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RESEARCH

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Clinical significance of obesity measurement indicators and carotid artery plaques in type 2 diabetes

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Abstract

Introduction To investigate the clinical significance of obesity measurement indicators in patients with type 2 diabetes mellitus(T2DM) complicated with carotid plaque.

Methods A total of 1009 subjects with T2DM were recruited in the cross-sectional study, and body measurements were collected. According to the results of carotid artery ultrasound, the study subjects were divided into T2DM without carotid plaque group (NCP: $n = 617$) and with carotid plaque group (WCP: $n = 392$).

Results Compared with the NCP group, the waist-to-hip ratio (WHR), waist-to-height ratio (WHtR), Chinese visceral fat index (CVAI), body roundness index (BRI), body fat index (BAI), body shape index (ABSI), and abdominal volume index (AVI) were significantly increased in the WCP group ($P < 0.05$). The results of multivariate stepwise logistic regression analysis showed that BAI, CVAI and ABSI had the greatest effect on carotid plaque ($P < 0.05$). After adjusting for multiple confounding factors, CVAI and ABSI remained independently associated with carotid plaques, and the combination of the three indicators exhibited superior predictive value for carotid plaques.

Conclusion CVAI and ABSI are closely related to the occurrence and development of carotid plaque in subjects with T2DM, and the combined application has a good effect on predicting carotid plaque.

Keywords Type 2 diabetes mellitus, Carotid plaque, CVAI, ABSI

Introduction

With the rapid economic development and continuous improvement of living standards, the incidence of diabetes has shown a rapid growth trend. Diabetes and its complications pose a serious threat to human health, with most diabetic patients often accompanied by at least one, or even multiple complications, significantly increasing the medical burden on society and patients [1, 2]. Among them, diabetic cardiovascular disease, as one of the most severe complications of diabetes, has become a major factor contributing to the mortality of diabetic patients [3], and has evolved into a global public health challenge. Anthropometric indices, such as Body Mass Index (BMI), Waist-to-Hip Ratio (WHR), Waist-to-Height Ratio (WHtR), Chinese Visceral Adiposity Index (CVAI), Body Roundness Index (BRI), Body Adiposity Index (BAI), and A Body Shape Index (ABSI), play an important role in assessing health status [4–7]. Previous studies have demonstrated that obesity-related indices, including BMI, WHR and WHtR have significant predictive value for metabolic diseases such as cardiovascular disease, diabetes, and fatty liver disease [8, 9]. However, the significance of other obesity-related indices in the context of

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the carotid artery has not been fully elucidated. In light of this, the present study aims to deeply analyze the correlation between various obesity-related indices and carotid plaques in patients with type 2 diabetes(T2DM), and further explore the application value of novel obesity indices in the clinical management of T2DM.

Methods

Study population

This study upholds the principles of the Declaration of Helsinki, and the study protocol was approved by the Human Research Ethics Committee of the Affiliated Hospital of Jiangsu University. All the patients recruited in this study signed informed consent.

The study recruited 1,009 patients (average age: 54 years) with type 2 diabetes mellitus from the Department of Endocrinology of the Affiliated Hospital of Jiangsu University. Among them, 642 were male and 367 were female. Inclusion criteria: patients who met the diagnostic criteria for type 2 diabetes mellitus according to the American Diabetes Association [10]. Exclusion Criteria:(1) Special types of diabetes, type 1 diabetes, and acute diabetic complications;(2) Various viral hepatitis, autoimmune diseases, hereditary hepatitis, and drug-induced liver diseases;(3) Patients with schizophrenia, manic-depressive illness, or addiction to drugs or alcohol;(4) Severe infectious diseases;(5) Individuals who have experienced severe cardiovascular diseases (such as myocardial infarction, heart failure, stroke) or pulmonary embolism within the past 6 months;(6) Pregnant and lactating women;(7) Individuals with a history of autoimmune diseases, acute infections, and malignancies. The flowchart of the sampling data is shown in Fig. 1.

Study methods

All subjects underwent anthropometric measurements, including height, weight, waist circumference, hip circumference, blood pressure, and heart rate, conducted by professional physicians using unified equipment. A questionnaire was used to collect information on age, gender, and other demographics. After an overnight fast of 8 to 12 h, all subjects underwent an oral glucose tolerance test and insulin stimulation test. Fasting plasma glucose (FPG) and 2-h postprandial glucose (2 hPG) were measured using the glucose oxidase method, while fasting insulin (FIns) and 2-h postprandial insulin (2 hIns) were measured by chemiluminescence. Glycated hemoglobin (HbA1c) was determined using high-performance liquid chromatography. Lipid profiles and liver and kidney function indicators were analyzed using a BEKMAN AU5800 automated biochemical analyzer. All participants underwent carotid ultrasound examination in the ultrasound department of our hospital by professional physicians. The measurement location for carotid intima-media thickness (CIMT) is typically chosen at the common

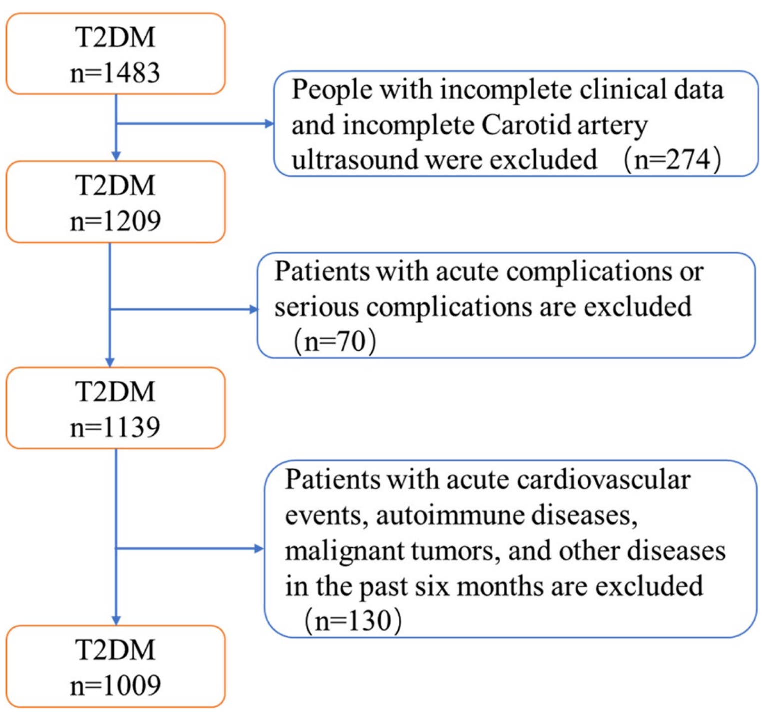

Fig. 1 The flowchart of the sampling data

carotid artery where the ultrasound image is clearly visible, approximately 1 cm from the start of the carotid bifurcation. The physician will measure the CIMT at the proximal, middle, and distal segments of the posterior wall of the artery, and the maximum value among these measurement sites will be taken for analysis. Carotid plaques were defined as local protrusions extending >0.5 mm into the arterial lumen, or exceeding 50% of the surrounding CIMT value, or with a CIMT >1.5 mm [11]. Based on the carotid ultrasound results, the study subjects were divided into a group of type 2 diabetics without carotid plaques (NCP: $n = 617$) and a group with carotid plaques (WCP: $n = 392$).

Standardized methods were used to conduct physical examinations and calculate obesity measurement indicators:

$$\text{Body Mass Index (BMI)}: \text{BMI} = \text{weight (kg)} / [\text{height (m)}]^2,$$

Statistical analysis

All statistical analyses were conducted using SPSS version 27.0. Normally distributed continuous variables were described using mean ± standard deviation, while those not normally distributed were described using median and interquartile range [M(P25, P75)]. The t-test was used for comparisons between two groups, and the χ^2 test was used for comparisons of categorical data between groups. Logistic regression analysis was employed to explore the correlation between obesity measurement indicators and the occurrence of carotid plaques. The ROC curve was used to assess the predictive value of obesity measurement indicators for carotid plaques. A P-value < 0.05 was considered statistically significant.

$$\text{Waist-to-Hip Ratio (WHR)}: \text{WHR} = \text{waist circumference (cm)} / \text{hip circumference (cm)},$$

$$\text{Waist-to-Height Ratio (WHtR)}: \text{WHtR} = \text{waist circumference (cm)} / \text{height (cm)},$$

$$\text{Visceral Adiposity Index (VAI)}: \text{VAI (men)} = \text{waist circumference} / (39.68 + 1.88 \times \text{BMI}) \times \text{triglycerides (mmol/L)} / 1.03 \times 1.31 / \text{HDL-C (mmol/L)},$$

$$\text{VAI (women)} = \text{waist circumference} / (36.58 + 1.89 \times \text{BMI}) \times \text{triglycerides (mmol/L)} / 0.81 \times 1.52 / \text{HDL-C (mmol/L)},$$

$$\text{Chinese Visceral Adiposity Index (CVAI)}: \text{CVAI (men)} = -267.93 + 0.68 \times \text{age} + 0.03 \times \text{BMI} + 4.00 \times \text{waist circumference (cm)} + 22.00 \times \log 10(\text{triglycerides [mmol/L]}) - 16.32 \times \text{HDL-C},$$

$$\text{CVAI (women)} = -187.32 + 1.71 \times \text{age} + 4.23 \times \text{BMI} + 1.12 \times \text{waist circumference (cm)} + 39.76 \times \log 10(\text{triglycerides [mmol/L]}) - 11.66 \times \text{HDL-C (mmol/L)},$$

$$\text{Lipid Accumulation Product (LAP)}: \text{LAP (men)} = [\text{waist circumference (cm)} - 65] \times \text{triglycerides (mmol/L)}, \text{LAP (women)} = [\text{waist circumference (cm)} - 58] \times \text{triglycerides (mmol/L)},$$

$$\text{Body Roundness Index (BRI)}: \text{BRI} = 364.2 - 365.5 \times [1 - \pi - 2 \times (\text{waist circumference [m]})^2 \times \text{height}^{-}2(\text{m})]^1/^2,$$

$$\text{Body Adiposity Index (BAI)}: \text{BAI} = [\text{hip circumference (m)} / \text{height}^2 / {}^3(\text{m})] - 18,$$

$$\text{A Body Shape Index (ABSI)}: \text{ABSI} = \text{waist circumference (m)} / [(\text{BMI})^2 / {}^3(\text{kg/m}^2) \times \text{height}^1/^2\ (\text{m})],$$

$$\text{Abdominal Volume Index (AVI)}: \text{AVI} = [\text{waist circumference}^2\ (\text{cm}) + 0.7 \times (\text{waist circumference} - \text{hip circumference})^2\ (\text{cm})] / 1000,$$

$$\text{Insulin resistance was assessed using the Homeostasis Model Assessment (HOMA)}: \text{HOMA-IR} = \text{fasting plasma insulin (FIns)} \times \text{fasting plasma glucose (FPG)} / 22.5.$$

Results

Comparison of general information and obesity measurement indicators between the two groups

Compared with the NCP group, the WCP group had a significantly older age, longer duration of disease, and significantly higher levels of DBP, BUN, ABSI, BAI, BRI, BUN, SCr, UA, CVAI, WHR, WHtR and AVI ($P < 0.05$, Table 1). Following Benjamini-Hochberg (BH) correction for multiple comparisons, the results demonstrated that key anthropometric indices, including DBP, BUN, ABSI, BAI, BRI, BUN, Cr, CVAI, WHtR and AVI remained significantly elevated in the WCP group compared to the NCP group, with statistically meaningful differences retained (adjusted $P < 0.05$) (Table 1). There was no statistically significant difference in other indicators between the two groups.

Table 1 Comparison of basic information and obesity measurement indicators in the subjects

Variable	NCP(*n* = 617)	WCP(*n* = 392)	*P*	*Adjust p*
Female [n(%)]	233(37.8%)	134(34.2%)	0.249	0.435
Age (year)	52.00(43.00,59.00)	60.00(53.00,66.00)	< 0.001	< 0.001
SBP(mmHg)	75(68.00,83.00)	75.00(66.00,81.00)	0.094	0.187
DBP(mmHg)	124.00(114.00,136.00)	128.00(116.00,141.00)	0.004	0.017
Disease duration (year)	2.00(0.00,8.41)	5.00(0.08,11.00)	< 0.001	< 0.001
Hypertensive[n(%)]	231 (37%)	168 (43%)	0.086	0.179
Antihypertensive drugs[n(%)]	211 (34%)	125 (32%)	0.448	0.582
smoking[n(%)]	156 (25%)	102 (26%)	0.794	0.855
Oral hypoglycemic drugs [n(%)]	345 (56%)	232 (59%)	0.307	0.464
Insulin[n(%)]	282 (46%)	165 (42%)	0.260	0.435
Antihyperlipidemics[n(%)]	46 (7.5%)	37 (9.4%)	0.264	0.435
BMI(kg/m2)	23.95(22.20,26.33)	24.15(22.28,26.08)	0.662	0.756
HbA1c(%)	9.80(8.20,11.20)	9.80(8.20,11.50)	0.377	0.555
FPG(mmol/L)	10.24(8.14,13.00)	10.21(7.85,13.12)	0.956	0.982
2 hPG(mmol/L)	19.18(16.07,22.90)	19.47(15.56,22.64)	0.930	0.982
FIns(uIU/ml)	5.97(3.67,9.95)	6.84(3.76,10.82)	0.052	0.126
2 hIns (uIU/ml)	21.56(13.15,39.50)	25.07(13.44,42.02)	0.148	0.276
TG (mmol/L)	1.77(1.26,2.57)	1.75(1.21,2.62)	0.591	0.715
TC (mmol/L)	4.83(4.25,5.54)	4.90(4.12,5.74)	0.441	0.582
HDL-c (mmol/L)	1.10(0.92,1.37)	1.15(0.96,1.35)	0.124	0.240
LDL-c (mmol/L)	2.82(2.32,3.45)	2.88(2.24,3.57)	0.613	0.715
BUN (U/L)	5.14(4.38,6.19)	5.57(4.61,6.62)	< 0.001	0.001
Scr (umol/L)	56.60(47.73,67.68)	60.30(49.70,70.90)	0.001	0.003
UA (umol/L)	275.50(222.50,325.75)	285.00(227.00,346.00)	0.031	0.086
WHR	0.93(0.89,0.96)	0.93(0.90,0.97)	0.002	0.076
WHtR	0.53(0.50,0.56)	0.54(0.51,0.58)	< 0.001	0.004
VAI	2.57(1.59,4.29)	2.34(1.53,4.12)	0.249	0.464
CVAI	109.90(85.04,132.89)	120.24(95.92,142.19)	< 0.001	< 0.001
LAP	47.81(29.12,75.73)	49.50(30.42,73.71)	0.577	0.803
BRI	3.93(3.36,4.57)	4.12(3.47,4.89)	< 0.001	0.003
BAI	25.95(23.79,28.88)	26.81(24.00,30.19)	0.010	0.039
ABSI	0.08(0.08,0.08)	0.08(0.08,0.09)	< 0.001	0.001
AVI	7.94(7.05,8.90)	8.12(7.16,9.22)	0.024	0.076
HOMA-IR	2.77(1.69,4.30)	2.73(1.87,4.92)	0.081	0.176

Note: *SBP* systolic blood pressure, *DBP* diastolic blood pressure, *TG* triglyceride, *TC* total cholesterol, *HDL-C* high-density lipoprotein cholesterol, *LDL-C* low-density lipoprotein cholesterol, *ALT* alanine aminotransferase, *AST* aspartate aminotransferase, *BUN* blood urea nitrogen, *HbA1c* glycosylated hemoglobin c, *FPG* fasting plasma glucose, *2 hPG* postprandial plasma glucose, *FIns* fasting plasma insulin, *2 hIns* postprandial plasma insulin, *WHR* Waist-to-Hip Ratio, *WHtR* Waist-to-Height Ratio, *VAI* Visceral Adiposity Index, *CVAI* Chinese Visceral Adiposity Index, *LAP* Lipid Accumulation Product, *BRI* Body Roundness Index, *BAI* Body Adiposity Index, *ABSI* A Body Shape Index, *AVI* Abdominal Volume Index, *HOMA-IR* Homeostasis Model Assessment of Insulin Resistance

Logistic regression analysis of the influence of anthropometric indices on carotid plaques

Logistic regression analysis was conducted to investigate the factors influencing carotid plaques, with the presence of carotid plaques in the study subjects as the dependent variable (absent =0, present =1). Anthropometric indices with statistical significance in the comparison of all baseline characteristics were used as independent variables. The results of univariate logistic regression analysis showed that WHR, WHtR, CVAI, BRI, BAI, ABSI, and AVI were influential factors for carotid plaques, with OR values of 1.254, 1.730, 1.768, 1.754, 1.503, 2.008, and 1.340, respectively (all $P < 0.05$, Table 2). The results of multivariate stepwise logistic regression analysis indicated that BAI, CVAI, and ABSI had a significant impact on carotid plaques. After further adjusting for multiple confounding factors, CVAI, and ABSI remained independently associated with carotid artery plaques (all $P < 0.05$, Table 3).

ROC curve analysis of the diagnostic efficacy of anthropometric indices for carotid plaques

ROC curve analysis was conducted with the presence of carotid plaques as the dependent variable. The results showed that ABSI had the highest area under the ROC curve [0.587 (0.551, 0.623)] with a cutoff value of 0.0831, followed by CVAI [0.583 (0.547, 0.619)], WHtR [0.563 (0.527, 0.600)], BRI [0.563 (0.527, 0.600)], BAI [0.548 (0.511, 0.585)], AVI [0.542 (0.506, 0.579)], and WHR [0.540 (0.503, 0.576)] (all $P < 0.05$, Table 4). ROC curves for BAI, CVAI, ABSI, and the combination of BAI +CVAI +ABSI were plotted (Fig. 2), with the area under the ROC curve for BAI +CVAI +ABSI being the highest at 0.611 ($P < 0.05$). Using the nricens package in R for the comparison of Net Reclassification Improvement (NRI) between models, the results showed that the combined prediction model demonstrated improved predictive value for carotid plaques compared to predictions made solely by BAI, CVAI, and ABSI alone (NRI (P): 0.14 (0.036), 0.010 (0.041), and 0.207 (< 0.001), respectively) (Supplementary Table 1). Further stratified analysis of these three indices by age and gender revealed that, for both males and females, the BAI, CVAI, and ABSI was significantly higher in the WCP group compared to the NCP group, with statistically significant differences($P <$ 0.05). Among subjects younger than 60 years old, the CVAI and ABSI was also significantly higher in the WCP group compared to the NCP group, with statistically significant differences($P <$ 0.05). However, among subjects older than 60 years old, only the CVAI was significantly higher in the WCP group compared to the NCP group, with statistically significant differences($P <$ 0.05). (Supplementary Fig. 1).

Table 2 Results of univariate logistic regression analysis on the influence of anthropometric indices on carotid plaques

Indicators	β	SE	Wald	OR(95%CI)	P
WHR	0.226	0.130	3.044	1.254(0.972,1.617)	0.081
WHtR	0.548	0.147	13.870	1.730(1.296,2.308)	0.000
CVAI	0.570	0.132	18.612	1.768(1.365,2.290)	0.000
BRI	0.562	0.147	14.686	1.754(1.316,2.338)	0.000
BAI	0.408	0.131	9.708	1.503(1.163,1.943)	0.002
ABSI	0.697	0.132	28.013	2.008(1.551,2.600)	0.000
AVI	0.293	0.137	4.546	1.340(1.024,1.754)	0.033

Table 3 Results of multivariate stepwise logistic regression analysis on the influence of anthropometric indices on carotid plaques

Indicators	β	SE	OR(95%CI)	*P*
unadjusted				
BAI	0.273	0.136	1.314(1.007,1.715)	0.044
CVAI	0.365	0.140	1.441(1.095,1.897)	0.009
ABSI	0.575	0.137	1.777(1.358,2.324)	0.000
After adjusting for confounding factors of disease course, smoking history, and medication history				
BAI	0.006	0.017	1.006(0.973,1.041)	0.713
CVAI	0.008	0.002	1.008(1.004,1.013)	0.001
ABSI	0.382	0.155	1.466(1.082,1.986)	0.014

Table 4 Diagnostic efficacy of anthropometric indices for carotid plaques

Indicators	Cutoff	Sensitivity	Specificity	AUC(95%CI)	*P*
WHR	0.9364	0.487	0.579	0.540(0.503,0.576)	0.033
WHtR	0.5655	0.319	0.789	0.563(0.527,0.600)	0.001
CVAI	123.2152	0.477	0.660	0.583(0.547,0.619)	0.000
BRI	4.6709	0.319	0.789	0.563(0.527,0.600)	0.001
BAI	27.1660	0.477	0.622	0.548(0.511,0.585)	0.010
ABSI	0.0831	0.518	0.661	0.587(0.551,0.623)	0.000
AVI	7.4468	0.691	0.375	0.542(0.506,0.579)	0.024

Discussion

Carotid plaques have been used as an indicator of systemic vascular atherosclerosis [12]. The carotid region is amenable to non-invasive studies and provides relatively accurate results. Carotid plaques play a major role in the development of cerebrovascular and cardiovascular diseases [13]. This population-based cross-sectional study provides evidence of the association between various anthropometric indices and carotid plaques, with

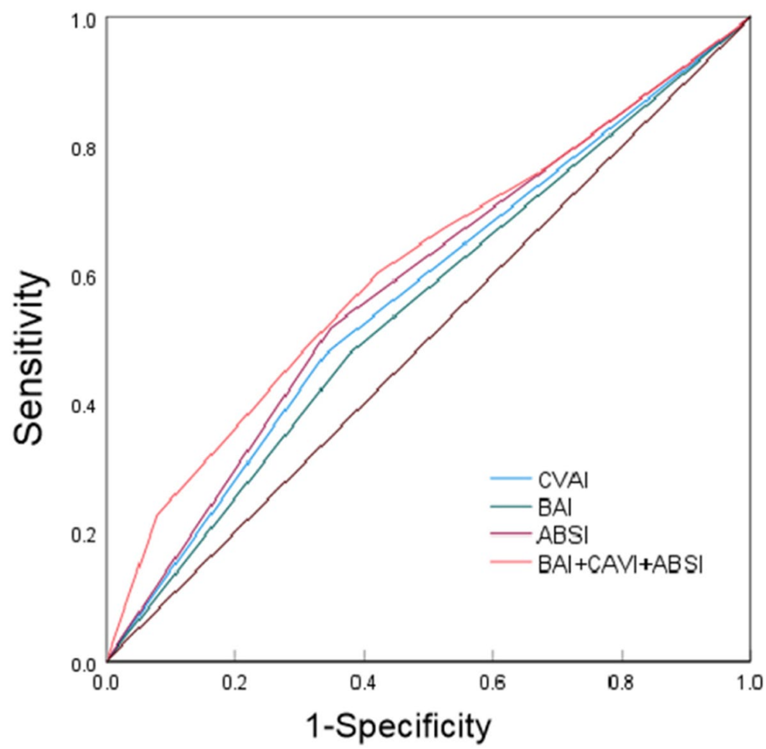

Fig. 2 Receiver Operating Characteristic (ROC) curve for predicting carotid plaques using BAI, CVAI, ABSI, and their combination

significantly higher indices such as ABSI, BAI, and CVAI being associated with carotid plaques.

ABSI, proposed by Krakauer et al. [14] in 2012 based on mortality data from the National Health and Nutrition Examination Survey (NHANES) 1999–2004, is a measure calculated using height, weight, waist circumference, and other indicators to assess abdominal obesity. ABSI is an obesity-related index calculated based on waist circumference, height, and body weight, which, compared to BMI, can better reflect an individual's fat distribution and the proportion of visceral fat [14]. Studies have shown that ABSI has a strong positive correlation with directly measured visceral fat content [15], and has unique advantages in predicting the risk of developing diabetes and all-cause mortality in middle-aged and elderly populations [16]. Leone et al. [17] reported that ABSI is an independent predictor of metabolic syndrome in obese children and adolescents. The results of this study show that ABSI is closely related to the occurrence of carotid plaques in type 2 diabetes subjects and has better predictive value for carotid plaques than other anthropometric indices. Similarly, in the study by Costo-Muriel et al. [18], multivariate analysis showed that only ABSI (OR: 1.15; 95% CI: 1.10–2.38; $P= 0.042$) was significantly positively associated with carotid atherosclerosis, independent of other confounding factors.

Bergmanet al. [19] introduced an index, the Body Adiposity Index (BAI), in samples of Mexican–American and African-American individuals. BAI, calculated using height and hip circumference, directly assesses the degree of body adiposity and can be measured without weighing. BAI can estimate obesity and cardiovascular risk, which has been confirmed in recent studies [20]. The results of this study found that BAI is independently associated with the occurrence of carotid plaques and has higher predictive value for carotid plaques than traditional obesity-related indices such as BMI and WHR. The study by Zwierzchowska et al. [21] found that BAI complements BMI and can be recommended for estimating body fat and cardiometabolic risk in intellectually disabled individuals. Due to its ease of measurement, BAI has high practical value.

CVAI is a newly developed visceral obesity index in Chinese adults, which is related to visceral fat area and insulin resistance [22, 23]. Previous studies have reported that CVAI is superior to BMI, WC, or VAI in the diagnosis of diabetes and prediabetes [24]. CVAI considers factors such as waist circumference and blood lipid levels during the calculation process, which are more related to the distribution of visceral fat and less affected by muscle mass. Therefore, CVAI can more accurately assess an individual's obesity level and health risks, reducing the interference of muscle mass on the results. CVAI is a visceral fat assessment index designed for the Chinese population, taking into account the influence of race, age and other factors on the distribution of visceral fat [25]. Therefore, compared with BMI, CVAI is more applicable in the Chinese population, and can more accurately assess individual obesity and health risks [26]. There is a nonlinear relationship between CVAI and the risk of new myocardial infarction in patients with hypertension and sleep apnea syndrome. When CVAI is ≥112, a higher CVAI is significantly correlated with the risk of new onset myocardial infarction [27]. In our study, CVAI was independently associated with carotid plaques and had certain predictive value.

This study has limitations that should be considered when interpreting the results. Firstly, the sample may not fully represent a broader population due to factors such as region, age, gender, and race influencing sample selection. Therefore, caution should be exercised when generalizing the findings to other populations. Secondly, the sample size imposes certain constraints on the results. Although efforts were made to collect sufficient data, the sample size may still be inadequate to reveal subtle differences or associations. Future research should increase the sample size to enhance the reliability and accuracy of the results. Finally, it is a cross-sectional study and cannot establish causality.

Conclusion

In summary, the results of this study found that the anthropometric indices CVAI, BAI, and ABSI have good predictive effects on carotid plaques and can be used as simple and feasible predictive indicators for high-risk populations of carotid plaques.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12872-025-04722-8.

Supplementary Material 1.

Supplementary Material 2.

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All the authors of this manuscript have made substantial contributions to this work.

Authors' contributions

XD designed the study. ZS, XC contributed to conduct the research and collect data. XZ, YM and MW was responsible for analyzing the data and writing the paper. XD and GY made suggestions and revised the paper. The submitted version has been read and approved by all authors.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

This study was approved by the Biomedical Research Ethics Committee of Jiangsu University Affiliated Hospital. All participants obtained written informed consent.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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