

Prevalence and associated risk factors of carotid plaque and artery stenosis in China: a population-based study

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Abstract Stroke is a critical health issue in China, and carotid artery stenosis and plaque play key roles in its prevalence. Despite the acknowledged significance of this condition, detailed information regarding the prevalence of carotid artery stenosis and plaque across the Chinese population has been scarce. This study analyzed data from the China Stroke High-risk Population Screening and Intervention Program for 2020–2021, focusing on 194 878 Chinese adults aged 40 years and above. It assessed the prevalence of carotid artery stenosis and plaque and identified their associated risk factors. Results revealed a standardized prevalence of 0.40% for carotid artery stenosis and 36.27% for carotid plaque. Notably, the highest rates of stenosis were observed in north and south China at 0.61%, while southwestern China exhibited the highest plaque prevalence at 43.17%. Key risk factors included older age, male gender, hypertension, diabetes, stroke, smoking, and atrial fibrillation. This study highlights significant geographical and demographic disparities in the prevalence of these conditions, underlining the urgent need for targeted interventions and policy reforms. These measures are essential for reducing the incidence of stroke and improving patient outcomes, addressing this significant health challenge in China.

Keywords carotid plaque; carotid artery stenosis; prevalence; risk factors; Bigdata Observatory Platform for stroke in China

Introduction

Stroke is a prevalent public health concern on a global scale, ranking as the second leading cause of death and the third leading cause of combined death and disability worldwide [1–3]. In recent years, stroke has emerged as the primary cause of mortality in China [4,5]. According to a study conducted in 2022, the standardized prevalence of stroke among individuals aged 40 years and above in China has exhibited a gradual increase from 2.28% in 2013 to 2.64% in 2021, posing a significant health burden [6].

Carotid artery stenosis, which can be caused by the

accumulation of carotid plaque, is a significant contributing factor to the occurrence of stroke [7]. Early intervention for individuals with carotid stenosis and plaque can effectively reduce the risk of stroke [8]. However, only a few studies have examined the prevalence of carotid plaque and artery stenosis in China, focusing on specific regions or populations [9,10]. These studies have yielded inconsistent results, underscoring the need for more comprehensive research to determine the prevalence of these conditions across the country. Numerous studies have consistently demonstrated that certain groups, including men, the elderly, those with lower income, smokers, and individuals with hypertension, dyslipidemia, and diabetes, among others, face an elevated risk of developing carotid plaque and artery stenosis [11–14]. Many of these risk factors can be controlled through healthy lifestyle behavior. However,

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previous studies have not systematically evaluated risk factors for carotid plaque and artery stenosis, and this lack of information imposes a hurdle to the development of effective primary prevention strategies and the provision of updated information to stakeholders.

To fill this knowledge deficit, we employ cross-sectional data from the 2020–2021 China Stroke High-risk Population Screening and Intervention Program (CSHPSIP). Our objective is to determine the prevalence of carotid artery stenosis and plaque across China, identify associated risk factors, and conduct a detailed analysis of the burden brought by these conditions in various subpopulations and geographic regions. This research will elucidate the extent of these conditions in China, informing stakeholders, policymakers, and healthcare practitioners.

Materials and methods

The methodology employed in this study adhered to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline [15]. The data used in this cross-sectional analysis were obtained from the Bigdata Observatory Platform for Stroke of China (BOSC), which is part of CSHPSIP, established by the China Stroke Prevention Project Committee (CSPPC) [16].

Study design and study participants

A nationwide cross-sectional study was executed from December 2020 to December 2021, involving hospital staff who conducted face-to-face interviews, physical examinations, and venous blood sample collection. This study is part of an ongoing population-based stroke prevention and control project that annually enrolls community-dwelling adults aged 40 years and above across 31 provinces in Chinese mainland. Participants were stratified into high-, medium-, and low-risk groups in accordance with the National Stroke Association's stroke risk scorecard criteria. Participants in the high-risk category underwent neck vascular ultrasound to detect carotid intimal thickening, plaque, stenosis, or occlusion. Moreover, high-risk individuals, along with those diagnosed with carotid stenosis or with a history of stroke or transient ischemic attack, were further subjected to comprehensive laboratory tests, lifestyle interventions, and early clinical management.

Eligibility for inclusion in this study was based on the following criteria: (1) community residents aged 40 years or older who had resided in their current location for a minimum of 6 months, (2) completion of the ultrasound examination of neck vessels to identify abnormalities, and (3) provision of informed consent.

Procedure

The study protocol was created by the General Office of CSPPC under the National Health Commission of the People's Republic of China. Hospital staff conducted face-to-face interviews and physical examinations and collected venous blood samples. A comprehensive questionnaire was utilized to collect data on demographic characteristics, laboratory test results, lifestyle-related risk factors, and individual and family medical histories.

The study adopted a stratified two-stage cluster sampling design to ensure a representative sample of Chinese mainland's national population. Initially, cities were classified into developed, developing, and undeveloped categories on that basis of criteria, such as per capita gross domestic product (GDP), commercial resource concentration, commercial hub status, resident vitality, lifestyle diversity, and potential for future growth. The second stage involved listing all communities or villages within the chosen primary sampling units (PSUs), each with at least 2000 residents aged 40 years or older. One community or village was then randomly selected from this list. All eligible residents of these communities or villages, aged 40 years and above, who had been residing in the area for at least 6 months and had provided informed consent, were invited to participate. Participants engaged in in-person interviews and health checks at the project hospital. Communities or villages with a response rate below 85% were not included in the study.

Screening sites with a workload of less than 400 and a sex ratio that exceeded 1.4 or less than 0.5 were excluded. Subsequently, after adjusting for losses due to follow-up, deaths, and data abnormalities, this study encompassed 524 741 adults aged 40 years and above. From this cohort, 194 878 individuals, who underwent ultrasound examinations of neck vessels, were selected for the final analysis, as illustrated in Fig. 1.

Diagnostic criteria

Carotid plaque was determined as the presence of one or more plaques in the carotid artery; carotid stenosis was characterized by a narrowing rate of 50% or more stenosis, including occlusion in any one of the neck arteries [17].

The definitions of the covariates were used to define and identify each risk factor. Obesity was determined based on a body mass index (BMI) of ≥ 28 kg/m², following Chinese adult guidelines. Hypertension was defined as having a systolic blood pressure of ≥ 140 mmHg or a diastolic blood pressure of ≥ 90 mmHg. Diabetes mellitus was diagnosed if the fasting plasma glucose level was ≥ 7.0 mmol/L. Hyperlipidemia was identified by abnormal fasting plasma markers, such as

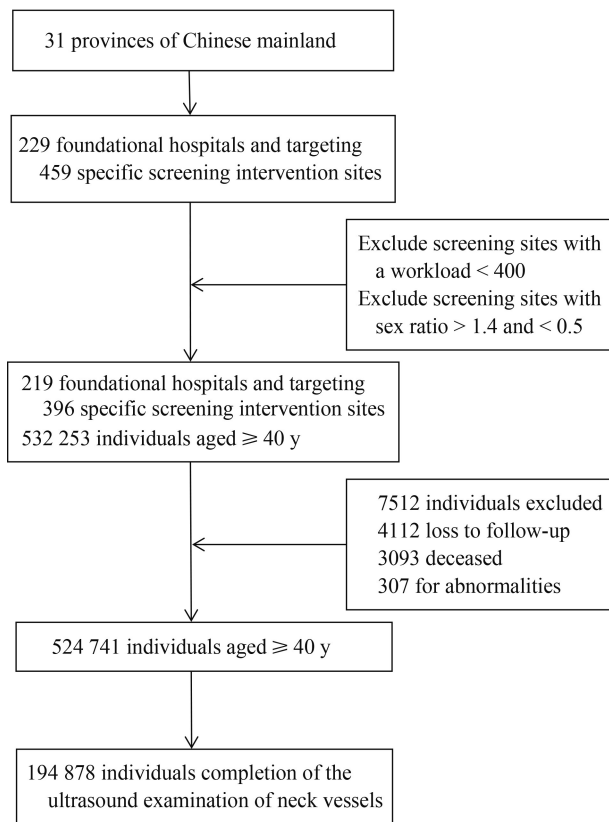


Fig. 1 Study flowchart.

total cholesterol levels of ≥ 6.22 mmol/L, triglycerides levels of ≥ 2.26 mmol/L, and high-density lipoprotein cholesterol levels of < 1.04 mmol/L. Stroke was diagnosed based on a certification or imaging certificate, i.e., computed tomography (CT)/magnetic resonance imaging (MRI), from a secondary or higher-level medical facility, specifically Level II and above hospitals. Atrial fibrillation was defined as either a self-reported history of persistent atrial fibrillation or confirmation through electrocardiogram (ECG) results. In addition, transient ischemic attack (TIA) and family history of stroke were considered part of the assessed medical histories.

In the current study, individuals identified as being at high risk for stroke were required to undergo carotid ultrasound examinations. The definition of a high-risk stroke population encompasses individuals who exhibit three or more of the following eight stroke-related risk factors: hypertension, hyperlipidemia, diabetes mellitus, atrial fibrillation, history of smoking, obesity, physical inactivity, and a family history of stroke. Moreover, individuals with a record of TIA or previous stroke episodes also fall within the high-risk category.

Statistical analysis

The study included 194 878 participants, whose characteristics were evaluated based on the locality of

their residence (rural or urban) and gender. In terms of descriptive statistics, categorical variables were displayed as frequencies along with their corresponding percentages, while continuous variables were presented through means accompanied by standard deviations (SDs). Various sociodemographic factors were evaluated, including age (10 year age bands), BMI categories (< 18.5 , $18.5\text{--}23.9$, $24.0\text{--}27.9$, ≥ 28.0), educational levels (primary school or below, middle school, high school, college and above), annual income levels (< 5000 , $5000\text{--}9999$, $10\ 000\text{--}19\ 999$, $\geq 20\ 000$ CNY), and geographical regions (northeast, north, northwest, southwest, south, central, east). The seven geographical regions of China encompassed northeast (Liaoning, Jilin, Heilongjiang), north (Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia), northwest (Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang), southwest (Chongqing, Sichuan, Guizhou, Yunnan, Xizang), south (Guangdong, Guangxi, Hainan), central (Henan, Hubei, Hunan), and east (Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong). In addition to these factors, the study examined a range of lifestyle risk factors and medical histories. These risk factors comprised obesity, hypertension, hyperlipidemia, diabetes mellitus, smoking, and alcohol consumption. Meanwhile, the investigated medical histories included stroke, atrial fibrillation, TIA, and family history of stroke.

The study involved an analysis of comprehensive data that concerned individuals with and without carotid plaque, and individuals with and without carotid artery stenosis. In addition, standardized prevalence rates were calculated to assess the prevalence of these conditions across various factors, including age groups, gender, residence, income level, educational level, BMI categories, and geographic location. Sampling weights were applied, incorporating design weights, nonresponse weights, and poststratification weights (Appendix 1 in Supplementary Material). Poststratification weights were specifically calibrated based on several key factors, including residency (distinguishing between rural and urban areas), geographic location (categorized into northeast, north, northwest, southwest, south, central, and east regions), gender (male or female), and age groups (40–49, 50–59, 60–69, 70–79, and 80 years or older). These weights were derived from the reliable data obtained from the 2010 China census. By employing these weighting techniques, this study aimed to ensure the representativeness and generalizability of the findings, accounting for any potential biases that might have arisen from the study design or nonresponse. This approach enhances the validity and robustness of the analysis, allowing for a more accurate estimation of the prevalence rates associated with carotid plaque and artery stenosis under investigation.

Within the analytical framework, we employed various statistical tests to explore relationships and differences within the collected data. For continuous variables, such as age or BMI, we employed *t*-tests to compare means among different groups. Meanwhile, chi-squared tests were utilized for categorical variables, allowing us to examine associations and dependencies among variables of interest. In addition, logistic regression was applied to calculate odds ratios (ORs) with their corresponding 95% confidence intervals (CIs), facilitating the investigation of associations among lifestyle risk factors, medical histories, and the presence of carotid plaque or artery stenosis. This approach allowed us to quantify the strength and precision of these relationships. By observing varied distributions of carotid artery stenosis and plaque burden among different populations, we further conducted subgroup analyses that focused on major risk factors across age groups (middle-aged individuals, $40 \leq \text{age} < 60$, and elders, $\text{age} \geq 60$), genders (male and female), and the seven geographical regions.

The PROC CORR and PROC REG methods were employed in SAS software to detect multicollinearity among various risk factors. The outcome of PROC CORR revealed that the factors exhibited relatively low correlation coefficients, with the highest being 0.436 (Table S1). Furthermore, tolerance values were found to be greater than 0.1 and the variance inflation factors were less than 10, indicating the absence of multicollinearity among the risk factors analyzed using PROC REG (Table S2).

Data analysis for this study was executed using SAS (version 9.4), while Python (version 3.9.12) was utilized for data visualization. A two-tailed *P* value of less than 0.05 was recognized as indicating statistical significance.

Results

Overview of study participants

During the study period from 2020 to 2021, 194 878 participants aged 40 years or older underwent ultrasound examination of neck vessels. Among them, 994 (0.5%) were classified as having carotid artery stenosis, while 86 498 (44.4%) had carotid plaque. The characteristics of the participants, stratified by sex and residence, are presented in Table 1. The mean age of the participants was 63.2 years (SD = 10.6). Females accounted for 54.2% of the participants, and 49.2% resided in urban areas. In addition, 8.2% of the participants had college education or higher, and 43.6% reported an annual income that exceeded 20 000 CNY. The distribution of participants across geographical regions demonstrated variability. East China accounted for the largest

proportion of participants, representing 28.5% of the total. By contrast, south China registered the smallest percentage, comprising only 4.1% of the participants.

The detailed demographic characteristics of individuals diagnosed with or without carotid artery stenosis and plaque are presented in Table S3. Among the 994 individuals diagnosed with carotid artery stenosis, the average age was significantly higher (mean 70.6 years, SD = 9.1) compared with those without carotid artery stenosis (mean 63.1 years, SD = 10.6). Furthermore, 872 (87.7%) of these individuals were aged 60 years or older, a proportion that significantly exceeded the 60.0% observed in the non-affected cohort. In addition, among the 86 498 patients with carotid plaque, 65 340 (75.6%) were aged 60 years or older, a rate that was notably higher than the 47.9% found among those without carotid plaque.

Standard prevalence of carotid artery stenosis and plaque

After adjustments by using the 2010 China standard population and other factors, the standardized prevalence rates for carotid artery stenosis and plaque in adults over 40 years were 0.40% (95% CI, 0.37%–0.42%) and 36.27% (95% CI, 36.05%–36.48%), respectively (Table 2). Significant age-related correlations were observed, with higher prevalence rates in older age brackets. Gender disparities were also notable. Males exhibited higher standardized prevalence rates for carotid artery stenosis (0.46%; 95% CI, 0.42%–0.51%) and plaque (38.44%; 95% CI, 38.12%–38.76%) compared with females (0.31%; 95% CI, 0.28%–0.35% for stenosis and 33.51%; 95% CI, 33.23%–33.80% for plaque). This trend persisted across all age groups, as illustrated in Fig. 2. In addition, carotid plaque prevalence was higher among individuals with urban residence (37.82%; 95% CI, 37.51%–38.13%), lower annual income (41.41%; 95% CI, 40.99%–41.83%), lower educational level (41.39%; 95% CI, 41.05%–41.73%), lower BMI (43.91%; 95% CI, 42.12%–45.69%), and various health conditions, including hypertension (42.47%; 95% CI, 42.20%–42.73%), diabetes mellitus (42.05%; 95% CI, 41.67%–42.43%), hyperlipidemia (37.73%; 95% CI, 37.43%–38.00%), stroke (59.59%; 95% CI, 58.88%–60.29%), TIA (43.26%; 95% CI, 41.93%–44.59%), atrial fibrillation (48.59%; 95% CI, 46.97%–50.22%), smoking (40.03%; 95% CI, 39.55%–40.51%), and alcohol consumption (37.57%; 95% CI, 37.10%–38.05%).

Geographic disparities in the prevalence of carotid artery stenosis and plaque were apparent. The north (0.61%; 95% CI, 0.53%–0.70%) and south (0.61%; 95% CI, 0.44%–0.78%) exhibited the highest rates of carotid artery stenosis, followed by the northeast (0.53%; 95% CI, 0.44%–0.63%), northwest (0.36%; 95% CI, 0.27%–

Table 1 Demographic profile of the study participants

Characteristics	All participants (<i>n</i> = 194 878)	Gender, <i>n</i> (%)			Residence, <i>n</i> (%)		
		Male (<i>n</i> = 89 172)	Female (<i>n</i> = 105 706)	<i>P</i> value	Urban (<i>n</i> = 95 872)	Rural (<i>n</i> = 99 006)	<i>P</i> value
Gender/Residence distribution	–	45.8%	54.2%	< 0.0001	49.2%	50.8%	< 0.0001
Mean age, years (SD)	63.2 (10.6)	63.0 (10.7)	63.3 (10.5)	< 0.0001	63.1 (10.8)	63.2 (10.3)	0.32
BMI, kg/m ² , mean (SD)	25.6 (4.0)	25.6 (3.8)	25.7 (4.1)	0.00	25.6 (3.9)	25.7 (4.0)	0.00
BMI groups, kg/m ² , <i>n</i> (%)							
< 18.5	2974 (1.5%)	1277 (1.4%)	1697 (1.6%)		1357 (1.4%)	1617 (1.6%)	
18.5–23.9	65 552 (33.6%)	28 788 (32.3%)	36 764 (34.8%)	< 0.0001	32 252 (33.6%)	33 300 (33.6%)	< 0.0001
24.0–27.9	76 912 (39.5%)	37 570 (42.1%)	39 342 (37.2%)		38 356 (40.0%)	38 556 (38.9%)	
≥28.0	49 440 (25.4%)	21 537 (24.2%)	27 903 (26.4%)		23 907 (24.9%)	25 533 (25.8%)	
Education, <i>n</i> (%)							
Primary school or lower	79 888 (41.0%)	29 486 (33.1%)	50 402 (47.7%)		23 529 (24.5%)	56 359 (56.9%)	
Junior high school	68 948 (35.4%)	34 210 (38.4%)	34 738 (32.9%)	< 0.0001	34 953 (36.5%)	33 995 (34.3%)	< 0.0001
High school	30 139 (15.5%)	16 141 (18.1%)	13 998 (13.2%)		23 369 (24.4%)	6770 (6.8%)	
College and above	15 903 (8.2%)	9335 (10.5%)	6568 (6.2%)		14 021 (14.6%)	1882 (1.9%)	
Annual income, CNY, <i>n</i> (%)							
0–5000	52 588 (27.0%)	18 500 (20.7%)	34 088 (32.2%)		14 092 (14.7%)	38 496 (38.9%)	
5000–9999	28 795 (14.8%)	12 705 (14.2%)	16 090 (15.2%)	< 0.0001	8541(8.9%)	20 254 (20.5%)	< 0.0001
10 000–19 999	28 582 (14.7%)	12 919 (14.5%)	15 663 (14.8%)		12 742(13.3%)	15 840 (16.0%)	
≥20 000	84 912 (43.6%)	45 047 (50.5%)	39 865 (37.7%)		60 497 (63.1%)	24 415 (24.7%)	
Seven geographical regions, <i>n</i> (%)							
North	33 180 (17.0%)	14 344 (16.1%)	18 836 (17.8%)		16 186 (16.9%)	16 994 (17.2%)	
Northeast	23 410 (12.0%)	9887 (11.1%)	13 523 (12.8%)		10 873 (11.3%)	12 537 (12.7%)	
East	55 589 (28.5%)	25 857 (29.0%)	29 732 (28.1%)		28 477 (29.7%)	27 112 (27.4%)	
Central	42 338 (21.7%)	19 357 (21.7%)	22 981 (21.7%)	< 0.0001	20 020 (20.9%)	22 318 (22.5%)	< 0.0001
South	7965 (4.1%)	3972 (4.5%)	3993 (3.8%)		5070 (5.3%)	2895 (2.9%)	
Southwest	17 057 (8.8%)	8365 (9.4%)	8692 (8.2%)		10 337 (10.8%)	6720 (6.8%)	
Northwest	15 339 (7.9%)	7390 (8.3%)	7949 (7.5%)		4909 (5.1%)	10 430 (10.5%)	
Risk factors, <i>n</i> (%)							
Obesity	49 440 (25.4%)	21 537 (24.2%)	27 903 (26.4%)	< 0.0001	23 907 (24.9%)	25 533 (25.8%)	< 0.0001
Hypertension	136 146 (69.9%)	63 184 (70.9%)	72 962 (69.0%)	< 0.0001	66 966 (69.8%)	69 180 (69.9%)	0.90
Diabetes mellitus	64 950 (33.3%)	28 648 (32.1%)	36 302 (34.3%)	< 0.0001	34 554 (36.0%)	30 396 (30.7%)	< 0.0001
Hyperlipidemia	113 025 (58.0%)	52 191 (58.5%)	60 834 (57.6%)	< 0.0001	58 747 (61.3%)	54 278 (54.8%)	< 0.0001
Stroke	18 533 (9.5%)	9410 (10.6%)	9123 (8.6%)	< 0.0001	9495 (9.9%)	9038 (9.1%)	< 0.0001
TIA	5335 (2.7%)	2211 (2.5%)	3124 (3.0%)	< 0.0001	2451 (2.6%)	2884 (2.9%)	< 0.0001
Atrial fibrillation	3620 (1.9%)	1649 (1.8%)	1971 (1.9%)	0.80	1965 (2.0%)	1655 (1.7%)	< 0.0001
Smoking	40 478 (20.8%)	38 111 (42.7%)	2367 (2.2%)	< 0.0001	19 038 (19.9%)	21 440 (21.7%)	< 0.0001
Drinking	39 372 (20.2%)	34 611 (38.8%)	4761 (4.5%)	< 0.0001	20 821 (21.7%)	18 551 (18.7%)	< 0.0001
Family history of stroke	35 431 (18.2%)	15 692 (17.6%)	19 739 (18.7%)	< 0.0001	19 418 (20.3%)	16 013(16.2%)	< 0.0001
Laboratory test, mean (SD)							
Systolic blood pressure, mm Hg	137.9 (18.2)	137.8 (17.4)	138.0 (18.9)	0.03	136.0 (17.5)	139.7 (18.8)	< 0.0001
Diastolic blood pressure, mm Hg	82.9 (10.6)	84.2 (10.8)	81.8 (10.4)	< 0.0001	82.4 (10.5)	83.4 (10.8)	< 0.0001
Total cholesterol, mmol/L	4.8 (1.3)	4.6 (1.2)	5.0 (1.3)	< 0.0001	4.8 (1.3)	4.8 (1.3)	0.10
HDL cholesterol, mmol/L	1.4 (0.6)	1.4 (0.6)	1.5 (0.6)	< 0.0001	1.4 (0.5)	1.5 (0.6)	< 0.0001

(Continued)

Characteristics	All participants (<i>n</i> = 194 878)	Gender, <i>n</i> (%)			Residence, <i>n</i> (%)		
		Male (<i>n</i> = 89 172)	Female (<i>n</i> = 105 706)	<i>P</i> value	Urban (<i>n</i> = 95 872)	Rural (<i>n</i> = 99 006)	<i>P</i> value
Fasting plasma glucose, mmol/L	5.8 (2.1)	5.7 (2.0)	5.8 (2.1)	< 0.0001	5.9 (2.0)	5.7 (2.1)	< 0.0001
Homocysteine, μ mol/L	15.8 (8.9)	17.5 (10.0)	14.3 (7.6)	< 0.0001	15.1 (8.3)	16.4 (9.4)	< 0.0001
Glycated hemoglobin (HbA1c)	5.8 (1.4)	5.8 (1.4)	5.8 (1.4)	0.50	5.8 (1.4)	5.7 (1.4)	< 0.0001

Table 2 Standardized prevalence of carotid artery stenosis and plaque among Chinese adults aged 40+ years

Characteristics	Carotid artery stenosis				Carotid plaque			
	Participants No.	Events No.	Standardized prevalence, % (95% CI)	<i>P</i> value	Participants No.	Events No.	Standardized prevalence, % (95% CI)	<i>P</i> value
Overall	194 878	994	0.40 (0.37–0.42)	–	194 878	86 498	36.27 (36.05–36.48)	–
Age group, year								
40–49	21 359	14	0.06 (0.02–0.09)		21 359	3586	15.66 (15.17–16.14)	
50–59	56 269	108	0.22 (0.18–0.26)		56 269	17 572	31.20 (30.82–31.59)	
60–69	59 522	299	0.50 (0.44–0.55)	< 0.0001	59 522	30 180	50.30 (49.89–50.70)	< 0.0001
70–79	45 521	416	1.01 (0.92–1.10)		45 521	27 582	61.14 (60.71–61.60)	
80+	12 207	157	1.48 (1.27–1.69)		12 207	7578	62.78 (61.92–63.63)	
Gender								
Male	89 172	599	0.46 (0.42–0.51)	< 0.0001	89 172	43 002	38.44 (38.12–38.76)	< 0.0001
Female	105 706	395	0.31 (0.28–0.35)		105 706	43 496	33.51 (33.23–33.80)	
Residence								
Urban	95 872	513	0.43 (0.39–0.47)	0.13	95 872	44 255	37.82 (37.51–38.13)	< 0.0001
Rural	99 006	481	0.37 (0.34–0.41)		99 006	42 243	35.31 (35.02–35.61)	
Annual income, CNY								
0–5000	52 588	306	0.53 (0.46–0.59)		52 588	24 730	41.41 (40.99–41.83)	
5000–9999	28 795	142	0.37 (0.30–0.44)	0.05	28 795	12 486	36.72 (36.15–37.26)	< 0.0001
10 000–19 999	28 582	132	0.36 (0.29–0.42)		28 582	12 470	36.51 (35.94–37.05)	
≥20 000	84 913	414	0.34 (0.30–0.38)		84 913	36 812	33.02 (32.71–33.34)	
Education								
Primary school or lower	79 888	428	0.46 (0.41–0.50)		79 888	38 040	41.39 (41.05–41.73)	
Junior high school	68 948	351	0.37 (0.32–0.41)	0.30	68 948	29 046	33.19 (32.85–33.55)	< 0.0001
High school	30 139	148	0.36 (0.29–0.42)		30 139	13 524	35.63 (35.08–36.16)	
College and above	15 903	67	0.32 (0.23–0.41)		15 903	5888	28.53 (27.83–29.24)	
BMI groups								
< 18.5	2974	27	0.84 (0.51–1.17)		2974	1491	43.91 (42.12–45.69)	
18.5–23.9	65 552	378	0.46 (0.41–0.51)	< 0.0001	65 552	29 103	36.31 (35.94–36.68)	< 0.0001
24.0–27.9	76 912	384	0.39 (0.34–0.43)		76 912	34 747	37.03 (36.69–37.37)	
≥28.0	49 440	205	0.31 (0.26–0.36)		49 440	21 157	34.66 (34.25–35.09)	
Seven geographical regions								
North	33 180	215	0.61 (0.53–0.70)		33 180	15 709	40.84 (40.32–41.38)	
Northeast	23 410	166	0.53 (0.44–0.63)		23 410	11 532	39.37 (38.75–40.00)	
East	55 589	228	0.33 (0.28–0.37)	< 0.0001	55 589	23 092	32.43 (32.04–32.82)	< 0.0001
Central	42 338	170	0.33 (0.28–0.39)		42 338	17 431	34.12 (33.68–34.59)	
South	7965	78	0.61 (0.44–0.78)		7965	3244	31.68 (30.66–32.70)	
Southwest	17 057	67	0.23 (0.16–0.30)		17 057	8659	43.17 (42.43–43.92)	

(Continued)

Characteristics	Carotid artery stenosis			<i>P</i> value	Carotid plaque			<i>P</i> value
	Participants No.	Events No.	Standardized prevalence, % (95% CI)		Participants No.	Events No.	Standardized prevalence, % (95% CI)	
Northwest	15 339	70	0.36 (0.27–0.46)		15 339	6831	35.92 (35.15–36.67)	
Obesity								
Yes	49 440	205	0.31 (0.26–0.36)	0.00	49 440	21 157	34.66 (34.25–35.09)	< 0.0001
No	145 438	789	0.43 (0.39–0.46)		145 438	65 341	36.85 (36.59–37.09)	
Hypertension								
Yes	136 146	795	0.48 (0.45–0.52)	< 0.0001	136 146	66 787	42.47 (42.20–42.73)	< 0.0001
No	58 732	199	0.24 (0.20–0.28)		58 732	19 711	25.46 (25.12–25.82)	
Diabetes mellitus								
Yes	64 950	412	0.54 (0.48–0.60)	< 0.0001	64 950	32 050	42.05 (41.67–42.43)	< 0.0001
No	129 928	582	0.34 (0.31–0.37)		129 928	54 448	33.94 (33.69–34.20)	
Hyperlipidemia								
Yes	113 025	581	0.39 (0.35–0.42)	0.77	113 025	51 909	37.73 (37.43–38.00)	< 0.0001
No	81 853	413	0.41 (0.36–0.45)		81 853	34 589	34.41 (34.08–34.73)	
Stroke								
Yes	18 533	230	1.15 (1.00–1.31)	< 0.0001	18 533	11 428	59.59 (58.88–60.29)	< 0.0001
No	176 345	764	0.34 (0.31–0.37)		176 345	75 070	34.53 (34.31–34.76)	
TIA								
Yes	5335	33	0.46 (0.28–0.64)	0.26	5335	2686	43.26 (41.93–44.59)	< 0.0001
No	189 543	961	0.39 (0.37–0.42)		189 543	83 812	36.09 (35.89–36.32)	
Atrial fibrillation								
Yes	3620	35	0.71 (0.44–0.99)	< 0.0001	3620	1985	48.59 (46.97–50.22)	< 0.0001
No	191 258	959	0.39 (0.36–0.42)		191 258	84 513	36.08 (35.87–36.30)	
Smoking								
Yes	40 478	272	0.46 (0.40–0.53)	< 0.0001	40 478	19 934	40.03 (39.55–40.51)	< 0.0001
No	154 400	722	0.37 (0.34–0.40)		154 400	66 564	34.88 (34.65–35.12)	
Drinking								
Yes	39 372	206	0.39 (0.32–0.45)	0.68	39 372	18 444	37.57 (37.10–38.05)	< 0.0001
No	155 506	788	0.40 (0.37–0.43)		155 506	68 054	35.80 (35.56–36.03)	
Family history of stroke								
Yes	35 431	184	0.39 (0.32–0.45)	0.79	35 431	16 766	39.74 (39.24–40.26)	< 0.0001
No	159 447	810	0.40 (0.37–0.43)		159 447	69 732	35.52 (35.29–35.76)	

0.46%), central (0.33%; 95% CI, 0.28%–0.39%), east (0.33%; 95% CI, 0.28%–0.37%), and southwest (0.23%; 95% CI, 0.16%–0.30%) (Fig. 3). Conversely, while the southwest displayed the highest incidence of carotid plaque, the south had the lowest. A province-level analysis might not yield meaningful insights due to the relatively low prevalence of carotid artery stenosis and the incomplete data from some provinces. Therefore, we focused our further analysis on the prevalence of carotid artery plaque across provinces. Significant regional disparities in the standardized prevalence of carotid plaque were evident across China's 31 provinces (Table S4). Yunnan recorded the highest prevalence at

56.3%, in stark contrast with Qinghai's lowest at 8.3%. These differences may be attributed to varying lifestyle habits and disparities in sample sizes among regions.

Risk factor analysis

Logistic regression was employed to explore the relationships between potential risk factors and the onset of carotid artery stenosis and plaque formation. The results, which are outlined in Table 3, revealed diverse correlations in terms of direction and strength. Factors, such as hypertension (OR = 1.23, 95% CI = 1.05–1.45), diabetes mellitus (OR = 1.28, 95% CI = 1.12–1.45),

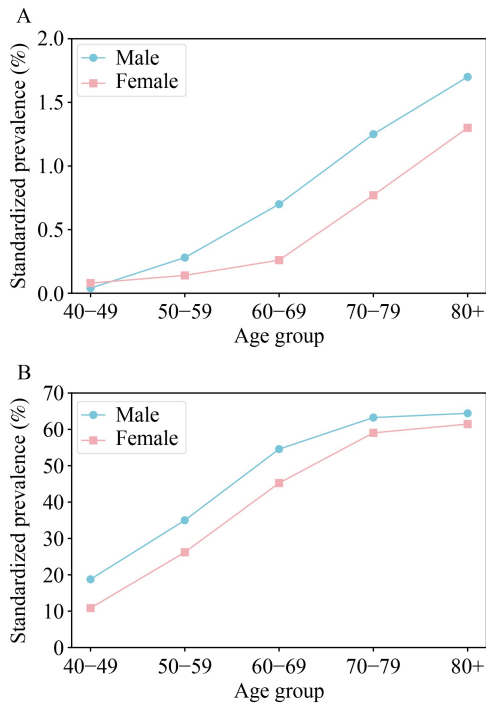


Fig. 2 Standardized prevalence of carotid artery stenosis (A) and carotid plaque (B) by age groups.

stroke (OR = 2.01, 95% CI = 1.72–2.33), atrial fibrillation (OR = 1.46, 95% CI = 1.02–2.01), and smoking (OR = 1.44, 95% CI = 1.22–1.70) consistently demonstrated an association with a higher risk of carotid artery stenosis, with stroke exhibiting the most potent link. Conversely, obesity (OR = 0.91, 95% CI = 0.77–1.06), hyperlipidemia (OR = 1.05, 95% CI = 0.92–1.20), TIA (OR = 1.23, 95% CI = 0.85–1.71), alcohol consumption (OR = 0.88, 95% CI = 0.74–1.04), and a family history of stroke (OR = 1.11, 95% CI = 0.94–1.30) showed no significant associations with carotid artery stenosis. For carotid plaque, a wide range of risk factors emerged, including hypertension, diabetes, hyperlipidemia, stroke, TIA, atrial fibrillation, smoking, drinking, and a family history of stroke, with stroke showing the strongest association (OR = 2.17, 95% CI = 2.10–2.24). However, obesity appeared to provide some protection (OR = 0.92, 95% CI = 0.90–0.94). These findings suggested the need for further analysis in specific subgroups.

Subgroup analysis

We conducted further subgroup analyses by age, gender, and geographical regions (Tables 4 and 5). The results appeared significant. Among participants aged 60 years and older, the major risk factors were largely consistent with those observed in the overall population. However, for patients under 60 years, stroke was the only risk factor for carotid artery stenosis, with an OR of 3.87 (95% CI =

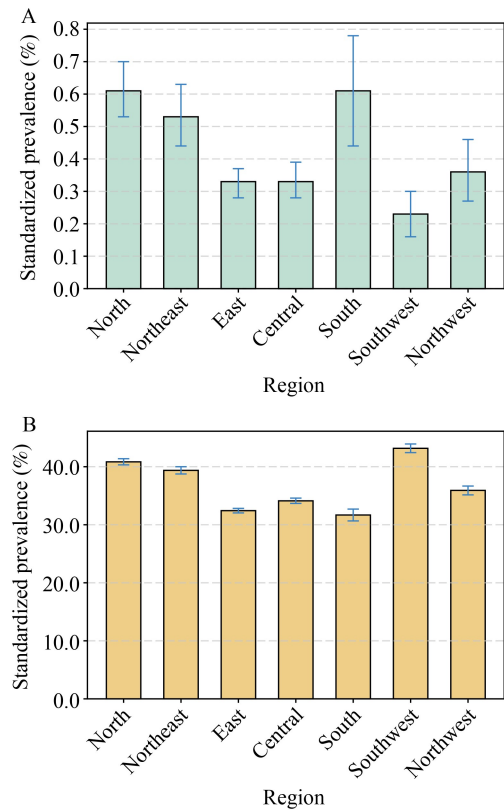


Fig. 3 Standardized prevalence of carotid artery stenosis (A) and carotid plaque (B) by regions.

2.25–6.28). For carotid plaque, multiple risk factors were identified across both age groups: hypertension (OR = 1.68, 95% CI = 1.63–1.74), diabetes mellitus (OR = 1.33, 95% CI = 1.28–1.38), hyperlipidemia (OR = 1.30, 95% CI = 1.26–1.35), stroke (OR = 2.25, 95% CI = 2.09–2.42), TIA (OR = 1.27, 95% CI = 1.14–1.41), family history of stroke (OR = 1.37, 95% CI = 1.31–1.42), smoking (OR = 1.29, 95% CI = 1.23–1.34), and drinking (OR = 1.11, 95% CI = 1.07–1.16). In the gender-specific analysis, for males, significant risk factors for carotid artery stenosis included diabetes mellitus (OR = 1.28, 95% CI = 1.08–1.51), stroke (OR = 2.07, 95% CI = 1.70–2.51), and smoking (OR = 1.29, 95% CI = 1.23–1.34). For females, significant risk factors were hypertension (OR = 1.47, 95% CI = 1.12–1.96), diabetes mellitus (OR = 1.23, 95% CI = 1.00–1.51), stroke (OR = 2.02, 95% CI = 1.56–2.57), atrial fibrillation (OR = 1.96, 95% CI = 1.19–3.03), and smoking (OR = 1.79, 95% CI = 1.01–2.93). Neither obesity (OR = 1.00, 95% CI = 0.97–1.03) nor alcohol consumption (OR = 0.97, 95% CI = 0.91–1.03) were associated with carotid plaque in females. Conversely, obesity displayed potential protective effects against carotid artery stenosis (OR = 0.84, 95% CI = 0.71–0.99) and plaque (OR = 0.94, 95% CI = 0.92–0.97) among participants aged 60 years and older.

Table 3 ORs for carotid artery stenosis and plaque

Characteristics	Carotid artery stenosis (<i>n</i> = 8689)		Carotid plaque (<i>n</i> = 86 498)	
	OR (95% CI)	<i>P</i> value	OR (95% CI)	<i>P</i> value
Age group, year				
40–49	1 (reference)	–	1 (reference)	–
50–59	2.87 (1.70–5.25)	< 0.0001	2.25 (2.16–2.34)	< 0.0001
60–69	6.74 (4.08–12.14)	< 0.0001	5.10 (4.90–5.30)	< 0.0001
70–79	12.59 (7.62–22.68)	< 0.0001	7.62 (7.32–7.94)	< 0.0001
80+	18.84 (11.20–34.39)	< 0.0001	8.11 (7.71–8.54)	< 0.0001
Gender				
Male	1 (reference)	–	1 (reference)	–
Female	0.60 (0.52–0.70)	< 0.0001	0.75 (0.74–0.76)	< 0.0001
Residence				
Urban	1 (reference)	–	1 (reference)	–
Rural	0.93 (0.80–1.08)	0.31	0.87 (0.85–0.88)	< 0.0001
Education				
Primary school or lower	1 (reference)	–	1 (reference)	–
Junior high school	1.18 (1.00–1.38)	0.26	0.80 (0.79–0.82)	< 0.0001
High school	1.12 (0.90–1.39)	0.84	0.90 (0.87–0.92)	< 0.0001
College and above	1.12 (0.83–1.49)	0.87	0.65 (0.62–0.67)	< 0.0001
Annual income, CNY				
0–5000	1 (reference)	–	1 (reference)	–
5000–9999	0.90 (0.73–1.09)	0.86	0.86 (0.84–0.89)	< 0.0001
10 000–19 999	0.86 (0.70–1.07)	0.50	0.87 (0.85–0.90)	0.00
≥20 000	0.87 (0.73–1.05)	0.53	0.86 (0.84–0.88)	< 0.0001
7 Geographical regions				
North	0.71 (0.55–0.93)	0.00	0.87 (0.84–0.91)	< 0.0001
Northeast	0.80 (0.61–1.05)	0.50	0.94 (0.91–0.98)	< 0.0001
East	0.37 (0.29–0.49)	< 0.0001	0.69 (0.67–0.71)	< 0.0001
Central	0.41 (0.32–0.54)	< 0.0001	0.68 (0.66–0.70)	< 0.0001
South	1 (reference)	–	0.67 (0.63–0.70)	< 0.0001
Southwest	0.36 (0.26–0.50)	< 0.0001	1 (reference)	–
Northwest	0.52 (0.37–0.72)	< 0.0001	0.78 (0.75–0.81)	< 0.0001
Risk factors				
Obesity				
No	1 (reference)	–	1 (reference)	–
Yes	0.91 (0.77–1.06)	0.22	0.92 (0.90–0.94)	< 0.0001
Hypertension				
No	1 (reference)	–	1 (reference)	–
Yes	1.23 (1.05–1.45)	0.01	1.91 (1.87–1.95)	< 0.0001
Diabetes mellitus				
No	1 (reference)	–	1 (reference)	–
Yes	1.28 (1.12–1.45)	0.00	1.35 (1.33–1.38)	< 0.0001
Hyperlipidemia				
No	1 (reference)	–	1 (reference)	–
Yes	1.05 (0.92–1.20)	0.44	1.16 (1.14–1.18)	< 0.0001

(Continued)

Characteristics	Carotid artery stenosis (<i>n</i> = 8689)		Carotid plaque (<i>n</i> = 86 498)	
	OR (95% CI)	<i>P</i> value	OR (95% CI)	<i>P</i> value
Stroke				
No	1 (reference)	–	1 (reference)	–
Yes	2.01 (1.72–2.33)	< 0.0001	2.17 (2.10–2.24)	< 0.0001
TIA				
No	1 (reference)	–	1 (reference)	–
Yes	1.23 (0.85–1.71)	0.26	1.28 (1.21–1.35)	< 0.0001
Atrial fibrillation				
No	1 (reference)	–	1 (reference)	–
Yes	1.46 (1.02–2.01)	0.03	1.53 (1.44–1.64)	< 0.0001
Smoking				
No	1 (reference)	–	1 (reference)	–
Yes	1.44 (1.22–1.70)	< 0.0001	1.28 (1.25–1.31)	< 0.0001
Drinking				
No	1 (reference)	–	1 (reference)	–
Yes	0.88 (0.74–1.04)	0.13	1.13 (1.11–1.16)	< 0.0001
Family history of stroke				
No	1 (reference)	–	1 (reference)	–
Yes	1.11 (0.94–1.30)	0.23	1.16 (1.13–1.18)	< 0.0001

Table 4 Risk factor analysis of carotid artery stenosis and plaque by age and gender

Risk factors	Participants aged < 60 years		Participants aged ≥60 years		Male		Female	
	OR (95% CI)	<i>P</i> value	OR (95% CI)	<i>P</i> value	OR (95% CI)	<i>P</i> value	OR (95% CI)	<i>P</i> value
For carotid artery stenosis								
Hypertension	1.31 (0.89–1.96)	0.18	1.27 (1.07–1.51)	0.01	1.09 (0.90–1.33)	0.38	1.47 (1.12–1.96)	0.01
Diabetes mellitus	1.23 (0.82–1.79)	0.30	1.28 (1.11–1.46)	0.00	1.28 (1.08–1.51)	0.00	1.23 (1.00–1.51)	0.04
Hyperlipidemia	0.94 (0.65–1.36)	0.72	1.03 (0.90–1.18)	0.71	1.00 (0.85–1.18)	0.98	1.12 (0.91–1.38)	0.31
Obesity	0.91 (0.59–1.36)	0.65	0.84 (0.71–0.99)	0.04	0.83 (0.66–1.02)	0.08	1.01 (0.80–1.27)	0.91
Stroke	3.87 (2.25–6.28)	< 0.0001	2.17 (1.85–1.54)	< 0.0001	2.07 (1.70–2.51)	< 0.0001	2.02 (1.56–2.57)	< 0.0001
TIA	0.75 (0.12–2.36)	0.69	1.27 (0.87–1.79)	0.19	1.01 (0.59–1.61)	0.96	1.45 (0.85–2.29)	0.14
Atrial fibrillation	1.52 (0.25–4.81)	0.56	1.58 (1.09–2.21)	0.01	1.10 (0.64–1.75)	0.72	1.96 (1.19–3.03)	0.00
Family history of stroke	1.27 (0.83–1.89)	0.25	0.98 (0.82–1.17)	0.84	1.03 (0.82–1.27)	0.81	1.17 (0.91–1.50)	0.21
Smoking	1.38 (0.88–2.13)	0.15	1.71 (1.44–2.01)	< 0.0001	1.34 (1.12–1.59)	0.00	1.79 (1.01–2.93)	0.03
Drinking	1.16 (0.73–1.79)	0.52	0.94 (0.78–1.13)	0.52	0.87 (0.72–1.04)	0.13	0.98 (0.56–1.58)	0.94
For carotid plaque								
Hypertension	1.68 (1.63–1.74)	< 0.0001	1.47 (1.43–1.51)	< 0.0001	1.44 (1.40–1.49)	< 0.0001	1.50 (1.45–1.55)	< 0.0001
Diabetes mellitus	1.33 (1.28–1.38)	< 0.0001	1.14 (1.11–1.17)	< 0.0001	1.15 (1.12–1.19)	< 0.0001	1.18 (1.15–1.21)	< 0.0001
Hyperlipidemia	1.30 (1.26–1.35)	< 0.0001	1.09 (1.06–1.11)	< 0.0001	1.07 (1.04–1.10)	< 0.0001	1.23 (1.19–1.26)	< 0.0001
Obesity	1.03 (0.99–1.07)	0.10	0.94 (0.92–0.97)	< 0.0001	0.96 (0.93–0.99)	0.02	1.00 (0.97–1.03)	0.97
Stroke	2.25 (2.09–2.42)	< 0.0001	1.53 (1.47–1.58)	< 0.0001	1.63 (1.55–1.70)	< 0.0001	1.50 (1.43–1.57)	< 0.0001
TIA	1.27 (1.14–1.41)	< 0.0001	1.17 (1.10–1.25)	< 0.0001	1.15 (1.05–1.26)	0.00	1.19 (1.10–1.28)	< 0.0001
Atrial fibrillation	1.15 (0.99–1.34)	0.07	1.29 (1.20–1.40)	< 0.0001	1.16 (1.05–1.29)	0.00	1.26 (1.14–1.38)	< 0.0001
Family history of stroke	1.37 (1.31–1.42)	< 0.0001	1.21 (1.17–1.25)	< 0.0001	1.25 (1.21–1.30)	< 0.0001	1.32 (1.27–1.36)	< 0.0001
Smoking	1.29 (1.23–1.34)	< 0.0001	1.19 (1.15–1.23)	< 0.0001	1.28 (1.24–1.31)	< 0.0001	1.33 (1.22–1.45)	< 0.0001
Drinking	1.11 (1.07–1.16)	< 0.0001	1.11 (1.07–1.15)	< 0.0001	1.18 (1.15–1.22)	< 0.0001	0.97 (0.91–1.03)	0.3597

Table 5 Region-specific risk factor analysis of carotid artery stenosis and plaque

Risk factors	North (n = 33 180)		Northeast (n = 23 410)		East (n = 55 589)		Central (n = 42 338)		South (n = 7965)		Southwest (n = 17 057)		Northwest (n = 15 339)	
	OR (95% CI)	P value	OR (95% CI)	P value	OR (95% CI)	P value	OR (95% CI)	P value	OR (95% CI)	P value	OR (95% CI)	P value	OR (95% CI)	P value
For carotid artery stenosis														
Male	1.78 (1.35–2.35)	<0.0001	1.81 (1.33–2.47)	0.00	2.53 (1.92–3.37)	<0.0001	1.68 (1.23–2.29)	0.00	0.85 (0.54–1.33)	0.47	1.89 (1.15–3.19)	0.01	3.51 (2.06–6.29)	<0.0001
Aged ≥60 years	5.45 (3.69–8.38)	<0.0001	2.30 (1.59–3.41)	<0.0001	6.14 (3.88–10.36)	<0.0001	6.11 (3.86–10.22)	<0.0001	13.63 (6.06–38.99)	<0.0001	6.09 (2.84–15.83)	<0.0001	3.19 (1.75–6.32)	0.00
< 5000 CNY annual income	1.16 (0.84–1.58)	0.37	0.86 (0.55–1.29)	0.47	1.65 (1.24–2.20)	0.00	1.14 (0.84–1.61)	0.45	0.76 (0.38–1.42)	0.42	0.65 (0.34–1.18)	0.18	1.63 (0.96–2.75)	0.07
Hypertension	1.06 (0.76–1.50)	0.76	1.07 (0.77–1.51)	0.69	1.66 (1.12–2.54)	0.02	1.63 (1.12–2.44)	0.01	0.76 (0.45–1.33)	0.31	2.77 (1.29–7.20)	0.02	1.80 (1.04–3.30)	0.04
Diabetes mellitus	1.44 (1.09–1.89)	0.01	0.95 (0.67–1.34)	0.78	1.35 (1.03–1.76)	0.03	1.37 (1.01–1.87)	0.04	1.29 (0.81–2.06)	0.28	1.34 (0.82–2.20)	0.24	1.65 (1.00–2.67)	0.04
Hyperlipidemia	1.09 (0.82–1.45)	0.56	0.88 (0.64–1.20)	0.41	1.13 (0.86–1.49)	0.37	0.98 (0.72–1.34)	0.88	1.22 (0.73–2.12)	0.47	1.10 (0.66–1.87)	0.72	1.15 (0.71–1.90)	0.58
Obesity	0.76 (0.54–1.05)	0.11	1.01 (0.66–1.49)	0.97	1.04 (0.76–1.42)	0.79	0.73 (0.46–1.09)	0.14	1.26 (0.72–2.14)	0.40	0.90 (0.49–1.57)	0.73	0.86 (0.48–1.49)	0.61
Stroke	2.84 (2.09–3.82)	<0.0001	1.30 (0.81–2.01)	0.25	2.17 (1.58–2.93)	<0.0001	1.39 (0.89–2.09)	0.13	1.65 (0.91–2.86)	0.09	6.34 (3.72–10.62)	<0.0001	1.68 (0.77–3.24)	0.15
TIA	1.74 (0.93–2.98)	0.06	0.83 (0.20–2.20)	0.74	1.06 (0.48–2.03)	0.87	1.13 (0.35–2.69)	0.81	2.81 (0.82–7.21)	0.06	0.56 (0.03–2.58)	0.49	1.26 (0.39–2.98)	0.65
Atrial fibrillation	1.13 (0.44–2.35)	0.78	0.65 (0.11–2.07)	0.55	1.59 (0.78–2.88)	0.16	1.78 (0.70–3.73)	0.17	2.01 (0.59–5.15)	0.19	3.41 (1.18–7.86)	0.01	1.44 (0.23–4.64)	0.62
Family history of stroke	1.17 (0.84–1.60)	0.35	0.70 (0.42–1.11)	0.15	1.10 (0.78–1.51)	0.57	0.70 (0.43–1.08)	0.13	2.51 (1.54–4.04)	0.00	0.79 (0.35–1.57)	0.54	1.08 (0.45–2.21)	0.86
For carotid plaque														
Male	1.81 (1.73–1.90)	<0.0001	1.52 (1.43–1.60)	<0.0001	1.39 (1.34–1.44)	<0.0001	1.30 (1.25–1.36)	<0.0001	1.29 (1.17–1.42)	<0.0001	1.16 (1.09–1.24)	<0.0001	1.26 (1.18–1.35)	<0.0001
Aged ≥60 years	4.14 (3.94–4.34)	<0.0001	3.06 (2.89–3.24)	<0.0001	3.55 (3.41–3.70)	<0.0001	3.74 (3.57–3.91)	<0.0001	3.77 (3.40–4.17)	<0.0001	2.30 (2.15–2.45)	<0.0001	3.27 (3.04–3.51)	<0.0001
< 5000 CNY annual income	0.99 (0.94–1.05)	0.75	1.28 (1.18–1.38)	<0.0001	1.03 (0.99–1.08)	0.14	0.83 (0.79–0.87)	<0.0001	0.88 (0.78–1.00)	0.05	1.44 (1.33–1.55)	<0.0001	0.95 (0.88–1.03)	0.22
Hypertension	1.80 (1.71–1.89)	<0.0001	1.84 (1.74–1.94)	<0.0001	2.02 (1.93–2.11)	<0.0001	1.89 (1.81–1.98)	<0.0001	1.71 (1.53–1.91)	<0.0001	1.15 (1.07–1.24)	0.00	1.32 (1.23–1.43)	<0.0001
Diabetes	1.44 (1.37–1.51)	<0.0001	1.11 (1.05–1.18)	0.0004	1.35 (1.30–1.40)	<0.0001	1.31 (1.25–1.37)	<0.0001	1.32 (1.20–1.46)	<0.0001	1.01 (0.95–1.08)	0.68	1.13 (1.04–1.22)	0.00
Hyperlipidemia	1.26 (1.20–1.32)	<0.0001	1.04 (0.98–1.09)	0.21	1.25 (1.21–1.30)	<0.0001	1.04 (0.99–1.08)	0.0802	1.14 (1.03–1.26)	0.01	0.76 (0.71–0.81)	<0.0001	0.91 (0.84–0.97)	0.01
Obesity	0.84 (0.80–0.88)	<0.0001	0.82 (0.77–0.88)	<0.0001	0.95 (0.91–0.99)	0.01	0.86 (0.82–0.90)	<0.0001	0.79 (0.71–0.88)	<0.0001	0.73 (0.69–0.78)	<0.0001	0.99 (0.92–1.08)	0.88
Stroke	2.09 (1.94–2.26)	<0.0001	1.60 (1.47–1.76)	<0.0001	2.23 (2.10–2.36)	<0.0001	1.83 (1.70–1.96)	<0.0001	2.37 (2.03–2.77)	<0.0001	1.55 (1.39–1.73)	<0.0001	1.62 (1.42–1.84)	<0.0001
TIA	1.44 (1.26–1.65)	<0.0001	1.12 (0.95–1.34)	0.19	1.34 (1.22–1.47)	<0.0001	1.25 (1.09–1.44)	0.00	1.26 (0.92–1.72)	0.16	1.20 (1.02–1.41)	0.02	1.18 (0.93–1.50)	0.18
Atrial fibrillation	1.20 (1.01–1.43)	0.04	1.06 (0.85–1.31)	0.63	1.17 (1.03–1.33)	0.01	1.08 (0.92–1.26)	0.37	1.27 (0.88–1.83)	0.20	1.06 (0.86–1.32)	0.58	1.08 (0.84–1.38)	0.55
Family history of stroke	1.26 (1.19–1.33)	<0.0001	1.07 (0.99–1.15)	0.05	1.17 (1.12–1.22)	<0.0001	0.96 (0.91–1.01)	0.14	0.95 (0.84–1.07)	0.39	0.96 (0.88–1.04)	0.33	1.23 (1.09–1.39)	0.00

Region-specific analysis revealed distinct patterns of risk factors across all seven regions. Advanced age (≥ 60 years) was identified as a risk factor for carotid artery stenosis and plaque in all the regions. The male gender increased the risk of carotid artery stenosis in the north, northeast, east, central, southwest, and northwest, and heightened the risk of carotid plaque across all the regions. In addition, a lower income (< 5000 CNY annually) was associated with an increased risk of carotid stenosis in the east and carotid plaque in the northeast and southwest. Hypertension was a significant risk factor for carotid artery stenosis in the east, central, southwest, and northwest. Similarly, diabetes mellitus escalated the risk of carotid artery stenosis in the north, east, central, and northwest, while stroke was linked to carotid artery stenosis in the north, east, and southwest. Atrial fibrillation increased the risk of carotid artery stenosis in the southwest, and a family history of stroke was particularly critical in the south. With regard to carotid plaque, hypertension and stroke were identified as risk factors in all seven regions. Diabetes was linked to carotid plaque in nearly all the regions except the southwest. In addition, the association between carotid plaque and TIA was significant in the north, east, central, and southwest regions. Atrial fibrillation was a significant risk factor in the north and east. Moreover, a family history of stroke was associated with a higher risk of developing carotid plaque in the north, east, and northwest.

Discussion

In contrast with earlier studies in China that employed smaller samples, this cross-sectional research presents a pioneering nationwide analysis of the prevalence of carotid artery plaque and stenosis. Encompassing 31 provinces, our study specifically targets a substantial cohort of individuals with an elevated risk of stroke.

From 2020 to 2021, the standardized prevalence of carotid artery plaque among Chinese adults over 40 years was 36.27%, while that for stenosis was 0.40%. These results were compared with the 2020 *Lancet Global Health* review, which reported global prevalences for the 30–79 age group of 21.1% for plaque and 1.5% for stenosis, indicating a higher prevalence of plaque and a lower prevalence of stenosis in our study [18]. Previous studies have indicated a general population prevalence rate of carotid artery stenosis that ranged from 0.56% to 6%, which are higher than our findings [19–22]. In addition, a study in northeast China identified a prevalence of carotid plaque at 40.0%, which closely aligned with our study's prevalence of 39.37% in the same region. Another Chinese study noted a 31% prevalence for carotid plaque [23], which was slightly

below our results. By contrast, a rural Chinese study reported a prevalence of 41.5% [24], which was slightly higher than our rural findings of 35.31%. These variations can arise from different definitions of carotid artery plaque and stenosis, variations in study design, and varying age distributions among study populations. However, our comprehensive sampling and larger sample size potentially yield more accurate results.

Our research suggests that carotid artery stenosis and plaque are more prevalent among males, the elderly, and individuals with conditions, such as hypertension, diabetes, stroke, atrial fibrillation, and smokers. These findings are consistent with previous studies [25–30]. Hypertension is a risk factor for both carotid conditions, potentially due to the pro-inflammatory and pro-oxidative effects of angiotensin II [31]. Diabetes elevates the risk for carotid artery stenosis and plaque, possibly because of its adverse effects on cerebrovascular circulation, similar to its effect on coronary and leg arteries [29]. In our study, hyperlipidemia is identified as a risk factor for carotid plaque due to its role in accelerating atherosclerotic plaque development through cholesterol deposition, heightened inflammation, and oxidative stress [32]. However, our findings do not show a significant relationship between hyperlipidemia and carotid artery stenosis, potentially due to the multifactorial nature of stenosis that may obscure hyperlipidemia's effect.

Our data did not show a direct link between alcohol consumption and carotid stenosis, although alcohol was associated with the risk of carotid plaque. Previous research on alcohol and carotid stenosis has been inconclusive; while moderate drinking may have a protective effect [33], heavy drinking may accelerate atherosclerosis [34]. Given our study's disadvantages in capturing alcohol quantity, further investigation is necessary to clarify these relationships. In our study, obesity demonstrated a protective role against carotid stenosis and plaque in older adults (age ≥ 60 years) and in males with carotid plaque. This observation may be explained by the "survival effect", wherein overweight individuals who reach old age may possess traits that protect them from adverse effects that are typically associated with excess weight [35]. In addition, the potential confounding effects of more comprehensive medical management of cardiovascular risk factors in obese individuals may also explain the observed protective effects. Previous research on the relationship between obesity and carotid atherosclerosis has reported mixed results. Some studies suggest that obesity and related measures are not associated with the severity of carotid artery stenosis and plaque [36,37]. However, a study on Chinese adults indicated that different obese phenotypes might increase the risk of carotid artery plaque [38], while another research that involved 750

individuals concluded that the prevalence of carotid artery plaque was inversely related to BMI [39]. A deeper analysis of the genetic factors or a targeted cohort study may provide a more definitive understanding of the relationship between obesity and carotid atherosclerosis.

Furthermore, our findings indicate that lower educational and income levels are potential risk factors for carotid plaque. This finding is consistent with the results of Bi *et al.* [40] and Zhang *et al.* [41]. It suggests that individuals with higher education and income levels may have greater health awareness and access to superior medical care, leading to lower detection rates of carotid plaque. Focusing on improving health education and access among vulnerable populations with lower levels of education and income is imperative for policymakers to mitigate health disparities. In addition, regional differences in disease prevalence are noteworthy. The north and south regions exhibit the highest rates of carotid artery stenosis, and this result is potentially linked to prevalent risk factors, such as diabetes and stroke, in these areas. This discrepancy can also arise from variations in healthcare quality across regions. For example, areas equipped with more advanced imaging tools and techniques may achieve earlier and more frequent diagnoses. Future research should explore the effects of diet, physical activity, and climate differences across regions to further analyze the reasons behind these disparities in prevalence.

However, several limitations must be acknowledged. First, this study focused on individuals who underwent carotid artery ultrasound examinations. This scenario may lead to a higher risk of detecting carotid artery stenosis and plaque compared with the general population. In addition, the assessment of carotid artery stenosis and plaque through ultrasound may be less reliable than magnetic resonance angiography or other forms of vascular imaging. Second, the sample size curtailed our capacity to provide in-depth provincial-level analyses. Nevertheless, our stratification of sampling sites into seven geographic categories facilitated a robust exploration of regional disparities. Third, this work is a cross-sectional study, and therefore, we cannot draw causal inferences that typically require longitudinal investigations. We can only establish associations between certain risk factors and the presence of carotid artery stenosis and plaque. Lastly, this study did not comprehensively incorporate potential confounding variables, such as dietary practices and medication adherence. Such oversight may result in an incomplete representation of the multifaceted interrelations between the identified risk factors and carotid artery conditions.

In summary, our research offers significant epidemiological data regarding the prevalence of carotid artery stenosis and plaque in China. For adults aged 40 years and above, the standardized prevalence rates for

carotid artery stenosis and plaque were 3.9% and 36.3% respectively. Promoting targeted interventions for these at-risk populations, bolstered by customized health education programs, is imperative for China's healthcare policymakers. In addition, increasing public awareness about the link between modifiable risk factors and these vascular anomalies is crucial. We believe that such strategies will effectively reduce the prevalence of carotid artery stenosis and plaque in China.

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Compliance with ethics guidelines

Conflicts of interest Qingjia Zeng, Chongyang Zhang, Xinyao Liu, Shengmin Yang, Muyuan Ma, Jia Tang, Tianlu Yin, Shanshan Zhao, Wenjun Tu, and Hongpu Hu declare no competing interests.

This study was approved by the appropriate Institutional and/or National Research Ethics Committee (the Ethics Committee of Capital Medical University Xuanwu Hospital), and the study was performed in accordance with the ethical standards as laid down in the 1964 *Declaration of Helsinki* and its later amendments or comparable ethical standards. Informed consent was obtained from all the patients for being included in the study.

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