Diabetes, Metabolic Syndrome and Obesity

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ORIGINAL RESEARCH

Comparison of Incidence of Metabolic Syndrome and Five Obesity- and Lipid-Linked Indicators for Predicting Metabolic Syndrome Among Normal-Weight and Overweight Adults

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Purpose: Metabolic syndrome (MetS) is an increasingly prevalent issue in China's public health landscape. Few studies have investigated the metabolic syndrome (MetS) in overweight people. We proposed to analyze and contrast the occurrence of MetS in normal-weight and overweight individuals and identify potential indicators for forecasting MetS in adults in Zhejiang Province.

Methods: This cohort study included 359 adults aged 40–65 years and followed up for five years in Zhejiang Province. The study assessed the predictive capabilities of five indicators linked to obesity and lipid levels, namely body mass index (BMI), waist-to-height ratio (WHtR), triglyceride-glucose index (TyGi), and their combined indices (TyG-BMI, TyG-WHtR). The evaluation was done employing the area under the Receiver Operating Characteristic (ROC) Curve (AUC). DeLong test was applied to compare area under different ROC curves.We evaluated the relationships between five variables and MetS using multivariate logistic regression.

Results: In normal-weight individuals, the five-year cumulative incidence of MetS was 21.85%, but in overweight people, it was 60.33%. After adjusting for confounding factors, BMI, WHtR, TyGi, TyG-BMI, and TyG-WHtR were independently linked to MetS in normal-weight individuals, while BMI, TyGi, TyG-BMI, and TyG-WHtR were independently linked to MetS in overweight individuals. In normal-weight individuals, the WHtR (AUC=0.738 and optimal threshold value =0.469) and TyG-WHtR (AUC=0.731 and optimal threshold value =4.121) had the larger AUC, which was significantly greater than that of the different three indicators. The TyG-BMI (AUC=0.769 and optimal threshold value = 211.099) was the best predictor of MetS in overweight individuals.

Conclusion: The five-year cumulative incidence of MetS in overweight people was approximately triple that of normal-weight people in Zhejiang Province. In the overweight population, the TyG-BMI performed better than the other indices in predicting MetS. WHtR and TyG-WHtR outperformed BMI, TyGi, and TyG-BMI in anticipating MetS in a normal-weight population.

Keywords: metabolic syndrome, normal weight, overweight, WHtR, BMI, TyG

Introduction

Metabolic syndrome (MetS) is distinguished by a series of metabolic dysfunctions encompassing hyperglycemia, dyslipidemia, central obesity, and hypertension.[1] People with MetS are approximately twofold elevated risk of developing cardiovascular disease contrasted with those without MetS.[2] With the development of the global economy, the incidence of metabolic syndrome is also rising rapidly. Approximately one in four people suffer from MetS globally.[3] A 2018 systematic review revealed that between 1991 and 1995, the occurrence of MetS in the Chinese population was 8.8%, which then rose to 29.3% between 2011 and 2015.[4] Fan Yao et al in 2021 manifested that the MetS occurrence was found to be 31.1% (30.0% in males and 32.3% in females). This suggests that almost 416 million people in our nation are affected by MetS.[5] This poses a major obstacle to the healthcare system.

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Obesity has emerged as a worldwide issue in public health,[6] which increases the risk of numerous diseases, including MetS,[7] diabetes mellitus (DM),[8] hypertension, sleep apnea-hypopnea syndrome, and stroke.[9] With dietary and lifestyle modifications, the incidence of overweight and obesity is likewise elevating quickly in China. Nevertheless, the overweight prevalence in the Chinese population is rapidly increasing and is significantly higher than that of obesity.[10,11] A real-world study based on obesity prevalence and related complications in 15.77 million adults in China was published in August 2023, with 34.8% being overweight and 14.1% obese.[12] The health problems associated with being overweight have not received much attention in China, and few studies have investigated the MetS in overweight people. It's worth exploring whether there is a difference in MetS between overweight and normal-weight individuals. Understanding the MetS risk factors in overweight people and preventing the occurrence of MetS-related diseases is helpful in reducing the burden on public health care in China.

Abdominal obesity and lipid metabolism disorder are important features of MetS. Various obesity- and lipid-linked measures have been created to forecast MetS. Lipid accumulation product,[13] visceral adiposity index (VAI),[14] and Chinese visceral adiposity index[15] are estimates of visceral fat that have been recently developed depending on waist circumference (WC), body mass index (BMI), and circulating lipids ((high-density lipoprotein cholesterol (HDL-C) and triglycerides(TG)), which perform well in predicting MetS. A recent meta-analysis of 232 participants by Khan et al[16] revealed that waist-to-height ratio (WHtR) and VAI were the most accurate predictors of MetS. Triglyceride and glucose-related factors such as the triglyceride-glucose (TyG) index (TyGi) and their related indices (TyG-BMI, TyG-WHtR) also provide a good predictive value for MetS.[17] Da-Hye et al[18] identified the TyGi is better than HOMA-IR in forecasting MetS. However, most of these studies did not include East Asian populations. Further studies involving Chinese adults are required to explore the relevance of these indicators in predicting MetS.

Using the study provided, many indications linked to obesity and lipids are used to anticipate MetS. In this research, we selected cost-effective and readily calculable indicators, such as BMI, WHtR, TyGi, TyG-BMI, and TyG-WHtR, and assessed their respective capacities to forecast MetS. Therefore, regional representative samples were selected in this investigation to contrast the MetS incidence between normal-weight and overweight individuals and identify potential regional representative obesity- and lipid-linked markers for predicting MetS among normal-weight and overweight adults in Zhejiang Province.

Material and Methods

Study Participants

This cohort research recruited volunteers between the ages of 40 and 65 from the Caihe community in the Jianggan District of Hangzhou. The recruitment process occurred from January to March 2010, while the follow-up was carried out in 2011, 2013, and 2015. The criteria for exclusion were as follows: (i) Individuals receiving glucocorticoids; (ii) Individuals with cirrhosis and ascites; (iii) Individuals with hyperthyroidism or hypothyroidism; (iv) Patients with cancer; (v) Individuals with severe impairments or mental disorders; (vi) Pregnant and breastfeeding women; (vii) Participants who have MetS at the beginning of the study; (viii) Individuals who have incomplete information; (ix) Individuals who were lost to follow-up; (x) BMI less than 18.5 kg/m2; (xi) BMI ≥ 28 kg/m2. The study received approval from the ethical committee of Sir Run Run Shaw Hospital. Figure 1 illustrates a flow diagram of the research participants. According to China's classification,[19] the subjects were categorized into BMI groups: normal-weight (BMI 18.5–23.9 kg/m²) and overweight (BMI 24.0–27.9 kg/m²).

Demographic Characteristics

The following information was obtained through rigorous questionnaires: Age, gender, marital status, educational levels, occupation nature, smoking behaviors, alcohol consumption, dietary habits, regular exercise, sleeping hours, and family history of metabolic disease (FHMD).

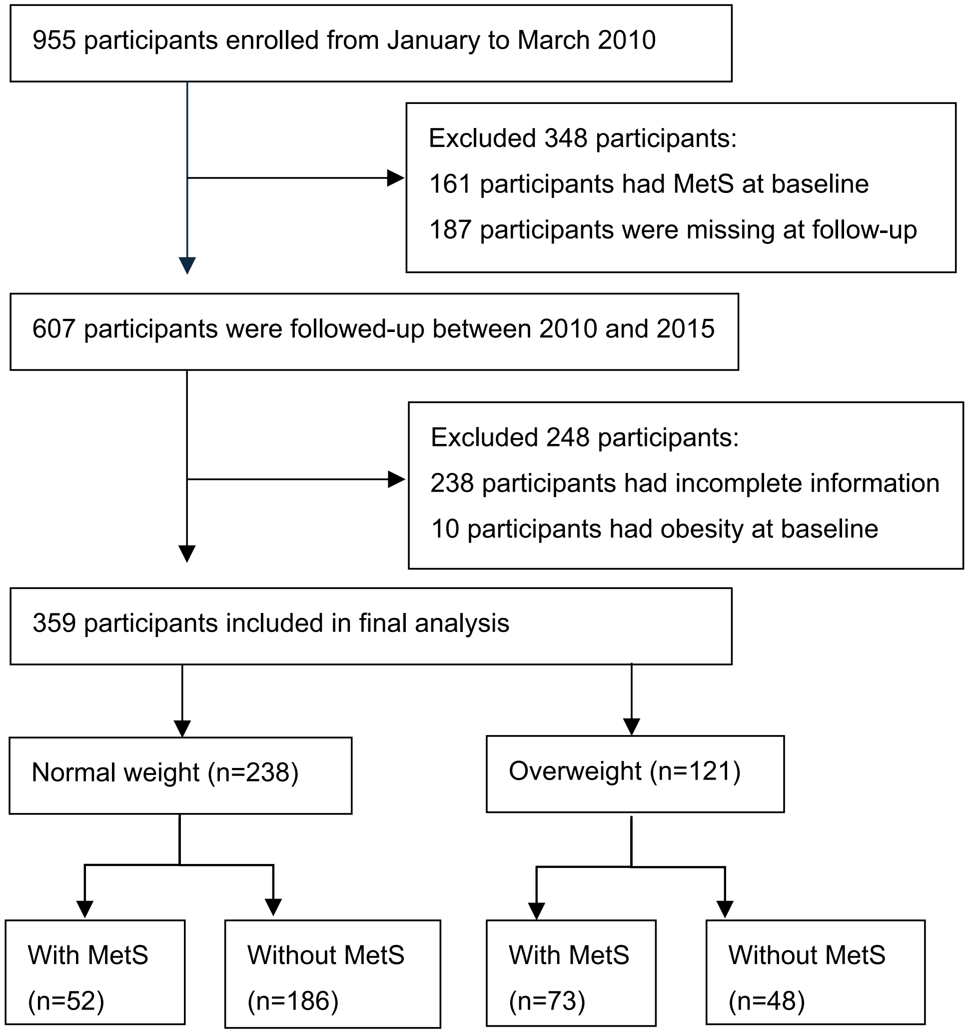

Figure 1 Flow chart of the current cohort.

The 8 covariates were classified as follows:

1. Marital status: (1) married and (2) single.
2. Educational levels: (1) high school or above and (2) below high school.
3. Occupation nature: (1) manual, (2) physical and mental, and (3) mental works.
4. Smoking behaviors: (1) smoker, (2) former smoker, and (3) non-smoker.
5. Alcohol consumption: (1) no drinking, (2) less than three times a month, and (3) three or more times a month.
6. Dietary habits: (1) main meat dishes, (2) balanced meat and vegetables, and (3) main vegetable dishes.
7. Regular exercise: more than one day of physical exercise per week.
8. FHMD: first-degree relatives with two or more metabolic diseases, including hypertension, diabetes, hyperlipidemia, and obesity.

Assessment of Anthropometric Measurements and Metabolic Profiles

Trained investigators assessed weight, height, WC, and blood pressure using established techniques that have previously been published.[20] Individuals fasted for at least 8 h before venous blood was collected to measure fasting plasma glucose

(FPG), TG, HDL-C, and other biochemical indicators. The five indices linked to obesity and lipids (BMI, WHtR, TyGi, TyG-BMI, and TyG-WHtR) are computed employing the subsequent formula:

(1) BMI = Weight (kg) / Height(m)^2
(2) WHtR = WC (cm) / Height (cm)
(3) TyGi = Ln [(TG (mg/dl) × glucose (mg/dl)/2)]
(4) TyG-BMI = TyG × BMI
(5) TyG-WHtR = TyG × WHtR

Metabolic Syndrome Definition

The definition of MetS was based on the standards established via the International Diabetes Federation (IDF 2005), with the WC cutoff adjusted for the Chinese population.[21] Abdominal obesity was classified as having a WC ≥ 90 cm in men and WC ≥ 80 cm in women. An individual was diagnosed with MetS when abdominal obesity plus at least two other components were present:

1) SBP ≥ 130 mmHg or DBP ≥ 85 mmHg or previous diagnosis of hypertension; 2) fasting plasma glucose ≥ 5.6 mmol/L or confirmed diagnosis diabetes; 3) triglycerides ≥ 1.7 mmol/L; 4) HDL-C < 1.04 mmol/ L for men and < 1.29 mmol/L for women.

Statistical Analysis

The study data were analyzed utilizing the SPSS program (Ver. 23.0). The chi-square or Fisher's exact tests were employed to categorize variables. In contrast, the *t*-test or the Mann–Whitney *U*-test was utilized to ascertain the significant disparities among continuous variables. The percentages represented the categorical variables, whereas the means ± standard deviations (SD) or the median and interquartile range were utilized to describe the continuous variables for normally distributed or skewed data, respectively. The study employed Receiver Operating Characteristic (ROC) curves to assess and ascertain the predictive precision of five indicators related to obesity and lipid levels. To ascertain the efficacy of these indicators in detecting MetS, the area under the curve (AUC) was computed. Differences between AUC were determined using DeLong's test. The determination of the threshold criteria was conducted utilizing the Youden index. The five indicators linked to lipids and obesity were allocated into two distinct categorical variables according to their optimal threshold values. The connections between indicators and MetS were ascertained utilizing binary logistic regression. Clinically relevant baseline variables or variables with $p < 0.2$ upon univariate analysis were entered into the multivariate analysis. After controlling for age, gender, UA, HDL-C, SBP, DBP, sleeping hours and FHMD, the OR and 95% CI for each obesity- and lipid-linked indicator concerning MetS were estimated. A p-value < 0.05 was deemed to be significant.

Results

General Information of Participants

Typically, 359 participants were enrolled in this investigation, including 238 normal-weight (66.3%) and 121 overweight (33.6%) individuals. Based on the baseline characteristics are listed in Table 1, there were significant variations between normal-weight and overweight individuals in gender, BMI, WHtR, UA, TG, HDL-C, TyGi, TyG-BMI, TyG-WHtR, SBP, DBP, and dietary habits ($p < 0.05$). Nevertheless, no significant variations were seen in age, FPG, sleeping hours, marital status, FHMD, regular exercise habits, smoking behaviors, alcohol consumption, occupation nature, and educational levels between the two groups ($p > 0.05$). Due to the significant disparities ($p < 0.05$), the primary analysis was conducted independently based on weight.

Different Baseline Features of People with or Without MetS During Follow-Up

Tables 2 and 3 present the fundamental features of the research participants, categorized by weight, both with and without MetS. The percentage of overweight individuals with MetS (60.33%) was significantly higher than that of normal-weight

Table 1 Baseline Characteristics of Participants According to Weight Differences

Variables	Normal weight (n=238)	Overweight (n=121)	*p* value
Age, years	53.91 ± 6.30	53.60 ± 6.53	0.670
Male, n (%)	88 (37.0)	63 (52.1)	0.006
BMI, kg/m2	21.67 ± 1.57	25.59 ± 1.13	<0.001
WHtR	0.46 ± 0.04	0.51 ± 0.03	<0.001
FPG, mmol/L	4.99 ± 0.93	4.98 ± 0.92	0.937
UA, µmol/L	272.45 ± 83.17	313.14 ± 92.57	<0.001
TG[a], mmol/L	1.23 (0.84,1.80)	1.39 (1.10,1.81)	0.003
HDL-C, mmol/L	1.50 ± 0.37	1.35 ± 0.34	<0.001
TyGi	8.46 ± 0.81	8.67 ± 0.58	0.012
TyG-BMI	183.50 ± 24.33	221.85 ± 18.51	<0.001
TyG-WHtR	3.86 ± 0.53	4.46 ± 0.38	<0.001
SBP, mmHg	118.87 ± 15.55	123.13 ± 14.97	0.013
DBP, mmHg	78.89 ± 8.88	82.74 ± 9.36	<0.001
Sleeping hours	7.18 ± 1.20	7.11 ± 1.36	0.581
Marital status, n (%)			0.393
Married	224 (94.1)	111 (91.7)	
Single	14 (5.9)	10 (8.3)	
FHMD, n (%)	108 (45.4)	53 (43.8)	0.776
Regular exercise, n (%)	97 (42.5)	52 (44.1)	0.786
Smoking behaviors, n (%)			0.054
Non-smoker	179 (75.2)	77 (63.6)	
Former smoker	10 (4.2)	10 (8.3)	
Smoker	49 (20.6)	34 (28.1)	
Alcohol consumption, n (%)			0.462
No drinking	145 (60.9)	66 (54.5)	
Less than three times a month	44 (18.5)	24 (19.8)	
Three or more times a month	49 (20.6)	31 (25.6)	
Dietary habits, n (%)			0.019
Main vegetable dishes	63 (26.5)	24 (19.8)	
Balance meats and vegetables	165 (69.3)	83 (68.6)	
Main meat dishes	10 (4.2)	14 (11.6)	
Occupation nature, n (%)			0.081
Manual work	44 (18.5)	32 (26.4)	
Physical and mental work	100 (42.0)	54 (44.6)	
Mental work	94 (39.5)	35 (28.9)	
Educational level, n (%)			0.754
High school or above	106 (44.54)	56 (46.23)	
Below high school	132 (55.46)	65 (53.77)	

Notes: Values are mean ± SD, n (%) or median (25th–75th percentile), unless otherwise stated. [a]The Mann–Whitney *U*-test was utilized to ascertain the significant disparities.

Abbreviations: BMI, body mass index; WHtR, waist-to-height ratio; FPG, fasting plasma glucose; UA, uric acid; TG, triglycerides; HDL-C, high-density lipoprotein cholesterol; TyGi, triglyceride and glucose index; TyG-BMI, TyG related to BMI; TyG-WHtR, TyG related to WHtR. SBP, systolic blood pressure; DBP, diastolic blood pressure; FHMD: family history of metabolic disease.

individuals (21.85%). There were significant variations in gender, BMI, WHtR, TG, TyGi, TyG-BMI, TyG-WHtR, SBP, and sleep hours between subgroups of participants with and without MetS among people with normal-weight ($p < 0.05$). Nevertheless, no significant distinctions were found in age, FPG, UA, HDL-C, DBP or FHMD ($p > 0.05$). Subgroups of overweight individuals with and without MetS manifested significant variations for BMI, FPG, UA, TG, HDL-C, TyGi,

Table 2 Baseline Characteristics of Normal-weight Participants with and without MetS

Variables	Normal weight		p value
	MetS− (n=186)	**MetS+ (n=52)**	
Age, years	53.70 ± 6.11	54.63 ± 6.97	0.348
Male, n (%)	78 (41.9)	10 (19.2)	0.003
BMI, kg/m2	21.49 ± 1.58	22.34 ± 1.35	0.001
WHtR	0.45 ± 0.04	0.48 ± 0.04	<0.001
FPG, mmol/L	4.93 ± 0.78	5.20 ± 1.30	0.058
UA, µmol/L	271.01 ± 80.27	277.59 ± 93.49	0.615
TG[a], mmol/L	1.16 (0.80, 1.65)	1.44 (1.04, 2.31)	0.008
HDL-C, mmol/L	1.52 ± 0.37	1.45 ± 0.36	0.236
TyGi	8.42 ± 0.62	8.75 ± 0.71	0.001
TyG-BMI	181.29 ± 21.05	195.51 ± 19.48	<0.001
TyG-WHtR	3.79 ± 0.46	4.20 ± 0.50	<0.001
SBP, mmHg	117.82 ± 15.10	122.62 ± 16.66	0.049
DBP, mmHg	78.32 ± 8.76	80.93 ± 9.10	0.061
Sleeping hours	7.27 ± 1.10	6.88 ± 1.29	0.033
Marital status, n (%)			0.740
Married	174 (93.5)	50 (96.2)	
Single	12 (6.5)	2 (3.8)	
FHMD, n (%)	84 (45.2)	24 (46.2)	0.899
Regular exercise, n (%)	78 (44.3)	19 (36.5)	0.319
Smoking behaviors, n (%)			0.536
Non-smoker	137 (73.7)	42 (80.8)	
Former smoker	8 (4.3)	2 (3.8)	
Smoker	41 (22.0)	8 (15.4)	
Alcohol consumption, n (%)			0.334
No drinking	110 (59.1)	35 (67.3)	
Less than three times a month	38 (20.4)	6 (11.5)	
Three or more times a month	38 (20.4)	11 (21.2)	
Dietary habits, n (%)			0.566
Main vegetable dishes	51 (27.4)	12 (23.1)	
Balance meats and vegetables	126 (67.7)	39 (75.0)	
Main meat dishes	9 (4.8)	1 (1.9)	
Occupation nature, n (%)			0.529
Manual work	35 (18.8)	9 (17.3)	
Physical and mental work	81 (43.5)	19 (36.5)	
Mental work	70 (37.6)	24 (46.2)	
Educational level, n (%)			0.960
High school or above	83 (44.6)	23 (44.2)	
Below high school	103 (55.4)	29 (55.8)	

Notes: Values are mean ± SD, n (%) or median (25th–75th percentile), unless otherwise stated. [a]The Mann–Whitney *U*-test was utilized to ascertain the significant disparities.

Abbreviations: MetS, metabolic syndrome; MetS−, without metabolic syndrome; MetS+, with metabolic syndrome; BMI, body mass index; WHtR, waist-to-height ratio; FPG, fasting plasma glucose; UA, uric acid; TG, triglycerides; HDL-C, high-density lipoprotein cholesterol; TyGi, triglyceride and glucose index; TyG-BMI, TyG related to BMI; TyG-WHtR, TyG related to WHtR. SBP, systolic blood pressure; DBP, diastolic blood pressure; FHMD: family history of metabolic disease.

TyG-BMI, TyG-WHtR, SBP, DBP, and FHMD ($p < 0.05$). However, no significant changes were found in age, gender, WHtR, or sleeping hours ($p > 0.05$). In addition, there were no significant disparities seen across MetS subgroups (normal-weight or overweight) for marital status, regular exercise, smoking behaviors, alcohol consumption, dietary habits, occupation nature, and educational level ($p > 0.05$).

Table 3 Baseline Characteristics of Overweight Participants with and without MetS

Variables	Overweight		*p* value
	MetS− (n=48)	**MetS+ (n=73)**	
Age, years	52.27± 6.43	54.47 ± 6.50	0.069
Male, n (%)	23 (47.9)	40 (54.8)	0.459
BMI, kg/m2	25.24 ± 1.00	25.83 ± 1.15	0.005
WHtR	0.51 ± 0.03	0.52 ± 0.03	0.204
FPG, mmol/L	4.74 ± 0.66	5.14 ± 1.03	0.018
UA, µmol/L	287.09 ± 93.73	330.27 ± 88.30	0.011
TG[a], mmol/L	1.20 (0.90, 1.49)	1.55 (1.29, 1.90)	<0.001
HDL-C, mmol/L	1.48 ± 0.35	1.27 ± 0.30	0.001
TyGi	8.41 ± 0.52	8.83 ± 0.56	<0.001
TyG-BMI	212.23 ± 13.51	228.17 ± 18.70	<0.001
TyG-WHtR	4.29 ± 0.37	4.57 ± 0.35	<0.001
SBP, mmHg	119.45 ± 13.34	125.56 ± 15.57	0.027
DBP, mmHg	80.38 ± 8.71	84.28 ± 9.51	0.024
Sleeping hours	7.23 ± 1.12	7.02±1.50	0.427
Marital status, n (%)			1.000
Married	44 (91.7)	67 (91.8)	
Single	4 (8.3)	6 (8.2)	
FHMD, n (%)	14 (29.2)	39 (53.4)	0.009
Regular exercise, n (%)	23 (51.1)	29 (39.7)	0.226
Smoking behaviors, n (%)			0.695
Non-smoker	31 64.6)	46 (63)	
Former smoker	5 (10.4)	5 (6.8)	
Smoker	12 (25)	22 (30.1)	
Alcohol consumption, n (%)			0.193
No drinking	31 (64.8)	35 (47.9)	
Less than three times a month	7 (14.6)	17 (23.3)	
Three or more times a month	10 (20.8)	21 (28.8)	
Dietary habits, n (%)			0.268
Main vegetable dishes	13 (27.1)	11 (15.1)	
Balance meats and vegetables	30 (62.5)	53 (72.6)	
Main meat dishes	5 (10.4)	9 (12.3)	
Occupation nature, n (%)			0.986
Manual work	13 (27.1)	19 (26)	
Physical and mental work	21 (43.8)	33 (45.2)	
Mental work	14 (29.2)	21 (28.8)	
Educational level, n (%)			0.770
High school or above	25 (52.1)	40 (54.8)	
Below high school	23 (47.9)	33 (45.2)	

Notes: Values are mean ± SD, n (%) or median (25th–75th percentile), unless otherwise stated. [a]The Mann–Whitney *U*-test was utilized to ascertain the significant disparities.

Abbreviations: MetS, metabolic syndrome; MetS−, without metabolic syndrome; MetS+, with metabolic syndrome; BMI, body mass index; WHtR, waist-to-height ratio; FPG, fasting plasma glucose; UA, uric acid; TG, triglycerides; HDL-C, high-density lipoprotein cholesterol; TyGi, triglyceride and glucose index; TyG-BMI, TyG related to BMI; TyG-WHtR, TyG related to WHtR. SBP, systolic blood pressure; DBP, diastolic blood pressure; FHMD: family history of metabolic disease.

ROC Curve of Five Obesity- and Lipid-Linked Indicators to Predict MetS

The ROC curves and AUC results of each MetS risk prediction parameter are shown in Figure 2 and Table 4. In normal-weight individuals, WHtR and TyG-WHtR were the most accurate predictors of MetS (AUC=0.738, 95% CI 0.661–0.816, AUC=0.731, 95% CI 0.651–0.812), surpassing the predictive power of BMI (AUC = 0.662, 95% CI 0.580–0.745),

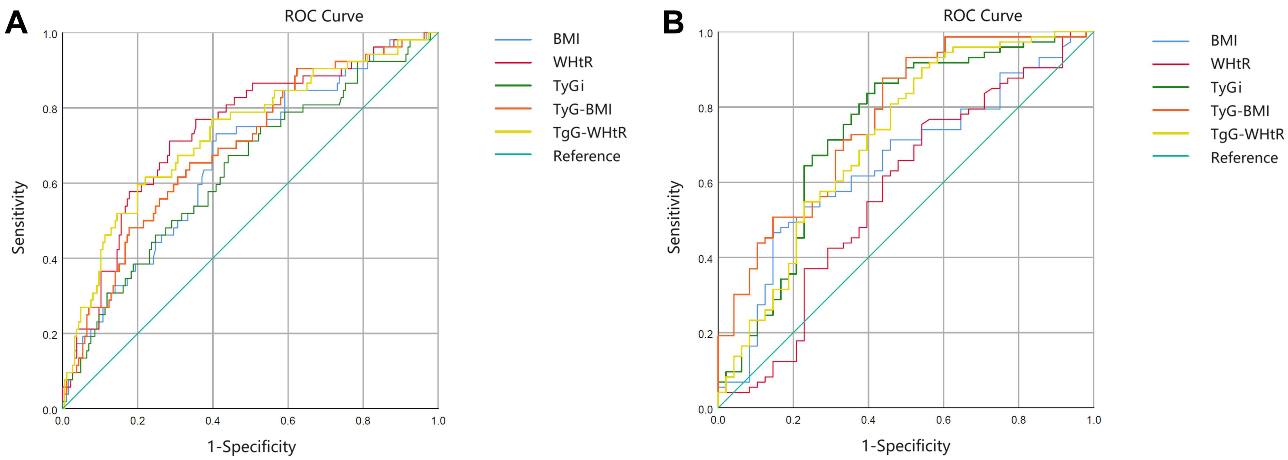

Figure 2 ROC curves of each indicator for predicting MetS risk in normal-weight (**A**) and overweight individuals (**B**).
Abbreviations: BMI, body mass index; WHtR, waist-to-height ratio; TyGi, triglyceride and glucose index; TyG-BMI, TyG related to BMI; TyG-WHtR, TyG related to WHtR.

TyGi (AUC = 0.636, 95% CI 0.549–0.723), and TyG-BMI (AUC = 0.693, 95% CI 0.613–0.774) after pairwise comparisons by the DeLong test in Table S1. The TyG-BMI indicator manifested the greatest AUC in overweight individuals (AUC = 0.769, 95% CI 0.682–0.855), surpassing the AUCs of the other four measures, BMI (AUC = 0.651, 95% CI 0.551–0.751), WHtR (AUC = 0.575, 95% CI 0.467–0.683), TyGi (AUC = 0.737, 95% CI 0.641–0.834) and TyG-

Table 4 Threshold Values Between Area Under the Curve, Sensitivity, and Specificity for Five Obesity- and Lipid-Related Indices to Detect MetS by Weight

MetS	BMI	WHtR	TyGi	TyG-BMI	TyG-WHtR
Normal weight					
Area under curve	0.662	0.738	0.636	0.693	0.731
95% CI	0.580, 0.745	0.661, 0.816	0.549, 0.723	0.613, 0.774	0.651, 0.812
p-value	<0.001	<0.001	0.003	<0.001	<0.001
Optimal threshold	22.082	0.469	8.483	190.596	4.121
Youden's index	0.322	0.427	0.232	0.315	0.397
Sensitivity (%)	73.100	71.200	67.300	65.400	59.600
Specificity (%)	59.140	71.500	55.914	66.129	80.107
Overweight					
Area under curve	0.651	0.575	0.737	0.769	0.715
95% CI	0.551, 0.751	0.467, 0.683	0.641, 0.834	0.682, 0.855	0.618, 0.812
p-value	0.005	0.162	<0.001	<0.001	<0.001
Optimal threshold	26.006	0.501	8.418	211.099	4.212
Youden's index	0.320	0.212	0.446	0.439	0.362
Sensitivity (%)	46.600	75.300	86.300	87.700	90.400
Specificity (%)	85.417	45.833	58.333	56.250	45.833

Abbreviations: BMI, body mass index; WHtR, waist-to-height ratio; TyGi, triglyceride and glucose index; TyG-BMI, TyG related to BMI; TyG-WHtR, TyG related to WHtR; CI, confidence interval.

WHtR (AUC = 0.715, 95% CI 0.618–0.812) (p value =0.013, 0.007, 0.048, 0.024 respectively). Table 4 presents the ideal threshold values for BMI, WHtR, TyGi, TyG-WHtR, and TyG-BMI in predictive MetS. The maximal Youden's index in a normal-weight population was 0.427 at a WHtR threshold value of 0.469 with a sensitivity of 71.2% and a specificity of 71.5%. When the TyG-BMI threshold value was 211.099 in overweight individuals, the maximum Youden's index was 0.439 with 87.7% sensitivity and 56.25% specificity.

Connections of Five Obesity- and Lipid-Linked Indicators with MetS

Based on the data are presented in Table 4, five indices linked to obesity and lipid levels were transformed into variables with two categories. Through multivariate logistic regression analysis, it was determined that following factors adjustments such as age, gender, UA, HDL-C, SBP, DBP, sleeping hours and FHMD, BMI, WHtR, TyGi, TyG-BMI, and TyG-WHtR were independently linked to MetS in normal-weight individuals, while BMI, TyGi, TyG-BMI, and TyG-WHtR were independently linked to MetS in overweight individuals (Table 5). The association intensity of WHtR (OR=7.994, 95% CI 3.600–17.751) and TyG-WHtR (OR=11.01, 95% CI 4.665–29.348) with MetS was greater than that of BMI, TyGi and TyG-BMI in normal-weight individuals, while TyG-BMI (OR=7.037, 95% CI 2.365–21.021) had the highest odds ratio for predicting MetS in overweight individuals (Table5).

Discussion

MetS is a significant worldwide public health issue that significantly affects people's lives and health expenditures.[3] With the rapid increase in China's aging population, rapid urbanization, and lifestyle modifications, The MetS prevalence has steadily elevated and is now a significant public health concern in China.[5] Considering the increasing incidence of MetS in China, we aimed to find one or several appropriate predictors of MetS in the normal-weight and overweight Chinese populations. We investigated the differences in the risk of MetS over five years among adults of different weights in Zhejiang Province. Moreover, the capacity to forecast five obesity- and lipid-linked indices, encompassing BMI, WHtR, TyGi, TyG-BMI, and TyG-WHtR, was ascertained in overweight populations for the first time in China. The outcomes revealed that the overweight population had a high incidence of MetS and that TyG-BMI had a good regional representative predictive value for MetS in the overweight population.

The cumulative incidence of MetS over five years was 21.85% in normal-weight adults and 60.33% in overweight adults, almost triple that of normal-weight individuals. This cumulative incidence was significantly greater than that manifested by Zhang Lin et al in a cohort study that included 3640 Chinese adults, and the four-year cumulative

Table 5 Associations of Five Obesity- and Lipid-Related Indices with MetS

MetS	BMI	WHtR	TyGi	TyG-BMI	TyG-WHtR
Normal weight					
Unadjusted OR (95% CI)	3.929 (1.992, 7.746)	5.646 (2.891, 11.028)	2.669 (1.396, 5.101)	3.778 (1.977, 7.219)	5.945 (3.071, 11.509)
p-value	<0.001	<0.001	0.003	<0.001	<0.001
Adjusted OR (95% CI)	3.245 (1.558, 6.761)	7.994 (3.600, 17.751)	2.591 (1.149, 5.844)	3.441 (1.568, 7.551)	11.701 (4.665, 29.348)
p-value	0.002	<0.001	0.022	0.002	<0.001
Overweight					
Unadjusted OR (95% CI)	5.106 (2.027, 12.866)	2.585 (1.187, 5.630)	8.820 (3.658, 21.264)	9.143 (3.713, 22.513)	7.978 (3.042, 20.920)
p-value	<0.001	0.017	<0.001	<0.001	<0.001
Adjusted OR (95% CI)	3.888 (1.323, 11.427)	2.393 (0.924, 6.201)	6.942 (2.487, 19.379)	7.037 (2.356, 21.021)	6.505 (2.032, 20.797)
p-value	0.014	0.072	<0.001	<0.001	<0.001

Note: Adjusted OR: adjusted for age, gender, UA, HDL, SBP, DBP, sleeping hours and FHMD.
Abbreviations: UA, uric acid; HDL-C, high-density lipoprotein cholesterol; SBP, systolic blood pressure; DBP, diastolic blood pressure; BMI, body mass index; WHtR, waist-to-height ratio; TyGi, triglyceride and glucose index; TyG-BMI, TyG related to BMI; TyG-WHtR, TyG related to WHtR; CI, confidence interval.

incidence was 18.43%.[22] This indicates that the MetS epidemic in Zhejiang Province is more severe than that in the whole country, especially in overweight people. Therefore, preventing and treating MetS in overweight individuals deserves more attention and intervention.

To our knowledge, no prior research has investigated the comparative predictive capacity of these five indicators linked to obesity and lipids in overweight Chinese populations for MetS. The investigation utilized multivariate logistic regression analysis to ascertain the implication of five indicators on the MetS risk in the two populations, which indicated that WHtR and TyG-WHtR had higher associations with MetS in the normal-weight population compared to the other three indices. Similarly, in a 2016 systematic literature review, Corrêa et al[23] observed that WHtR outperformed WC and BMI in assessing MetS. After adjusting for potential confounding factors, Yuqing et al[17] discovered that TyG-WHtR was significantly correlated with MetS, while the association intensity was greater than that of BMI, TyGi, and TyG-BMI. Yuting et al[24] manifested that TyG-BMI was a reliable and applicable indicator for evaluating the MetS of Chinese people. Our results in the overweight population further confirmed this finding. TyG-BMI had higher associations with MetS compared to the other four indicators.

ROC curve analysis was executed to assess further the predictive capacity of the five obesity- and lipid-linked markers for MetS. The WHtR and TyG-WHtR exhibited a larger AUC in the normal-weight population (0.738 and 0.731, respectively) than BMI, TyGi and TyG-BMI. This is similar to Lihong et al's[25] study, indicating that WHtR is suggested as an initial screening marker for MetS in individuals who are neither overweight nor obese. In contrast, the TyG-BMI exhibited the largest AUC among the overweight population, making it the best indicator for MetS. This is similar to the results of another large cohort study[22] manifested that TyG-BMI is the most reliable biomarker of MetS in adult males in China. This initial investigation suggests that the predictive value of WHtR and TyG-BMI for MetS varies among individuals with different body weights in China. WHtR can be an effective indicator for forecasting MetS in normal-weight individuals but not in overweight individuals. TyG-BMI is more effective for forecasting the MetS risk in overweight persons contrasted with normal-weight individuals.

Furthermore, differences between the two populations were observed (Table S2). For example, after adjusting for age, gender, UA, HDL-C, SBP and DBP, sleeping hours (OR=0.729, 95% CI 0.543–0.979) were associated with MetS occurrence in the normal-weight population. Short sleep duration was associated with higher risk of metabolic syndrome. However, this phenomenon was not found in the overweight population. Multiple research projects has examined the correlation between the amount of time spent sleeping, the quality of sleep, and MetS. A systematic analysis manifested a U-shaped connection between the time spent sleeping and the MetS risk.[26] Another systematic review of 22 articles demonstrated that difficulty falling asleep, difficulty maintaining sleep, and poor sleep efficiency increased the risk of MetS.[27] Moreover, our study confirmed that sleeping hours may be associated with MetS, and compared to overweight people, normal-weight people should arrange sleep time reasonably to reduce the risk of MetS.

Another risk factor that differs between overweight and normal-weight individuals in developing MetS is FHMD (OR=3.458, 95% CI 1.387–8.619) (Table S2). In this study, after adjusting for age, gender, UA, HDL-C, SBP and DBP, FHMD was an important autonomous risk factor for developing MetS in overweight but not normal-weight individuals. Previous studies[28] have confirmed that having a family history of diabetes in the first degree is a separate and significant risk factor for MetS. Piotr et al[29] demonstrated that more than 50% of the participants with a family history of MetS were overweight or had a lipid disorder. These studies suggest that a family history of MetS plays an important role in MetS development. Combined with our study, FHMD may be a more important risk factor for overweight people that deserves attention.

Our research is a component of a longitudinal, nationally representative dataset. This investigation is the first of its kind to ascertain the predictive value of five obesity- and lipid-linked markers in overweight persons in China for MetS prediction. There are several limitations associated with this research. Initially, the research population was derived only from a solitary community in China's southern region, resulting in a restricted level of representation. Additional research and validation should be conducted to examine the actual impact of indicators across various demographics thoroughly. Furthermore, the examination of relationships based on gender was not conducted due to constraints imposed by the sample size. Finally, although a considerable number of individuals were not included in the follow-up, there were no significant statistical variations in the fundamental features between the 187 participants who were lost and the 359 participants who were followed up. Hence, the 359 individuals who were followed up may accurately serve as a representative sample of the total research population.

Conclusion

With the development and changes in the living environment and society, the incidence of MetS in Zhejiang Province has increased. The incidence of MetS differs significantly between normal-weight and overweight individuals. The cohort study data from 2010 to 2015 indicate that the five-year cumulative incidence in normal-weight and overweight populations was 21.85% and 60.33%, respectively. WHtR and TyG-WHtR outperformed BMI, TyGi, and TyG-BMI in predicting MetS in normal-weight individuals. Simultaneously, the TyG-BMI index outperformed different indices in its ability to predict MetS in individuals who are overweight. In addition to these indicators, normal-weight persons may have an elevated risk of MetS due to their sleeping patterns. FHMD might serve as an autonomous risk factor for MetS in overweight persons.

Data Sharing Statement

The data presented in this study are available on reasonable request from the corresponding author. The data are not publicly available due to restrictions eg their containing information that could compromise the privacy of research participants.

Ethics Statement

The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board (or Ethics Committee) of Sir Run Run Shaw Hospital (Approval ID: 20100114; Approval date: 14 January 2010).

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

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Disclosure

The authors report no conflicts of interest in this work.

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