirofiban and/or aspirin was continued until the 24-h follow-up CT; in the absence of hemorrhagic transformation, treatment was transitioned between 24 and 72 h to dual antiplatelet therapy with aspirin 100 mg once daily and ticagrelor (180-mg loading dose followed by 90 mg twice daily), whereas antiplatelet therapy was individualized in patients with hemorrhagic transformation, ranging from complete withdrawal to aspirin monotherapy.

The primary procedural endpoint was cervical internal carotid artery recanalization strategy (aspiration alone vs. PTA±stent). The secondary procedural endpoint was successful intracranial reperfusion (mTICI 2b–3). Procedure-related complications, including vessel dissection or perforation, were recorded as safety outcomes.

Clinical and imaging follow-up

All patients underwent non-contrast CT at 24 h, or earlier if clinical deterioration occurred. Hemorrhagic transformation was classified as HI1, HI2, PH1, or PH2 according to ECASS II criteria [11]; isolated

subarachnoid hemorrhage was recorded separately. The extent of acute ischemic change was assessed using ASPECTS. Symptomatic intracranial hemorrhage (sICH) was defined according to ECASS II.

In patients with carotid stent implantation, stent reocclusion was recorded during admission. Clinical outcome was assessed using NIHSS and mRS at discharge, and functional prognosis was assessed using mRS at 90 days (good functional outcome was defined as mRS 0–2). Recurrence of stroke/TIA during clinical follow-up was also recorded.

Statistical Analysis

Categorical variables are presented as frequencies and percentages, and continuous variables as mean (standard deviation [SD]) or median (interquartile range [IQR]), as appropriate. Patients were classified according to cervical recanalization strategy as aspiration alone or PTA±stent. Continuous variables were compared using the Mann–Whitney U test and categorical variables using the χ^2 test or Fisher exact test. Multivariable logistic regression was used to identify variables independently associated with PTA±stent. Based on clinical relevance and univariable findings, dystrophic calcification, male sex, current smoking, ischemic heart disease, and tapered occlusion-cap morphology were entered simultaneously into the multivariable logistic regression model. Adjusted odds ratios and 95% confidence intervals were reported. A secondary analysis compared patients with and without dystrophic calcification. Two-sided $p < 0.05$ was considered statistically significant. Analyses were performed using R version 3.6.1 (R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

During the study period, 93 consecutive patients were screened. Four patients (4.3%) were excluded because of common carotid artery occlusion, 2 (2.2%) because of bilateral carotid occlusion, and 8 (8.6%) because CTA plaque assessment was not feasible owing to severe imaging artifacts, occlusion of a pre-existing carotid stent, or unavailable source images. Therefore, 79 patients (84.9%) were included in the final analysis.

Cervical internal carotid artery recanalization was achieved in all patients: 40 (50.6%) with aspiration alone and 39 (49.4%) with PTA±stent. Stent implantation was required in 14 patients. Baseline demographic, clinical, and imaging variables according to cervical recanalization strategy are summarized in Table 1. Male sex and dystrophic calcification were more frequent among patients treated with PTA±stent. Occlusion morphology, string sign, intracranial occlusion site, and laterality were not significantly associated with cervical treatment strategy.

Procedural, imaging, and clinical outcomes are summarized in Table 2. No procedure-related vessel dissection or perforation occurred. Fourteen patients (17.7%) received intravenous tirofiban and three (3.8%) received intravenous acetylsalicylic acid. Stent occlusion occurred in 3 of 14 patients (21.4%).

In multivariable logistic regression (Table 3), dystrophic calcification (OR, 4.84; 95% CI, 1.37–17.06; p = 0.014) and male sex (OR, 4.97; 95% CI, 1.43–17.31; p = 0.012) were independently associated with

PTA±stent. The remaining covariates were not significantly associated with PTA±stent.

Dystrophic calcification was present in 22 patients. Baseline, imaging, and outcome variables according to calcification phenotype are shown in Table 4; no additional variables differed significantly between groups.

DISCUSSION

The central finding of this study is that dystrophic calcification on CTA and male sex were independently associated with cervical reconstruction with PTA±stent in patients with AIS due to anterior circulation tandem lesions. In practice, escalation from aspiration alone to PTA±stent is often decided during the procedure after initial unsuccessful maneuvers. Our findings suggest that preprocedural CTA may provide procedurally relevant information, particularly through characterization of carotid calcification.

The association between dystrophic calcification and the use of PTA±stent is biologically plausible: heavily calcified plaques can limit the passage of the guide catheter through them, increasing the need for percutaneous transluminal angioplasty (PTA). In this context, angioplasty and/or stent placement may be required to cross the stenosis, restore flow, and maintain vessel patency. These findings are consistent with procedural experience and identify a preprocedural imaging feature associated with the use of PTA±stent. The association with male sex should be interpreted cautiously because no prespecified biological mechanism was tested.

This finding is clinically relevant because it may facilitate preprocedural planning, including device selection, balloon and stent availability, access planning, and preparation for distal protection when appropriate. It may also support antithrombotic planning when carotid stenting is anticipated, with the potential to reduce procedural delays and unnecessary maneuvers. However, these specific procedural benefits require confirmation in prospective studies.

The dystrophic phenotype provides information that does not appear to be redundant with other imaging variables. In our registry, markers such as string sign and tapered/blunt occlusion morphology did not consistently discriminate between strategies. This suggests that these markers could capture anatomical or hemodynamic dimensions, but not necessarily the biomechanics of the plaque (stiffness, recoil, resistance to aspiration/angioplasty). In contrast, the dystrophic phenotype could be a direct indicator of this mechanical behavior, which would explain its persistence after adjustment.

Our observations are biologically plausible from a biomechanical point of view: the circumferential load and distribution of calcium increase wall stiffness, hindering crossing, favoring wall recoil after PTA and compromising adequate stent expansion, leading to greater residual stenosis and embolic risk [12, 13]. When recanalizing the carotid artery, a higher calcified plaque volume has been associated with increased residual stenosis and restenosis [12], whereas calcification involving > 50% of the vessel circumference has been associated with poorer outcomes after carotid artery stenting [13].

Meta-analyses have shown that emergency carotid stenting, compared with isolated PTA, is associated with higher rates of reperfusion and functional independence, without significant differences in sICH or mortality [1–8]. Our findings were consistent with previously reported safety data, although the present study was not powered to assess differences in hemorrhagic complications. In addition, our study identifies a preprocedural imaging feature associated with a greater likelihood of cervical reconstruction using PTA, with or without stenting. These findings are consistent with recent evidence supporting acute carotid stenting as a safe and effective strategy [7, 8].

Unlike previous studies of the rim sign, which focused primarily on histopathologic markers of plaque vulnerability [14, 15], our study addressed an operational procedural question: whether plaque morphology on baseline CTA is associated with the cervical recanalization strategy used during acute EVT. Our findings suggest that plaque architecture may influence procedural strategy. However, the proposed classification is not intended to dictate treatment and requires external validation before clinical implementation.

The PTA±stent group achieved a higher rate of successful intracranial reperfusion (mTICI ≥2b), possibly because cervical reconstruction improved inflow and stabilized final flow. However, this angiographic advantage did not translate into better 90-day functional outcomes. This may reflect the influence of multiple factors, including baseline infarct burden, treatment time, microvascular reperfusion, reperfusion injury, complications, comorbidity, and post-acute care, as well as confounding by indication in this observational cohort

The main limitations of this study are its retrospective, single-center, nonrandomized design and the potential for confounding by indication, because the cervical treatment strategy was determined by operator judgment and angiographic complexity. The modest sample size and wide confidence intervals limit the precision and generalizability of the results. Because PTA and stenting were analyzed as a combined outcome, our findings should not be interpreted as specifically predicting the need for stent implantation. In addition, because plaque assessment was performed by consensus, interobserver agreement could not be formally evaluated. External validation and standardized assessment of interobserver and intraobserver reproducibility are required before this marker can be incorporated into treatment algorithms.

CONCLUSIONS

In AIS due to anterior circulation tandem occlusions, dystrophic carotid calcification on CTA was independently associated with the use of cervical PTA±stent after adjustment for clinical and imaging variables. Preprocedural plaque characterization may facilitate technical and antithrombotic planning. External validation and formal assessment of observer reproducibility are required before this marker can be incorporated into standardized treatment algorithms.

Abbreviations

AIS
acute ischemic stroke
ASPECTS
Alberta Stroke Program Early CT Score
CAS
carotid artery stenting
CI
confidence interval
CT
computed tomography
CTA
computed tomography angiography
DSA
digital subtraction angiography
ECASS
European Cooperative Acute Stroke Study
EVT
endovascular treatment
HI1
hemorrhagic infarction type 1
HI2
hemorrhagic infarction type 2
HU
Hounsfield units
ICA
internal carotid artery
IQR
interquartile range
IV
intravenous
MCA
middle cerebral artery
mRS
modified Rankin Scale
MT
mechanical thrombectomy
mTICI
modified Thrombolysis in Cerebral Infarction
NCCT
non-contrast computed tomography

NIHSS
National Institutes of Health Stroke Scale
OR
odds ratio
PH1
parenchymal hematoma type 1
PH2
parenchymal hematoma type 2
PTA
percutaneous transluminal angioplasty
ROI
region of interest
rt-PA
recombinant tissue plasminogen activator
SAH
subarachnoid hemorrhage
SD
standard deviation
sICH
symptomatic intracranial hemorrhage
TCAR
transcarotid artery revascularization
TIA
transient ischemic attack.

Declarations

Author Contribution

Conceptualization: all authors. Methodology: A.L.R and J.G.G. Data curation: A.N.G.Formal analysis and investigation: A.L.R. and J.G.G.Validation: A.L.R. Visualization: A.L.R. and J.G.G. Writing—original draft preparation: A.L.R. and J.G.G. Supervision: A.L.R.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request, subject to patient privacy and institutional data-protection requirements.

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Tables

Table 1
Baseline demographic, clinical, and imaging characteristics according to cervical ICA recanalization strategy

Age, years, median (IQR)	**TOTAL (n = 79)**	**Aspiration alone (n = 40)**	**PTA ± stent (n = 39)**	***p-value***
	68 (60, 76)	**70 (60.5, 79)**	**64 (60, 75)**	**0.233**
Male sex (n, %)	54 (68.4%)	23 (57.5%)	31 (79.5%)	0.036
Risk factors (n, %)				
Hypertension	51 (64.6%)	26 (65%)	25 (64.1%)	0.934
Dyslipidemia	39 (49.4%)	17 (42.5%)	22 (56.4%)	0.216
Diabetes	14 (17.7%)	6 (15%)	8 (20.5%)	0.521
Atrial fibrillation	2 (2.5%)	1 (2.5%)	1 (2.6%)	1
Current smoking	30 (38%)	11 (27.5%)	19 (48.7%)	0.052
Previous stroke/TIA	11 (13.9%)	4 (10%)	7 (17.9%)	0.308
Ischemic heart disease	6 (7.6%)	1 (2.5%)	5 (12.8%)	0.108
Heart failure	6 (7.6%)	3 (7.5%)	3 (7.7%)	1
Peripheral arterial disease	5 (6.3%)	1 (2.5%)	4 (10.3%)	0.201
Chronic kidney disease	7 (8.9%)	3 (7.5%)	4 (10.3%)	0.712
Baseline mRS, median (IQR)	0 (0, 1)	0 (0, 1)	0 (0, 0)	0.294
Baseline NIHSS, median (IQR)	17 (13, 20)	16.5 (13, 19)	18 (13, 20)	0.206
Baseline ASPECTS, median (IQR)	9 (7, 10)	8 (7, 10)	9 (8, 10)	0.980
IV thrombolysis, rt-PA (n, %)	32 (40.5%)	18 (45%)	14 (35.9%)	0.410
Left laterality (n, %)	42 (53.2%)	21 (52.5%)	21 (53.8%)	0.905
Occlusion morphology (n, %)				0.142
Blunt	32 (40.5%)	13 (32.5%)	19 (48.7%)	
Tapered	47 (59.5%)	27 (67.5%)	20 (51.3%)	
String sign (n, %)	21 (26.6%)	13 (32.5%)	8 (20.5%)	0.228
Intracranial occlusion site (n, %)				0.594
MCA-M1	49 (62%)	26 (65%)	23 (59%)	
MCA-M2	11 (13.9%)	4 (10%)	7 (17.9%)	

Age, years, median (IQR)	**TOTAL (n = 79)**	**Aspiration alone (n = 40)**	**PTA ± stent (n = 39)**	***p-value***
	68 (60, 76)	**70 (60.5, 79)**	**64 (60, 75)**	**0.233**
ICA terminus	19 (24.1%)	10 (25%)	9 (23.1%)	
Carotid plaque composition (n, %)				0.153
Soft-predominant	62 (78.5%)	34 (85%)	28 (71.8%)	
Calcified-predominant	17 (21.5%)	6 (15%)	11 (28.2%)	
Calcification pattern (n, %)				0.022
None	17 (21.5%)	13 (32.5%)	4 (10.3%)	
Eggshell	40 (50.6%)	20 (50%)	20 (51.3%)	
Dystrophic	22 (27.8%)	7 (17.5%)	15 (38.5%)	
Dystrophic calcification (vs. none/eggshell) (n, %)	22 (27.8%)	7 (17.5%)	15 (38.5%)	0.038

ICA Internal Carotid Artery; *PTA* Percutaneous Transluminal Angioplasty; *IQR* Interquartile Range; *TIA* Transient Ischemic Attack; *mRS* Modified Rankin Scale; *NIHSS* National Institutes of Health Stroke Scale; *ASPECTS* Alberta Stroke Program Early CT Score; *IV* Intravenous; *rt-PA* Recombinant tissue plasminogen activator; *MCA* Middle Cerebral Artery; *MCA-M2* Middle Cerebral Artery M2 segment.

Table 2
Procedural, imaging, and clinical outcomes according to cervical ICA recanalization strategy

Successful reperfusion (mTICI ≥2b) (n, %)	**TOTAL (n = 79)**	**Aspiration alone (n = 40)**	**PTA ± stent (n = 39)**	***p-value***
	64 (81%)	**28 (70%)**	**36 (92.3%)**	**0.012**
Final mTICI (n, %)				0.214
0	8 (10.1%)	7 (17.5%)	1 (2.6%)	
2a	8 (10.1%)	5 (12.5%)	3 (7.7%)	
2b	36 (45.6%)	16 (40%)	20 (51.3%)	
2c	12 (15.2%)	5 (12.5%)	7 (17.9%)	
3	15 (19%)	7 (17.5%)	8 (20.5%)	
Intracranial hemorrhagic findings at 24 h, n (%)				0.569
No	55 (69.6%)	28 (70%)	27 (69.2%)	
HI1	7 (8.9%)	3 (7.5%)	4 (10.3%)	
HI2	5 (6.3%)	1 (2.5%)	4 (10.3%)	
PH1	3 (3.8%)	2 (5%)	1 (2.6%)	
PH2	5 (6.3%)	4 (10%)	1 (2.6%)	
SAH	4 (5.1%)	2 (5%)	2 (5.1%)	
ASPECTS at 24 h, median (IQR)	7 (4, 8)	6 (4, 8)	7 (4, 9)	0.306
sICH (n, %)	7 (8.9%)	4 (10%)	3 (7.7%)	1
NIHSS at discharge, median (IQR)	6 (2, 15)	8 (2, 16)	4 (1, 12)	0.112
mRS at discharge, median (IQR)	4 (2, 5)	4 (3, 5)	3 (2, 5)	0.120
mRS at 90 days, median (IQR)	3 (2, 4)	3 (2, 4)	3 (1, 4)	0.252
Good outcome (mRS 0–2 at 90 days) (n, %)	33 (41.8%)	14 (35%)	19 (48.7%)	0.216
Stroke/TIA recurrence (n, %)	3 (3.8%)	1 (2.5%)	2 (5.1%)	0.615

ICA Internal Carotid Artery; *PTA* Percutaneous Transluminal Angioplasty; *mTICI* Modified Thrombolysis in Cerebral Infarction; *ECASS* European Cooperative Acute Stroke Study; *ASPECTS* Alberta Stroke Program Early CT Score; *IQR* Interquartile Range; *sICH* Symptomatic Intracranial Hemorrhage; *NIHSS* National Institutes of Health Stroke Scale; *mRS* Modified Rankin Scale; *TIA* Transient Ischemic Attack

Table 3
Multivariable logistic regression analysis of factors associated with PTA±stent in tandem occlusions

Dystrophic calcification	**Adjusted OR (95% CI)**	***p-value***
	4.84 (1.37–17.06)	**0.014**
Male sex	4.97 (1.43–17.31)	0.012
Current smoking	2.17 (0.7–6.23)	0.151
Ischemic heart disease	8.17 (0.61–109.22)	0.112
Occlusion morphology: tapered	0.40 (0.14–1.14)	0.087
Values are adjusted odds ratios (ORs) with 95% confidence intervals (CIs) derived from a multivariable logistic regression model including all listed covariates.		

Table 4
Subanalysis by carotid plaque phenotype on CT angiography (dystrophic vs. non-dystrophic calcification): baseline characteristics, imaging findings, and outcomes.

Age, years, median (IQR)	**TOTAL (n = 79)**	**Non-dystrophic (n = 57)**	**Dystrophic (n = 22)**	***p-value***
	68 (60, 76)	**67 (59, 75)**	**71 (64, 80)**	**0.069**
Male sex (n, %)	54 (68.4%)	42 (73.7%)	12 (54.5%)	0.101
Risk factors (n, %)				
Hypertension	51 (64.6%)	36 (63.2%)	15 (68.2%)	0.676
Dyslipidemia	39 (49.4%)	25 (43.9%)	14 (63.6%)	0.115
Diabetes	14 (17.7%)	8 (14%)	6 (27.3%)	0.196
Atrial fibrillation	2 (2.5%)	1 (1.8%)	1 (4.5%)	0.482
Current smoking	30 (38%)	22 (38.6%)	8 (36.4%)	0.855
Previous stroke/TIA	11 (13.9%)	7 (12.3%)	4 (18.2%)	0.488
Ischemic heart disease	6 (7.6%)	3 (5.3%)	3 (13.6%)	0.340
Chronic heart failure	6 (7.6%)	3 (5.3%)	3 (13.6%)	0.340
Peripheral arterial disease	5 (6.3%)	3 (5.3%)	2 (9.1%)	0.614
Chronic kidney disease	7 (8.9%)	5 (8.8%)	2 (9.1%)	1
Occlusion morphology (n, %)				0.964
Blunt	32 (40.5%)	23 (40.4%)	9 (40.9%)	
Tapered	47 (59.5%)	34 (59.6%)	13 (59.1%)	
String sign (n, %)	21 (26.6%)	16 (28.1%)	5 (22.7%)	0.630
Intracranial occlusion site (n, %)				1
MCA-M1	49 (62%)	35 (61.4%)	14 (63.6%)	
MCA-M2	11 (13.9%)	8 (14%)	3 (13.6%)	
ICA terminus	19 (24.1%)	14 (24.6%)	5 (22.7%)	
Left laterality (n, %)	42 (53.2%)	32 (56.1%)	10 (45.5%)	0.394
Successful reperfusion (mTICI ≥2b) (n, %)	64 (81%)	45 (78.9%)	19 (86.4%)	0.539
Final mTICI (n, %)				0.149
0	8 (10.1%)	5 (8.8%)	3 (13.6%)	

Age, years, median (IQR)	TOTAL (n = 79)	Non-dystrophic (n = 57)	Dystrophic (n = 22)	*p-value*
	68 (60, 76)	**67 (59, 75)**	**71 (64, 80)**	**0.069**
2a	8 (10.1%)	8 (14%)	0 (0%)	
2b	36 (45.6%)	27 (47.4%)	9 (40.9%)	
2c	12 (15.2%)	6 (10.5%)	6 (27.3%)	
3	15 (19%)	11 (19.3%)	4 (18.2%)	

IQR Interquartile Range; *TIA* Transient Ischemic Attack; *MCA* Middle Cerebral Artery; *MCA-M2* Middle Cerebral Artery M2 segment; *ICA* Internal Carotid Artery; *mTICI* Modified Thrombolysis in Cerebral Infarction.

Figures

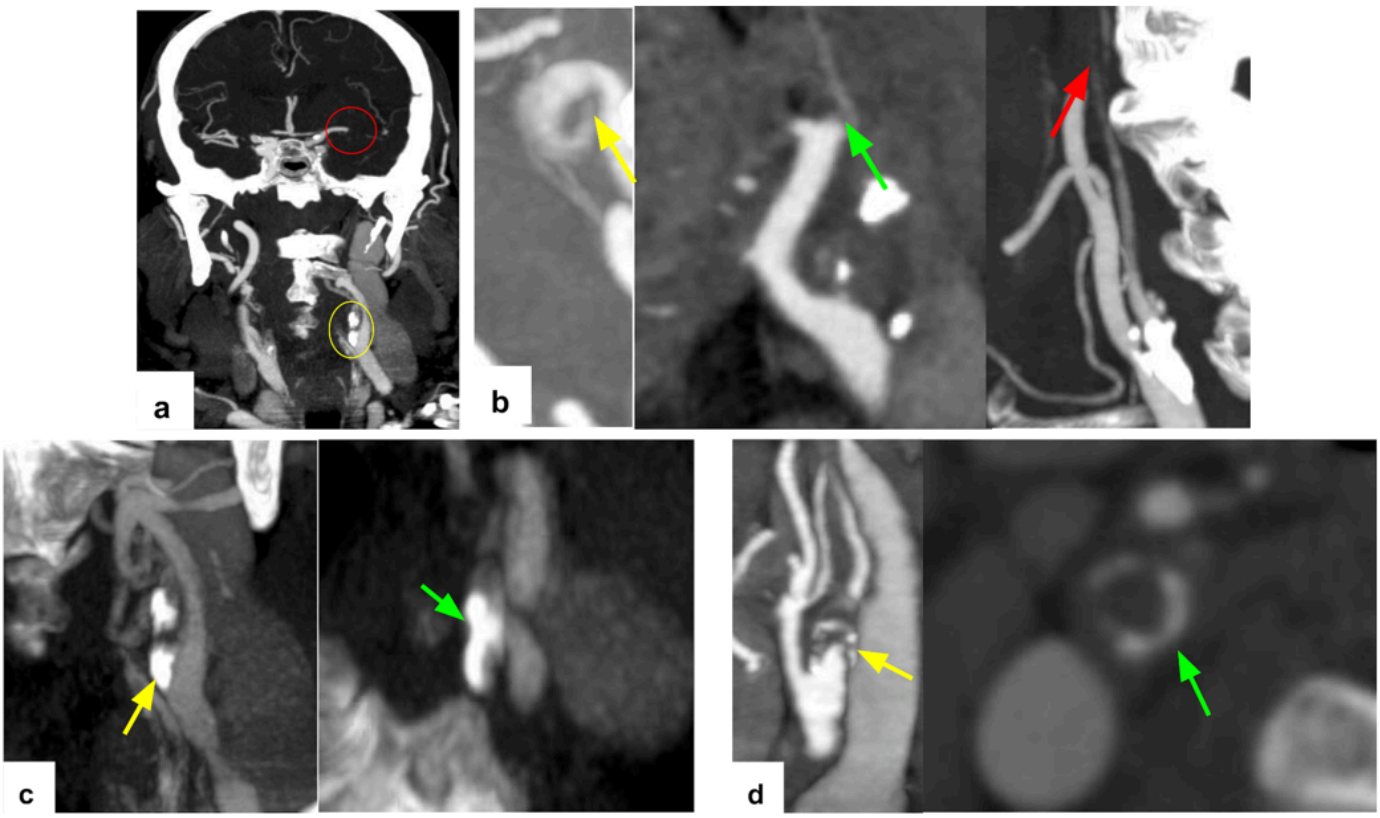


Figure 1

Morphological biomarkers on CT angiography in acute ischemic stroke with tandem lesion. (a) Coronal CTA reconstruction showing a left middle cerebral artery large-vessel occlusion (red circle) and an ipsilateral cervical carotid lesion (yellow circle), consistent with a tandem lesion. (b) CTA reconstructions of the carotid bifurcation illustrating tapered occlusion, blunt occlusion, and residual filiform

opacification (string sign). (c) Examples of dystrophic calcification, defined as thick, irregular, or nodular calcification ≥2 mm. (d) Examples of eggshell calcification, defined as thin peripheral calcification <2 mm