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Prevalence and clinical implications of calcification in internal carotid artery stenosis: a retrospective study

Fengli Fu^{1†}, Xiaoli Liu^{2,3†}, Rui Zhang⁴, Siran Zhang², Jianhua Mao¹, Yan Li², Shu Wan^{3,5*} and Shanhu Xu^{2,3*}

Abstract

Background Calcification is common in advanced atheromatous plaque, but its clinical significance remains unclear. This study aimed to assess the prevalence of plaque calcification in the moderate-to-severe internal carotid artery stenosis and investigate its relationship with ipsilateral ischemia.

Methods The retrospective study included 178 patients detected with proximal internal carotid artery (pICA) stenosis of $\geq 50\%$ on multidetector computed tomography at Zhejiang Hospital from January 2019 to March 2023. Association between plaque calcification characteristics (calcification thickness, position, type, circumferential extent, calcium volume and calcium score) and ipsilateral cerebrovascular events was analyzed.

Results The 178 patients (mean age 71.24 ± 10.02 years, 79.78% males) had 224 stenosed pICAs overall. Plaque calcification was noted in 200/224 (89.29%) arteries. Calcification rates were higher in older age-groups. Calcification volume ($r=0.219$, $p < 0.001$) and calcification score ($r=0.230$, $p < 0.001$) were correlated with age. Ipsilateral ischemic events were significantly more common in the noncalcification group than in the calcification group ($\chi^2=4.160$, $p=0.041$). The most common calcification type was positive rim sign calcification (87/200, 43.50%), followed by bulky calcification (66/200, 33.00%); both were significantly associated with ischemic events ($\chi^2=10.448$, $p=0.001$ and $\chi^2=4.552$, $p=0.033$, respectively). Calcification position, thickness, and circumferential extent, and calcification volume and score, were not associated with ischemic events. In multivariate analysis, positive rim signs (OR=2.795, 95%CI 1.182–6.608, $p=0.019$) was an independent predictor of ischemic events.

Conclusions Plaque calcification in proximal internal carotid artery is common, and prevalence increases with age. Calcification characteristics could be predictive of ipsilateral ischemic events. The positive rim sign within plaque is a high-risk factor for a future ischemic event.

Keywords Internal carotid artery, Plaque calcification, Ischemic stroke, Positive rim sign, Multidetector computed tomographic angiography

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Internal carotid artery (ICA) stenosis is being frequently encountered in clinical practice due to aging of the population and improvements in vascular imaging techniques. ICA stenosis is an advanced stage of atherosclerosis, with widely varying clinical presentations; some patients may be asymptomatic while others may present with transient ischemic symptoms or severe ischemic stroke [1]. According to the degree of stenosis, ICA stenosis is classified as mild (<50%), moderate (50–69%), or severe (70–99%) [2, 3]. The proximal internal carotid artery (pICA), where there is marked alteration in blood flow velocity, is the region most prone to stenosis and plaque formation. The degree of stenosis is related to risk of ipsilateral ischemic stroke and an important consideration when deciding whether to opt for surgical or interventional treatment [4].

In addition to the degree of stenosis, morphology and composition of the plaque are also valuable imaging parameters. Specific plaque features, such as intraplaque hemorrhage, large lipid-necrotic core, and plaque ulceration are known risk factors for future ischemic stroke [5, 6], but these characteristics are not routinely assessed. Calcification in atherosclerotic plaque, which has long been recognized, is believed to result from the interaction of factors such as chronic inflammation, autophagy defects, endoplasmic reticulum stress, and mitochondrial dysfunction [7]. Calcification was once considered a passive degenerative process and a possible contributor to plaque stability [8]; however, the understanding of vascular calcification has changed in recent years. In the coronary arteries, calcification is associated with significant vessel stenosis and is an established predictor of future cardiac events and sudden death [9, 10]. However, the significance of calcification in the cerebral vasculature is still incompletely understood. Some authors have found that calcification is a protective factor [11], while others claim that it is associated with increased risk of stroke [12–14]. One study found that the presence and severity of intracranial artery calcification are linked to a higher risk of stroke, but that calcification might actually have a protective effect when stenosis already exists [15]. There is consensus, however, that plaque calcification changes blood dynamics by inducing arterial remodeling processes and increasing arterial stiffness and interface stresses [8, 16]. For the clinician, assessment of calcification can help in determining plaque stability and stroke risk and in making treatment decisions, especially regarding the need for aggressive interventions. Multi-detector computed tomographic angiography (MDCTA) can provide valuable information on luminal stenosis and plaque characteristics [6].

The aim of this study was to assess the incidence of plaque calcification in patients with moderate-to-severe pICA stenosis and to investigate the relationship between calcification and ipsilateral ischemia.

Method

Study design and participants

This retrospective observational study was conducted at Zhejiang Hospital after obtaining approval from the Zhejiang hospital ethics committee (2023-40-K). The need for informed consent was waived because of the retrospective nature of the study.

All patients diagnosed with pICA stenosis on carotid MDCTA between January 2019 and March 2023 were identified. pICA was defined as the part of the internal carotid artery extending 2 cm from the bifurcation of the common carotid artery. The degree of stenosis was calculated by two experienced radiologists using North American Symptomatic Carotid Endarterectomy Trial (NASCET) criteria on contrast computed tomographic angiography (CTA) images [3]. Patients were excluded from the study if (1) they had mild (<50%) stenosis ($n=4825$) or suspicion of occlusion ($n=53$); (2) there was history of previous endarterectomy or stenting treatment ($n=15$); (3) there were other possible causes for stenosis such as dissection ($n=28$), thrombosis ($n=6$), moyamoya disease ($n=3$), and fibromuscular dysplasia ($n=2$); or (5) there was incomplete CT imaging data ($n=3$) or clinical data ($n=11$). For patients who had undergone repeat CTA examinations ($n=86$), only the data at the earliest detection of pICA stenosis were included for analysis. A total of 178 patients (with 224 stenosed pICAs) met the eligibility criteria. Figure 1 shows the patient selection process. The majority of the participants were from outpatient or inpatient visits to our neurology department and were associated with cerebrovascular symptoms; while some patients were detected by CTA screening for nonspecific symptoms such as dizziness, headache, and cognitive impairment. There were also a small percentage of asymptomatic screened patients.

Data collection

Two neurologists retrieved the baseline demographic and clinical data of patients from the electronic medical records. Data were collected on demographics (age, sex); lifestyle factors (cigarette smoking, alcohol drinking); comorbidities (hypertension, diabetes, coronary artery disease, atrial fibrillation); current medications (antiplatelet drugs and statins); and laboratory test results (white blood cell count, C-reactive protein, blood sugar, triglyceride, low-density lipoprotein, high-density lipoprotein, serum creatinine, blood urea nitrogen, glomerular filtration rate (GFR), and alkaline phosphatase). Only test results obtained one week before or after carotid MDCTA were collected.

MDCT technique

MDCTA was performed using a NeuViz scanner (NeuSoft Medical Systems, China) or a dual-source Somatom

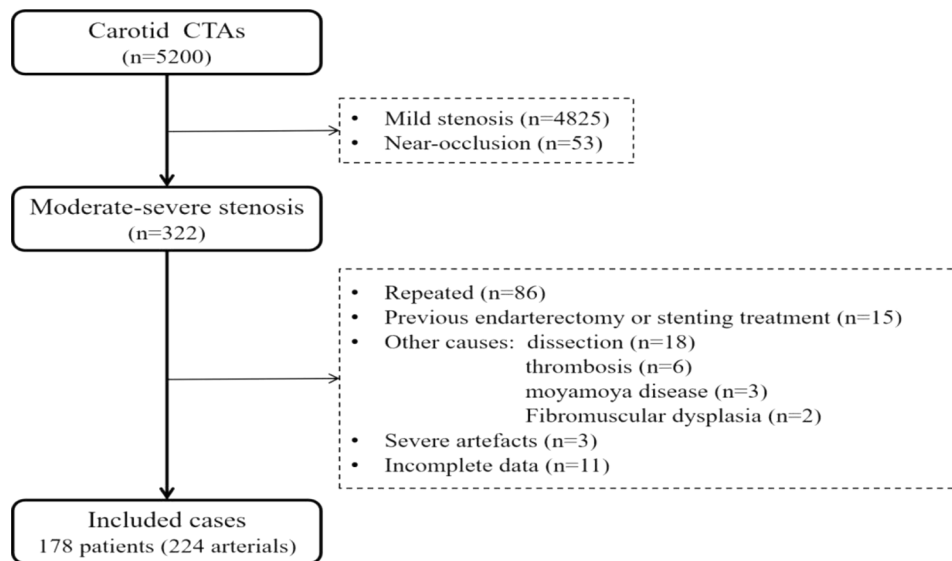


Fig. 1 Flowchart of participant selection (CTA: computed tomographic angiography; pICA: proximal internal carotid artery)

Force scanner (Siemens, Germany). Scanning was performed from the aortic arch to the first cervical intervertebral disc. Established standard-of-care CTA protocols were followed. Multiplanar reformatted images were reviewed on a PACS workstation on CTA settings, with modifications made as required to depict CTA lumen markers and calcification. The images were evaluated by two senior radiologists.

Evaluation of calcification

A standardized evaluation protocol was used for assessment of plaque calcification at the stenosis. Calcification was defined as a region with ≥ 1 contiguous pixels with CT attenuation ≥ 130 Hounsfield units in each image slice [17]. The calcification was graded according to location, circumferential extent, thickness, and type. According to location, the calcification was classified as inner (intimal), outer (near the adventitia), or mixed (both intimal and adventitial). According to circumferential extent, it was classified as single calcification (including spotty calcification) occupying $< 90^\circ$ of carotid wall circumference, occupying 90° – 270° of carotid wall circumference, or occupying $> 270^\circ$ of carotid wall circumference [18]. Thickness of calcification in the plaque was measured on the largest longitudinal section of the plaque by using the centimeter scale accompanying the radiograph. Type of calcification was classified as superficial spotty calcification, bulky calcification, or rim calcification (Fig. 2). A superficial spotty calcification was defined as presence of calcification with diameter < 3 mm in the area adjacent to the vessel lumen with no visible gap to the lumen on any cross-sectional images, occupying only one side and extending $< 90^\circ$ of the artery circumference on cross-sectional images [17, 19]. Bulky calcification was defined

as calcification measuring 2 mm in thickness. Positive rim calcification (positive rim sign) was defined as calcification measuring < 2 mm in thickness, with adjacent soft plaque measuring > 2 mm in thickness; conversely, negative rim sign was defined as calcification measuring < 2 mm in thickness, with adjacent soft plaque measuring < 2 mm in thickness [20].

Calcium volume and calcium burden was calculated on CTA using the Agatston scoring method [21]. Image data were transferred to a computer workstation (syngo.via; Siemens, Germany) for image postprocessing, and plaque calcification was quantified in noncontrast CT. A threshold of 130 Hounsfield units was used to identify calcification.

Patient grouping

Ischemic event was defined as a cerebral infarction or transient ischemic attack (TIA) on the ipsilateral side of the stenosis, with a time window of up to 3 months after symptom onset. The clinical information relies on clear medical history or confirmation by magnetic resonance imaging (MRI) or CT imaging. pICAs were classified into two groups: ischemia or nonischemia group based on the occurrence of ipsilateral ischemic episodes.

Statistical analysis

Statistical analysis was performed using SPSS 19 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as means \pm standard deviation and compared using the Student's *t*-test or the Mann-Whitney *U* test. Categorical variables were expressed as percentages and compared using the chi-squared test or the Fisher exact test. Correlation between calcification score and age was evaluated using Spearman rank correlation coefficient.

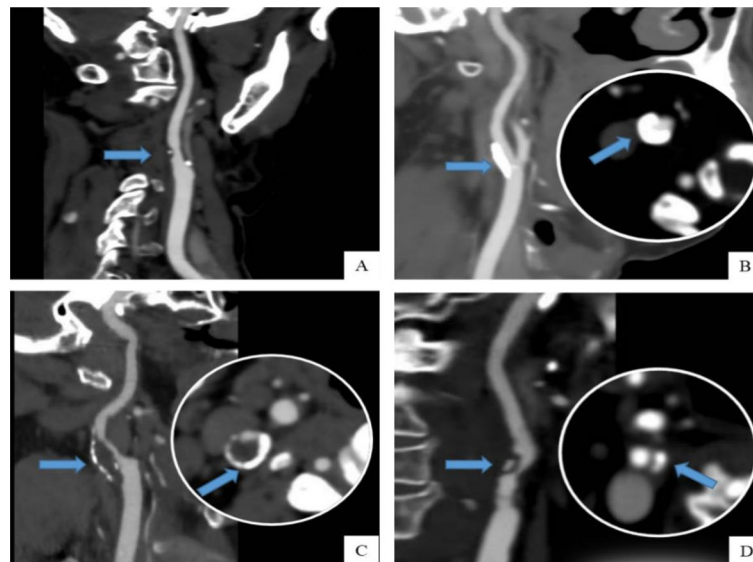


Fig. 2 Representative figures of calcification types (arrowheads) on CTA. **(A)** superficial spotty calcium; **(B)** bulky calcification extending 180°-270° of artery circumference; **(C)** positive rim sign extending > 270° of artery circumference; **(D)** negative rim sign extending < 90° of artery circumference

Table 1 Baseline characteristics of the patients ($n = 178$)

Characteristic	Data
Age, yr	71.24 ± 10.02
Males	142 (79.78)
Hypertension	141 (79.21)
Diabetes	53 (29.77)
Coronary artery disease	38 (21.35)
Atrial fibrillation	11 (6.18)
Current smoker	47 (26.40)
Current drinker	46 (25.84)
Ischemic events	91 (51.12)
Anterior circulation ischemic events	78 (43.82)
Ipsilateral anterior circulation ischemic events	69 (31.39)
Statin use	40 (22.47)
Antiplatelet use	47 (26.40)
Side of stenosis	
Left	68 (38.20)
Right	64 (35.96)
Bilateral	46 (25.84)

Data are mean ± standard deviation or n (%)

Univariate and multivariate logistic regression analyses were used to identify the factors associated with the presence of calcification and ischemic event. Odds ratios (OR) and 95% confidence intervals (CI) were calculated. Statistical significance was at $p \leq 0.05$.

Results

Patients

There were a total of 224 stenosed pICAs among the 178 patients included in this study (132 patients had unilateral stenosis and 46 had bilateral stenosis). The 178 patients included 142 (79.78%) males and 36 (20.22%) females. The mean age of the patients was 71.24 ± 10.02

years (range, 37–91 years). Comorbidities included hypertension (141/178, 79.21%), diabetes (53/178, 29.77%), coronary artery disease (38/178, 21.35%), and atrial fibrillation (11/178, 6.18%). There were 47/178 (26.40%) current smokers and 46/178 (25.84%) current drinkers. While 40/178 (22.47%) patients were on statins, 47/178 (26.40%) were on antiplatelet drugs. A total of 91/178 (51.12%) patients were admitted due to ischemic cerebral events (78 with anterior circulation ischemic events and 13 with posterior circulation ischemic events). While 69/178 (38.76%) patients had ipsilateral ischemic events, including 2 /178(1.12%) had bilateral stenosis and cerebral infarctions. Table 1 shows the characteristics of the study population.

Among the 224 stenosed pICAs, there were 122 (54.46%) cases of moderate stenosis and 102 (45.53%) cases of severe stenosis. The left pICA was stenosed in 114/224 (50.89%) cases and the right pICA in 110/224 (49.11%) cases.

Presence of calcification and correlation with age

Calcification was identified in 200/224 (89.29%) stenosed pICAs. Mean age was significantly higher in patients with calcification than in patients without calcification (71.98 ± 9.05 years vs. 64.92 ± 12.29 years; $z = 2.627$, $p = 0.009$). Prevalence of calcification tended to increase with age; the calcification rates were 80.00% (20/25), 85.93% (55/64), 91.21% (83/91), and 95.45% (42/44), respectively, in the <60-, 60-69-, 70-79-, and ≥ 80-year age-groups (Fig. 3). Calcification volume ($r = 0.219$, $p < 0.001$) and calcification score ($r = 0.230$, $p < 0.001$) were correlated with age (Fig. 4). GFR was significantly lower in the calcification group than in the noncalcification

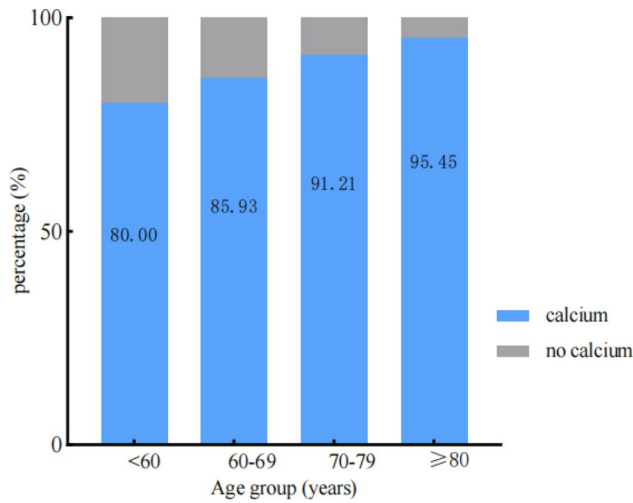


Fig. 3 Calcification rate by age-group

group (82.00 ± 22.50 mL/min/1.73 m² vs. 92.45 ± 22.93 mL/min/1.73 m²; $z = -2.025$, $p = 0.043$). Sex composition, comorbidities, and personal history were comparable between the two groups (Table 2).

In multivariable logistic regression analysis, only age was an independent predictor of calcification (OR=1.065, 95% CI: 1.016–1.116, $p = 0.008$). GFR was not independently associated with presence of calcification (OR=0.991, 95% CI: 0.970–1.012, $p = 0.388$).

Relationship between calcification and ipsilateral ischemia

Of the 178 patients, 66 (including two patients with bilateral stenosis) had anterior circulation stroke and 3

Table 2 Clinical features in the calcification and noncalcification groups

Characteristic	Calcification group (n = 200)	Noncalcification group (n = 24)	p
Age, yr	71.98 ± 9.05	64.92 ± 12.29	0.009*
Male	164 (82.00)	20 (83.33)	0.872
Comorbidities			
Hypertension	159 (79.50)	18 (75.00)	0.609
Diabetes	65 (32.50)	5 (20.83)	0.244
Coronary artery disease	45 (22.50)	2 (8.33)	0.107
Atrial fibrillation	13 (6.50)	0 (0.00)	0.370
Laboratory data			
Creatinine (umol/L)	83.05 ± 28.95	73.65 ± 20.05	0.124
GFR (mL/min/1.73m ²)	82.00 ± 22.50	92.45 ± 22.93	0.043*
blood sugar (mmol/L)	6.47 ± 3.14	5.36 ± 1.49	0.203
Calcium (mmol/L)	2.22 ± 0.14	2.23 ± 0.11	0.898
Phosphorus (mmol/L)	1.09 ± 0.20	1.07 ± 0.13	0.350
Triglyceride (mmol/L)	1.41 ± 0.81	1.09 ± 0.20	0.164
Cholesterol (mmol/L)	4.03 ± 1.18	3.97 ± 0.93	0.796
HDL (mmol/L)	1.06 ± 0.28	1.11 ± 0.30	0.449
LDL (mmol/L)	2.43 ± 1.00	2.38 ± 0.84	0.802
Clinical data			
Statin use	48 (24.00)	4 (16.67)	0.421
Antiplatelet use	58 (29.00)	6 (25.00)	0.682
Moderate stenosis	113 (56.50)	9 (37.50)	0.077
Left arterial stenosis	102 (51.00)	12 (50.00)	0.926
Ipsilateral symptom	59 (29.50)	12 (50.00)	0.041*

Data are mean ± standard deviation or n (%) GFR: glomerular filtration rate; HDL: High-density lipoprotein; LDL: Low-density lipoprotein *Statistically significant

patients experienced TIA prior to MDCT examination.

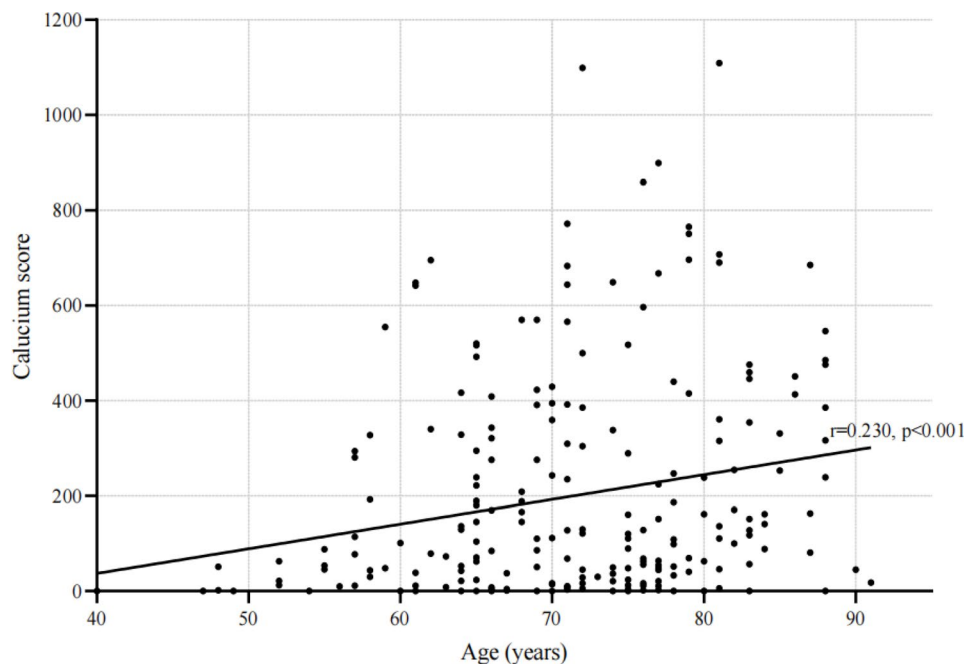


Fig. 4 Scatter plot of age versus calcification score

The incidence of ipsilateral ischemic events was significantly higher in the noncalcification group than in the calcification group (12/24 vs. 59/200; $\chi^2=4.160$, $p=0.041$).

In the calcification group, ipsilateral ischemic symptoms occurred in 59/200 (29.50%) cases but not in 141/200 (70.50%) cases. There was no significant difference in clinical data between the ischemic and non-ischemic cases (shown in Supplement Table). The mean thickness of calcification was 1.74 ± 0.91 mm (range, 0.10–5.60 mm). Calcium volume ($z=-0.171$, $p=0.864$) and calcium score ($z=-0.256$, $p=0.798$) were not significantly different between patients with and without ischemic symptoms. Occurrence of ipsilateral ischemia was not significantly associated with calcification thickness ($p=0.119$), calcification location ($p=0.077$), or circumferential extent of calcification ($p=0.066$).

The most common calcification type was positive rim sign calcification (87/200, 43.50%), followed by bulky calcification (66/200, 33.00%), negative rim sign calcification (38/200, 19.00%), and superficial spotty calcification (27/200, 13.50%). Positive rim sign was significantly associated with ipsilateral ischemia ($\chi^2=10.448$, $p=0.001$), as also bulky calcification ($\chi^2=4.552$, $p=0.033$). Table 3 shows the distribution of different factors in the ischemia and nonischemia groups.

In univariate analysis, the positive rim sign was a risk factor for ipsilateral ischemic event (OR=2.762, 95% CI 1.477–5.165, $p=0.001$) and bulky calcification (OR=0.469, 95%CI 0.232–0.948, $p=0.035$) were protective factors. In multivariate analysis, after adjustments for age, sex, and stenosis degree, positive rim sign remained an independent predictor of ipsilateral ischemic event (OR=2.795, 95%CI 1.182–6.608, $p=0.019$). Table 4 shows the results of univariate and multivariate analysis.

Discussion

This study found that plaque calcification is present in 89.29% of moderately to severely stenosed proximal internal carotid arteries. The high prevalence indicates the important role of calcification in process of atherosclerotic stenosis. The precise mechanisms of calcification in atherosclerosis remain uncertain, but it appears to be related to aging. In this study, the prevalence of calcification increased with age. Calcification volume and scores also tended to increase with age. Previously identified risk factors for arterial calcification include diabetes mellitus, hypertension, smoking, elevated plasma cholesterol, elevated triglycerides, low HDL cholesterol, and obesity [14]; these are also risk factors for arterial stenosis, which may be the reason why they were comparable between patients with and without ischemic symptoms in this study.

Table 3 Relationship between calcification characteristics and ipsilateral ischemia

Calcification characteristic	Ischemia group (n = 59)	Nonischemia group (n = 141)	p
Thickness, cm	0.16±0.08	0.18±0.09	0.119
Position	3 (5.08)	7 (4.96)	0.077
Inner	44 (74.58)	83 (58.87)	
Outer	12 (20.34)	51 (36.17)	
Mixed			
Circumferential extent	18 (30.51)	46 (32.62)	0.066
< 90°	20 (33.90)	66 (46.81)	
90°-270°	21 (35.59)	29 (20.57)	
> 270°			
Calcification type			
Spotty	6(10.17)	21 (14.89)	0.373
Bulky	13(22.03)	53 (37.59)	0.033*
Positive rim sign	36 (61.02)	51 (36.17)	0.001*
Negative rim sign	7 (11.86)	31 (21.99)	0.096
Calcium volume, cc	171.66±169.51	179.84±189.30	0.864
Calcium score, cc	214.21±215.94	226.18±242.22	0.798

Data are mean±standard deviation or n (%) *Statistically significant

Table 4 Univariate and multivariate logistic regression analyses of the association between calcification characteristics and ipsilateral ischemia

Variable	Univariate analysis		Multivariate analysis	
	OR (95% CI)	p	OR (95% CI)	p
Age	1.002(0.969–1.037)	0.888	1.002(0.967–1.04)	0.932
Sex(male)	1.683(0.793–3.572)	0.175	2.342(1.042–5.263)	0.039*
stenosis degree (moderate)	1.525(0.827–2.809)	0.176	1.476(0.772–2.822)	0.239
Positive rim sign	2.762(1.477–5.165)	0.001*	2.795 (1.182–6.608)	0.019*
Bulky calcification	0.469 (0.232–0.948)	0.035*	0.885 (0.342–2.291)	0.802

OR odds ratio; CI: confidence interval *Statistically significant

Literature reports on the association between calcification and ischemic events are inconsistent. According to some studies, calcified plaques are stable plaques and associated with fewer ipsilateral ischemic events [11, 22], especially if calcification accounts for more than 45% of the total plaque volume [23]. Other studies have found that plaque calcification has no clinical significance [20, 24]. Some authors have reported a double peak in the symptom rates with increase in calcium score [25]. The inconsistency between studies might be due to differences in study populations, the definition of calcification types, and the methods used to quantify calcification. In this study, we discovered that there was a lower probability of an ischemia event occurring in the presence of carotid calcification (29.50% vs. 50.00%). The characteristics of calcification, however, are more significant in our understanding.

In our opinion, the clinical impact of arterial calcification is mainly decided by four factors: presence of calcification, calcium burden, location of calcification, and calcification type. Calcification with the rim sign is the most common type of calcification seen in clinical practice [20]. According to the maximum soft plaque thickness, it is classified as positive rim sign (>2 mm soft plaque thickness) and negative rim sign (<2 mm soft plaque thickness). In the present study, positive rim sign calcification was the calcification type most strongly associated with symptomatic status, with 36 of 59 cases being associated with ipsilateral ischemia. This finding is consistent with previous studies [20, 26]. The high risk may be related to the presence of a relatively large lipid-necrotic core and intraplaque hemorrhage. Eisenmenger et al. reported that the CTA rim sign of adventitial calcification with internal soft plaque is highly predictive of intraplaque hemorrhage [26], which is a characteristic of high-risk unstable plaque. The positive rim sign possibly indicates positive remodeling of the carotid. Arterial remodeling is thought to reflect adaptation of the vessel wall to mechanical and hemodynamic stimuli. Arterial remodeling can be inward (negative) or outward (positive) and hypertrophic or eutrophic [27]. Positive arterial remodeling is thought to be related to presence of vulnerable carotid plaque and risk of ischemic stroke [27, 28], but the mechanisms remain unclear.

In this study, other common types of calcification such as bulky calcification and superficial spotty calcification were not associated with risk of ischemic events. Bulky calcification, also called late-stage “macrocalcification”, may be linked to the healing process after an inflammatory response; the presence of more differentiated smooth muscle cells and a more organized extracellular matrix probably confers plaque stability [29]. Nevertheless, bulky calcifications have been found to be associated with cerebral ischemic events resulting from downstream microemboli [30], and it may also increase the difficulty of interventional surgery. Meanwhile, microcalcification, also called spotty calcification, is likely to exist in lipid-rich plaques and to be associated with inflammatory processes and high-risk plaque characteristics such as plaque ulceration and intraplaque hemorrhage [29]. Spotty calcification detected on coronary CTA is reported to be an important risk factor in patients with acute coronary syndrome [31]. Zhang et al. found that spotty calcification was markedly more prevalent in patients with stroke than in controls, with a threshold of more than three spotty calcifications indicating increased risk of stroke [19]. However, Saba et al. did not find any relationship between spotty calcification and risk of stroke [20]. The present study also found no association between superficial spotty calcification and ischemic events; this may have been because of the different definition used for

spotty calcifications and the failure to consider its location and numbers. A previous study has found that intimal or superficial spotty calcifications are more likely to be associated with stroke occurrence than adventitial spotty calcifications [32]. Calcification closer to the lumen may cause greater stiffness mismatch and higher stress concentration [29]. In this study, due to the small number of plaques with superficial spotty calcifications, a more detailed analysis was not conducted.

Some limitations of this study should be acknowledged. First, this was a retrospective study with a small sample based on medical records. No additional investigation was carried out to validate the cerebral ischemic events in the study. The diversity of TIA symptoms raises the possibility of diagnostic bias. It is required to further validate the predictive value of these parameters for future ischemic events. Second, there is a potential for selection biases. Patients without an ischemic event but undergoing CTA for other reasons may exhibit better socioeconomic status, a healthier lifestyle, and a more favorable lipid profile compared to patients with symptomatic ischemic events. In order to ascertain the differences between the two groups, we conducted difference information regarding medication use and vascular-related disorders. However, there were still potentially ignored differences. Third, although statistical significance was discovered in multivariate regression, we did not further investigate the role of gender risk in the occurrence of ischemia events due to the limited sample size and gender imbalance. Additional research may be required. Fourth, the degree of ICA stenosis was established using NASCET criteria; these criteria are not applicable when there is collapse of the distal lumen, as is seen in severe stenosis [33]. The results may have also been impacted by the use of two different models of MDCT scanners. Fifth, we did not analyze the effect of other components within the plaque, vascular remodeling and collateral circulation status, which may affect the occurrence of ischemic events.

Conclusions

Calcification is common in stenosed proximal internal carotid arteries, with calcification prevalence increasing with age. Calcification characteristics may have more clinical significance than the presence of calcification. Plaque calcification with positive rim sign is a high-risk factor for ischemic events.

Abbreviations

CTA	Computed tomographic angiography
CI	Confidence intervals
GFR	Glomerular filtration rate
HDL	High-density lipoprotein
ICA	Internal carotid artery
LDL	Low-density lipoprotein
MDCTA	Multidetector computed tomographic angiography
MRI	Magnetic resonance imaging

NASCET North American Symptomatic Carotid Endarterectomy Trial
 OR Odds ratios
 pICA Proximal internal carotid artery
 TIA Transient ischemic attack

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12883-024-03788-9>.

Supplementary Material 1

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Author contributions

FF, XL, SW, and SX conceived and designed the study. FF and JM analyzed MDCTA images; SZ and YL evaluated and acquired clinical data; RZ completed statistical analysis, SX drafted the manuscript. XL and SW revised the report. All authors read and approved the final manuscript. SW and SX are the guarantors and attest that all listed authors meet authorship criteria.

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Data availability

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical approval and consent to participate

The informed consent was waived because of the retrospective nature of the study, and the study was approved by the Ethics committee of Zhejiang Hospital (2023-40-k). All methods were carried out in accordance with relevant guidelines and regulation under the 'Ethics approval and consent to participate'.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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