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ORIGINAL RESEARCH

Gender-Specific Predictive Utility of Twelve Anthropometric Indices for Metabolic Syndrome in Chinese Lahu Adults with Dyslipidemia

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Objective: To evaluate the gender-specific predictive performance of 12 anthropometric indices for metabolic syndrome (MetS) among Lahu ethnic adults with dyslipidemia.

Methods: This cross-sectional study employed stratified cluster sampling in two Lahu communities in southwest China. MetS was defined according to the National Cholesterol Education Program Adult Treatment Panel III (NCEP ATPIII) criteria. Twelve indices were assessed: body mass index (BMI), waist circumference (WC), lipid accumulation product (LAP), visceral adiposity index (VAI), a body shape index (ABSI), body adiposity index (BAI), body roundness index (BRI), relative fat mass (RFM), uric acid-to-HDL-C ratio (UHR), triglyceride-glucose index (TyG), cardiometabolic index (CMI), and Chinese visceral adiposity index (CVAI). Receiver operating characteristic (ROC) curve analysis evaluated predictive performance, and binary logistic regression assessed associations with MetS and its components.

Results: This study of 1257 Lahu adults with dyslipidemia (48.5% male) revealed a 23.4% MetS prevalence, significantly higher in females (29.2% vs 17.2%, $p<0.001$). The TyG index emerged as the strongest MetS predictor in both sexes (AUC: males 0.828, females 0.784), followed by CMI, VAI, LAP and CVAI with moderate predictive ability (AUC range: 0.678–0.779). Other indices showed limited predictive value, while ABSI was not significant. For MetS components, BRI showed strong associations with elevated BP in both genders (males: 1.666[1.228–2.261]; females: 1.804[1.388–2.344]) and with elevated TG (1.644[1.248–2.166]) in males. Female-specific associations included VAI with reduced HDL-C, and BMI/CVAI with elevated FPG.

Conclusion: Among dyslipidemic Lahu adults, all indices except ABSI demonstrated predictive efficacy for MetS, with the TyG index outperforming all others. These simple, low-cost indices could be applied for early MetS screening or risk stratification in this population, particularly in rural or resource-limited settings. Notably, gender-specific differences should be considered in clinical applications.

Keywords: metabolic syndrome, anthropometric indices, ethnic minorities, dyslipidemia, triglyceride-glucose index, gender differences, Lahu population

Introduction

Metabolic syndrome (MetS), a cluster of interrelated metabolic abnormalities including abdominal obesity, dyslipidemia, hypertension, and hyperglycemia, affects 12.5–31.4% of adults globally, representing a critical public health challenge with substantial cardiovascular and diabetic morbidity.[1] Central to MetS pathophysiology is dyslipidemia, marked by hypertriglyceridemia and reduced high-density lipoprotein cholesterol (HDL-C).[2] These lipid abnormalities are intrinsically linked to visceral adiposity and insulin resistance (IR).[3,4] Dyslipidemia not only independently elevates cardiovascular disease (CVD) risk but also synergistically amplifies atherogenesis and type 2 diabetes mellitus (T2DM) development through interactions with other metabolic components.[5,6] Individuals with dyslipidemia represent a particularly high-risk subgroup for MetS progression, as lipid abnormalities often precede or co-occur with other metabolic disturbances,[7,8] making them an important

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target population for early screening initiatives. Therefore, establishing an effective approach for identifying individuals at high risk of MetS among populations with dyslipidemia is of critical clinical importance.

Anthropometric indices are simple, cost-effective, and practical tools for the early detection of individuals at high risk of metabolic disorders and related chronic diseases,[9–11] making them particularly valuable in low-resource or rural communities with limited access to laboratory examinations, especially among underrepresented ethnic minority populations. Traditional anthropometric indices such as body mass index (BMI) and waist circumference (WC) are widely used for MetS risk stratification, yet their diagnostic accuracy is limited by poor sensitivity to visceral adiposity and gender-specific variations.[12] Recent studies highlight the potential of novel indices, including the lipid accumulation product (LAP), visceral adiposity index (VAI), and triglyceride-glucose index (TyG), to better capture metabolic dysregulation.[13,14] Nevertheless, the generalizability of these indices to underrepresented ethnic groups or populations with dyslipidemia remains largely unexplored. Furthermore, the predictive performance of these indices may differ between dyslipidemic and general populations due to altered lipid-metabolism interactions, underscoring the need for population-specific validation.[15]

Beyond biological factors, ethnic minorities exhibit unique metabolic profiles due to genetic, cultural, and lifestyle interactions.[16,17] The Lahu ethnic group, one of the oldest indigenous minorities in China, remains underrepresented in metabolic health research despite its distinct potential genetic predispositions and sociocultural practices (eg, low total energy intake, high cereal-based macronutrient ratios, and diminished animal-source food consumption).[18,19] Furthermore, distinct hormonal profiles, adipose tissue distribution, and lifestyle patterns collectively drive clinically significant divergences in the prevalence and clustering of MetS components across genders.[20,21] To our knowledge, this is the first study to systematically evaluate the predictive performance of 12 anthropometric indices, including conventional (BMI, WC) and novel measures (LAP, VAI, a body shape index [ABSI], body adiposity index [BAI], body roundness index [BRI], relative fat mass [RFM], uric acid [UA] to HDL-C ratio [UHR], TyG, cardiometabolic index [CMI], Chinese visceral adiposity index [CVAI]), for MetS and its components among dyslipidemic Lahu adults using a gender-specific approach. The findings will enable early identification and risk stratification of high-risk phenotypes, inform precision strategies for MetS prevention and management in this ethnic minority population, and support the development of targeted public health interventions.

Materials and Methods

Study Design and Participants

This cross-sectional investigation utilized stratified cluster sampling in two Lahu ethnic communities in southwest China (2009–2010). Inclusion criteria comprised: (1) Lahu ethnicity with age ≥18 years; (2) Local residency duration >5 years. Exclusion criteria included: acute/chronic infections, hepatic/renal dysfunction, pregnancy, or malignancy. The participant recruitment process is detailed in Figure 1.

Data Collection and Variable Specification

Data Collection

General demographic and clinical characteristics of the participants were collected through structured questionnaires, including age, gender, ethnicity, educational attainment, history of diabetes, hypertension status, smoking and alcohol consumption habits, and physical activity levels.

Biochemical Analysis

Fasting venous blood samples were collected after an overnight fast of ≥8 hours and immediately transported to the clinical laboratory of The First Affiliated Hospital of Kunming Medical University for analysis. Serum concentrations of total cholesterol (TC), triglycerides (TG), HDL-C, low-density lipoprotein cholesterol (LDL-C), UA, and fasting plasma glucose (FPG) were determined using standardized enzymatic methods by Olympus AU5400. Glycated hemoglobin A1c (HbA1c) levels were measured through high-performance liquid chromatography.

Anthropometric Measurements

Standardized anthropometric assessments included height, weight, WC, hip circumference (HC), systolic blood pressure (SBP), and diastolic blood pressure (DBP). Participants were measured fasting in light clothing without shoes. Height and weight were

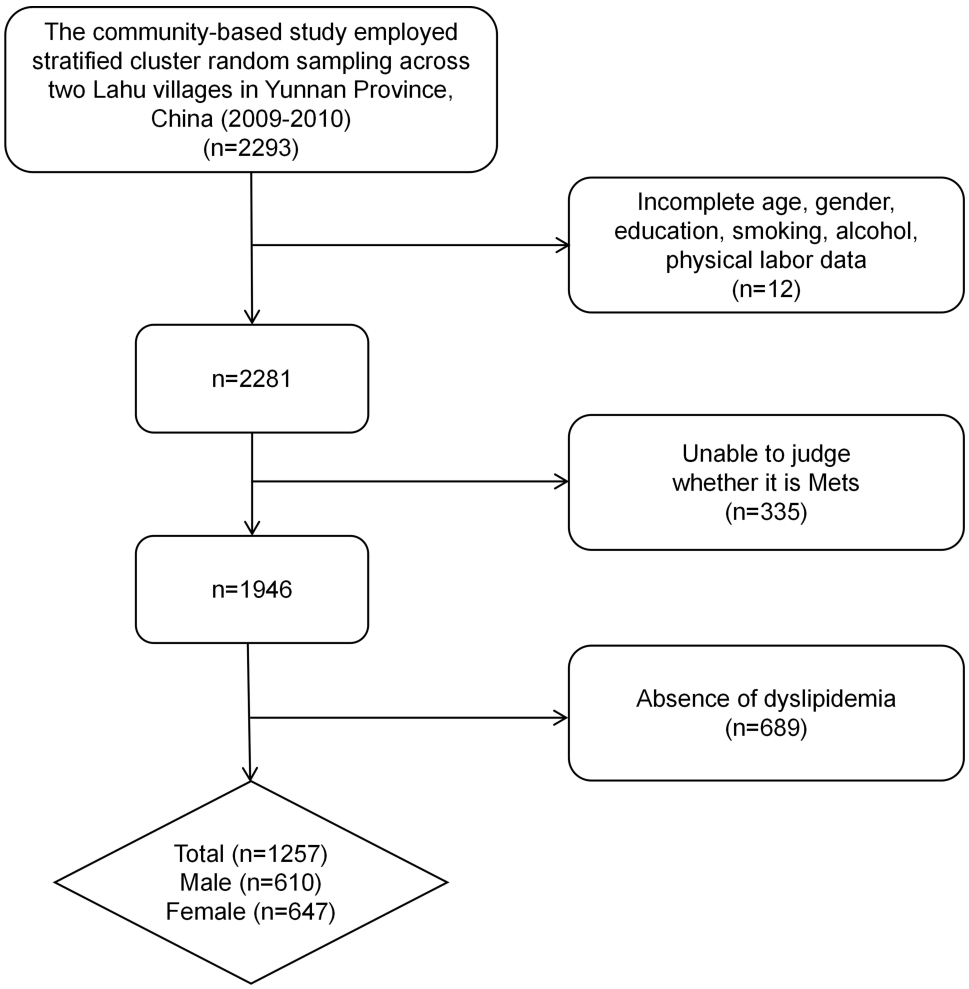

Figure 1 Study flowchart.

measured using a calibrated mechanical stadiometer. Waist circumference was measured at the midaxillary midpoint between the iliac crest and 12th rib using a non-elastic tape, with hip circumference assessed at maximal gluteal protrusion. Blood pressure was measured using a mercury sphygmomanometer (bench-top model), following a 30-minute caffeine/smoking abstinence and 5-minute seated rest, with triplicate right-arm readings averaged. Calibration was conducted in accordance with the standard operating procedures before each measurement, and all instruments were regularly calibrated during the data collection period to ensure measurement accuracy.

Additional anthropometric indices including BMI, LAP,[12] VAI,[22] ABSI,[23] BAI,[24] BRI,[14] RFM,[25] UHR,[26] TyG,[13] CMI,[13] CVAI[27] were calculated using established formulae as detailed in Supplementary Table 1. The predefined WC thresholds in LAP calculations (males: WC ≤65 cm → 66 cm; females: WC ≤58 cm → 59 cm) prevented negative values in 10.6% of males (65/610) and 5.6% of females (36/647). Similarly, CVAI negative values (indicating extremely low visceral adiposity) were reset to 0 in 11.3% of males (69/610) and 6.3% of females (41/647), reflecting ethnic-specific adiposity patterns.

Definitions and Criteria

MetS

Multiple definitions of metabolic syndrome have been proposed by international organizations, including World Health Organization (WHO), National Cholesterol Education Program (NCEP), International Diabetes Federation (IDF), Chinese Diabetes Society (CDS), and Joint Interim Statement (JIS), with differing emphasis on core components: IDF, NCEP, and JIS criteria prioritize central obesity, while the WHO definition focuses on insulin

resistance.[28] The NCEP-Adult Treatment Panel III (ATPIII) criteria were selected in the present study because they assign equal weight to all five components without a mandatory prerequisite, identify a higher proportion of high-risk individuals, and show stronger associations with cardiovascular disease in Asian populations.[28,29] This definition also allows unbiased assessment of anthropometric indices by avoiding a priori emphasis on central adiposity; it has been widely validated in Asian cohorts and is recommended by the American Heart Association/National Heart, Lung, and Blood Institute (AHA/NHLBI) for clinical risk stratification.[30]

Accordingly, MetS was diagnosed according to the revised NCEP-ATPIII criteria,[30] requiring ≥3 of: (1) Elevated WC/Abdominal adiposity: WC≥102cm (male)/≥88 cm (female); (2) Elevated TG: TG ≥1.69 mmol/L (150 mg/dL) or lipid-lowering treatment; (3) Reduced HDL-C: HDL-C <1.03 mmol/L (40 mg/dL) (male)/<1.30 mmol/L (50 mg/dL) (female) or specific therapy; (4) Elevated blood pressure (BP): BP≥130/85 mmHg or antihypertensive medication use; (5) Elevated FPG: FPG ≥100 mg/dL (5.55 mmol/L) or glucose-lowering therapy.

Dyslipidemia

Defined by NCEP-ATPIII[31] as meeting ≥1 criterion: (1) TC ≥6.2 mmol/L; (2) TG ≥2.3 mmol/L; (3) LDL-C ≥4.1 mmol/L; (4) HDL-C <1.0 mmol/L.

Sociobehavioral Variables

Education: Literate (completed primary education; ≥6 years of schooling) vs illiterate.
Smoking status: Current smokers (≥1 cigarette/day for >6 months) vs. non-smokers.
Alcohol consumption: Regular drinkers (≥1 alcoholic beverage/week) vs. abstainers.
Physical activity:[32] (1) Low-intensity: Sedentary/semi-sedentary (eg, office work), (2) High-intensity: Manual labor (eg, farming, construction).
Overweight/obesity: According to the Working Group on Obesity in China (WGOC), a BMI ≥24 kg/m^2 is classified as overweight, while a BMI ≥28 kg/m^2 is defined as obesity.[33]

Statistical Analysis

All statistical analyses were performed using SPSS Statistics version 27.0. Normally distributed continuous variables were expressed as mean ± standard deviation (SD), while non-normally distributed variables were reported as median (interquartile range [IQR]). Categorical variables were summarized as counts (percentages). For intergroup comparisons, Student's *t*-test was utilized for normally distributed continuous variables, non-parametric Mann–Whitney *U*-test was used for non-normally distributed continuous variables, and Pearson's χ^2-test or Fisher's exact probability tests were employed for categorical variables. Bivariate correlations were assessed through Spearman's rank correlation coefficient due to non-normally distributed data. Binary logistic regression models were constructed to evaluate associations between anthropometric indices and MetS along with its individual components, reporting odds ratios (ORs) with 95% confidence intervals (CIs). Multivariable analyses adjusted for age, smoking status, alcohol consumption and physical activity levels. The predictive capacity of MetS indicators was examined via receiver operating characteristic (ROC) curve analysis, with diagnostic performance quantified by the area under the ROC curve (AUC). The optimal cutoff value was determined by the maximum Youden index (sensitivity + specificity - 1), and comparisons of AUCs were performed using the DeLong test.[34] All statistical tests were two-tailed, and a *p*-value <0.05 defined statistical significance.

Results

Study Population Characteristics

This study included 1257 Lahu adults with dyslipidemia (48.5% male, 51.5% female), characterized by low HDL-C (median 0.79 mmol/L; 89.9% <1.0 mmol/L) and low overweight/obesity rates (9.9% and 2.0%, respectively). MetS prevalence was 23.4%, with females disproportionately affected (29.2% vs. males 17.2%, p<0.001). Gender differences were notable: males had higher smoking, alcohol consumption and high-intensity physical activity (all p<0.001), while females exhibited higher FPG, LDL-C, HDL-C, and TC, but lower SBP (all p<0.05). Abdominal adiposity was exclusive to females (4.0%) (Table 1). Participants with MetS were older (males: 42 vs. 37; females: 45 vs. 38 years, all p<0.01)

Table 1 Demographic and Clinical Characteristics of the Study Population

Characteristics	Total (N=1257)	Male (N=610)	Female (N=647)	Z/χ^2	*p*
Age (years)	39(28, 50)	38(28, 50)	40(28, 52)	−1.426	0.154
<30	348(27.70%)	173(28.40%)	175(27.00%)	2.608	0.456
30-44	429(34.10%)	213(34.90%)	216(33.40%)		
45-59	325(25.90%)	158(25.90%)	167(25.80%)		
≥60	155(12.30%)	66(10.80%)	89(13.80%)		
Education				4.750	0.056
Illiterate	1013(80.60%)	505(82.80%)	508(78.50%)		
Literate	244(19.40%)	105(17.20%)	139(21.50%)		
Smoking				157.636	<0.001
Yes	752(59.80%)	474(77.70%)	278(43.00%)		
No	505(40.20%)	136(22.30%)	369(57.00%)		
Alcohol consumption				133.510	<0.001
Yes	555(44.20%)	371(60.80%)	184(28.40%)		
No	702(55.80%)	239(39.20%)	463(71.60%)		
Physical activity				41.618	<0.001
High-intensity	678(53.90%)	386(63.30%)	292(45.10%)		
Low-intensity	579(46.10%)	224(36.70%)	355(54.90%)		
Elevated WC				25.031	<0.001
No	1231(97.90%)	610(100.00%)	621(96.00%)		
Yes	26(2.10%)	0(0.00%)	26(4.00%)		
Elevated FPG				21.435	<0.001
No	820(65.20%)	437(71.60%)	383(59.20%)		
Yes	437(34.80%)	173(28.40%)	264(40.80%)		
Elevated BP				0.489	0.479
No	979(77.90%)	470(77.00%)	509(78.70%)		
Yes	278(22.10%)	140(23.00%)	138(21.30%)		
Elevated TG				2.912	0.088
No	765(60.90%)	386(63.30%)	379(58.60%)		
Yes	492(39.10%)	224(36.70%)	268(41.40%)		
Reduced HDL-C				0.715	0.398
No	83(6.60%)	44(7.20%)	39(6.00%)		
Yes	1174(93.40%)	566(92.80%)	608(94.00%)		
MetS components				26.190	<0.001
<=1	447(35.60%)	242(39.70%)	205(31.70%)		
2	516(41.10%)	263(43.10%)	253(39.10%)		
≥3	294(23.40%)	105(17.20%)	189(29.20%)		
MetS				25.227	<0.001
No	963(76.60%)	505(82.80%)	458(70.80%)		
Yes	294(23.40%)	105(17.20%)	189(29.20%)		
FPG (mmol/L)	5.2(4.8, 5.7)	5.2(4.7, 5.6)	5.3(4.9, 5.8)	−6.367	<0.001
HbA1c (%)	6.5(6.1, 6.8)	6.5(6.1, 6.8)	6.5(6.1, 6.8)	−0.350	0.727
SBP (mmHg)	110(100, 120)	114(105, 120)	110(100, 120)	−3.511	<0.001
DBP (mmHg)	70(70, 80)	75(70, 80)	70(68, 80)	−1.309	0.190
TC (mmol/L)	3.47(2.89, 4.18)	3.39(2.82, 4.04)	3.52(2.96, 4.37)	−3.245	0.001
TG (mmol/L)	1.43(0.99, 2.34)	1.40(1.01, 2.27)	1.45(0.98, 2.40)	−0.751	0.453
HDL-C (mmol/L)	0.79(0.67, 0.91)	0.79(1.62, 0.90)	0.80(0.67, 0.92)	−2.136	0.033
LDL-C (mmol/L)	2.02(1.64, 2.58)	1.99(1.62, 2.45)	2.06(1.69, 2.74)	−3.029	0.002
BMI (kg/m^2)	20.55(19.13, 22.27)	20.47(19.20, 22.07)	20.61(19.02, 22.83)	−1.374	0.169
BMI <24	1108(88.10%)	565(92.60%)	543(83.90%)	23.192	<0.001
Overweight	124(9.90%)	39(6.40%)	85(13.10%)		
Obesity	25(2.00%)	6(1.00%)	19(2.90%)		

(*Continued*)

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Table 1 (Continued).

Characteristics	Total (N=1257)	Male (N=610)	Female (N=647)	Z/χ^2	*p*
WC (cm)	70(65, 76)	70(67, 76)	70(64, 75)	−4.151	<0.001
LAP	11.77(4.78, 24.21)	7.64(2.91, 18.73)	15.50(7.92, 30.73)	−9.718	<0.001
VAI	2.55(1.76, 4.10)	2.04(1.44, 3.24)	3.13(2.10, 4.77)	−11.025	<0.001
ABSI	7.58(7.16, 8.00)	7.54(7.20, 7.95)	7.63(7.11, 8.05)	−0.435	0.664
BAI	26.70(25.39, 29.43)	25.53(24.72, 26.78)	28.35(26.55, 30.99)	−19.270	<0.001
BRI	4.26(3.80, 4.84)	4.02(3.63, 4.49)	4.54(4.02, 5.10)	−12.172	<0.001
RFM	26.17(19.56, 33.14)	19.54(16.64, 22.59)	33.01(29.67, 36.75)	−29.344	<0.001
UHR	15.08(11.64, 18.73)	17.24(13.96, 20.38)	12.86(10.58, 16.07)	−13.996	<0.001
TyG	8.67(8.29, 9.21)	8.63(8.27, 9.14)	8.73(8.31, 9.26)	−2.165	0.030
CMI	0.83(0.57, 1.29)	0.80(0.57, 1.28)	0.85(0.57, 1.31)	−0.996	0.319
CVAI	40.39(19.13, 67.97)	34.71(14.91, 57.89)	47.29(25.77, 75.63)	−6.492	<0.001

Abbreviations: MetS, metabolic syndrome; FPG, Fasting Plasma Glucose; HbA1c, Glycated hemoglobin A1c; SBP, Systolic Blood Pressure; DBP, Diastolic Blood Pressure; TC, Total Cholesterol; TG, Triglycerides; HDL-C, High-Density Lipoprotein Cholesterol; LDL-C, Low-Density Lipoprotein Cholesterol; BMI, Body Mass Index; WC, Waist Circumference; CVAI, Chinese Visceral Adiposity Index; CMI, Cardiometabolic Index; TyG, Triglyceride-Glucose Index; UHR, Uric Acid to HDL-C Ratio; RFM, Relative Fat Mass; BRI, Body Roundness Index; BAI, Body Adiposity Index; ABSI, A Body Shape Index; VAI, Visceral Adiposity Index; LAP, Lipid Accumulation Product.

and had elevated BMI, WC, LAP, VAI, BAI, BRI, RFM, UHR, TyG, CMI and CVAI (all p<0.05). Within-sex comparisons revealed MetS females had 11.6-fold higher abdominal obesity (11.6% vs 0.9%) and more low-intensity activity, while MetS males showed higher alcohol use (all p<0.05) (Table 2).

Table 2 Demographic and Clinical Characteristics of the Study Population with and without MetS by Sex

Characteristics	Male				Female			
	without MetS	with MetS	$t/Z/\chi^2$	p_{male}	without MetS	with MetS	Z/χ^2	p_{female}
Age (years)	37(27, 49)	42(32, 52)	−2.830	0.005	38(27, 48)	45(32, 57)	−4.625	<0.001
<30	156(30.90%)	17(16.20%)	9.787	0.020	139(30.30%)	36(19.00%)	20.053	<0.001
30-44	173(34.20%)	40(38.10%)			160(34.90%)	56(29.60%)		
45-59	124(24.60%)	34(32.40%)			110(24.00%)	57(30.20%)		
≥60	52(10.30%)	14(13.30%)			49(10.70%)	40(21.20%)		
Education			1.959	0.162			0.114	0.736
Illiterate	423(83.80%)	82(78.10%)			358(78.20%)	150(79.40%)		
Literate	82(16.20%)	23(21.90%)			100(21.80%)	39(20.60%)		
Smoking			0.772	0.380			1.585	0.208
Yes	389(77.00%)	85(81.00%)			204(44.50%)	74(39.20%)		
No	116(23.00%)	20(19.00%)			254(55.50%)	115(60.80%)		
Alcohol consumption			4.963	0.026			3.143	0.076
Yes	297(58.80%)	74(70.50%)			121(26.40%)	63(33.30%)		
No	208(41.20%)	31(29.50%)			337(73.60%)	126(66.70%)		
Physical activity			1.467	0.226			5.338	0.021
High-intensity	325(64.40%)	61(58.10%)			220(48.00%)	72(38.10%)		
Low-intensity	180(35.60%)	44(41.90%)			238(52.00%)	117(61.90%)		
Elevated WC			–	–			40.211	<0.001
No	505(100.00%)	105(100.00%)			454(99.10%)	167(88.40%)		
Yes	0(0.00%)	0(0.00%)			4(0.90%)	22(11.60%)		
Elevated FPG			115.789	<0.001			182.903	<0.001
No	407(80.60%)	30(28.60%)			348(76.00%)	35(18.50%)		
Yes	98(19.40%)	75(71.40%)			110(24.00%)	154(81.50%)		

(*Continued*)

Table 2 (Continued).

Characteristics	Male				Female			
	without MetS	with MetS	t/Z/χ^2	p_{male}	without MetS	with MetS	Z/χ^2	p_{female}
Elevated BP			155.571	<0.001			138.137	<0.001
No	438(86.70%)	32(30.50%)			416(90.80%)	93(49.20%)		
Yes	67(13.30%)	73(69.50%)			42(9.20%)	96(50.80%)		
Elevated TG			131.015	<0.001			121.149	<0.001
No	371(73.50%)	15(14.30%)			331(72.30%)	48(25.40%)		
Yes	134(26.50%)	90(85.70%)			127(27.70%)	141(74.60%)		
Reduced HDL-C			0.426	0.514			7.211	0.007
No	38(7.50%)	6(5.70%)			35(7.60%)	4(2.10%)		
Yes	467(92.50%)	99(94.30%)			423(92.40%)	185(97.90%)		
FPG (mmol/L)	5.1(4.6, 5.4)	5.7(5.3, 6.1)	−8.768	<0.001	5.2(4.8, 5.5)	5.8(5.6, 6.3)	−11.797	<0.001
HbA1c (%)	6.5(6.1, 6.9)	6.4(6.1, 6.7)	−1.725	0.084	6.5(6.1, 6.9)	6.4(6.0, 6.7)	−2.187	0.029
SBP (mmHg)	110(102, 120)	130(120, 140)	−10.417	<0.001	110(100, 118)	120(107, 130)	−8.836	<0.001
DBP (mmHg)	70(70, 80)	83(80, 90)	−8.646	<0.001	70(65, 80)	80(70, 85)	−8.729	<0.001
TC (mmol/L)	3.24(2.75, 3.90)	3.84(3.40, 4.53)	−5.953	<0.001	3.41(2.88, 4.12)	4.04(3.18, 4.66)	−4.933	<0.001
TG (mmol/L)	1.23(0.96, 1.78)	2.43(1.85, 3.70)	−9.466	<0.001	1.20(0.90, 1.90)	2.34(1.84, 3.29)	−9.569	<0.001
HDL-C (mmol/L)	0.79(1.57, 0.89)	0.79(0.69, 0.91)	−0.889	0.374	0.80(1.61, 0.92)	0.83(0.67, 0.93)	−0.826	0.409
LDL-C (mmol/L)	1.91(1.57, 2.33)	2.35(1.97, 2.88)	−6.533	<0.001	2.00(1.61, 2.53)	2.48(1.95, 2.92)	−5.221	<0.001
BMI (kg/m^2)	20.39(19.16, 21.81)	21.49(19.49, 23.37)	−3.646	<0.001	20.48(18.93, 22.22)	21.08(19.39, 24.00)	−3.578	<0.001
WC (cm)	70(67, 76)	74(70, 80)	−4.154	<0.001	69(64, 74)	70(65, 80)	−3.040	0.002
LAP	6.60(2.51, 14.03)	24.01(6.80, 42.67)	−7.337	<0.001	12.48(6.63, 23.52)	27. 44(14.68, 45.13)	−8.345	<0.001
VAI	1.91(7.16, 2.72)	3.69(2.52, 6.18)	−8.860	<0.001	2.69(7.11, 3.96)	4.69(3.33, 6.84)	−9.867	<0.001
ABSI	7.53(7.16, 7.94)	7.63(7.25, 8.08)	−1.714	0.087	7.61(7.11, 8.00)	7.65(7.16, 8.11)	−1.014	0.311
BAI	25.39(24.72, 26.63)	25.96(24.85, 27.13)	−2.196	0.028	28.10(26.55, 30.52)	29.09(26.86, 32.29)	−2.968	0.003
BRI	3.95(3.61, 4.43)	4.23(3.80, 4.71)	−3.595	<0.001	4.50(3.99, 5.01)	4.76(4.07, 5.54)	−3.093	0.002
RFM	19.28±4.33	21.33±4.12	−4.436	<0.001	32.62(29.33, 36.07)	34.29(30.03, 38.64)	−3.145	0.002
UHR	17.03(13.82, 20.00)	18.40(14.77, 23.00)	−2.686	0.007	12.72(10.44, 15.70)	13.56(11.23, 17.12)	−2.724	0.006
TyG	8.53(8.23, 8.92)	9.78(9.31, 10.07)	−10.595	<0.001	8.52(8.24, 8 .92)	9.60(9.27, 10.01)	−11.383	<0.001
CMI	0.74(0.53, 1.08)	2.35(1.53, 3.32)	−9.002	<0.001	0.73(0.53, 1.08)	1.89(1.33, 2.91)	−10.241	<0.001
CVAI	32.09(12.45, 53.38)	52.92(32.21, 79.31)	−5.747	<0.001	39.88(18.87, 64.96)	74.64(40.68, 95.46)	−8.744	<0.001

Abbreviations: MetS, metabolic syndrome; FPG, Fasting Plasma Glucose; HbA1c, Glycated hemoglobin A1c; SBP, Systolic Blood Pressure; DBP, Diastolic Blood Pressure; TC, Total Cholesterol; TG, Triglycerides; HDL-C, High-Density Lipoprotein Cholesterol; LDL-C, Low-Density Lipoprotein Cholesterol; BMI, Body Mass Index; WC, Waist Circumference; CVAI, Chinese Visceral Adiposity Index; CMI, Cardiometabolic Index; TyG, Triglyceride-Glucose Index; UHR, Uric Acid to HDL-C Ratio; RFM, Relative Fat Mass; BRI, Body Roundness Index; BAI, Body Adiposity Index; ABSI, A Body Shape Index; VAI, Visceral Adiposity Index; LAP, Lipid Accumulation Product.

Correlation Analysis of Anthropometric Indices with MetS Parameters

Most anthropometric indices showed weak but significant gender-specific MetS parameters correlations. For FPG, ABSI/WC correlated weakly in males (r=0.10/0.09) versus BMI/BAI in females (r=0.16/0.10; all p<0.05). CVAI demonstrated stronger female FPG association (r=0.24 vs male 0.12, all p<0.01). BMI, WC, LAP, BAI, BRI, RFM, and CVAI positively correlated with BP in both sexes (SBP: males r=0.14–0.19, females r=0.15–0.29; DBP: males r=0.14–0.22, females r=0.13–0.32, all p<0.01). ABSI correlated with DBP in both sexes (r=0.11–0.16) and SBP in females only (r=0.16; all p<0.01). UHR showed female-specific negative BP correlations (r=−0.08, p<0.05), while CMI/TyG/VAI had male-specific positive associations (SBP r=0.11–0.18; DBP r=0.09–0.13; all p<0.05). Lipid analysis revealed LAP/VAI/TyG/CMI correlated with all parameters (all p<0.01), whereas BAI showed no significant associations (p>0.05). Males exhibited additional weak BMI-TG (r=0.10) and WC/ABSI/BRI/RFM-lipid correlations (TC r=0.10–0.16; TG r=0.09-–0.18; LDL-C r=0.12–0.18; all p<0.05) (Figure 2).

Predictive Performance of Anthropometric Indices

As shown in Figure 3 and Table 3, ROC analysis confirmed the TyG index as the optimal MetS predictor in both genders (AUCs: males 0.828, females 0.784; p<0.05), significantly outperforming all other indices (all p < 0.05 in DeLong test;

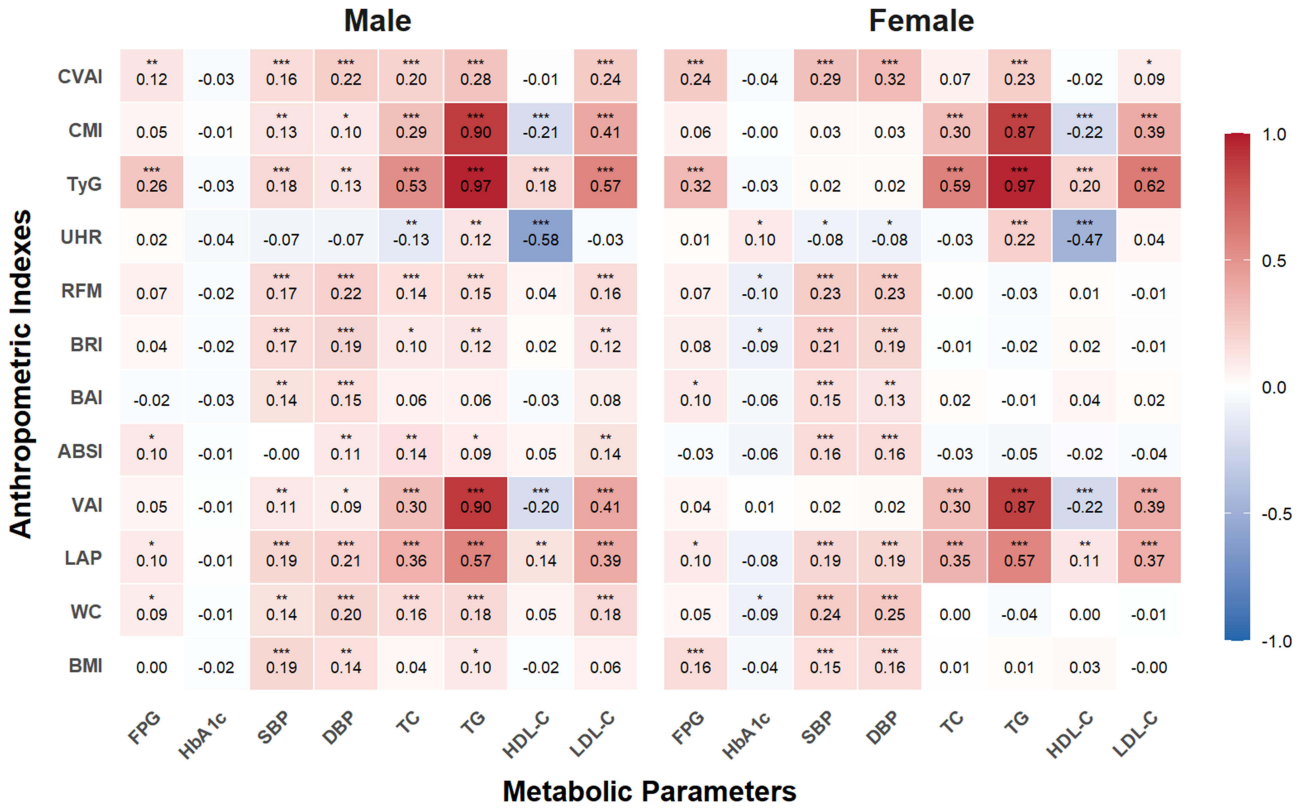

Figure 2 Correlation between anthropometric indexes and metabolic parameters by sex. Values in the table represent Spearman correlation coefficients (*p<0.05, **p<0.01, ***p<0.001).

Abbreviations: CVAI, Chinese Visceral Adiposity Index; CMI, Cardiometabolic Index; TyG, Triglyceride-Glucose Index; UHR, Uric Acid-to-HDL-C Ratio; RFM, Relative Fat Mass; BRI, Body Roundness Index; BAI, Body Adiposity Index; ABSI, A Body Shape Index; VAI, Visceral Adiposity Index; LAP, Lipid Accumulation Product; WC, Waist Circumference; BMI, Body Mass Index; FPG, Fasting Plasma Glucose; HbA1c, Glycated hemoglobin A1c; SBP, Systolic Blood Pressure; DBP, Diastolic Blood Pressure; TC, Total Cholesterol; TG, Triglycerides; HDL-C, High-Density Lipoprotein Cholesterol; LDL-C, Low-Density Lipoprotein Cholesterol.

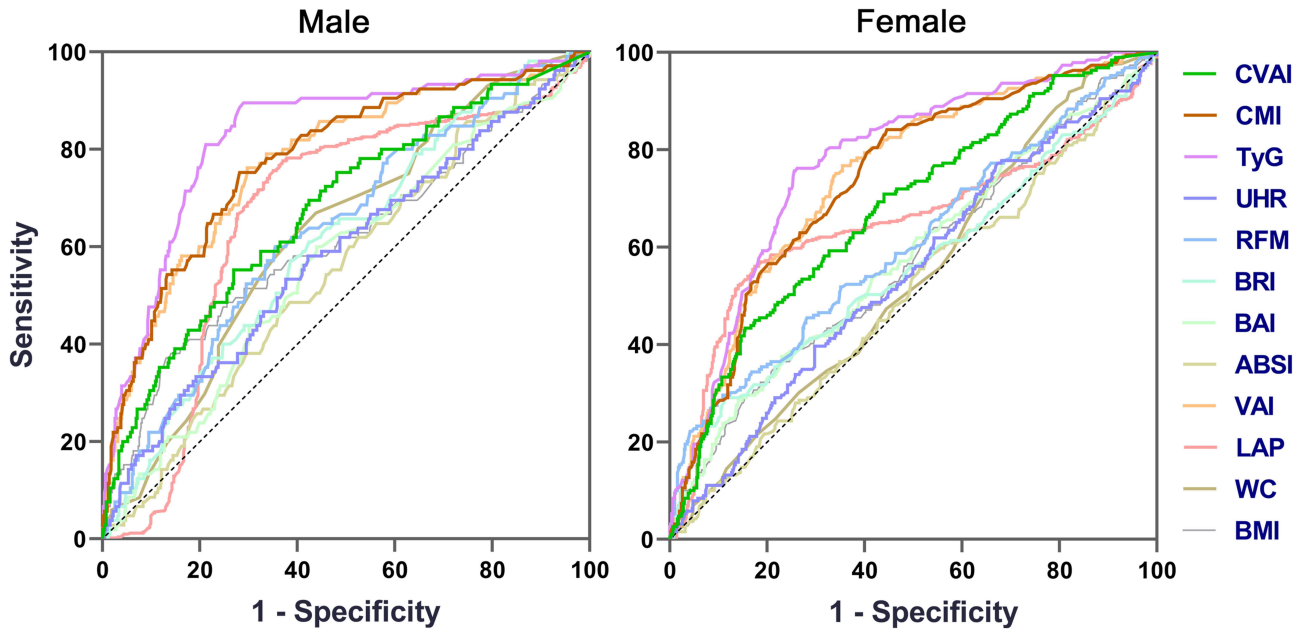

Figure 3 ROC curves for anthropometric indices in predicting MetS by sex.

Abbreviations: CVAI, Chinese Visceral Adiposity Index; CMI, Cardiometabolic Index; TyG, Triglyceride-Glucose Index; UHR, Uric Acid-to-HDL-C Ratio; RFM, Relative Fat Mass; BRI, Body Roundness Index; BAI, Body Adiposity Index; ABSI, A Body Shape Index; VAI, Visceral Adiposity Index; LAP, Lipid Accumulation Product; WC, Waist Circumference; BMI, Body Mass Index.

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Table 3 AUC and Cut off Values of Anthropometric Indexes for Prediction of MetS by Sex

Variables	Gender	AUC	Std. Error	95% CI	*p*	Optimal Cutoffs	J-Youden	Sensitivity	Specificity
BMI	Male	0.613	0.033	0.548~0.678	<0.001	22.58	0.240	0.381	0.859
	Female	0.589	0.025	0.540~0.639	<0.001	22.38	0.167	0.392	0.775
WC	Male	0.628	0.031	0.567~0.690	<0.001	73.50	0.231	0.562	0.669
	Female	0.576	0.026	0.525~0.626	0.002	79.50	0.152	0.270	0.882
LAP	Male	0.727	0.030	0.668~0.787	<0.001	19.99	0.430	0.590	0.840
	Female	0.708	0.023	0.663~0.753	<0.001	16.54	0.339	0.725	0.614
VAI	Male	0.775	0.026	0.723~0.826	<0.001	2.51	0.465	0.762	0.703
	Female	0.746	0.021	0.705~0.788	<0.001	3.27	0.418	0.767	0.651
ABSI	Male	0.553	0.030	0.494~0.612	0.087	7.20	0.117	0.848	0.269
	Female	0.525	0.025	0.475~0.575	0.311	8.00	0.088	0.339	0.749
BAI	Male	0.568	0.031	0.508~0.628	0.028	25.63	0.160	0.600	0.560
	Female	0.574	0.026	0.524~0.624	0.003	31.85	0.153	0.286	0.867
BRI	Male	0.611	0.029	0.554~0.669	<0.001	4.09	0.186	0.610	0.576
	Female	0.577	0.026	0.526~0.629	0.002	5.41	0.193	0.291	0.902
RFM	Male	0.635	0.029	0.577~0.693	<0.001	20.67	0.246	0.600	0.646
	Female	0.579	0.026	0.527~0.630	0.002	38.52	0.178	0.270	0.908
UHR	Male	0.583	0.032	0.521~0.645	0.007	17.74	0.159	0.581	0.578
	Female	0.568	0.025	0.519~0.617	0.006	15.44	0.135	0.397	0.738
TyG	Male	0.828	0.024	0.782~0.874	<0.001	8.82	0.606	0.895	0.711
	Female	0.784	0.020	0.746~0.823	<0.001	8.95	0.515	0.757	0.758
CMI	Male	0.779	0.026	0.728~0.830	<0.001	1.01	0.471	0.752	0.719
	Female	0.756	0.021	0.715~0.796	<0.001	0.79	0.417	0.841	0.576
CVAI	Male	0.678	0.030	0.620~0.736	<0.001	51.40	0.283	0.552	0.731
	Female	0.718	0.023	0.674~0.763	<0.001	73.54	0.341	0.524	0.817

Abbreviations: BMI, Body Mass Index; WC, Waist Circumference; CVAI, Chinese Visceral Adiposity Index; CMI, Cardiometabolic Index; TyG, Triglyceride-Glucose Index; UHR, Uric Acid to HDL-C Ratio; RFM, Relative Fat Mass; BRI, Body Roundness Index; BAI, Body Adiposity Index; ABSI, A Body Shape Index; VAI, Visceral Adiposity Index; LAP, Lipid Accumulation Product.

see Supplementary Table 2). CMI (males 0.779, females 0.756), VAI (males 0.775, females 0.746), LAP (males 0.727, females 0.708), and CVAI (males 0.678, females 0.718) exhibited moderate predictive capacity (all $p<0.05$). Conventional indices (BMI, WC) and other novel indices (UHR, RFM, BAI, BRI) showed limited predictive value (AUC range: 0.525–0.635; all $p<0.05$), while ABSI demonstrated non-significant predictive utility across genders ($p>0.05$). The TyG index showed the highest male sensitivity (89.5%, cutoff=8.82), while CMI achieved peak female sensitivity (84.1%, cutoff=0.79). For specificity, BMI performed best in males (85.9%, cutoff=22.58 kg/m^2) and RFM in females (90.8%, cutoff=38.52).

Associations of Anthropometric Indices with MetS and Its Components

The TyG index consistently demonstrated strong association with MetS across all models (fully adjusted OR [95% CI]: 9.63 [6.09–15.24] in males; 6.76 [4.71–9.70] in females). CMI (males 3.189[2.418–4.207], females 2.802[2.172–3.615]), VAI (males 1.578[1.413–1.761], females 1.308[1.222–1.400]), and BRI (males 1.619[1.165–2.250], females 1.439 [1.144–1.809]) also showed notable associations. BMI had modest associations (males 1.230[1.124–1.346], females 1.126[1.059–1.198]) exceeding WC and other novel indices. ABSI showed no significant association (all $p>0.05$), while BAI was marginally significant in females only (1.098[1.040–1.160]) (Figure 4 and Supplementary Table 3).

Supplementary Tables 4–7 reveal sex-specific Mets components associations: BMI (1.062[1.002–1.124]) and CVAI (1.009[1.002–1.017]) weakly associated with elevated FPG in females only. For elevated BP, BRI showed strong bilateral associations (males: 1.666[1.228–2.261]; females: 1.804[1.388–2.344]), with ABSI female-specific (1.636[1.253–2.137]) and TyG/VAI/CMI male-specific (1.607[1.171–2.208], 1.141[1.044–1.247], 1.433[1.151–1.784]). UHR had female-protective BP effects (0.941[0.897–0.987]) but positively associated with elevated TG bilaterally (males: 1.046[1.015–1.077]; females: 1.075[1.039–1.113]). BRI showed strong male-specific elevated TG association (1.644[1.248–2.166]).

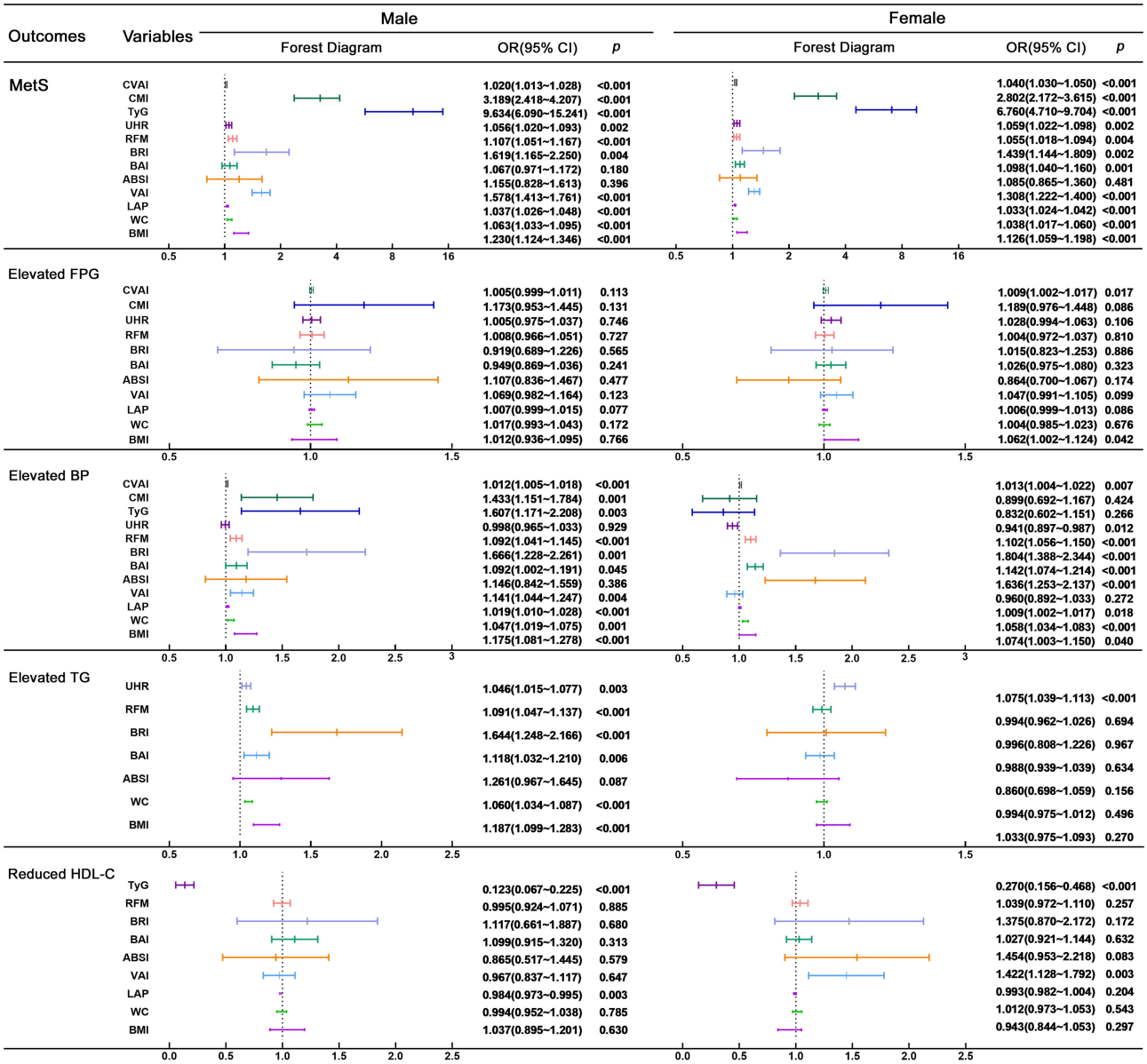

Figure 4 Forest diagram of OR for anthropometric indices and MetS and its components after adjustment for age, smoking, alcohol consumption and Physical activity.
Abbreviations: CVAI, Chinese Visceral Adiposity Index; CMI, Cardiometabolic Index; TyG, Triglyceride-Glucose Index; UHR, Uric Acid-to-HDL-C Ratio; RFM, Relative Fat Mass; BRI, Body Roundness Index; BAI, Body Adiposity Index; ABSI, A Body Shape Index; VAI, Visceral Adiposity Index; LAP, Lipid Accumulation Product; WC, Waist Circumference; BMI, Body Mass Index.

Reduced HDL-C patterns included TyG's bilateral protection (males: 0.123[0.067–0.225]; females: 0.270[0.156–0.468]), VAI's female risk (1.422[1.128–1.792]), and LAP's male protection (0.984[0.973–0.995]). Notably, after full adjustment, ABSI showed substantial attenuation in elevated BP associations (−17.1% in males/-6.6% in females), with males losing statistical significance (final model p>0.05). BRI exhibited significant elevated BP attenuation (−14.3%/-10.0%), MetS reduction (−6.9%/-6.5%), and a 15.6% elevated TG increase in males (all p<0.05).

Discussion

This study demonstrates the TyG index's superior MetS predictive performance in Lahu adults with dyslipidemia, showing robust associations persisting after adjustment for age and lifestyle factors (smoking, alcohol, physical activity) in both genders, consistent with prior studies,[26,35,36] suggesting its potential clinical utility in assessing visceral adiposity dysfunction and core MetS components like IR and dyslipidemia.[37,38] While TyG positively correlated with FPG, TC,

TG, and LDL-C as expected,[39–42] we observed two unexpected findings: a weak positive association between TyG and HDL-C (contrasting with the reported inverse relationships in type 2 diabetes mellitus (T2DM),[41] obesity,[39] and MONW populations[42]), and no significant correlation between TyG and HbA1c (unlike findings in Tunisian T2DM studies[26]). These discrepancies may stem from differences in population characteristics (our Lahu participants had a 93.4% prevalence of reduced HDL-C and a median HbA1c of 6.5%), the targeted disease, and study designs. The optimal TyG cutoffs identified herein (male: 8.82; female: 8.95) provide a practical reference for screening and risk stratification in this specific population. As a simple and inexpensive tool, our findings support integrating the TyG index into community-based screening programs to enhance early detection of high-risk individuals, especially in rural or resource-limited areas. Furthermore, the distinctly low obesity rate in this population (BMI ≥28 kg/m^2: 2.00%) highlights the potential of TyG for early detection of metabolically unhealthy normal-weight individuals. Nevertheless, the optimal cutoffs may vary due to population-specific factors such as genetic background, dietary patterns, and body composition,[43–45] even though the TyG index demonstrates high predictive ability for Mets among general population of different countries or ethnicities.[46–48] Further validation in other ethnic populations is warranted to establish whether these cutoffs require population-specific calibration.

CMI, VAI, LAP, and CVAI demonstrated moderate predictive accuracy for Lahu MetS and showed consistent significant correlations with dyslipidemia components, aligning with studies from Italy,[49,50] Mexico[51] and Iran,[52] validating novel indices integrating lipid profiles with fat distribution as cost-effective tools for identifying visceral lipid accumulation and metabolic dysfunction.[14,53] Among these indexes, elevated CMI exhibited a strong association with MetS risk (OR: males 3.189, females 2.802), likely attributable to the TG/HDL-C ratio's robust linkage to metabolic disorders, IR, and obesity,[54] coupled with WC/height ratio's superior capacity in assessing abdominal adiposity.[55]

Conventional indices (BMI/WC) exhibited limited MetS predictive sensitivity, consistent with other Asian studies,[14,56] due to their inability to differentiate fat/lean mass or central/peripheral fat distribution, thus failing to evaluate visceral adiposity and insulin resistance – key pathological features of MetS.[57] Similarly, anthropometric indices (RFM, BAI, and BRI) based solely on height and waist/hip circumference demonstrated poor predictive value, aligning with Italian research[50] but contrasting with Latin America,[25] Europe[58] and Israel studies,[59] suggesting population-specific applicability potentially influenced by fat distribution patterns. Notably, these five indices all emerged as elevated BP risk factors, though their relative predictive performance varied across studies.[60,61] While Yazdi reported a 2.9-fold higher MetS risk with elevated UHR,[62] we observed weaker associations, possibly attributable to our dyslipidemic population's exceptionally low HDL-C levels. Contrary to studies endorsing ABSI's metabolic risk assessment value,[63,64] we found no significant predictive power, likely resulting from ethnic differences in body proportions and muscle distribution, as ABSI's reliance on WC adjusted for height and BMI may inadequately capture visceral adiposity in lower-BMI populations.[65,66] Furthermore, elevated ABSI, BRI and RFM correlated with higher TC, TG and LDL-C levels in males, indicating their partial efficacy in predicting male lipid metabolism abnormalities, consistent with findings by Fahami,[67] Calderón-García,[63] Yu,[60] Kobo[59] across both genders.

Our findings underscore the importance of gender-stratified approaches in metabolic assessment, as emphasized in prior studies.[20,35] For instance, females showed exclusive VAI–HDL-C associations and higher BRI specificity for MetS (90.2% vs. 57.6% in males), while males exhibited a 42.5% higher OR for the TyG–MetS association and unique relationships between TyG/CMI and elevated BP, as well as between BRI/RFM/WC/BMI and elevated TG. These disparities may originate from biological factors (divergent fat distribution - males' visceral vs females' subcutaneous;[68–70] hormonal variations in SHBG/TT/LH/estrogen)[71,72] and behavioral differences (male-predominant smoking/alcohol/high-intensity exercise).[73–75] Lifestyle adjustments significantly modified ABSI/BRI-MetS/MetS components relationships, consistent with CKD population findings showing substantial interactions between anthropometric indices and variables including age, comorbidities, dietary patterns, and physical activity levels.[76]

It should be noted that our data were collected in 2009–2010. Rapid economic development and lifestyle changes in rural China, including higher fat/sugar diets and reduced physical activity, may have altered metabolic risk profiles.[77,78] Thus, absolute prevalence and optimal cutoff values may differ in contemporary populations.[79,80] Nevertheless, relative index performance and gender-specific patterns remain valid,[45,50,81] as they reflect underlying biological relationships less affected by secular trends.[82,83] Furthermore, the low obesity prevalence in our Lahu sample may affect indices validated in overweight/obese populations. For example, a study in obese Caucasian individuals reported a TyG cutoff of 4.72 for

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MetS,[48] whereas our dyslipidemic but largely non-obese Lahu population showed markedly higher optimal cutoffs (males: 8.82; females: 8.95). These findings emphasize the need for population-specific validation prior to clinical application.

Several limitations of this study should be acknowledged: (1) as a cross-sectional design, temporality and causality between anthropometric indicators and MetS cannot be established; prospective studies are needed to validate their predictive value; (2) residual confounding may remain despite multivariable adjustment; (3) restricted generalizability due to unique genetic and lifestyle characteristics of the Lahu ethnic group in southwest China, the enrollment of only dyslipidemic participants, and the low obesity prevalence in our sample; (4) the modified LAP and CVAI formulas, with LAP adjusted per established methods[84] while CVAI required novel modifications to handle negative values, may introduce potential bias or variability in external validation and affect cross-study comparability; (5) selection bias cannot be excluded due to excluded participants; (6) no multiple comparison corrections were applied in this exploratory study of an underrepresented population to reduce Type II error, which may increase Type I error; thus, results should be interpreted cautiously and require verification; (7) While the total sample size appears reasonable, the lack of a pre-specified power analysis limits the interpretation of statistical reliability, particularly for analyses of individual MetS components.

Conclusion

This cross-sectional study identifies the TyG index as a robust MetS predictor among Lahu adults with dyslipidemia, with superior performance across genders. While CMI, VAI, LAP and CVAI showed moderate predictive value, WC, BMI, UHR, RFM, BAI, and BRI had limited utility, with ABSI showing no significant predictive capacity. As a simple, low-cost tool, the TyG index holds promise for community-based MetS screening in dyslipidemic populations residing in rural or resource-limited settings. However, these findings establish associations rather than causality or prospective prediction, pertain specifically to an underrepresented ethnic minority with distinct lifestyle and metabolic traits, and require validation in prospective cohorts and diverse populations before broader implementation, with sex differences warranting consideration in clinical application.

Data Sharing Statement

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

Ethics Approval and Consent to Participate

The study was conducted in accordance with the Declaration of Helsinki and was approved by the Institutional Review Board of The First Affiliated Hospital of Kunming Medical University (No. 2025L165). All participants provided written informed consent prior to data collection.

Author Contributions

J.C.: Methodology, Investigation, Data curation, Formal analysis, Writing – original draft;
W.C.G.: Methodology, Investigation, Data curation, Writing – original draft;
H.J.Y.: Methodology, Conceptualization, Supervision, Writing – review and editing;
H.F.L.: Methodology, Conceptualization, Supervision, Funding acquisition, Writing – review and editing;

All authors gave final approval of the version to be published; have agreed on the journal to which the article has been submitted and agreed to be accountable for all aspects of the work.

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Disclosure

The authors declare no competing interests.

References

1. Noubiap JJ, Nansseu JR, Lontchi-Yimagou E, et al. Geographic distribution of metabolic syndrome and its components in the general adult population: a meta-analysis of global data from 28 million individuals. *Diabetes Res Clin Pract*. 2022;188:109924. doi:10.1016/j.diabres.2022.109924
2. Pirillo A, Casula M, Olmastroni E, Norata GD, Catapano AL. Global epidemiology of dyslipidaemias. *Nat Rev Cardiol*. 2021;18(10):689–700. doi:10.1038/s41569-021-00541-4
3. Kerr AG, Andersson DP, Dahlman I, Rydén M, Arner P. Adipose insulin resistance associates with dyslipidemia independent of liver resistance and involves early hormone signaling. *Arteriosclerosis Thrombosis Vasc Biol*. 2023;43(6):1054–1065. doi:10.1161/ATVBAHA.123.319227
4. Lemieux I, Després JP. Metabolic syndrome: past, present and future. *Nutrients*. 2020;12(11):3501. doi:10.3390/nu12113501
5. Ogbu ISI, Ogbu CC, Ndukwe M, Agunwah E, Eze C, Okeke NJ. Lipid profile in metabolic syndrome associated with diabetes, hypertension, chronic kidney disease and apparent Health. *Int J Multidis Res Anal*. 2022;5(10):2886–2891. doi:10.47191/ijmra/v5-i10-42
6. Wilson PW, D'Agostino RB, Parise H, Sullivan L, Meigs JB. Metabolic syndrome as a precursor of cardiovascular disease and type 2 diabetes mellitus. *Circulation*. 2005;112(20):3066–3072. doi:10.1161/CIRCULATIONAHA.105.539528
7. Mandal GK, Prasad S, Agrawal BK, Manhas S, Bhutani K. To study various complications present amongst metabolic syndrome patients and control subjects. *Indian J Public Health Res Dev*. 2020;11(7):283–287.
8. Fruchart JC, Hermans MP, Fruchart-Najib J, Kodama T. Selective peroxisome proliferator-activated receptor alpha modulators (SPPARMα) in the metabolic syndrome: is pemafibrate light at the end of the tunnel? *Curr Atherosclerosis Rep*. 2021;23(1):3. doi:10.1007/s11883-020-00897-x
9. Zhang L, Liu Z, Si D, et al. Comparative predictive values of anthropometric indices for cardiometabolic multimorbidity in middle-aged and older adults: a prospective study from the CHARLS study. *BMC Public Health*. 2025;26(1):333. doi:10.1186/s12889-025-26060-2
10. Rezaee A, Darroudi S, Yavari A, et al. Novel anthropometric and lipid indices as predictors of chronic kidney disease: insights from a decade-long cohort study. *J Health Popul Nutr*. 2025;44(1):227. doi:10.1186/s41043-025-00924-0
11. Quirino-Vela L, Mayoral-Chavez M, Pérez-Cervera Y, et al. Cardiometabolic risk assessment by anthropometric and biochemical indices in Mexican population. *Front Endocrinol*. 2025;16:1588469. doi:10.3389/fendo.2025.1588469
12. Zhang X, Wang Y, Li Y, et al. Optimal obesity- and lipid-related indices for predicting type 2 diabetes in middle-aged and elderly Chinese. *Sci Rep*. 2024;14(1):10901. doi:10.1038/s41598-024-61592-4
13. Kurniawan LB. Triglyceride-glucose index as a biomarker of insulin resistance, diabetes mellitus, metabolic syndrome, and cardiovascular disease: a review. *Ejifcc*. 2024;35(1):44–51.
14. Li Y, Gui J, Liu H, et al. Predicting metabolic syndrome by obesity- and lipid-related indices in mid-aged and elderly Chinese: a population-based cross-sectional study. *Front Endocrinol*. 2023;14:1201132. doi:10.3389/fendo.2023.1201132
15. Zaid M, Ameer F, Munir R, et al. Anthropometric and metabolic indices in assessment of type and severity of dyslipidemia. *J Physiol Anthropol*. 2017;36(1):19. doi:10.1186/s40101-017-0134-x
16. Adjei NK, Samkange-Zeeb F, Boakye D, et al. Ethnic differences in metabolic syndrome in high-income countries: a systematic review and meta-analysis. *Rev Endocr Metab Disord*. 2024;25(4):727–750. doi:10.1007/s11154-024-09879-9
17. Ghorbani Z, Shoaibinobarian N, Zamani E, et al. Supplementing the standard diet with brown rice bran powder might effectively improve the metabolic syndrome characteristics and antioxidant status: an open label randomized controlled trial. *Food Funct*. 2025;16(2):750–762. doi:10.1039/D4FO03642E
18. Ge K, Zhai F, Wang Q. Effect of nationality on dietary pattern and meal behavior in China. *Am J Clin Nutrition*. 1997;65(4 Suppl):1290s–1294s. doi:10.1093/ajcn/65.4.1290S
19. Zhang X, Li J, Wen J. Genetic variation of 17 autosomal STR loci in the Lahu population from Yunnan and phylogenetic structure exploration among 28 populations. *Legal Med*. 2022;56:102050. doi:10.1016/j.legalmed.2022.102050
20. Sultana M, Hasan MM, Hasan T. Gender difference in metabolic syndrome and quality of life among elderly people in Noakhali, Bangladesh. *Heliyon*. 2025;11(1):e41734. doi:10.1016/j.heliyon.2025.e41734
21. De Paoli M, Zakharia A, Werstuck GH. The role of estrogen in insulin resistance: a review of clinical and preclinical data. *Am J Pathol*. 2021;191(9):1490–1498. doi:10.1016/j.ajpath.2021.05.011
22. Zhu Y, Huang Y, Sun H, et al. Novel anthropometric indicators of visceral obesity predict the severity of hyperlipidemic acute pancreatitis. *Lipids Health Dis*. 2024;23(1):120. doi:10.1186/s12944-024-02112-1
23. Park Y, Kim NH, Kwon TY, Kim SG. A novel adiposity index as an integrated predictor of cardiometabolic disease morbidity and mortality. *Sci Rep*. 2018;8(1):16753. doi:10.1038/s41598-018-35073-4
24. Maciel de Oliveira C, França da Rosa F, de Oliveira Alvim R, et al. Body mass index is superior to other body adiposity indexes in predicting incident hypertension in a highly admixed sample after 10-year follow-up: the Baependi heart study. *J Clin Hypertension*. 2022;24(6):731–737. doi:10.1111/jch.14480
25. Chaquila JA, Ramirez-Jeri G, Miranda-Torvisco F, Baquerizo-Sedano L, Aparco JP. Predictive ability of anthropometric indices for risk of developing metabolic syndrome: a cross-sectional study. *J Int Med Res*. 2024;52(11):3000605241300017. doi:10.1177/03000605241300017
26. Kwas H, Rajhi H, Rangareddy H. Association between the triglyceride-glucose index and serum uric acid to high-density lipoprotein (HDL) cholesterol ratio in type 2 diabetes mellitus in Gabes City, Tunisia. *Cureus*. 2024;16(8):e68235. doi:10.7759/cureus.68235
27. Xia MF, Chen Y, Lin HD, et al. A indicator of visceral adipose dysfunction to evaluate metabolic health in adult Chinese. *Sci Rep*. 2016;6(1):38214. doi:10.1038/srep38214
28. Wen J, Yang J, Shi Y, et al. Comparisons of different metabolic syndrome definitions and associations with coronary heart disease, stroke, and peripheral arterial disease in a rural Chinese population. *PLoS One*. 2015;10(5):e0126832. doi:10.1371/journal.pone.0126832
29. Tanomsup S, Aekplakorn W, Sritara P, et al. A comparison of components of two definitions of the metabolic syndrome related to cardiovascular disease and all-cause mortality in a cohort study in Thailand. *Diabetes Care*. 2007;30(8):2138–2140. doi:10.2337/dc07-0388

30. Grundy SM, Cleeman JI, Daniels SR, et al. Diagnosis and management of the metabolic syndrome: an American heart association/national heart, lung, and blood institute scientific statement. *Circulation*. 2005;112(17):2735–2752. doi:10.1161/CIRCULATIONAHA.105.169404
31. Cleeman JI. Executive summary of the third report of the national cholesterol education program (NCEP) expert panel on detection, evaluation, and treatment of high blood cholesterol in adults (Adult treatment panel III). *JAMA*. 2001;285(19):2486–2497. doi:10.1001/jama.285.19.2486
32. Hu G, Tuomilehto J, Silventoinen K, Barengo N, Jousilahti P. Joint effects of physical activity, body mass index, waist circumference and waist-to-Hip ratio with the risk of cardiovascular disease among middle-aged Finnish men and women. *Eur Heart J*. 2004;25(24):2212–2219. doi:10.1016/j.ehj.2004.10.020
33. Zhou BF. Predictive values of body mass index and waist circumference for risk factors of certain related diseases in Chinese adults--study on optimal cut-off points of body mass index and waist circumference in Chinese adults. *Biomed Environ Sci*. 2002;15(1):83–96.
34. DeLong ER, DeLong DM, Clarke-Pearson DL. Comparing the areas under two or more correlated receiver operating characteristic curves: a nonparametric approach. *Biometrics*. 1988;44(3):837–845. doi:10.2307/2531595
35. Lee SH, Han K, Yang HK, et al. A novel criterion for identifying metabolically obese but normal weight individuals using the product of triglycerides and glucose. *Nut Diabetes*. 2015;5(4):e149. doi:10.1038/nutd.2014.46
36. Jiang M, Li X, Wu H, et al. Triglyceride-glucose index for the diagnosis of metabolic syndrome: a cross-sectional study of 298,652 individuals receiving a health check-up in China. *Int J Endocrinol*. 2022;2022:3583603. doi:10.1155/2022/3583603
37. Liu Y, Gao L, Wu M, et al. Effect of adipose tissue deposition on insulin resistance in middle-aged and elderly women: based on QCT and MRI mDIXON-Quant. *J Diabetes Invest*. 2025;16(2):292–297. doi:10.1111/jdi.14352
38. Yang Q, Xu H, Zhang H, et al. Serum triglyceride glucose index is a valuable predictor for visceral obesity in patients with type 2 diabetes: a cross-sectional study. *Cardiovasc Diabetol*. 2023;22(1):98. doi:10.1186/s12933-023-01834-3
39. El-Sehrawy A, Khachatryan LG, Kubaev A, et al. Triglyceride-glucose index: a potent predictor of metabolic risk factors and eating behavior patterns among obese individuals. *BMC Endocr Disord*. 2025;25(1):71. doi:10.1186/s12902-025-01887-3
40. Yang H, Chen Y, Liu C. Triglyceride-glucose index is associated with metabolic syndrome in women with polycystic ovary syndrome. *Gynecol Endocrinol*. 2023;39(1):2172154. doi:10.1080/09513590.2023.2172154
41. Babic N, Valjevac A, Zaciragic A, Avdagic N, Zukic S, Hasic S. The Triglyceride/HDL ratio and triglyceride glucose index as predictors of glycemic control in patients with diabetes mellitus type 2. *Med Archiv*. 2019;73(3):163–168. doi:10.5455/medarh.2019.73.163-168
42. Morales-Gurrola G, Simental-Mendía LE, Castellanos-Juárez FX, Salas-Pacheco JM, Guerrero-Romero F. The triglycerides and glucose index is associated with cardiovascular risk factors in metabolically obese normal-weight subjects. *J Endocrinol Invest*. 2020;43(7):995–1000. doi:10.1007/s40618-020-01184-x
43. Min J, Goodale H, Xue H, Brey R, Wang Y. Racial-ethnic disparities in obesity and biological, behavioral, and sociocultural influences in the United States: a systematic review. *Adv Nutrition*. 2021;12(4):1137–1148. doi:10.1093/advances/nmaa162
44. Wang L, Gao P, Zhang M, et al. Prevalence and ethnic pattern of diabetes and prediabetes in China in 2013. *JAMA*. 2017;317(24):2515–2523. doi:10.1001/jama.2017.7596
45. Wan H, Cao H, Ning P. Superiority of the triglyceride glucose index over the homeostasis model in predicting metabolic syndrome based on NHANES data analysis. *Sci Rep*. 2024;14(1):15499. doi:10.1038/s41598-024-66692-9
46. Nabipoorashrafi SA, Seyedi SA, Rabizadeh S, et al. The accuracy of triglyceride-glucose (TyG) index for the screening of metabolic syndrome in adults: a systematic review and meta-analysis. *Nutrition Metab Cardiovasc Dis*. 2022;32(12):2677–2688. doi:10.1016/j.numecd.2022.07.024
47. Kang SW, Kim SK, Kim YS, Park MS. Risk prediction of the metabolic syndrome using TyG Index and SNPs: a 10-year longitudinal prospective cohort study. *Mol Cell Biochem*. 2023;478(1):39–45. doi:10.1007/s11010-022-04494-1
48. Primo D, Izaola O, de Luis DA. Triglyceride-glucose index cutoff point is an accurate marker for predicting the prevalence of metabolic syndrome in obese caucasian subjects. *Ann Nutr Metab*. 2023;79(2):238–245. doi:10.1159/000526988
49. Lazzer S, D'Alleva M, Isola M, et al. Cardiometabolic index (CMI) and visceral adiposity index (VAI) highlight a higher risk of metabolic syndrome in women with severe obesity. *J Clin Med*. 2023;12(9):3055. doi:10.3390/jcm12093055
50. Tamini S, Bondesan A, Caroli D, Sartorio A. The lipid accumulation product index (LAP) and the cardiometabolic index (CMI) are useful for predicting the presence and severity of metabolic syndrome in adult patients with obesity. *J Clin Med*. 2024;13(10):2843. doi:10.3390/jcm13102843
51. Datta Banik S, Pacheco-Pantoja E, Lugo R, et al. Evaluation of anthropometric indices and lipid parameters to predict metabolic syndrome among adults in Mexico. *Diab Metab Syndr Obes*. 2021;14:691–701. doi:10.2147/DMSO.S281894
52. Jafari A, Ilaghi M, Najafipour H, Shadkam M. Assessing three novel composite anthropometric-metabolic indices for predicting 10-year incidence of metabolic syndrome: findings from the kerman coronary artery disease risk factors study (KERCADRS). *Hormones*. 2025;24(2):433–441. doi:10.1007/s42000-024-00622-2
53. Konstantinova ED, Maslakova TA, Ogorodnikova SY. The predictive capability of several anthropometric indices for identifying the risk of metabolic syndrome and its components among industrial workers. *Sci Rep*. 2024;14(1):15327. doi:10.1038/s41598-024-66262-z
54. Yang Y, Wang B, Yuan H, Li X. Triglycerides to high-density lipoprotein cholesterol ratio is the best surrogate marker for insulin resistance in nonobese middle-aged and elderly population: a cross-sectional study. *Int J Endocrinol*. 2021;2021:6676569. doi:10.1155/2021/6676569
55. Song J, Li Y, Zhu J, Liang J, Xue S, Zhu Z. Non-linear associations of cardiometabolic index with insulin resistance, impaired fasting glucose, and type 2 diabetes among US adults: a cross-sectional study. *Front Endocrinol*. 2024;15:1341828. doi:10.3389/fendo.2024.1341828
56. Duan Y, Zhang W, Li Z, et al. Predictive ability of obesity- and lipid-related indicators for metabolic syndrome in relatively healthy Chinese adults. *Front Endocrinol*. 2022;13:1016581. doi:10.3389/fendo.2022.1016581
57. Oliveros E, Somers VK, Sochor O, Goel K, Lopez-Jimenez F. The concept of normal weight obesity. *Prog Cardiovasc Dis*. 2014;56(4):426–433. doi:10.1016/j.pcad.2013.10.003
58. Ramírez-Manent JI, López-González ÁA, Tomás-Gil P, Riutord-Sbert P, Garrido-Sepulveda L, Vicente-Herrero MT. Relationship between abdominal volume index and body adiposity index and scales of insulin resistance and metabolic syndrome. *Diagnostics*. 2023;13(21):3356.
59. Kobo O, Leiba R, Avizohar O, Karban A. Relative fat mass is a better predictor of dyslipidemia and metabolic syndrome than body mass index. *Cardiovasc Endocrinol Metab*. 2019;8(3):77–81. doi:10.1097/XCE.0000000000000176
60. Yu P, Huang T, Hu S, Yu X. Predictive value of relative fat mass algorithm for incident hypertension: a 6-year prospective study in Chinese population. *BMJ open*. 2020;10(10):e038420. doi:10.1136/bmjopen-2020-038420

61. Abolhasani M, Maghbouli N, Karbalai Saleh S, et al. Which anthropometric and metabolic index is superior in hypertension prediction among overweight/obese adults? *Integr Blood Pressure Control*. 2021;14:153–161. doi:10.2147/IBPC.S340664
62. Yazdi F, Baghaei MH, Baniasad A, Naghibzadeh-Tahami A, Najafipour H, Gozashti MH. Investigating the relationship between serum uric acid to high-density lipoprotein ratio and metabolic syndrome. *Endocrinol Diabetes Metabol*. 2022;5(1):e00311. doi:10.1002/edm2.311
63. Calderón-García JF, Roncero-Martín R, Rico-Martín S, et al. Effectiveness of body roundness index (BRI) and a body shape index (ABSI) in predicting hypertension: a systematic review and meta-analysis of observational studies. *Int J Environ Res Public Health*. 2021;18(21):11607. doi:10.3390/ijerph182111607
64. Parra-Soto S, Lasserre-Laso N, Troncoso-Pantoja C, et al. Índice de obesidad ABSI y su asociación con diabetes mellitus tipo 2 en adultos chilenos: un estudio transversal de la ENS 2016-2017. *Rev Méd Chile*. 2023;151(6):687–695. doi:10.4067/s0034-98872023000600687
65. Haldar S, Chia SC, Henry CJ. Body composition in Asians and caucasians: comparative analyses and influences on cardiometabolic outcomes. *Adv Food Nutr Res*. 2015;75:97–154.
66. Lear SA, Toma M, Birmingham CL, Frohlich JJ. Modification of the relationship between simple anthropometric indices and risk factors by ethnic background. *Metabolism*. 2003;52(10):1295–1301. doi:10.1016/S0026-0495(03)00196-3
67. Fahami M, Hojati A, Farhangi MA. Body shape index (ABSI), body roundness index (BRI) and risk factors of metabolic syndrome among overweight and obese adults: a cross-sectional study. *BMC Endocr Disord*. 2024;24(1):230. doi:10.1186/s12902-024-01763-6
68. Li H, Konja D, Wang L, Wang Y. Sex differences in adiposity and cardiovascular diseases. *Int J Mol Sci*. 2022;23(16):9338.
69. Mancuso P, Bouchard B. The impact of aging on adipose function and adipokine synthesis. *Front Endocrinol*. 2019;10:137. doi:10.3389/fendo.2019.00137
70. Luo Y, Liu L, Liu M, et al. Relationship between body composition and insulin resistance evaluated by the TyG index: a retrospective study among Chinese population. *Clin Endocrinol*. 2025;102(3):264–272. doi:10.1111/cen.15171
71. Zhang Z, Chen Y, Li N, et al. Gonadal hormones and metabolic syndrome in middle-aged and elderly males: results from a prospective cohort study in China. *Front Endocrinol*. 2024;15:1365283. doi:10.3389/fendo.2024.1365283
72. Petroni ML, Caletti MT, Dalle Grave R, Bazzocchi A, Aparisi Gómez MP, Marchesini G. Prevention and treatment of sarcopenic obesity in women. *Nutrients*. 2019;11(6):1302. doi:10.3390/nu11061302
73. Kim M, Kim J, Lee I. Interactive associations of smoking and physical activity with metabolic syndrome in adult men in Korea. *Front Public Health*. 2023;11:1281530. doi:10.3389/fpubh.2023.1281530
74. Park EJ, Shin HJ, Kim SS, et al. The effect of alcohol drinking on metabolic syndrome and obesity in Koreans: big data analysis. *Int J Environ Res Public Health*. 2022;19(9):4949.
75. Sheng J, Abshire DA, Heiney SP, Wirth MD. Acculturation, physical activity, and metabolic syndrome in Asian American adults. *J Transcult Nurs*. 2022;33(6):675–684. doi:10.1177/10436596221114150
76. Chen X, Wu Z, Hou X, et al. Association between anthropometric indices and chronic kidney disease: insights from NHANES 2009-2018. *PLoS One*. 2025;20(2):e0311547. doi:10.1371/journal.pone.0311547
77. Pan F, Wang Z, Wang H, et al. Association between ultra-processed food consumption and metabolic syndrome among adults in china-results from the china health and nutrition survey. *Nutrients*. 2023;15(3):752. doi:10.3390/nu15030752
78. He Y, Li Y, Bai G, et al. Prevalence of metabolic syndrome and individual metabolic abnormalities in China, 2002-2012. *Asia Pacific J Clin Nutrition*. 2019;28(3):621–633. doi:10.6133/apjcn.201909_28(3).0023
79. Zhang X, Wang Y, Huang F, et al. Multiple trajectories of any intensities of physical activity are better than sustained sedentary time on improving waist circumference and body mass index among Chinese adults: China health and nutrition survey, 2004-2018. *Nutrition Res*. 2022;107:1–11. doi:10.1016/j.nutres.2022.08.004
80. Negasheva MA, Khafizova AA, Movsesian AA. Secular trends in height, weight, and body mass index in the context of economic and political transformations in Russia from 1885 to 2021. *Am J Human Biol*. 2024;36(2):e23992. doi:10.1002/ajhb.23992
81. Ferreira JRS, Libardi MC, Do Prado CB, Zandonade E, Bezerra O, Salaroli LB. Predicting metabolic syndrome by lipid accumulation product, visceral adiposity index and body roundness index in Brazilian rural workers. *BMC Public Health*. 2025;25(1):544. doi:10.1186/s12889-025-21624-8
82. Duren DL, Nahhas RW, Sherwood RJ. Do secular trends in skeletal maturity occur equally in both sexes? *Clin Orthopaedics Related Res*. 2015;473(8):2559–2567. doi:10.1007/s11999-015-4213-1
83. Mansukoski L, Johnson W. How can two biological variables have opposing secular trends, yet be positively related? A demonstration using timing of puberty and adult height. *Ann Hum Biol*. 2020;47(6):549–554. doi:10.1080/03014460.2020.1795256
84. Shao Q, Wu YL, Jiang F, et al. The relationship between lipid accumulation product and the risk of diabetes. *Chin J Dis Control Prevent*. 2022;26(02):125–130+243.