

Diagnostic Value of Insulin Resistance Indices and Nomogram Models in Identifying Pre-Metabolic Syndrome: A Population-Based Study from Southeast China

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Abstract

Background

Metabolic syndrome (MetS) is a risk factor for cardiovascular diseases and cancer, with its pre-stage (preMetS) also conferring risk. MetS incidence is rising annually, yet the absence of unified diagnostic criteria presents challenges for primary healthcare workers. Insulin resistance (IR) indicators are widely used for MetS screening, but research on their ability to identify preMetS is limited.

Objective

To estimate preMetS prevalence among adults in Fuzhou City, compare differences and agreement among three diagnostic criteria, and examine the association and diagnostic value of six IR indicators for preMetS.

Methods

9155 permanent Fuzhou residents underwent face-to-face questionnaires, physical examinations, and laboratory tests. Direct method calculated age- and sex-standardized prevalence for preMetS and MetS. Agreement among three criteria for preMetS/MetS classification was assessed using consistency tests. Univariate/multivariate logistic regression and restricted cubic spline analyses explored IR-preMetS associations. Diagnostic performance was compared via area under the curve (AUC). A nomogram model incorporating indicators and age was developed to enhance diagnostic capability.

Results

Among 8997 participants, revised ATP III criteria yielded the highest age-standardized preMetS and MetS prevalence (International Diabetes Federation (IDF) criteria the lowest), irrespective of sex. Revised ATP III showed high agreement with Joint Committee for Developing Chinese Guidelines (JCDCG) (Kappa = 0.700–0.820) but low agreement with IDF (Kappa = 0.316–0.377). The triglyceride-glucose index (TyG) was the optimal screening indicator (AUC = 0.731, 95%CI:0.718–0.744; cutoff = 7.736). In normal-weight individuals, TyG and triglyceride to high-density lipoprotein ratio (TG/HDL) showed comparable performance (P delong > 0.05). The nomogram combining age and TG/HDL demonstrated superior preMetS screening ability (P delong < 0.05) and better goodness-of-fit.

Conclusion

Revised ATP III and JCDCG showed high consistency for MetS classification, with ATP III being more suitable for large-scale screening. TyG is an effective preMetS identifier in Southeast Chinese adults, while waist-to-height ratio (WHtR) is a valuable non-invasive screening indicator. The "Age + TG/HDL" nomogram model optimizes preMetS diagnostic accuracy.

1. Introduction

Metabolic Syndrome (MetS) is a cluster of metabolic risks—including central obesity, elevated blood pressure, dysglycemia, and dyslipidemia—that elevate cardiovascular disease risk. Having one or two MetS components

defines pre-metabolic syndrome (preMetS), an early risk stage. Although preMetS carriers face lower immediate risks than MetS patients, they remain highly susceptible to gastrointestinal diseases^[1], cardiovascular diseases (CVD)^[2], cancer^{[3][4]}, and dementia. PreMetS lacks a unified definition. Previous studies have used various standards based on having fewer than the required MetS components^{[5][6][7][8]}. Due to divergent definitions proposed by international bodies^{[9][10][11]}, global preMetS prevalence estimates vary widely, hindering study comparability^{[12][13][14]}. Thus, investigating preMetS epidemiology using multiple criteria (IDF, Revised ATP III, and JCDCG) is vital to standardize definitions and clinical approaches. While anthropometric and insulin resistance (IR) indices screen effectively for MetS^{[15][16][17][18]}, their performance in screening preMetS among non-MetS populations requires exploration. Traditional measures like BMI and waist-to-height ratio (WHtR) demonstrate predictive value for cardiometabolic risk^[19], and emerging indices like A Body Shape Index (ABSI) show screening potential. Given that IR is the core mechanism of MetS^[20], direct IR screening is valuable. However, gold-standard IR measurement requires complex, invasive procedures^[21] unsuited for routine practice. Traditional anthropometric surrogates reflect IR to some extent^{[22][23][24]} but lack precision. Consequently, novel, simple IR indices like the triglyceride-glucose (TyG) index^[25] and the triglyceride to high-density lipoprotein ratio (TG/HDL)^[26] have been proposed. Metabolic risks in normal-weight individuals are frequently neglected^[27]; yet, metabolically unhealthy normal-weight individuals face 1.5- to 2-fold increased risks of diabetes and CVD^{[28][29]}. Moreover, WHO recommends excluding individuals with established type 2 diabetes or CVD from MetS screening to focus on primary prevention^[30]. Therefore, identifying simple, efficient markers for preMetS screening across diverse populations holds high public health value. This study aims to estimate preMetS prevalence among adults in Fuzhou, China, evaluate and compare the screening utility of various IR indices under different diagnostic criteria, calculate optimal cutoffs, and develop a diagnostic nomogram model combining age with the top performing indicators.

2. Populations and Methods

2.1 Study Populations

This population-based cross-sectional survey was conducted in Fuzhou, China, between June and December 2022. Permanent residents (residing ≥ 6 months) aged ≥ 18 years were recruited using multistage stratified cluster random sampling. Out of 9,155 recruited participants (response rate: 95.75%), 8,997 were included after excluding those with missing variables. For further preMetS-specific analyses, 2,795 MetS patients (Revised ATP III criteria) were excluded, leaving 6,202 subjects. The study was approved by the Ethics Review Committee of Fuzhou CDC (Approval No: 2022002). All participants provided informed consent, and protocols adhered to the Declaration of Helsinki.

2.2 Data measurements

Trained primary healthcare professionals conducted face-to-face standardized questionnaires covering demographics, medical history, and lifestyles (exercise, smoking, alcohol, sleep). Physical examinations measured height, weight, waist circumference (WC; averaged over two measurements), and blood pressure (BP; averaged over three measurements using UR-9000F). Venous blood was collected after fasting. Serum total cholesterol (TC), low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), triglycerides (TG), and uric acid were measured via colorimetric/enzymatic methods, and fasting plasma glucose (FPG) via the hexokinase method, using a Hitachi 7100 analyzer.

2.3 Description of variables

(1) Non-smokers were classified as low risk^[31]. Regular physical activity was defined as at least 150 minutes of moderate-intensity activity per week or 75 minutes of vigorous activity per week (or an equivalent combination)^[31]. Food frequency questionnaire assessed various food intake over the past year^[32]. Low-risk alcohol consumption was defined as moderate drinking (females: 5–15 grams/day; males: 5–30 grams/day)^[33]. Healthy weight was defined as a BMI of 18.5–24.0 kg/m²^[31]. Adequate sleep time (7–8 hours/day) was classified as low risk^[34].

(2) Insulin Resistance-Related Indicators^{[27][35]}: BMI: weight(kg)/height²(m). WHtR: WC(cm)/height(m). ABSI: WC/(BMI^{2/3}*height^{1/2}). TYG: LN(TG(mg/dL) * FPG(mg/dL)/2). TG/HDL: TG/HDL-C.

(3) Metabolic Syndrome Diagnostic Criteria:

Three widely used diagnostic criteria for MetS were applied in this study: the International Diabetes Federation (IDF) criteria^[36], the revised Adult Treatment Panel III (ATP III) criteria^[37], and the Joint Committee for Developing Chinese Guidelines (JCDCG) criteria^[38]. The specific components and cut-off points for each criterion are detailed accordingly (Table 1, Supplementary Materials).

Table 1

Diagnostic criteria for metabolic syndrome according to the IDF, revised ATP III, and JCDCG definitions.

Component	IDF Criteria (2005)	Revised ATP III Criteria (2005)	JCDCG Criteria (2007)
Prerequisite	Central obesity (Chinese criteria: Male WC $\geq$ 90 cm, Female WC $\geq$ 85 cm) is mandatory.	None	None
High triglycerides (TG)	$\geq$ 1.7 mmol/L or on specific treatment	$\geq$ 1.7 mmol/L or on specific treatment	$\geq$ 1.70 mmol/L
Low HDL-C	Male $<$ 1.03 mmol/L Female $<$ 1.29 mmol/L or on specific treatment	Male $<$ 1.03 mmol/L Female $<$ 1.29 mmol/L or on specific treatment	$<$ 1.03 mmol/L
Hypertension	SBP $\geq$ 130 mmHg or DBP $\geq$ 85 mmHg or diagnosis and treatment of hypertension	SBP $\geq$ 130 mmHg or DBP $\geq$ 85 mmHg or diagnosis and treatment of hypertension	SBP $\geq$ 130 mmHg or DBP $\geq$ 85 mmHg or diagnosis and treatment of hypertension
High fasting blood glucose	$\geq$ 5.6 mmol/L or previously diagnosed type 2 diabetes	$\geq$ 5.6 mmol/L or previously diagnosed type 2 diabetes	$\geq$ 6.1 mmol/L or 2-hour postprandial glucose $\geq$ 7.8 mmol/L or previously diagnosed diabetes
Diagnosis of MetS	Central obesity + any two of the other four components	Any three of the five components	Any three of the five components
Diagnosis of PreMetS (This study)	Having one or two of the metabolic abnormalities listed, without mandatory central obesity.	Having one or two of the five metabolic abnormalities.	Having one or two of the five metabolic abnormalities.
Notes: IDF, International Diabetes Federation; Revised ATP III, Adult Treatment Panel III of the National Cholesterol Education Program, Revised; JCDCG, Joint Committee for Developing Chinese Guidelines on Prevention and Treatment of Dyslipidemia; WC, Waist Circumference; HDL-C, High-Density Lipoprotein Cholesterol; SBP, Systolic Blood Pressure; DBP, Diastolic Blood Pressure.			

2.4 Statistical methods

Continuous and categorical variables were compared using independent t-tests and chi-square tests, respectively. Z-scores were calculated for IR indices. Binary logistic regression analyzed the associations between IR indices and preMetS, adjusting for demographics and lifestyles. Diagnostic performance was evaluated using the area under the receiver operating characteristic curve (AUC), sensitivity, specificity, and Youden's index. To construct the nomogram model, backward stepwise logistic regression ($\$P < 0.05\$$ for inclusion, $\$P > 0.1\$$ for exclusion) was performed on significant IR indices and covariates (only age was retained due to its strong impact). Calibration curves were plotted to assess model fit. Analyses were performed using SPSS 26.0 and R (version 4.2.0).

3. Results

3.1 Prevalence rates of pre-metabolic syndrome and metabolic syndrome were examined, and a comparison was made among three different definitions."

We employed three definitions to classify MetS in the entire population. The prevalence and characteristics of reMetS and MetS exhibit variations based on the definitions utilized within the Chinese population. When employing three different standard definitions, IDF preMetS demonstrated the lowest age-standardized prevalence, while Revised ATP III exhibited the highest age-standardized prevalence rate for both males and females. Furthermore, Revised ATP III displayed the highest overall prevalence of MetS as well as among women, whereas JCDCG criteria showcased the highest prevalence of MetS among men (Table 2).

Table 2
Comparison of the PreMetS and MetS prevalence rates based on three MetS criteria.

	PreMetS		MetS	
	N (crude prevalence)	Standardized prevalence	N (crude prevalence)	Standardized prevalence
All(n = 8997)				
Revised ATP III	4470(49.68%)	48.53%	2795(31.07%)	23.59%
IDF	956(10.63%)	9.77%	1926(21.41%)	16.30%
JCDCG	4466(49.64%)	46.72%	2687(29.87%)	22.52%
Male(n = 3925)				
Revised ATP III	2053(52.31%)	49.87%	1124(28.64%)	24.47%
IDF	384(9.78%)	9.77%	757(19.29%)	16.78%
JCDCG	1993(50.78%)	48.05%	1220(31.08%)	26.23%
Female(n = 5072)				
Revised ATP III	2417(47.65%)	47.40%	1671(32.95%)	23.17%
IDF	572(11.28%)	9.74%	1169(23.05%)	16.11%
JCDCG	2473(48.76%)	45.56%	1467(28.92%)	19.97%
Notes: IDF: International Diabetes Federation; Revised ATP III: Adult Treatment Panel III of the National Cholesterol Education Program, Revised; JCDCG: Joint Committee for Developing Chinese Guidelines on Prevention and Treatment of Dyslipidemia.				

3.2 Consistency and Differences in Diagnoses

The revised ATP III, IDF, and JCDCG criteria for the diagnosis of preMetS are consistent, as shown in the Table1. Irrespective of gender, there was better consistency between the Revised ATP III and JCDCG standards, with kappa values ranging from 0.700 to 0.820. However, the consistency with the IDF standard was lower, with kappa values ranging from 0.316 to 0.377. Notably, the consistency of preMetS definitions between JCDCG and Revised ATP III criteria in males (kappa = 0.820) was higher than in females (kappa = 0.700) (Table 3).

Table 3
Consistency among various definitions of PreMetS.

	Revised ATP III		JCDCG	
	kappa	95%CI	kappa	95%CI
All(n = 8997)				
Revised ATP III	-	-	0.752	(0.740–0.764)
IDF	0.350	(0.340–0.361)	0.310	(0.300–0.321)
Male(n = 3925)				
Revised ATP III	-	-	0.820	(0.804–0.836)
IDF	0.316	(0.362–0.392)	0.274	(0.258–0.289)
Female(n = 5072)				
Revised ATP III	-	-	0.700	(0.683–0.718)
IDF	0.377	(0.362–0.392)	0.341	(0.326–0.357)
Notes: CI: Confidence Interval; IDF: International Diabetes Federation; Revised ATP III: Adult Treatment Panel III of the National Cholesterol Education Program, Revised; JCDCG: Joint Committee for Developing Chinese Guidelines on Prevention and Treatment of Dyslipidemia.				

3.2 Comparison of basic characteristics of pre-metabolic syndrome population under Revised ATP III criteria

Given the higher prevalence of Revised ATP III in preMetS screening and the simplicity of omitting the 2h-OGTT, the Revised ATP III definition was utilized for subsequent analyses. A total of 6,202 subjects participated in this study. Among the five components comprising the preMetS group, hypertension exhibited the largest population, followed by abnormal blood glucose levels; compared to the normal group, all five components showed a significantly higher proportion ($P < 0.05$). Furthermore, baseline characteristics—including age, weight, waist circumference (WC), body mass index (BMI), waist-to-height ratio (WHtR), A Body Shape Index (ABSI), triglyceride-glucose index (TyG), TG/HDL ratio, blood pressure readings, and lipid indices (except HDL-C)—were also significantly higher in the preMetS group than in the Normal group ($P < 0.001$) (Table 4).

The preMetS group had a higher proportion of rural residents, those with less than a high school education, and married individuals, and a lower proportion of individuals with healthy lifestyles (including not smoking, moderate to vigorous exercise, adequate sleep, and a healthy diet) ($P < 0.05$). However, there was no significant difference in gender distribution between the two groups ($P > 0.05$). (Table 5)

Table 4
Comparison of PreMetS Components (n%) and Laboratory Test Results ($\bar{x} \pm s$) among Study Subjects

Variables	All(n = 6202)	Normal (n = 1732)	PreMetS (n = 4470)	χ^2	P
Abdominal obesity				436.290	< 0.001
YES	956 (15.4)	0 (0)	956 (21.4)		
NO	5246 (84.6)	1732 (100.0)	3514 (78.6)		
Hypertension				1408.900	< 0.001
YES	2302 (37.1)	0 (0)	2302 (51.3)		
NO	3900 (62.9)	1732 (100.0)	2168 (48.7)		
Abnormal blood sugar				676.570	< 0.001
YES	1376 (22.2)	0 (0)	1376 (30.5)		
NO	4826 (77.8)	1732 (100.0)	3094 (69.5)		
Low HDL-C				519.870	< 0.001
YES	1106 (17.8)	0 (0)	1106 (24.7)		
NO	5096 (82.2)	1732 (100.0)	3364 (75.3)		
High TG				433.040	< 0.001
YES	950 (15.3)	0 (0)	950 (21.3)		
NO	5252 (84.7)	1732 (100.0)	3520 (78.7)		
SBP (mmHg)	124.44 $\pm$ 17.24	114.65 $\pm$ 9.72	128.24 $\pm$ 18.00	-38.109	< 0.001
DBP (mmHg)	77.60 $\pm$ 9.81	72.97 $\pm$ 6.44	79.40 $\pm$ 10.29	-29.474	< 0.001
FBG(mmol/L)	5.25 $\pm$ 1.60	4.80 $\pm$ 0.47	5.43 $\pm$ 1.83	-21.260	< 0.001
OGTT-2h(mmol/L)	6.95 $\pm$ 2.83	6.26 $\pm$ 1.69	7.24 $\pm$ 3.15	-15.197	< 0.001
TC(mmol/L)	5.00 $\pm$ 1.23	4.80 $\pm$ 0.92	5.08 $\pm$ 1.33	-9.311	< 0.001
TG (mmol/L)	1.29 $\pm$ 0.82	0.98 $\pm$ 0.31	1.41 $\pm$ 0.92	-27.288	< 0.001
HDL-C (mmol/L)	1.44 $\pm$ 0.39	1.55 $\pm$ 0.37	1.39 $\pm$ 0.39	15.023	< 0.001
LDL-C (mmol/L)	2.88 $\pm$ 0.85	2.68 $\pm$ 0.77	2.95 $\pm$ 0.87	-11.963	< 0.001
SUA (mmol/L)	324.78 $\pm$ 92.05	302.43 $\pm$ 79.60	333.44 $\pm$ 95.05	-13.011	< 0.001
Cre (mmol/L)	68.89 $\pm$ 20.96	66.50 $\pm$ 18.30	69.81 $\pm$ 21.84	-6.047	< 0.001
BUN(mmol/L)	5.24 $\pm$ 2.72	4.99 $\pm$ 2.02	5.34 $\pm$ 2.94	-5.302	< 0.001
BMI (kg/m ²)	23.07 $\pm$ 3.82	21.94 $\pm$ 3.15	23.50 $\pm$ 3.96	-16.260	< 0.001

Notes: IDF, International Diabetes Federation; Revised ATP III, Adult Treatment Panel III of the National Cholesterol Education Program, Revised; JCD CG, Joint Committee for Developing Chinese Guidelines on Prevention and Treatment of Dyslipidemia.

Variables	All(n = 6202)	Normal (n = 1732)	PreMetS (n = 4470)	χ^2	P
WC(cm)	80.16 ± 10.61	76.42 ± 6.64	81.61 ± 11.47	-22.192	< 0.001
WHtR(cm)	0.50 ± 0.07	0.47 ± 0.04	0.51 ± 0.07	-24.452	< 0.001
TYG	7.62 ± 0.51	7.34 ± 0.36	7.73 ± 0.51	-33.808	< 0.001
TG/HDL	0.97 ± 0.82	0.66 ± 0.26	1.09 ± 0.93	-28.567	< 0.001
ABSI	7.84 ± 0.73	7.71 ± 0.50	7.89 ± 0.79	-10.801	< 0.001
Notes: IDF, International Diabetes Federation; Revised ATP III, Adult Treatment Panel III of the National Cholesterol Education Program, Revised; JCD CG, Joint Committee for Developing Chinese Guidelines on Prevention and Treatment of Dyslipidemia.					

SBP, Systolic Blood Pressure; DBP, Diastolic Blood Pressure; FBG, Fasting Blood Glucose; PBG, Postprandial blood Glucose; TC, Total Cholesterol; HDL-C, High-Density Lipoprotein Cholesterol; LDL-C, Low-Density Lipoprotein Cholesterol; BUN, Blood Urea Nitrogen; TYG: Triglyceride-glucose index; TG/HDL: Triglyceride-to-high-density lipoprotein cholesterol ratio; WHtR: Waist-to-height ratio; BMI: Body mass index; ABSI: A body shape index; WC: Waist circumference.

Table 5
Comparison of Baseline Characteristics among Study Subjects, n (%) and ($\bar{x} \pm s$)

Variables	All(n = 6202)	Normal (n = 1732)	PreMetS(n = 4470)	χ^2	P
Gender				3.678	0.055
Male	2801 (45.2)	748 (43.2)	2053 (45.9)		
Female	3401 (54.8)	984 (56.8)	2417 (54.1)		
Age (years)	55.88 $\pm$ 14.62	50.19 $\pm$ 14.72	58.08 $\pm$ 13.98	-19.205*	< 0.001
Residence				17.810	< 0.001
Urban	3828 (61.7)	1142 (65.9)	2686 (60.1)		
Rural	2374 (38.3)	590 (34.1)	1784 (39.9)		
Education level				122.165	< 0.001
High school and above	1865 (30.1)	700 (40.5)	1165 (26.1)		
Below high school	4334 (69.9)	1030 (59.5)	3304 (73.9)		
Marital status				3.863	0.049
Married	5360 (86.5)	1471 (85.1)	3889 (87.0)		
Separated/divorced	838 (13.5)	258 (14.9)	580 (13.0)		
Smoking				4.241	0.039
Never smoked	5260 (84.8)	1496 (86.4)	3764 (84.2)		
Smoking/quitting smoking	940 (15.2)	236 (13.6)	704 (15.8)		
Drinking alcohol				1.899	0.168
No alcohol/moderate alcohol consumption	5951 (96.0)	1672 (96.5)	4279 (95.7)		
Binge drinking	251 (4.0)	60 (3.5)	191 (4.3)		
Exercise status				6.912	0.009
Moderate to vigorous exercise	1223 (19.7)	379 (21.9)	844 (18.9)		
Lack of exercise	4979 (80.3)	1353 (78.1)	3626 (81.1)		
* indicates the T-statistic of the t test					

Variables	All(n = 6202)	Normal (n = 1732)	PreMetS(n = 4470)	χ^2	P
Sleep duration (h/d)				23.204	< 0.001
7–8	2826 (45.6)	875 (50.5)	1951 (43.7)		
< 7 or > 9	3368 (54.4)	856 (49.5)	2512 (56.3)		
Diet				28.046	< 0.001
A Healthy Diet	2523 (40.7)	797 (46.0)	1726 (38.6)		
Under nutrition/over-nutrition	3679 (59.3)	935 (54.0)	2744 (61.4)		
* indicates the T-statistic of the t test					

3.3 Correlation analysis between insulin resistance related indicators and pre-metabolic syndrome

All measures related to insulin resistance exhibited a positive association with preMetS, even after controlling for all covariates. Notably, TG/HDL displayed the strongest correlation with preMetS (OR = 10.48, 95%CI: 8.51–12.90). Conversely, WC demonstrated the weakest association (OR = 1.09, 95%CI: 1.08–1.10) (Table 6).

Further investigation of this correlation was conducted using a multivariate logistic regression model with restricted cubic splines and smooth curve fitting. The restricted cubic spline curves revealed a nonlinear positive correlation between all insulin resistance indices and preMetS ($P_{\text{nonlinear}} < 0.001$). After reaching their respective inflection points, the risk of preMetS increases more rapidly for TG/HDL, TYG, WC, and WHtR. Additionally, the magnitude of risk changes for ABSI and BMI is smaller compared to the other four indicators. (Fig. 1).

Table 6
Correlation Analysis between Insulin Resistance Indicators and PreMetS

Index	OR (95%CI) ^a	P	OR (95%CI) ^b	P	OR (95%CI) ^c	P
TYG	6.85(5.92–7.93)	< 0.001	6.72(5.79–7.79)	< 0.001	6.53(5.56–7.69)	< 0.001
TG/HDL	10.71(8.81–13.02)	< 0.001	11.69(9.57–14.28)	< 0.001	10.48(8.51–12.90)	< 0.001
ABSI	1.93(1.72–2.16)	< 0.001	1.66(1.48–1.87)	< 0.001	1.62(1.44–1.83)	< 0.001
WC	1.09(1.08–1.10)	< 0.001	1.10(1.09–1.11)	< 0.001	1.09(1.08–1.10)	< 0.001
BMI	1.24(1.21–1.27)	< 0.001	1.26(1.23–1.29)	< 0.001	1.23(1.20–1.26)	< 0.001
WHtR	5.02(4.38–5.74)	< 0.001	4.62(4.03–5.29)	< 0.001	4.20(3.64–4.84)	< 0.001
Note: ^a Model 1: Uncorrected; ^b Model 2: Corrected for gender, age; ^c Model 3: Model 2 + education, marital status, smoking, drinking, sleep, diet, exercise time, TC, LDL-c, SUA, Cre, and BUN.						

Note

The red area represents the 95% confidence interval (CI). Each model is adjusted for gender, age, education, marital status, smoking, drinking, sleep duration, diet, exercise time, cholesterol, low-density lipoprotein cholesterol, uric acid, creatinine, and blood urea nitrogen. TYG: Triglyceride-Glucose Index, TG/HDL: Triglyceride/High-Density Lipoprotein Cholesterol ratio, WHtR: Waist to height ratio, BMI: body mass index, ABSI: A Body Shape Index, WC: Waist Circumference.

3.4 The screening ability of insulin resistance-related indicators for pre-metabolic syndrome

The ROC curve for the screening ability of insulin resistance-related indicators for preMetS risk is shown in the figure below. The AUC and related parameters of TYG and TG/HDL are all greater than those of traditional indicators. The AUC value for TYG is 0.731 (95% CI: 0.718–0.744), which is larger than the AUC of other indicators ($P_{\text{delong}} < 0.05$). The Youden index is 0.352 (sensitivity = 0.867, specificity = 0.485), with an optimal cutoff value of 7.736. (Fig. 2 and Table 7).

Note

TYG: Triglyceride-Glucose Index, TG/HDL: Triglyceride/High-Density Lipoprotein Cholesterol ratio, WHtR: Waist to height ratio, BMI: body mass index, ABSI: A Body Shape Index, WC: Waist Circumference.

Table 7
ROC Analysis of Insulin Resistance Indices for Screening PreMetS

Variables	Cut-off	Sensitivity	Specificity	Youden	AUC (95%CI)	P
TYG	7.736	0.867	0.485	0.352	0.731(0.718–0.744)	-
TG/HDL	0.899	0.822	0.507	0.329	0.722(0.709–0.735)	0.023
WHtR	0.503	0.763	0.546	0.309	0.705(0.692–0.719)	0.004
BMI	22.492	0.601	0.631	0.232	0.662(0.648–0.677)	< 0.001
ABSI	7.794	0.573	0.584	0.157	0.601(0.586–0.617)	< 0.001
WC	81.625	0.782	0.488	0.270	0.682(0.668–0.696)	< 0.001

Notes: * indicates the P value from the DeLong test comparing the AUC with that of TYG. TYG: Triglyceride-glucose index, TG/HDL: Triglyceride-to-high-density lipoprotein cholesterol ratio, WHtR: Waist-to-height ratio, BMI: Body mass index, ABSI: A body shape index, WC: Waist circumference.

3.5 The ability of insulin resistance related indicators combined with nomogram model to screen pre-metabolic syndrome

After conducting multivariate logistic regression analysis to screen the variables, we excluded those that were difficult to obtain and had a score lower than 5 in the nomogram. Subsequently, we established the nomogram model and plotted its calibration curve and ROC curve (Fig. 3).

The diagnostic performance of the TG/HDL and TYG nomogram models surpassed that of all insulin resistance indicators. The AUC (95% CI) for the TG/HDL and TYG nomogram models were 0.766 (0.754–0.779) and 0.771 (0.759–0.784), respectively, with consistent screening abilities between TG/HDL and TyG ($P_{\text{delong}} > 0.05$). However,

the TG/HDL nomogram model exhibited better fit with an R2 value of 0.267 compared to R2(TYG) = 0.239, along with smaller errors indicated by MAE(TG/HDL) = 0.005 > MAE(TYG) = 0.025 (Table 8).

Note

Top left: ROC curve for insulin resistance index screening PreMetS; top right: calibration curve for TG/HDL; bottom: column chart for TG/HDL. TYG: Triglyceride-Glucose Index, TG/HDL: Triglyceride/High-Density Lipoprotein Cholesterol, WHtR: Waist to height ratio, BMI: body mass index, ABSI: A Body Shape Index, WC: Waist Circumference.

Table 8
ROC Analysis of Column Chart Models for Screening PreMetS Using Insulin Resistance Index

Variables	Cut-off	Sensitivity	Specificity	Youden	AUC (95%CI)	P*	R2	MAE	MSE
TYG + age	71.965	0.783	0.618	0.401	0.766(0.754–0.779)	-	0.239	0.025	9.90E-04
TG/HDL + age	8.056	0.755	0.650	0.405	0.771(0.759–0.784)	0.129	0.267	0.005	3.00E-05
WHtR + age	17.753	0.794	0.553	0.346	0.730(0.716–0.743)	< 0.001	0.182	0.017	4.10E-04
BMI + age	14.755	0.682	0.636	0.318	0.719(0.705–0.733)	< 0.001	0.162	0.010	1.40E-04
ABSI + age	30.501	0.620	0.63	0.250	0.664(0.649–0.679)	< 0.001	0.094	0.002	1.00E-05
WC + age	20.506	0.701	0.632	0.333	0.724(0.710–0.737)	< 0.001	0.174	0.017	4.20E-04
Note: * indicates the p-value of the DeLong test for AUC comparison with TYG and age column chart. TYG: Triglyceride-glucose index, TG/HDL: Triglyceride/high-density lipoprotein cholesterol ratio, WHtR: Waist to height ratio, BMI: Body mass index, ABSI: A Body Shape Index, WC: Waist circumference.									

3.5 Subgroup Analysis

The ROC analysis in Table S6 demonstrates the superior screening ability of insulin resistance-related parameters and conventional measures for identifying preMetS risk among individuals with normal weight. TYG and TG/HDL exhibit larger AUC values and related parameters compared to traditional indicators. Specifically, the AUC value of TYG is 0.727 (95%CI: 0.711–0.743), surpassing that of other indicators significantly (Pdelong < 0.05) (Table 9).

Table 9
ROC Analysis of Insulin Resistance Indicators for Screening PreMetS in the Normal Weight Subgroup

Variables	Cut-off	Sensitivity	Specificity	Youden	AUC (95%CI)	P*
TYG	7.730	0.864	0.488	0.352	0.727(0.711–0.743)	-
TG/HDL	0.899	0.831	0.509	0.340	0.718(0.702–0.734)	0.084
WHtR	0.493	0.731	0.489	0.221	0.643(0.625–0.661)	< 0.001
BMI	20.893	0.388	0.756	0.144	0.589(0.570–0.608)	< 0.001
ABSI	7.794	0.537	0.621	0.158	0.600(0.581–0.618)	< 0.001
WC	79.025	0.702	0.462	0.164	0.612(0.593–0.630)	< 0.001

Notes: * indicates the p-value from the DeLong test for AUC of the column chart between TYG and age. TYG: Triglyceride-Glucose Index, TG/HDL: Triglyceride/High-Density Lipoprotein Cholesterol ratio, WHtR: Waist to height ratio, BMI: body mass index, ABSI: A Body Shape Index, WC: Waist Circumference.

4. Discussion

This study compared the prevalence and consistency of preMetS across three definitions of MetS: Revised ATP III, IDF, and JCDCG. When using the three different definitions, the IDF definition had the lowest age-standardized prevalence of preMetS and MetS, regardless of gender, while the Revised ATP III definition had the highest age-standardized prevalence. Additionally, among the general population and women, the Revised ATP III definition had the highest prevalence of MetS, while the JCDCG definition had the highest prevalence of MetS among men. To date, the concept of preMetS has been rarely used in prevalence studies, and there is significant variability in prevalence rates across different studies. To establish a standardized framework, previous similar studies have widely utilized the "1–2 components" definition, which strongly supports its rationality as a clinical indicator for a "high-risk pre-state"^{[39][40]}.

In previous studies, the prevalence of preMetS ranged from 12.1%^[14] to 24%^[41], whereas in this study, the prevalence of preMetS ranged from 9.77% to 48.53% across different definitions. This substantial variation fundamentally arises because individual components are defined differently across the three standards, meaning that the comparison is essentially an evaluation of different criteria combinations. This discrepancy between our findings and past literature is primarily due to the exclusion of individuals with diabetes and CVD in those studies, and secondarily, the current trend of rising chronic disease prevalence, with a significant time interval between this study and previous ones. Additionally, the elderly population accounted for a high proportion in this study, with an average age of 55.88 years. As age increases, the prevalence of underlying diseases also rises, and MetS patients are more common in the elderly population^[42].

Previous studies in the Chinese population have also investigated differences in MetS prevalence due to MetS definitions^[43], but no studies have further analyzed preMetS. There are significant differences in preMetS participants identified by MetS definitions from different countries and organizations. In this study, the preMetS prevalence defined by the IDF was significantly lower than the other two definitions, as the IDF definition of preMetS specifically includes abdominal obesity, with overly stringent inclusion criteria. The revised ATP III and JCDCG definitions show good consistency, with the main difference being the low overlap rate in the prevalence of abnormal blood glucose and low HDL-C. However, the revised ATP III reduces postprandial blood glucose measurements, making it more suitable for large-scale screening programs in the Chinese population. Using different criteria to

define preMetS, the main differences lie in the variations in waist circumference (WC) and blood glucose levels across different populations, emphasizing the importance of standardized definitions to ensure comparability of survey results across different countries and time periods^{[44][45][46]}.

This study found that the four indicators of obesity (BMI), abdominal obesity (WC, WHtR), and visceral obesity (ABSI), as well as the two insulin resistance indicators (TYG and TG/HDL), exhibit significant differences in their ability to screen for preMetS. After adjusting for confounding factors, all indicators were associated with preMetS, with TYG and TG/HDL showing the strongest associations. Further analysis revealed that the TYG index had the strongest predictive ability for preMetS, while age significantly enhanced the diagnostic capability of TG/HDL. Hypertension and hyperglycemia had the highest prevalence among the five components in this study, serving as the primary risk factors for preMetS and major contributors to the progression of metabolic dysfunction^[47], a process closely associated with insulin resistance. The good performance of TYG and TG/HDL in screening for preMetS may be related to their higher association with insulin resistance^[48]. Additionally, we found that WHtR may be an important non-invasive screening indicator for preMetS (AUC > 0.7). In previous studies^[49], WHtR was identified as one of the cost-effective and non-invasive screening indicators for MetS in non-obese individuals, consistent with the findings of this study.

This study further evaluated normal-weight adults in the Fuzhou region, where TYG and TG/HDL demonstrated the best screening performance. Studies have shown that individuals with normal weight but metabolic risk have a higher cardiovascular risk^[49]. Additionally, due to normal BMI, people often overlook their metabolic risk. Therefore, it is necessary to screen for metabolic risk in individuals with normal weight.

This study employed a method involving multiple measurements of hematological indicators or physical measurements, thereby making large-scale community preMetS screening more convenient and feasible. preMetS and MetS multi-process diagnosis is difficult to implement in community screening due to the need for cumbersome physical examinations and clinical indicators^[50]. Furthermore, using different instruments to conduct complex examinations of the five risk factors in large-scale screening programs may reduce efficiency^{[51][52]} and result in significant measurement errors. TYG, TG/HDL, and WHtR all demonstrate good performance (AUC > 0.7) and require fewer measurements compared to the five MetS component measurements. Therefore, applying these three indicators for preMetS screening (revised ATP III) is more convenient in primary healthcare clinical practice.

5. Clinical and public health potential

Firstly, in the three classifications of MetS, the IDF criteria are deemed inappropriate, as they overly emphasize abdominal obesity and overlook individuals with unhealthy metabolism. Secondly, following MetS screening, the remaining "healthy" population can still be differentiated using the retained screening indicators, thereby further enhancing the utility of these indicators. Lastly, we have found that WHtR may be the only non-invasive and effective indicator for preMetS (JCDCG) screening.

6. Strengths and Limitations

The strength of this study lies in including a sufficient number of samples and incorporated certain indicators for MetS screening, further exploring the additional effects of these indicators. However, the study has some limitations. Firstly, although the AUC in our study was greater than 0.7, it did not exceed 0.8, indicating that these screening indicators are considered good but not excellent. Secondly, we observed significant numerical changes in

age in the column chart, while variables related to gender and lifestyle habits showed smaller variations. However, it remains unknown whether these numerical changes might be influenced by different ethnicities or regions. Thirdly, the participants in our study were all residents of coastal areas in China, and the results may not be suitable for extrapolation to other countries or inland regions. Further prospective cohort studies with larger sample sizes and more detailed data are needed to assess the identification value of each indicator in different populations.

7. Conclusion

The consistency between the revised ATP III and JCDCG in MetS tri-classification is good. TYG has the best identification ability for preMetS (revised ATP III and JCDCG). Additionally, WHtR has equally good identification ability for preMetS (JCDCG). The nomogram model with TG/HDL has the best identification ability. In conclusion, the consistency of MetS tri-classification is better in the revised ATP III and JCDCG. TYG is an effective indicator for identifying preMetS in adults in Southeast China. WHtR is a non-invasive indicator for screening preMetS (JCDCG). The diagnostic capabilities are improved with the inclusion of age and TG/HDL in the nomogram model, with less error.

Abbreviations

IDF	
International Diabetes Federation	
Revised ATP III	
Adult Treatment Panel III of the National Cholesterol Education Program, Revised	
JCDCG	
Joint Committee for Developing Chinese Guidelines on Prevention and Treatment of Dyslipidemia. SBP, Systolic	
Blood Pressure	
DBP	
Diastolic Blood Pressure	
FBG	
Fasting Blood Glucose	
PBG	
Postprandial blood Glucose	
TC	
Total Cholesterol	
HDL-C	
High-Density Lipoprotein Cholesterol	
LDL-C	
Low-Density Lipoprotein Cholesterol	
BUN	
Blood Urea Nitrogen	
TYG: Triglyceride-glucose index	
TG/HDL: Triglyceride-to-high-density lipoprotein cholesterol ratio	
WHtR: Waist-to-height ratio	
BMI: Body mass index	
ABSI: A body shape index	
WC: Waist circumference. AUC: area under the curve.	

Declarations

Ethics approval and consent

This study was approved by the Ethics Committee of the Fuzhou Center for Disease Control and Prevention (approval number: 2022002). Informed consent was obtained from all participants and/or their legal guardians for this study. There is no conflict of interest in this study.

Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

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Authors' contributions

Conceptualization and methodology, Xiaoyang Zhang and Youqiong Xu; writing—original draft preparation, Zuxian Hu, Rusen Li and Zhaoxun Xie; writing—review and editing, Xinfeng Huang and Ruoming Huang; validation, Lu Lu; formal analysis, Hong Li. All authors have read and agreed to the published version of the manuscript.

Declaration of Interest Statement

The authors declare no potential conflicts of interest.

Acknowledgments

None.

Consent for publication

Not applicable.

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Figures

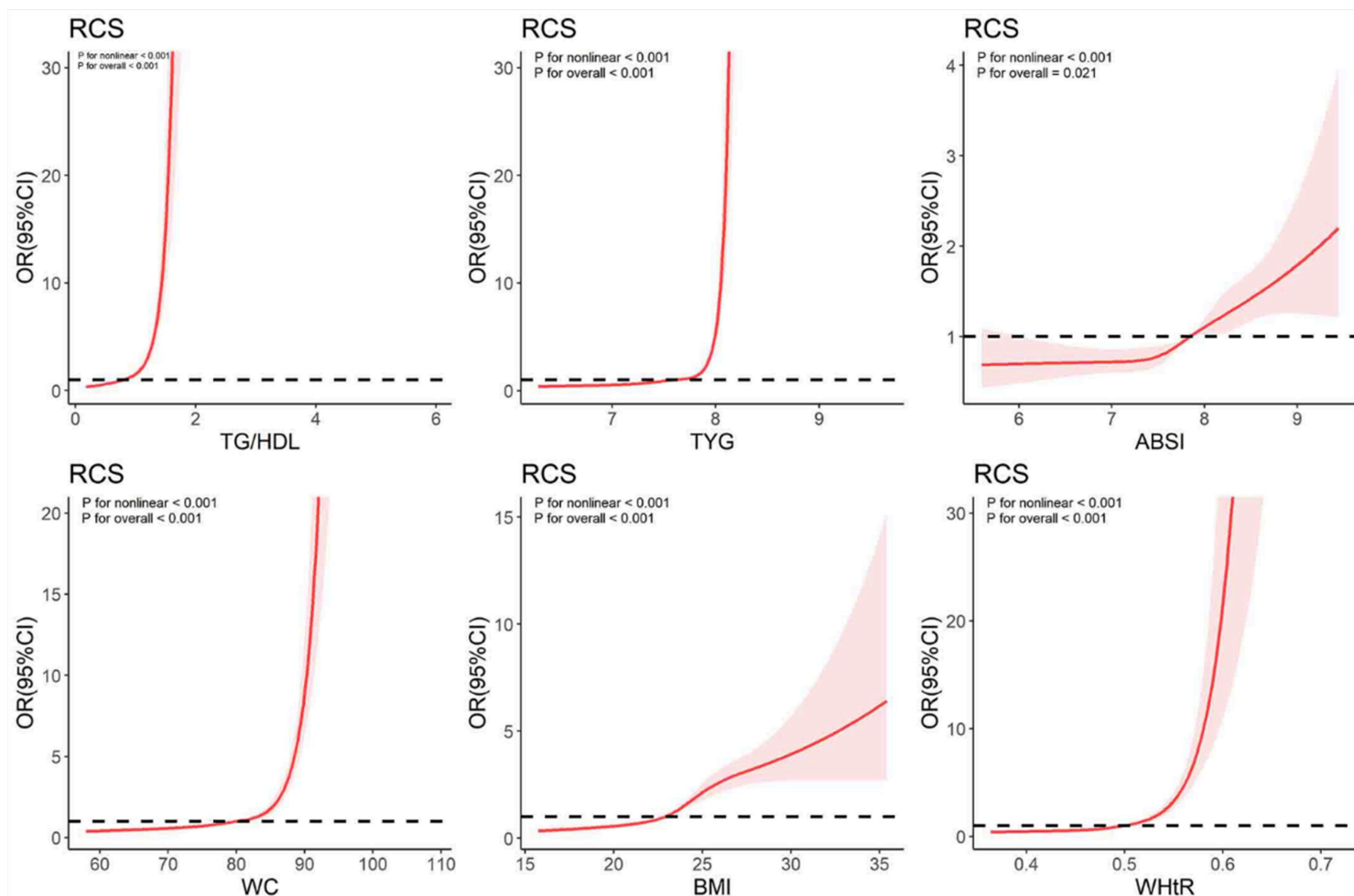


Figure 1

Restrictive cubic spline modeling of the association between insulin resistance indices and PreMetS (Revised ATP III)

Note: The red area represents the 95% confidence interval (CI). Each model is adjusted for gender, age, education, marital status, smoking, drinking, sleep duration, diet, exercise time, cholesterol, low-density lipoprotein cholesterol, uric acid, creatinine, and blood urea nitrogen. TYG: Triglyceride-Glucose Index, TG/HDL: Triglyceride/High-Density Lipoprotein Cholesterol ratio, WHtR: Waist to height ratio, BMI: body mass index, ABSI: A Body Shape Index, WC: Waist Circumference.

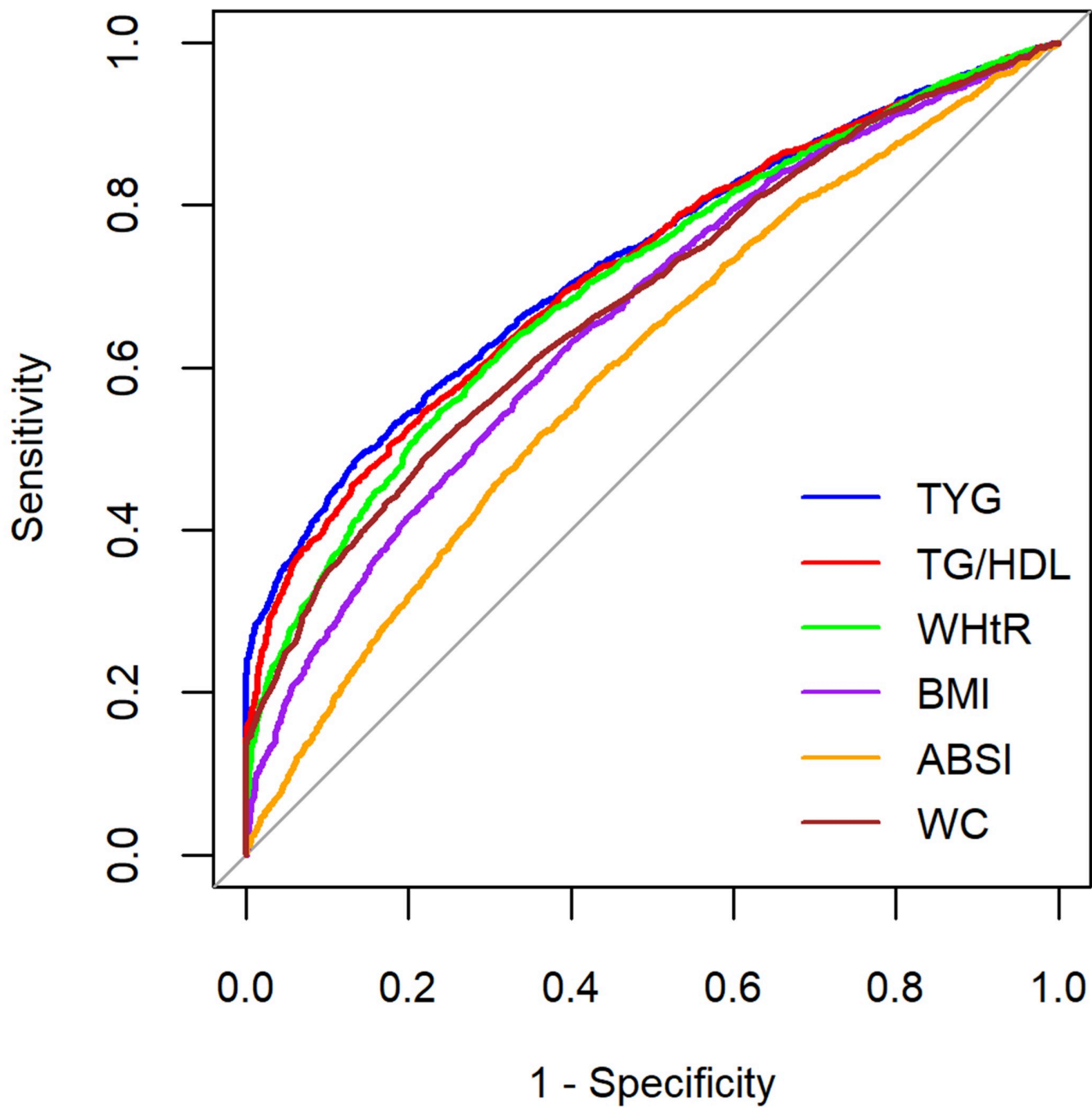


Figure 2

The ROC curves for PreMetS screening

Note: TYG: Triglyceride-Glucose Index, TG/HDL: Triglyceride/High-Density Lipoprotein Cholesterol ratio, WHtR: Waist to height ratio, BMI: body mass index, ABSI: A Body Shape Index, WC: Waist Circumference.

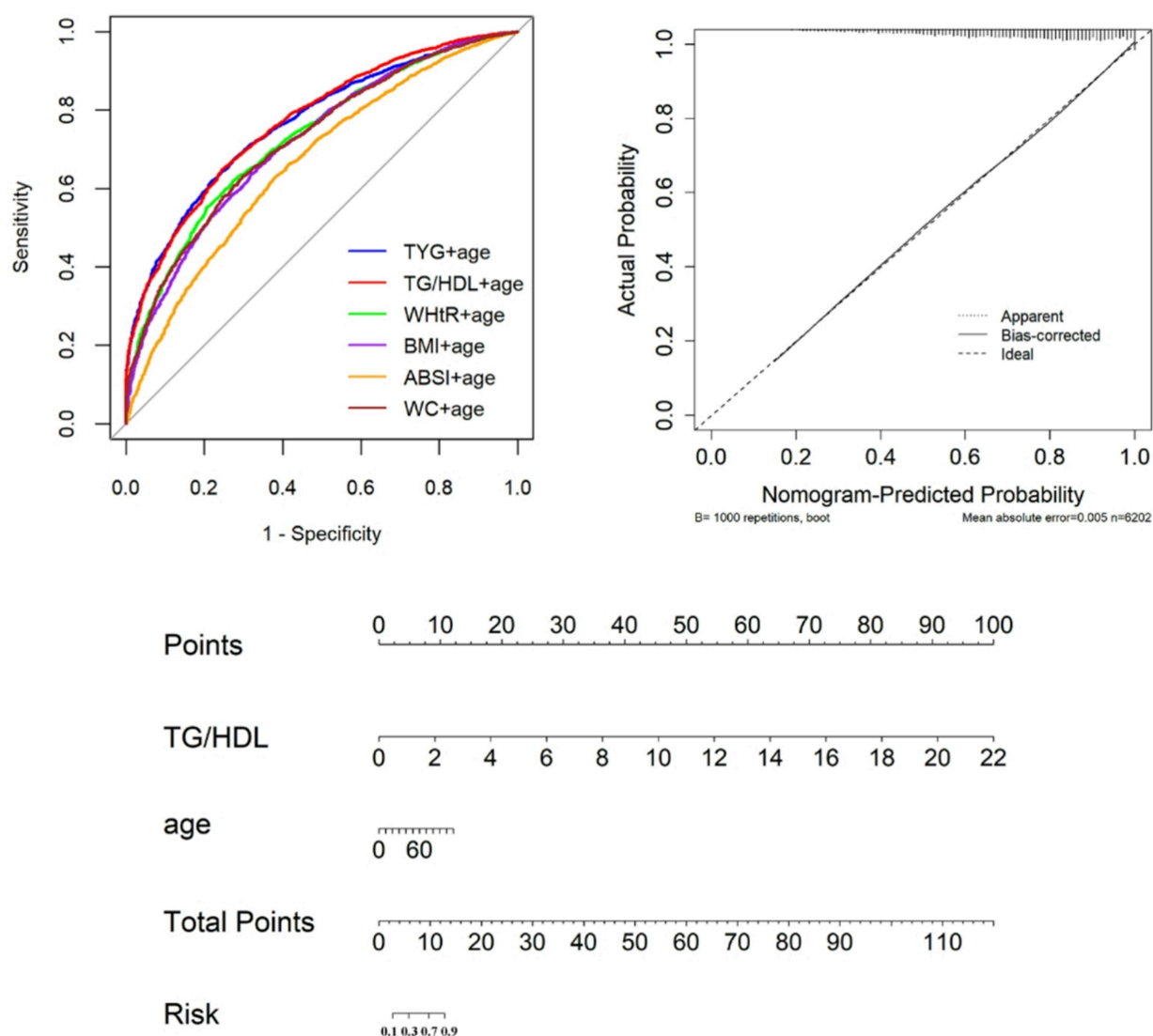


Figure 3

Comparison of ROC Curves for Insulin Resistance Index Screening PreMetS and Calibration Curve and Column Chart for TG/HDL.

Note: Top left: ROC curve for insulin resistance index screening PreMetS; top right: calibration curve for TG/HDL; bottom: column chart for TG/HDL. TYG: Triglyceride-Glucose Index, TG/HDL: Triglyceride/High-Density Lipoprotein Cholesterol, WHtR: Waist to height ratio, BMI: body mass index, ABSI: A Body Shape Index, WC: Waist Circumference.