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ORIGINAL RESEARCH

Sex-Specific Associations Between Anthropometric Indices and Left Ventricular Hypertrophy in Middle-Aged and Elderly Individuals with Type 2 Diabetes Mellitus

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Objective: To investigate the associations of anthropometric indicators and left ventricular hypertrophy (LVH) in middle-aged and elderly individuals with type 2 diabetes mellitus (T2DM).

Methods: This was a cross-sectional study. A total of 3330 individuals were recruited from three tertiary hospitals across China between July 2018 and June 2023. Demographic characteristics, biochemical parameters, and echocardiographic measurements were systematically collected. Anthropometric indices, including body mass index (BMI), waist-to-hip ratio (WHR), waist-to-height ratio (WHtR), body adiposity index (BAI), body roundness index (BRI), and weight-adjusted-waist index (WWI) were calculated using standardized protocols. Multivariable binary logistic regression models were employed to evaluate the associations between anthropometric indices and LVH. The diagnostic accuracy was assessed using receiver operating characteristic (ROC) curve analysis.

Results: Multivariable logistic regression analysis revealed that WHR (OR:1.128, 95% CI:1.043, 1.220) and BRI (OR:1.455, 95% CI:1.011, 2.094) were independently associated with increased LVH risk in middle-aged males. Among middle-aged females, BAI (OR:1.112, 95% CI:1.046, 1.182), WHtR (OR:1.048, 95% CI:1.007, 1.090), and BRI (OR:1.234, 95% CI:1.040, 1.465) demonstrated significant associations with LVH. However, in the elderly population, none of the variables showed a statistically significant association with LVH ($P>0.05$). ROC curve analysis identified WHR as the strongest predictor in middle-aged males (AUC:0.674, 95% CI:0.584, 0.764), whereas BAI exhibited the highest discriminatory accuracy among middle-aged females (AUC:0.578, 95% CI:0.523, 0.633).

Conclusion: Sex-specific associations between obesity indices and LVH were observed in middle-aged individuals with T2DM, necessitating distinct risk-stratification strategies: prioritizing abdominal obesity in males and comprehensive adiposity distribution in females. Notably, the broad relevance of BRI in both sexes highlights its clinical utility.

Keywords: type 2 diabetes mellitus, anthropometric indices, left ventricular hypertrophy, sex differences

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Introduction

Type 2 diabetes mellitus (T2DM), a chronic metabolic disorder characterized by insulin resistance (IR) and beta-cell dysfunction, poses a significant global public health challenge. According to 11th edition of the International Diabetes Federation Diabetes Atlas, an estimated 589 million adults (aged 20~79 years) are living with diabetes worldwide in 2024, more than 90% of whom have T2DM.[1] Cardiovascular disease (CVD) is the primary cause of mortality in individuals with T2DM, accounting for 66.3% of deaths, of which 10.5% are attributed to heart failure (HF).[2] Asymptomatic structural or functional cardiac abnormalities may be considered precursors to HF,[3] and diabetes is strongly associated with alterations in left ventricular structure and function.[4] Diabetes-related pathological conditions, including obesity, IR, and dysregulated glucose and lipid metabolism, induce cardiomyocyte hypertrophy and fibrosis, ultimately driving left ventricular remodeling.[5–7] Left ventricular hypertrophy (LVH), a common cardiac manifestation in diabetes, impairs both systolic and diastolic function and substantially elevates the risk of adverse cardiovascular outcomes such as death and HF.[8,9] Notably, LVH and diastolic dysfunction are more common in women than men.[10,11] Given its significant prognostic value, identifying modifiable determinants for LVH is essential for the development of precision cardiology strategies aimed at improving cardiovascular outcomes in individuals with T2DM.

Obesity is a independent predictor for LVH.[5] Obesity contributes to LVH through multiple interconnected pathways. Hemodynamically, increased total blood volume and cardiac output elevate cardiac workload, leading to left ventricular wall thickening, chamber dilation, and remodeling.[12] At a molecular level, visceral adipose tissue releases pro-inflammatory adipokines (eg, IL-6, TNF-α, CRP), which trigger chronic inflammation, endothelial dysfunction, and vascular fibrosis, thereby promoting arteriosclerosis.[13] Furthermore, the release of excessive free fatty acids from metabolically active visceral fat induces direct lipotoxic effects on the myocardium, disrupting its structure and function.[14] Body fat distribution, particularly visceral and ectopic fat, plays a pivotal role in CVD risk stratification.[15] Sex-specific patterns of adipose tissue distribution are well recognized: males typically exhibit greater visceral adiposity, whereas females tend to store more gluteofemoral subcutaneous fat.[16] Anthropometric indices are widely used in epidemiological studies as practical obesity measures. Body mass index (BMI) estimates general adiposity, while waist circumference (WC) is commonly used to assess abdominal obesity. However, both indices do not account for variations in fat distribution nor distinguish between fat and muscle, contributing to the "obesity paradox" wherein individuals with normal BMI may still exhibit elevated cardiovascular risks due to abnormal fat distribution.[17] At the same BMI, females generally exhibit approximately 10% higher body fat percentage than males.[18] Practical and low-cost techniques such as skinfold thickness and bioelectrical impedance analysis (BIA) are prone to measurement error and cannot accurately quantify visceral fat. Whereas dual-energy X-ray absorptiometry (DXA) is limited by cost, portability, and an inability to differentiate fat depots despite its high precision for whole-body composition. Although advanced imaging modalities such as computed tomography and magnetic resonance imaging can accurately quantify fat distribution, their clinical application remains limited due to high cost and operational complexity. Consequently, several alternative anthropometric indices have been developed to overcome the limitations of traditional measures. These include waist-to-hip ratio (WHR) and waist-to-height ratio (WHtR), both established markers of central obesity,[19] as well as three newer indices: body adiposity index (BAI), body roundness index (BRI), and weight-adjusted-waist index (WWI). These metrics integrate parameters such as weight, height, WC, and hip circumference (HC) to provide a more comprehensive reflection of body shape, fat distribution, and visceral adiposity.[20–22] The aforementioned indices have exhibited significant associations with diabetes mellitus, hypertension, and CVD, and have demonstrated superior predictive value over conventional measures, particularly with respect to sex-specific differences in risk stratification.[23,24] Previous studies have investigated the associations between certain anthropometric indices and LVH. For instance, Cai et al[25] revealed that BRI could be an independent risk factor for LVH in Chinese adults with hypertension. Nevertheless, the impact of multiple anthropometric indices on LVH occurrence in individuals with T2DM, and whether this impact may vary across sex and age groups were still unclear.

This population-based cross-sectional study aimed to investigate the sex-specific associations between seven non-invasive anthropometric indices (WC, BMI, WHR, WHtR, BAI, BRI, WWI) and LVH prevalence in middle-aged and elderly individuals with T2DM. Furthermore, we evaluated the diagnostic potential of these adiposity metrics as cost-effective tools for identifying individuals at increased cardiometabolic risk, with the goal of informing precision-based strategies for cardiovascular risk stratification in clinical practice.

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Methods

Study Population

This cross-sectional study was conducted between July 2018 and June 2023. A total of 5506 individuals with T2DM were recruited from the endocrinology departments of three tertiary Grade A hospitals in Jiangsu Province, China. Participants were eligible if they met the diagnostic criteria for T2DM[26] and were aged 45 years or older. Exclusions were applied for several reasons: missing covariates information; absence of echocardiographic indices; severe comorbidities and acute complications (including malignancy, heart failure, hepatic or renal failure, chronic kidney disease, congenital heart disease, cardiomyopathy, coagulation dysfunction, etc). Finally, 3,330 participants were enrolled in the present analysis (Figure 1). The study protocol adhered to the principles of the Helsinki Declaration and was approved by the ethical review board of local hospitals (approval numbers: 2021-LWKY-020). All participants provided written informed consent before enrollment.

Echocardiography Measurements

Echocardiogram analyses were performed by the professional sonographer. Cardiac structural and functional parameters were measured using an M-mode Philips ultrasonograph (EPIQ 7C, Philips, Holland). Each parameter was recorded for three consecutive cardiac cycles and the average value was used for analysis. The proper alignment of imaging planes and recordings was confirmed according to established standard protocols.[27] Left ventricular internal dimensions, interventricular septal thickness (IVST), and left ventricular posterior wall thickness (LVPWT) were measured at end-diastole following the recommendations of the American Society of Echocardiography.[28] Left ventricular mass (LVM) was calculated using the Devereux formula: LVM (g) = $0.8\times1.04\times[(\text{IVST}+\text{LVEDD}+\text{LVPWT})^3 - (\text{LVEDD})^3] +0.6$.[29] Body surface area (BSA) was calculated according to the equations: BSA (male, m^2) = $0.0057\times$height (cm) $+0.0121\times$weight (kg)$+0.0882$, BSA (female, m^2) = $0.0073\times$height (cm)$+0.0127\times$weight (kg)-0.2106.[30] Left ventricular mass index (LVMI, g/m^2) was derived by dividing LVM by BSA. LVH was defined as LVMI $\geq$115 g/m^2 in men and $\geq$95 g/m^2 in women.[31]

Covariates and Definitions

Covariates were collected during a single clinic visit through face-to-face interviews conducted by medical practitioners and trained nurses using a standardized questionnaire. Information gathered encompassed sociodemographic characteristics, physical examination data, lifestyle factors, serological biomarkers, medical history, medication use.

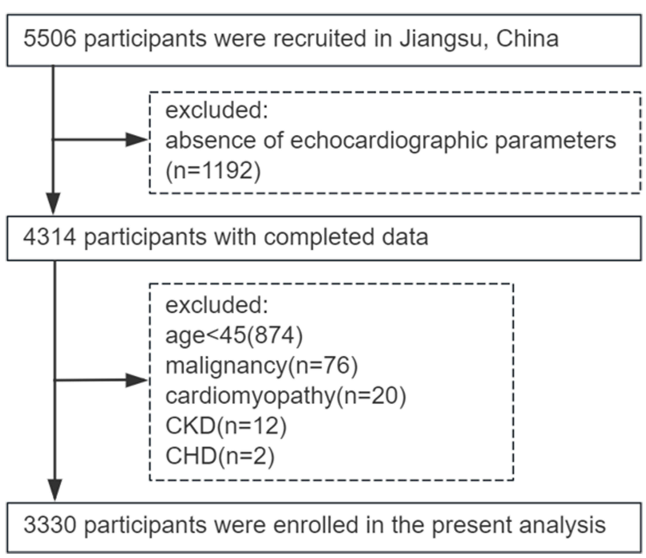

Figure 1 Flow chart of the study subjects.
Abbreviations: CKD, chronic kidney disease; CHD, congenital heart disease.

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Sociodemographic factors covered age, gender, educational level, and duration of diabetes. According to the age classification criteria in China, middle-aged and elderly adults were defined as those aged 45–59 years and ≥60 years, respectively.[32] Lifestyle assessments focused on current smoking and alcohol consumption. Blood pressure and heart rate (HR) were measured three times at two-minute intervals following at least five minutes of rest, using a standardized automatic electronic sphygmomanometer (HBP-1100U, Omron, China). Fasting venous blood samples were collected for biochemical analyses. Fasting plasma glucose (FPG), total cholesterol (TC), triglycerides (TG), high-density lipoprotein cholesterol (HDL-C), and low-density lipoprotein cholesterol (LDL-C) were detected on a fully automatic biochemical analyzer (Cobas C702, Roche). Glycated hemoglobin A1c (HbA1c) was determined by high-performance liquid chromatography (D-10, Bole, USA). All laboratory instruments and equipment were regularly calibrated to ensure measurement accuracy. Medical history encompassing hypertension, hyperlipidemia, coronary heart disease (CHD), stroke, peripheral arterial disease (PAD) was ascertained through a combination of self-reports, medical records, and standardized clinical assessments. Medication profiles were systematically documented, including current use of anti-hypertensives (yes/no) and specific agents classes employed, such as angiotensin converting enzyme inhibitor (ACEI), angiotensin II receptor blockers (ARB), calcium channel blockers (CCB), beta-blockers, and diuretics. Use of lipid-lowering medications and antidiabetic agents, particularly sodium-glucose co-transporter-2 inhibitor (SGLT-2i) and glucagon-like peptide-1 receptor agonists (GLP-1RA), was also recorded.

Anthropometric Measures

Anthropometric indicators were measured and calculated by professionally trained diabetes specialist nurses according to standardized procedures. Body weight and height were measured to the nearest 0.1 kg and 0.1 cm, respectively, using an electronic physical examination scale (HNH-318, Omron, China). Participants were assessed while wearing lightweight clothing, barefoot, and without headwear. WC was measured with participants standing naturally, with relaxed abdomens and arms hanging freely at the sides. A non-elastic and flexible tape was horizontally encircled at the midpoint between the lower margin of the rib cage and the iliac crest along the bilateral mid-axillary lines. HC was measured with participants standing upright, using the same tape to encircle the most prominent part of the buttocks horizontally. Both WC and HC were recorded to the nearest 0.1 cm. BMI was calculated as weight in kilograms divided by the square of the height in meters. WHR was calculated by dividing WC by HC. WHtR was calculated by dividing WC by height. BAI was calculated using formula as: $BAI=(HC(cm)/height(m)^{3/2})-18$.[20] BRI was calculated using formula as: $BRI=364.2–365.5\times\{1-[(WC(m)/2\pi)/(0.5\times height(m))]^2\}^{1/2}$.[21] WWI was calculated using formula as: $WWI=WC(cm)/weight(kg)^{1/2}$.[22]

Statistical Analyses

Continuous variables were summarized as mean±standard deviation (SD) for normally distributed data or as median and interquartile range (IQR) for non-normally distributed data. Categorical variables were expressed as frequencies and percentages. Group comparisons were performed using one-way analysis of variance (ANOVA) for normally distributed continuous variables, the Kruskal–Wallis test for non-normally distributed continuous variables, and the Chi-square test for categorical variables, as appropriate based on data characteristics. When statistically significant differences were identified, post hoc multiple comparisons were performed using the Bonferroni correction.

The associations between anthropometric indicators and LVH was examined using multivariable binary logistic regression analyses, incorporating three models. Model 1 was unadjusted. Model 2 adjusted for age, educational level, duration of diabetes, current smoking, current drinking, hypertension, hyperlipidemia, coronary heart disease, stroke, peripheral arterial disease, antihypertensive agents, lipid-lowering agents, antidiabetic agents, SGLT-2i, GLP-1RA, ACEI, ARB, CCB, beta-blockers, diuretics. Model 3 was fully adjusted, further including diastolic blood pressure (DBP), systolic blood pressure (SBP), HR, HbA1c, TG, and TC. Multicollinearity among variables was assessed via the variance inflation factor (VIF), with a threshold of VIF > 5 indicating significant multicollinearity. Variables demonstrating multicollinearity were subsequently addressed through variable reduction approaches. Receiver operating characteristic (ROC) curves were constructed to evaluate the discriminatory performance of each anthropometric indicator in assessing LVH risk among individuals with T2DM. The diagnostic ability of each indicator was quantified by calculating the area under the ROC curve (AUC). All the statistical analyses were performed using SPSS 26.0. The tests were two-sided, and a *P*-value < 0.05 was recognized statistically significant.

Results

Study Sample

The baseline characteristics were presented in Table 1. According to gender and age, participants were divided into four groups: middle-aged males (44.0%), middle-aged females (24.7%), elderly males (17.4%), and elderly females (13.9%). The prevalence of LVH was highest in the elderly females group, followed by middle-aged females group (*P*<0.05). Among males, compared to the middle-aged group, the elderly group exhibited a longer diabetes duration, higher SBP, HDL-C, WWI, BAI, and LVMI, along with lower DBP, HR, HbA1c, TG, TC, and LDL-C. They also had higher proportions of hypertension, CHD, stroke, and more individuals using antihypertensive agents, lipid-lowering

Table 1 Baseline Characteristics of Study Population

Variable	Overall (n=3330)	Male		Female		*P* value
		Middle-Aged Group (n=1464)	Elderly Group (n=580)	Middle-Aged Group (n=822)	Elderly Group (n=464)	
Age (years)	56 (51,61)	52 (49,56)	64 (62,67)[a]	54 (51,57)[ab]	66 (63,69)[ac]	<0.001
Educational level (%)						
Less than high school	2494 (74.9)	976 (66.7)	440 (75.9)[a]	656 (79.8)[a]	422 (90.9)[abc]	<0.001
High school or above	836 (25.1)	488 (33.3)	140 (24.1)[a]	166 (20.2)[a]	42 (9.1)[abc]	
Duration of diabetes (months)	85 (24,131)	65 (14,123)	116.5 (52,185)[a]	74 (12,124)[b]	122 (53,189)[ac]	<0.001
DBP (mmHg)	78 (71,85)	80 (73,88)	77 (71,85)[a]	77 (70,85)[a]	74 (68,81)[abc]	<0.001
SBP (mmHg)	128 (117,140)	126 (116,138)	131 (120,143)[a]	127 (117,139)[b]	135 (123,145)[abc]	<0.001
HR (bpm)	76 (70,83)	78 (70,84)	73 (69,80)[a]	76 (72,82)[b]	75 (70,81)[abc]	<0.001
BSA (m^2)	1.86 (1.73,1.98)	1.95 (1.86,2.04)	1.89 (1.80,2.01)[a]	1.73 (1.65,1.85)[ab]	1.70 (1.61,1.80)[abc]	<0.001
Current smokers (%)	1100 (33.0)	838 (57.2)	254 (43.8)[a]	6 (0.7)[ab]	2 (0.4)[ab]	<0.001
Current drinkers (%)	1236 (37.1)	902 (61.6)	298 (51.4)[a]	24 (2.9)[ab]	12 (2.6)[ab]	<0.001
FPG (mmol/L)	8.07 (6.41,10.60)	8.15 (6.49,10.71)	7.98 (6.44,10.23)	8.11 (6.39,11.14)	7.93 (6.18,10.06)	0.169
HbA1c (%)	8.7 (7.4,10.4)	8.9 (7.4,10.5)	8.3 (7.4,9.8)[a]	9.0 (7.4,10.7)[b]	8.2 (7.3,9.7)[ac]	<0.001
TG (mmol/L)	1.58 (1.08,2.53)	1.78 (1.14,2.83)	1.36 (0.89,1.91)[a]	1.62 (1.14,2.42)[b]	1.56 (1.08,2.32)[ab]	<0.001
TC (mmol/L)	4.71 (3.97,5.50)	4.63 (3.98,5.45)	4.37 (3.61,5.01)[a]	4.96 (4.19,5.73)[ab]	4.83 (4.00,5.66)[b]	<0.001
HDL-C (mmol/L)	1.13 (0.94,1.36)	1.03 (0.88,1.25)	1.14 (0.96,1.40)[a]	1.20 (1.02,1.42)[ab]	1.27 (1.06,1.50)[abc]	<0.001
LDL-C (mmol/L)	2.73 (2.16,3.28)	2.79 (2.23,3.29)	2.50 (1.87,3.00)[a]	2.83 (2.22,3.40)[b]	2.78 (2.10,3.25)[bc]	<0.001
History of diseases (%)						
Hypertension	1926 (57.8)	788 (53.8)	388 (66.9)[a]	434 (52.8)[b]	316 (68.1)[ac]	<0.001
Hyperlipidemia	1006 (30.2)	436 (29.8)	164 (28.3)	242 (29.4)	164 (35.3)	0.066
Coronary heart disease	134 (4.0)	46 (3.1)	48 (8.3)[a]	10 (1.2)[ab]	30 (6.5)[ac]	<0.001
Stroke	496 (14.9)	110 (7.5)	166 (28.6)[a]	78 (9.5)[b]	142 (30.6)[ac]	<0.001
Peripheral arterial disease	12 (0.4)	4 (0.3)	2 (0.3)	6 (0.7)	0 (0)	0.193
Medications (%)						
Antihypertensive agents	1618 (48.6)	676 (46.2)	316 (54.5)[a]	358 (43.6)[b]	268 (57.8)[ac]	<0.001
Lipid-lowering agents	544 (16.3)	214 (14.6)	118 (20.3)[a]	114 (13.9)[b]	98 (21.1)[ac]	<0.001
Antidiabetic agents	2858 (85.8)	1234 (84.3)	512 (88.3)	692 (84.2)	420 (90.5)[ac]	0.001
SGLT-2i	348 (10.5)	196 (13.4)	54 (9.3)	70 (8.5)[a]	28 (6.0)[a]	<0.001
GLP-1RA	122 (3.7)	84 (5.7)	14 (2.4)[a]	14 (1.7)[a]	10 (2.2)[a]	<0.001
ACEI	50 (1.5)	26 (1.8)	4(0.7)	14 (1.7)	6(1.3)	0.297
ARB	720 (21.6)	276 (18.9)	158 (27.2)[a]	152 (18.5)[b]	134 (28.9)[ac]	<0.001
Beta-blockers	130 (3.9)	58 (4.0)	28 (4.8)	18 (2.2)[b]	26 (5.6)[c]	0.010
CCB	646 (19.4)	262 (17.9)	140 (24.1)[a]	124 (15.1)[b]	120 (25.9)[ac]	<0.001
Diuretics	218 (6.5)	80 (5.5)	28 (4.8)	62 (7.5)	48 (10.3)[ab]	<0.001

(*Continued*)

Table 1 (Continued).

Variable	Overall (n=3330)	Male		Female		P value
		Middle-Aged Group (n=1464)	Elderly Group (n=580)	Middle-Aged Group (n=822)	Elderly Group (n=464)	
Anthropometric indices						
BMI (kg/m^2)	25.46(23.53,27.62)	25.51(23.86,27.47)	25.15(23.01,27.58)	25.43(23.15,27.79)	25.46(23.34,27.66)	0.166
WC (cm)	91.0 (85.5,96.5)	92.0 (87.0,98.0)	92.0 (87.0,98.0)	88.0 (82.5,95.0)^{ab}	90.0 (83.5,96.0)^{abc}	<0.001
WHR	0.95 (0.91,0.98)	0.95 (0.92,0.98)	0.96 (0.92,0.99)	0.93 (0.89,0.97)^{ab}	0.95 (0.91,0.99)^{c}	<0.001
WHtR	0.55 (0.52,0.59)	0.54 (0.51,0.58)	0.55 (0.52,0.59)	0.56 (0.52,0.60)^{ab}	0.58 (0.54,0.63)^{abc}	<0.001
WWI	10.94 (10.56,11.43)	10.77 (10.40,11.14)	10.90 (10.62,11.41)^{a}	11.13 (10.66,11.68)^{ab}	11.44 (10.91,12.00)^{abc}	<0.001
BAI	27.57(25.28,30.54)	25.89(23.96,28.03)	26.79(24.63,28.55)^{a}	30.24(27.52,32.89)^{ab}	31.11(28.59,33.92)^{abc}	<0.001
BRI	4.39 (3.74,5.27)	4.22 (3.61,4.92)	4.31 (3.70,5.20)	4.58 (3.83,5.46)^{ab}	4.95 (4.13,6.04)^{abc}	<0.001
Echocardiographic parameters						
IVST (mm)	9 (9,10)	9 (9,10)	10 (9,10)^{a}	9 (8,10)^{ab}	9 (9,10)^{bc}	<0.001
LVEDD (mm)	47 (45,50)	48 (45,51)	48 (45,51)	46 (43,48)^{ab}	46 (44,49)^{ab}	<0.001
LVPWT (mm)	9 (9,10)	9 (9,10)	9 (9,10)^{a}	9 (8,9)^{ab}	9 (8,10)^{b}	<0.001
LVM (g)	147.78(127.81,169.92)	152.95(132.82,176.04)	158.21(137.25,180.72)^{a}	133.85(117.91,154.97)^{ab}	142.71(123.30,162.11)^{abc}	<0.001
LVMI (g/m^2)	79.88(69.95,90.51)	78.58(68.71,89.63)	83.62(73.50,93.18)^{a}	77.52(67.48,88.01)^{b}	83.25(74.69,93.51)^{ac}	<0.001
LVH (%)	264 (7.9)	34 (2.3)	24 (4.1)	114 (13.9)^{ab}	92 (19.8)^{abc}	<0.001

Notes: Continuous data are presented as mean±standard deviation or median (interquartile range); categorical data are presented as frequencies (percentages). [a]$P<0.05$ vs middle-aged males, [b]$P<0.05$ vs elderly males, [c]$P<0.05$ vs middle-aged females using Bonferroni post hoc test.

Abbreviations: ACEI, angiotensin converting enzyme inhibitor; ARB, angiotensin II receptor antagonist; BAI, body adiposity index; BMI, body mass index; BRI, body roundness index; BSA, body surface area; CCB, calcium channel blockers; DBP, diastolic blood pressure; FPG, fasting plasma glucose; GLP-1RA, glucagon-like peptide-1 receptor agonist; HbA1c, glycated hemoglobin A1c; HDL-C, high-density lipoprotein cholesterol; HR, heart rate; IVST, interventricular septal thickness; LDL-C, low-density lipoprotein cholesterol; LVEDD, left ventricular end-diastolic diameter; LVH, left ventricular hypertrophy; LVM, left ventricular mass; LVMI, left ventricular mass index; LVPWT, left ventricular posterior wall thickness; SBP, systolic blood pressure; SGLT-2i, sodium-glucose co-transporter 2 inhibitor; TC, total cholesterol; TG, triglycerides; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio; WWI, weight-adjusted-waist index.

medications, ARB, and CCB, but lower rates of smoking, alcohol consumption, and GLP-1RA usage (P<0.05). Among females, compared with the middle-aged group, the elderly group showed a longer diabetes duration, higher SBP, HDL-C, WC, WHR, WHtR, WWI, BAI, BRI, and LVMI, along with lower DBP, HR, HbA1c, and LDL-C. They also had higher proportions of hypertension, CHD, stroke, and were more likely to use antihypertensive agents, lipid-lowering agents, antidiabetic agents, ARB, beta-blockers, and CCB (P<0.05). Within the middle-aged subgroup, compared to males, females were older and had higher levels of TC, HDL-C, WHtR, WWI, BAI, and BRI, but lower DBP, WC, and WHR. They also showed lower rates of CHD and fewer individuals using SGLT-2i and GLP-1RA (P<0.05). In the elderly group, compared to males, females exhibited higher SBP, HR, TG, TC, LDL-C, HDL-C, WHtR, WWI, BAI, and BRI, along with lower DBP and WC. They also had a higher proportion of individuals using diuretics (P<0.05).

The Effects of Anthropometric Indices on the Incidence of LVH in Middle-Aged and Elderly Individuals with T2DM

Multivariable-adjusted logistic regression analysis revealed linear associations of WHR and BRI in middle-aged males, BAI, WHtR, and BRI in middle-aged females with LVH risk in the fully adjusted model, with the adjusted ORs of 1.128 (95% CI: 1.043, 1.220), 1.455 (95% CI: 1.011, 2.094), 1.112 (95% CI: 1.046, 1.182), 1.048 (95% CI: 1.007, 1.090), 1.234 (95% CI: 1.040, 1.465), respectively. In the elderly, all indices were not significant (P>0.05) (Table 2).

The Discriminatory Ability of Each Anthropometric Indicator in Assessing LVH Risk Among Middle-Aged and Elderly Individuals with T2DM

The AUC values for all anthropometric indices in the elderly males had no statistical significances (P>0.05), and all AUCs were less than 0.5 in the elderly females, indicating poor discriminatory ability. Therefore, only the ROC curves and corresponding AUCs for middle-aged males and females were presented to illustrate the associations between

Table 2 Relationships Between Anthropometric Indices and Left Ventricular Hypertrophy Risk in Middle-Aged and Elderly Individuals with Type 2 Diabetes Mellitus

Variable	Model 1		Model 2		Model 3	
	OR (95% CI)	*P* value	OR (95% CI)	*P* value	OR (95% CI)	*P* value
Middle-aged male						
WC	1.064 (1.024, 1.105)	0.001	1.052 (1.004, 1.103)	0.035	1.040 (0.990, 1.093)	0.121
BMI	1.162 (1.055, 1.279)	0.002	1.161 (1.021, 1.320)	0.023	1.129 (0.988, 1.291)	0.075
WHR	1.161 (1.085, 1.241)	<0.001	1.146 (1.061, 1.239)	<0.001	1.128 (1.043, 1.220)	0.003
WHtR	1.108 (1.044, 1.176)	<0.001	1.107 (1.023, 1.197)	0.011	1.081 (0.998, 1.172)	0.056
WWI	2.083 (1.145, 3.792)	0.016	1.896 (0.974, 3.692)	0.060	1.668 (0.858, 3.243)	0.132
BAI	1.055 (0.950, 1.172)	0.314	1.032 (0.906, 1.175)	0.635	1.009 (0.887, 1.149)	0.887
BRI	1.562 (1.213, 2.012)	<0.001	1.621 (1.140, 2.305)	0.007	1.455 (1.011, 2.094)	0.044
Middle-aged female						
WC	1.015 (0.994, 1.038)	0.162	1.021 (0.996, 1.046)	0.108	1.019 (0.992, 1.046)	0.174
BMI	1.042 (0.988, 1.099)	0.133	1.062 (0.995, 1.134)	0.068	1.063 (0.994, 1.138)	0.074
WHR	1.019 (0.985, 1.054)	0.277	1.019 (0.981, 1.058)	0.338	1.004 (0.963, 1.046)	0.865
WHtR	1.037 (1.004, 1.071)	0.029	1.050 (1.011, 1.090)	0.011	1.048 (1.007, 1.090)	0.020
WWI	1.329 (0.993, 1.780)	0.056	1.458 (1.048, 2.029)	0.025	1.388 (0.978, 1.970)	0.066
BAI	1.065 (1.013, 1.119)	0.013	1.097 (1.034, 1.163)	0.002	1.112 (1.046, 1.182)	<0.001
BRI	1.167 (1.014, 1.343)	0.032	1.243 (1.056, 1.462)	0.009	1.234 (1.040, 1.465)	0.016
Elderly male						
WC	1.020 (0.972, 1.069)	0.424	1.012 (0.954, 1.073)	0.693	1.007 (0.942, 1.076)	0.846
BMI	1.042 (0.916, 1.186)	0.532	0.999 (0.858, 1.163)	0.987	0.958 (0.801, 1.147)	0.641
WHR	1.054 (0.984, 1.129)	0.137	1.066 (0.965, 1.176)	0.207	1.090 (0.977, 1.217)	0.122
WHtR	1.054 (0.969, 1.147)	0.220	1.027 (0.932, 1.132)	0.594	1.026 (0.918, 1.146)	0.656
WWI	1.584 (0.780, 3.216)	0.203	1.407 (0.594, 3.332)	0.437	1.431 (0.556, 3.684)	0.458
BAI	1.043 (0.912, 1.193)	0.537	0.988 (0.845, 1.155)	0.882	0.962 (0.804, 1.152)	0.675
BRI	1.269 (0.858, 1.877)	0.233	1.120 (0.711, 1.765)	0.624	1.105 (0.660, 1.852)	0.703
Elderly female						
WC	0.971 (0.947, 0.995)	0.020	0.972 (0.944, 1.000)	0.051	0.973 (0.944, 1.003)	0.081
BMI	0.927 (0.866, 0.991)	0.026	0.943 (0.873, 1.017)	0.129	0.950 (0.876, 1.030)	0.215
WHR	0.984 (0.948, 1.020)	0.371	0.984 (0.942, 1.027)	0.454	0.990 (0.946, 1.035)	0.654
WHtR	0.961 (0.926, 0.998)	0.041	0.962 (0.920, 1.005)	0.082	0.963 (0.920, 1.009)	0.111
WWI	0.876 (0.657, 1.168)	0.366	0.823 (0.594, 1.142)	0.244	0.817 (0.581, 1.148)	0.244
BAI	0.944 (0.886, 1.005)	0.072	0.944 (0.879, 1.015)	0.118	0.940 (0.873, 1.013)	0.106
BRI	0.827 (0.695, 0.984)	0.032	0.828 (0.677, 1.012)	0.065	0.832 (0.674, 1.027)	0.087

Notes: Model 1 was unadjusted; Model 2 adjusted for age, educational level, duration of diabetes, current smoking, current drinking, hypertension, hyperlipidemia, coronary heart disease, stroke, peripheral arterial disease, antihypertensive agents, lipid-lowering agents, antidiabetic agents, sodium-glucose co-transporter 2 inhibitor, glucagon-like peptide-1 receptor agonist, angiotensin converting enzyme inhibitor, angiotensin II receptor antagonist, calcium channel blockers, beta-blockers, diuretics; Model 3 was fully adjusted, further incorporating diastolic blood pressure, systolic blood pressure, heart rate, glycated hemoglobin A1c, triglycerides, total cholesterol.
Abbreviations: BAI, body adiposity index; BMI, body mass index; BRI, body roundness index; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio; WWI, weight-adjusted-waist index.

anthropometric indices and LVH. WHR demonstrated the highest AUC for LVH (AUC=0.674, 95% CI: 0.584, 0.764) in the middle-aged males. BAI exhibited the highest AUC (AUC=0.578, 95% CI: 0.523, 0.633) in the middle-aged females (Table 3 and Figure 2).

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Table 3 The Area Under the Curves of Each Anthropometric Measure for the Presence of Left Ventricular Hypertrophy

Variable	Middle-Aged Male				Middle-Aged Female			
	AUC (95% CI)	Sensitivity	Specificity	*P* value	AUC (95% CI)	Sensitivity	Specificity	*P* value
WC	0.639 (0.543, 0.734)	0.471	0.786	0.004	0.544 (0.492, 0.596)	0.667	0.442	0.100
BMI	0.658 (0.558, 0.758)	0.765	0.576	0.002	0.559 (0.506, 0.613)	0.719	0.448	0.029
WHR	0.674 (0.584, 0.764)	0.941	0.359	<0.001	0.522 (0.467, 0.576)	0.930	0.170	0.433
WHtR	0.646 (0.548, 0.744)	0.471	0.804	0.004	0.564 (0.510, 0.617)	0.649	0.535	0.020
WWI	0.609 (0.519, 0.700)	0.882	0.330	0.018	0.540 (0.483, 0.596)	0.807	0.289	0.168
BAI	0.579 (0.480, 0.677)	0.588	0.708	0.118	0.578 (0.523, 0.633)	0.684	0.493	0.006
BRI	0.646 (0.548, 0.744)	0.471	0.804	0.004	0.564 (0.510, 0.617)	0.649	0.535	0.020

Abbreviations: BAI, body adiposity index; BMI, body mass index; BRI, body roundness index; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio; WWI, weight-adjusted-waist index.

Discussion

In this study, we explored the relationships between various anthropometric indices and LVH among middle-aged and elderly individuals with T2DM. Based on data from a cross-sectional survey, we identified significant differences in the associations between distinct anthropometric indices and LVH risk across gender and age subgroups. These findings elucidate the potential utility of obesity-related anthropometric measures in identifying T2DM population at elevated risk for LVH, a key predictor of adverse cardiovascular outcomes.

After multivariable adjustment, no significant associations were observed between anthropometric indices and LVH in elderly individuals with T2DM. Age is a well-established independent risk factor for LVH.[33] Advancing age contributes to left ventricular remodeling characterized by hypertrophy and myocardial fibrosis, even without conditions increasing cardiac afterload (eg, hypertension).[34] Older adults are prone to age-related sarcopenia alongside increased ectopic fat deposition, particularly intermuscular adipose tissue (IMAT) and hepatic fat infiltration.[35,36] Therefore, the aforementioned obesity metrics may inadequately capture these age-specific adipose distribution patterns. Additionally, the higher comorbidity burden and absolute cardiovascular risk in this population could obscure the relative contribution of adiposity to cardiac dysfunction. The widespread use of glucose-lowering medications, antihypertensive, and lipid-lowering agents in elderly population could further confound the adiposity-cardiac remodeling relationships.

The associations of different anthropometric indicators for LVH showed significant gender disparities among middle-aged individuals with T2DM. BRI demonstrated positive associations with LVH risk irrespective of sex. As a metric

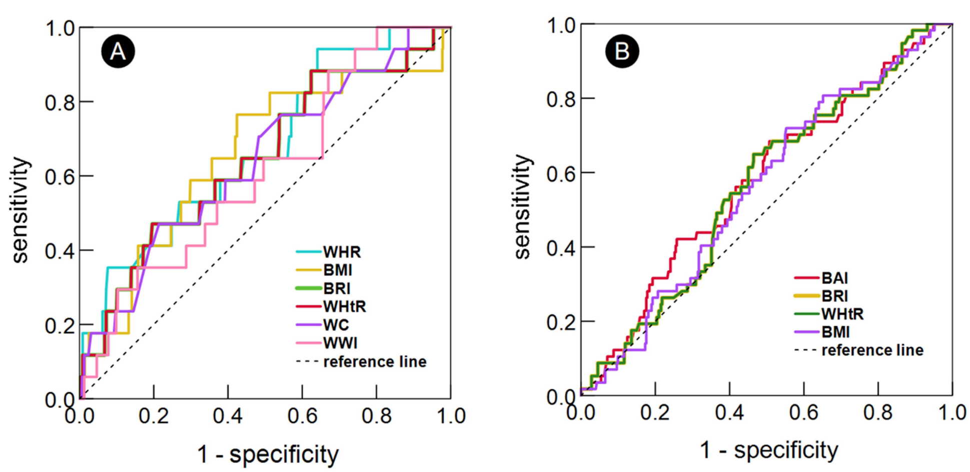

Figure 2 The receiver operating characteristic curves of anthropometric indicators to identify subjects with left ventricular hypertrophy in middle-aged individuals with type 2 diabetes mellitus. (**A**) the middle-aged males; (**B**) the middle-aged females.
Abbreviations: BAI, body adiposity index; BMI, body mass index; BRI, body roundness index; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio; WWI, weight-adjusted-waist index.

integrating height and WC, BRI provides improved estimation of body fat percentage and visceral adiposity compared to traditional indices such as BMI, WC or HC.[21] Previous research by Cai et al[25] further revealed that BRI may be an independent risk factor for LVH among hypertensive adults in China. In addition, WHR in middle-aged males and WHtR in middle-aged females also have positive associations with LVH risk. Zhang et al[37] demonstrated that WHtR-defined abdominal obesity was associated with LVH in males, while both WHtR and WHR-defined abdominal obesity were linked to LVH in females. WHR and WHtR are established markers of central obesity and exhibit significant associations with cardiovascular risk factors, including hypertension, T2DM, and dyslipidemia.[23] The inconsistencies between these findings and the current study may arise from the following factors. First, Zhang et al[37] focused on the general population, whereas this study primarily involved individuals with T2DM. Diabetes is known to exacerbate visceral fat accumulation and myocardial fibrosis through mechanisms such as IR, dysregulated glucose and lipid metabolism, and chronic inflammation, resulting in more complex cardiac structural remodeling.[4] Second, males predominantly accumulate fat in abdominal regions.[16] In contrast, premenopausal females tend to store subcutaneous adipose tissue preferentially in the gluteofemoral regions, while postmenopausal estrogen deficiency triggers adipose redistribution and abdominal fat accumulation.[38] As our study included a higher proportion of postmenopausal women, in whom abdominal adiposity is more prominent, WHtR may better reflect the risk of LVH in this female subgroup. BAI showed LVH associations exclusively in middle-aged females, potentially reflecting sex-specific fat distribution patterns. Bergman et al[20] established BAI's strong correlation (via HC and height) with the "gold standard" DXA-measured body fat percentage without requiring gender adjustment. Given menopausal fat redistribution in middle-aged females, BAI may serve as an additional indicator of LVH risk. These findings underscore the importance of sex-stratified anthropometric assessment in middle-aged individuals with T2DM. Specifically, monitoring abdominal adiposity in males and overall fat distribution in females is essential.

In middle-aged males, the WHR demonstrated superior predictive value for LVH compared to WC. Middle-aged males tend to accumulate fat in the abdomen (ie, central obesity), while their hip circumference remains relatively stable.[16] Abdominal fat, especially visceral fat, is closely associated with an increased risk of cardiovascular diseases and metabolic disorders. In contrast, hip fat is predominantly subcutaneous and poses comparatively lower health risks.[39] WC only reflects the absolute amount of total abdominal fat and fails to account for individual differences in hip size or characteristics of subcutaneous fat distribution. By adjusting for subcutaneous fat in the hips, the WHR may more accurately identify the unhealthy central fat distribution pattern. Therefore, WHR is more reliable than WC when assessing health risks in middle-aged males. In contrast, anthropometric indices demonstrated limited diagnostic utility for LVH in middle-aged females with T2DM. Several factors may account for this observation. Estrogen confers cardioprotective effects through vasodilation, inhibition of vascular smooth muscle proliferation and migration, and lipid metabolism regulation[40,41]. However, the perimenopausal and postmenopausal decline in estrogen attenuates these benefits.[42] Older women exhibited the highest prevalence of LVH, followed by middle-aged women, a pattern likely linked to postmenopausal estrogen decline, which drives visceral fat accumulation and metabolic disturbances.[38] Furthermore, females exhibit higher overall adiposity with preferential subcutaneous gluteofemoral deposition, which confers lower cardiometabolic risk than male-predominant visceral obesity.[16] Visceral adipose tissue demonstrates greater metabolic activity and stronger associations with hypertension, diabetes, and metabolic syndrome.[43] Meanwhile, myocardial fibrosis affects males to a greater degree than females,[44] potentially due to heightened myocardial expression of renin-angiotensin-aldosterone system (RAAS) genes.[45] Estrogen may mitigate myocardial fibrosis through inhibition of sympathetic activity and suppression of RAAS activation.[46] These sex-specific hormonal and metabolic factors may account for the lack of significant associations between anthropometric indices and LVH in females. Despite these limitations, anthropometric indices, particularly WHR in males, remain valuable for cardiovascular risk stratification in individuals with T2DM. Future research should aim to validate the prognostic utility of these indices in diverse populations and across different clinical contexts.

Our study findings support the incorporation of these simple, non-invasive, and cost-effective anthropometric indices into clinical diabetes management for LVH risk stratification. By facilitating targeted referral for comprehensive cardiac assessment, this stratified screening approach optimizes resource allocation—notably in both well-equipped and resource-limited healthcare contexts—while improving access to timely cardiac evaluation. Widespread adoption of this strategy has the potential to enhance early LVH detection, fortify primary prevention, and thereby reduce the future burden of heart failure among patients with diabetes, a particularly vulnerable population.

This study has several strengths. First, this study systematically compared the associations between seven distinct obesity indices and LVH in middle-aged and elderly individuals with T2DM. Few studies have compared such a large number of indices specifically in the study population. Second, the sex- and age-stratified analyses elucidated the heterogeneous associations between various anthropometric indices and LVH, underscoring the necessity for precise cardiovascular risk stratification and management strategies in T2DM.

However, this study also has limitations. Firstly, as an observational study, we cannot establish a causal relationship between anthropometric indices and LVH. Future longitudinal studies are warranted to clarify the temporal associations between these indices and LVH development. Secondly, the study population was restricted to individuals with T2DM from tertiary hospitals in China, which may limit the generalizability of the findings to other population or settings. Additionally, although detailed information on medication use was collected, including drug classes known to influence myocardial remodeling, data on the duration of medication exposure were not available. Consequently, adjustments were made only for medication classes (yes/no) in the analysis, without further stratification by treatment duration. This methodological constraint may introduce residual confounding bias, as variations in drug exposure time could modulate the observed associations. Finally, the relatively small proportion of participants with LVH in the study sample may have reduced the statistical power to detect significant differences between subgroups.

Conclusions

In conclusion, among middle-aged individuals with T2DM, various obesity indices show sex-specific associations with LVH, with the BRI being significantly relevant to LVH in both sexes. This underscores the necessity for sex-specific risk management: prioritizing abdominal obesity in males and comprehensive adiposity distribution in females. Integrating these anthropometric indices into clinical practice can optimize cardiovascular risk management in this high-risk population.

Data Sharing Statement

The data in our study could be made available upon request to the corresponding authors.

Ethics Approval and Consent to Participate

The study protocol was approved by the Affiliated Hospital of Integrated Traditional Chinese and Western Medicine of Nanjing University of Chinese Medicine Ethics Committee, and all participants provided informed consent in adherence to the Declaration of Helsinki.

Author Contributions

G.L. and Q.T. contributed to the study conceptualization, formal analysis, and original draft writing. Q.C., R.Z., C.W., D. F., Z.S., and D.Z. were involved in investigation, data curation, visualization, and writing review and editing. X. C. provided supervision, formal analysis, and writing review and editing. X.Y. and R.Z.contributed to research conceptualization, critically writing review and editing, and provided funding acquisition. All authors have agreed on the journal to which the article has been submitted. All authors reviewed and agreed on all versions of the article before submission, during revision, the final version accepted for publication, and any significant changes introduced at the proofing stage. All authors agree to take responsibility and be accountable for all aspects of the work.

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Disclosure

The authors declare no conflict of interest.

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