

Diagnostic Performance of the TyG Index in Detecting Metabolic Syndrome: A Cross-Sectional Study from Western Iran



Maziar Afshar¹, Maryam Afraie², Mobin Azami¹, Kamran Zamani¹, Farhad Moradpour^{2,*} and Yousef Moradi^{2,*}

¹Student Research Committee, Kurdistan University of Medical Sciences, Sanandaj, Iran

²Department of Epidemiology and Biostatistics, Faculty of Medicine, Kurdistan University of Medical Sciences, Sanandaj, Iran

Abstract:

Background: Metabolic Syndrome (MetS) is a prevalent endocrine disorder characterized by metabolic abnormalities such as abdominal obesity, dyslipidemia, hypertension, and impaired glucose metabolism. Early identification and screening are vital for effective management. The triglyceride-glucose (TyG) index, derived from fasting triglycerides and glucose levels, is emerging as a potential surrogate marker for insulin resistance and MetS. This study evaluates the TyG index as a standalone predictor of MetS risk and progression.

Methods: This cross-sectional study utilized data from the Dehghan Prospective Cohort Study (DehPCS), involving 3,800 participants aged 35–70 from western Iran. MetS was defined using World Health Organization (WHO) criteria. The diagnostic performance of the TyG index, its variants, and anthropometric indices was assessed using regression analysis, receiver operating characteristic (ROC) curves, and the area under the curve (AUC).

Results: MetS prevalence in the study population was 35.19%. The TyG-WHtR (waist-to-height ratio) index demonstrated the highest AUC (0.86) in the total population, with sensitivity and specificity of 84.56% and 72.23%, respectively. In males, the TyG-WC (waist circumference) index showed the highest AUC (0.90, sensitivity: 79.29%, specificity: 85.4%). In females, the TyG index alone ranked highest with an AUC of 0.87 (sensitivity: 76.12%, specificity: 87.1%).

Conclusion: The TyG index and its anthropometric variants showed excellent diagnostic accuracy for MetS, highlighting their potential as cost-effective screening tools, especially in resource-constrained settings. Further validation across diverse populations is recommended.

Keywords: Metabolic syndrome, TyG index, Insulin resistance, Anthropometric indices, Diagnostic performance.

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* Address correspondence to this author at the Department of Epidemiology and Biostatistics, Faculty of Medicine, Kurdistan University of Medical Sciences, Sanandaj, Iran; E-mail: yousefmoradi211@yahoo.com, farhadmepid@yahoo.com

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1. INTRODUCTION

Metabolic Syndrome (MetS) is a common endocrine disorder associated with a high rate of complications and mortality. It is a prevalent, chronic condition related to physiological, biochemical, clinical, and metabolic factors,

characterized by a combination of metabolic abnormalities, including abdominal obesity, high blood pressure, dyslipidemia, and impaired glucose metabolism. Recent lifestyle changes have increased the prevalence of this syndrome [1]. Various factors, such as age, gender, race,

place of residence, and ethnicity, influence the prevalence of MetS, leading to varying rates from less than 10% to 84% in different populations [2]. In 2020, approximately 25.8 million children and 35.5 million adolescents worldwide were affected by MetS [1, 3].

MetS induces a chronic low-grade inflammatory state, leading to adipose tissue inflammation, which predisposes individuals to cardiovascular diseases, arthritis, and non-alcoholic fatty liver disease [4]. It also disrupts the antioxidant systems by overloading reactive oxygen species, causing DNA and protein modifications and lipid peroxidation [5]. Studies have identified insulin resistance (IR) as the link between metabolic and hemodynamic abnormalities in individuals with MetS [6]. IR plays a crucial role in the development of MetS and is one of its primary causes [7].

Given the importance of early diagnosis of MetS, various criteria and methods are used to assess an individual's condition. Identifying predictive parameters for the condition is essential for diagnosing and managing patients with MetS [8].

One method for measuring insulin resistance and MetS is the hyperinsulinemic-euglycemic glucose clamp technique, which is an invasive and time-consuming procedure. While it directly measures IR, its high cost limits its use in areas with high prevalence and among the general population [9]. The Homeostatic Model Assessment of Insulin Resistance (HOMA-IR) is another method for evaluating IR, using fasting glucose and insulin levels. Although accurate, its use is limited due to the lack of insulin availability in all laboratories and its high cost [10].

Considering the challenges and difficulties associated with these tests, the need to find an alternative marker without the requirement for insulin has become increasingly important [11]. Triglycerides and HDL-C, being readily available and cost-effective, can serve as suitable substitutes for insulin-requiring tests [10].

Recent studies have indicated that elevated triglyceride levels impair glucose metabolism in skeletal muscles, leading to insulin resistance. A new index called the Triglyceride-Glucose (TyG) index, derived from fasting plasma glucose (FPG) and fasting triglycerides (TG), has been developed as a potential alternative to IR with high sensitivity and specificity [12]. This index was first proposed and validated by Simental-Mendía and colleagues [13]. The TyG index is a simple tool that expresses insulin resistance and, due to its simplicity, availability, and low cost, serves as a good screening marker for MetS. Studies have shown that this index is associated with type 2 diabetes, hypertension, cardiovascular events, and fatty liver disease [14]. Recent studies have evaluated the performance of this index, and their results suggest that the TyG index performs similarly to HOMA-IR in measuring insulin resistance and is more accurate and effective than other tools in predicting and diagnosing MetS [15].

MetS is highly prevalent both globally and in Iran, underscoring the need for effective diagnostic and

screening tools. While numerous indices have been developed and evaluated in recent studies, their comparative effectiveness remains an area of ongoing research. This study seeks to assess the diagnostic accuracy of the TyG index as a potential early detection tool for MetS.

2. MATERIALS AND METHODS

2.1. Study Design and Data Source

2.1.1. Study Population and Sample Size

This study was a cross-sectional analytical investigation that utilized data from the Dehghan Prospective Cohort Study (DehPCS), which is a part of the Prospective Epidemiological Research Studies in Iran (PERSIAN) national study. DehPCS recruited 3,996 adults aged 35 to 70 years from the general population of Dehghan City between February 2018 and March 2019 [16].

The sample size for this study was determined based on the expected prevalence of Metabolic Syndrome (MetS) in the target population. Previous studies conducted in Iran reported a MetS prevalence of approximately 35% [17]. To achieve a margin of error of $\pm 3\%$ with a 95% confidence level, a minimum sample size of 3,500 participants was required. Accounting for potential exclusions due to incomplete data or non-compliance, we recruited 3,996 participants from the Dehghan Prospective Cohort Study (DehPCS).

Statistical power analysis was performed using STATA software version 17 to ensure the adequacy of the sample size for detecting statistically significant associations between the TyG index and MetS. The analysis confirmed that the sample size provided sufficient power ($>80\%$) to detect meaningful differences in diagnostic accuracy across indices and subgroups. This rigorous approach ensures the reliability and robustness of our findings.

DehPCS aimed to determine the prevalence, mortality, and associated risk factors for non-communicable diseases in western Iran. Participants were permanent residents of Dehghan city with at least one year of residency and Iranian citizenship. Individuals who were unable to communicate due to physical or mental disorders and those who declined to participate were excluded from the data analysis.

2.1.2. Data Collection and Measurements

Face-to-face interviews and physical examinations were conducted by trained teams using online software designed specifically for this study. Participants' ages were confirmed using official identification cards. Educational levels were evaluated based on the number of years of education and the highest completed educational degree. Information about smoking and alcohol consumption was obtained. A fasting blood sample (25 ml) and urine sample (at least 10 ml) were collected from each participant by experienced technicians and labeled. Weight and height were measured using a SECA scale and

a stadiometer with an accuracy of 0.1 cm. Body Mass Index (BMI) was calculated by dividing weight (kg) by the square of height (m²).

2.1.3. Exposure Assessment

The primary exposure variable of interest is the TyG index, calculated using the formula 1 [13].

Formula 1: TyG index = $\ln$

$$\left(\frac{\text{fasting triglycerides } \left(\frac{\text{mg}}{\text{dL}} \right) \times \text{fasting glucose } \left(\frac{\text{mg}}{\text{dL}} \right)}{2} \right)$$

While both natural logarithm (Ln) and base-10 logarithm (Log10) can be used interchangeably, this study employs the natural logarithm (Ln), as it is more commonly used in metabolic studies involving the TyG index and provides a more direct relationship with the underlying biological processes.

Fasting blood samples collected during baseline visits are used for this calculation (Table 1). Additionally, the three measures of visceral fat were determined using the following equations (Detailed formulas are provided in Table 1) [18-20]:

Table 1. Definitions and formulas for all indices used in the study.

TyG Index	$\ln[\text{TG (mg/dL)} * \text{Fasting Glucose (mg/dL)}/2]$
TyG -BMI	TyG index * BMI
TyG -WC	TyG index * WC
TyG - WHpR (waist hip rate)	TyG index * WHpR
TyG - WHtR (waist circumference-to-height ratio)	TyG index * WHtR
Visceral adiposity index (VAI)	((waistcircumference/ (36.58+(1.89* BMI))) *(TG /0.81) *(1.52/ HDL mmol)) for female subjects ((waistcircumference/ (39.68+(1.88* BMI))) *(TG /1.03) *(1.31/ HDL mmol)) for male subjects
Lipid accumulation product (LAP)	(Waist circumference in cm - 65) × (Triglyceride in mmol/L) for male subjects (Waist circumference in cm - 58) × (Triglyceride in mmol/L) for female subjects
Termed waist-triglyceride index (WTI)	$\ln[\text{TG (mg/dL)} * \text{Waist circumference (cm)} /2]$

Table 2. Baseline characteristics of study participants, stratified by gender.

	Total (n=3865)	Male (n=1692)	Female (2173)	p-value
Age (years) means ±SD	48.34 ± 8.92	48.81 ± 8.89	47.98 ± 8.92	0.0045*
Education n(%)				
Illiterate	1206 (31.20)	181 (10.70)	1025 (47.17)	<0.0001**
Middle school	1075 (27.81)	443 (26.18)	632 (29.08)	
High school	1086 (28.10)	668 (39.48)	418 (19.24)	
Academic	498 (12.88)	400 (23.64)	98 (4.51)	
Marital status n(%)				
Single	44 (1.15)	4 (0.24)	40 (1.87)	<0.0001**
Married	3514 (91.80)	1673 (98.88)	1841 (86.19)	
Divorced - Widow	270 (7.05)	15 (0.89)	255 (11.94)	
Smoking n(%)	897 (23.69)	762 (45.66)	135 (6.37)	<0.0001**
Alcohol	464 (12.13)	421 (25.22)	43 (1.99)	<0.0001**
Laboratory data (means ±SD)				
FBS(mg%)	98.26 ± 32.40	97.08 ± 30.48	99.17 ± 33.80	0.046*
HDL (mg/dl)	46.37 ± 11.04	44.09 ± 10.63	48.14 ± 11.03	<0.0001*
LDL	114.69 ± 32.87	111.65 ± 31.88	117.02 ± 33.43	<0.0001*
Triglyceride (mg%)	155.74 ± 100.83	163.89 ± 117.72	149.40 ± 84.90	<0.0001*
Anthropometry				
Waist circumferenc(cm)	97.27 ± 10.82	94.8 ± 10.49	99.19 ± 10.69	<0.0001*
Hip circumference (cm)	104.43 ± 8.21	102.48 ± 7.19	105.94 ± 8.63	<0.0001*
WHpR	0.93 ± 0.001	0.92 ± 0.001	0.93 ± 0.001	<0.0001*
WHtR	0.60 ± 0.001	0.55 ± 0.001	0.63 ± 0.001	<0.0001*
SBP	110.80 ± 18.88	111.40 ± 18.17	110.34 ± 19.40	0.082*
DBP	69.37 ± 9.90	70.16 ± 10.21	68.77 ± 9.62	<0.0001*
BMI	28.01 ± 4.57	26.34 ± 4.06	29.31 ± 4.57	<0.0001*
TyG index	8.75 ± 0.62	8.78 ± 0.64	8.74 ± 0.61	0.049*
TyG -BMI	246.05 ± 47.22	232.16 ± 43.97	256.87 ± 46.84	<0.0001*

	Total (n=3865)	Male (n=1692)	Female (2173)	p-value
TyG -WC	853.84 ± 125.20	834.59 ± 124.95	868.84 ± 123.35	<0.0001*
TyG - WHpR	8.16 ± 0.01	8.11 ± 0.02	8.19 ± 0.02	0.009*
TyG - WHtR	5.28 ± 0.01	4.90 ± 0.01	5.57 ± 0.01	<0.0001*
VAI	2.73 ± 0.03	2.41 ± 0.05	2.98 ± 0.04	<0.0001*
LAP	65.88 ± 0.82	58.39 ± 1.30	71.69 ± 1.04	<0.0001*
WTI	8.77 ± 0.01	8.78 ± 0.01	8.77 ± 0.01	0.605*
MET	39.29 ± 8.36	41.66 ± 11.50	37.46 ± 3.74	<0.0001*
Mets n(%)	1360 (35.19)	368 (21.75)	992 (45.65)	<0.0001**
Hypertension n(%)	755 (19.62)	218 (12.97)	537 (24.77)	<0.0001**

*T test **chi-square tests.

TyG Index: Reflects insulin resistance based on fasting triglycerides and glucose levels.

TyG-BMI: Adjusts the TyG index for overall body mass to account for general adiposity.

TyG-WC: Incorporates waist circumference to assess central obesity, a key component of MetS.

TyG-WHtR: Uses the waist-to-height ratio to provide a more accurate measure of abdominal fat distribution.

VAI (Visceral Adiposity Index): Estimates visceral fat accumulation based on waist circumference, BMI, triglycerides, and HDL levels.

LAP (Lipid Accumulation Product): Combines waist circumference and triglyceride levels to estimate lipid-related metabolic risk.

WTI (Waist-Triglyceride Index): Integrates waist circumference and triglyceride levels to assess metabolic risk [21].

2.1.4. Outcome Assessment

The primary focus of this research was the evaluation of Metabolic Syndrome (MetS). The diagnosis of MetS in participants was determined using laboratory results and clinical examinations based on the World Health Organization (WHO) guidelines. According to these guidelines, MetS is defined as the presence of insulin resistance or impaired glucose tolerance, accompanied by at least two of the following criteria:

Obesity:

Body mass index (BMI) > 30 kg/m², and/or

Waist-to-hip ratio > 0.9 in men or > 0.85 in women.

Dyslipidemia:

Triglycerides > 150 mg/dL (1.7 mmol/L), and/or

High-density lipoprotein (HDL) cholesterol < 35 mg/dL (0.9 mmol/L) in men or < 39 mg/dL (1.0 mmol/L) in women.

Hypertension:

Blood pressure ≥ 140/90 mmHg.

Microalbuminuria:

Urinary albumin excretion rate ≥ 20 µg/min, or

Albumin-to-creatinine ratio ≥ 30 mg/g.

Participants meeting the diagnostic criteria were identified and categorized accordingly to facilitate

statistical analyses of the TyG index and its anthropometric variants in predicting MetS [22, 23].

2.1.5. Covariates

Possible factors (potential confounding variables) that could affect the outcome include characteristics like age, gender, education level, occupation, smoking habits, and existing health conditions.

2.2. Statistical Analysis

After data collection and entry into STATA software version 17, data analysis commenced. Descriptive statistics, such as mean and standard deviation, were used to describe quantitative variables, while raw numbers, percentages, or frequencies were used to report qualitative data. To evaluate the association between the TyG index, other indices and MetS, a regression analysis was employed while considering potential confounding variables, including educational level, gender, occupation, underlying diseases, age, and smoking status. Moreover, the AUC (Area Under the Curve), sensitivity, and specificity were also calculated, together with their respective 95% confidence intervals, for the calculation of diagnostic parameters.

3. RESULTS

Overall, sufficient information on the TyG index and MetS was available for 3,865 participants (95.05%) from the DehPCS cohort, including 1,692 men and 2,173 women. The mean age of participants in the total population was 48.34 ± 8.92, with 48.81 ± 8.89 for males and 47.98 ± 8.92 for females. Of the total population studied, 1,360 individuals (35.19%) had MetS. The demographic and laboratory characteristics of the study groups are summarized in Table 2. In total, this study compared eight indices, with detailed information provided in Table 1. The mean values of these eight indices in the total population are as follows: TyG Index: 8.75 ± 0.62, TyG-BMI: 246.05 ± 47.22, TyG-WC: 853.84 ± 125.20, TyG-WHpR: 8.16 ± 0.01, TyG-WHtR: 5.28 ± 0.01, VAI: 2.73 ± 0.03, LAP: 65.88 ± 0.82, WTI: 8.77 ± 0.01 (Table 2).

Table 3 presents the overall association between the studied indices and MetS in this study. As shown, in the female population, the strongest association with MetS was observed for the TyG index (Adjusted OR 95% CI: 34.12 (24.82 - 46.90)), followed by the WTI index

(Adjusted OR 95% CI: 32.48 (23.65 - 44.61)). For the male population, the strongest association was found for the TyG-WHtR index (Adjusted OR 95% CI: 21.56 (15.18 - 30.60)), with the WTI index ranking second (Adjusted OR 95% CI: 11.92 (8.81 - 16.14)) (Table 3).

Table 4 presents the results of comparing the predictive power of MetS and the AUC for different indices. In the total population, the highest AUC value of

0.86 with a sensitivity of 84.56 and specificity of 72.23 was observed for the TyG-WHtR index (95% CI: 0.85-0.87, p -value: <0.0001) (Table 4, Figs. 1 and 2). In the male population, the highest AUC of 0.90 with a sensitivity of 79.29 and specificity of 85.4 was found for the TyG-WC index (95% CI: 0.88-0.91, p -value: <0.0001). In the female population, the TyG index ranked first, with an AUC of 0.87, a sensitivity of 76.12, and a specificity of 87.1 (95% CI: 0.85-0.88, p -value: <0.0001) (Table 4, Figs. 1 and 2).

Table 3. Adjusted odds ratios (95% CI) for associations between metabolic syndrome and studied indices, stratified by gender.

	Adjusted Odds Ratio (95%CI)	Adjusted Odds Ratio (95%CI)
	Women	Men
TyG index	34.12 (24.82 - 46.90)*	10.38 (7.85 - 13.72)*
TyG -BMI	1.02 (1.022 - 1.027)*	1.04 (0.56 - 1.20)*
TyG -WC	1.01 (1.010 - 1.013)*	1.019 (1.01 - 1.02)*
TyG - WHpR	7.27 (6.04 - 8.76)*	8.78 (6.82 - 11.31)*
TyG - WHtR	5.98 (5.00 - 7.14)*	21.56 (15.18 - 30.60)*
VAL	3.73 (3.30 - 4.21)*	1.72 (1.58 - 1.86)*
LAP	1.03 (1.02 - 1.03)*	1.049 (1.044 - 1.05)*
WTI	32.48 (23.65 - 44.61)*	11.92 (8.81 - 16.14)*

Adjusted for age (years); education; alcohol; smoker; physical activity, Marital status, * p -value <0.0001.

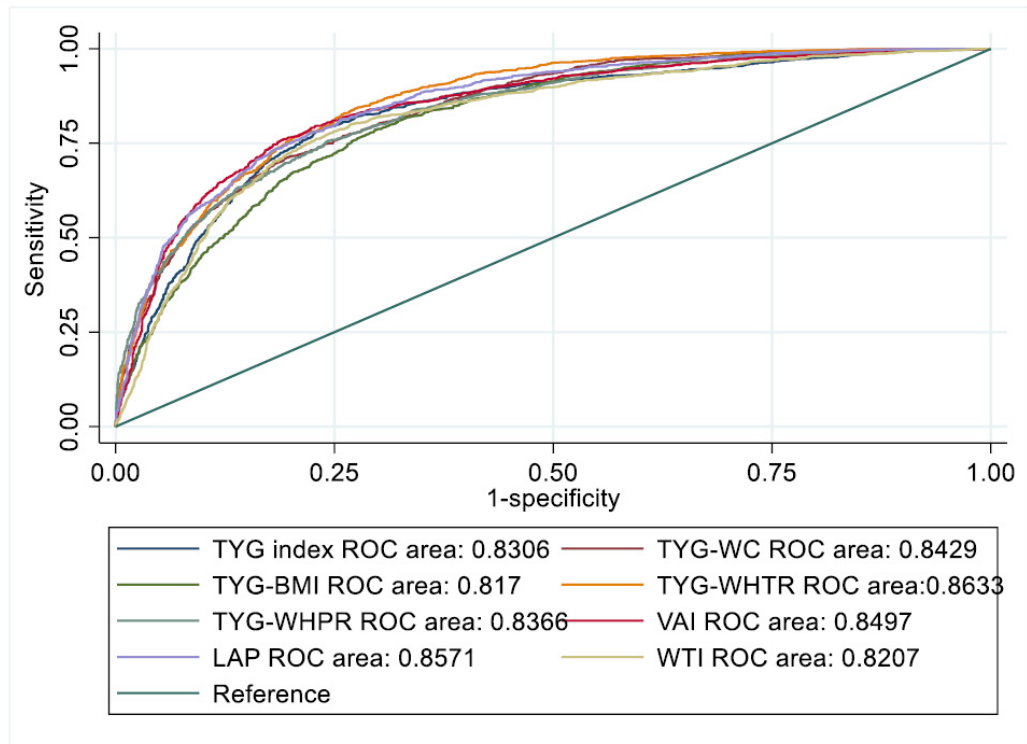


Fig. (1). ROC curve for assessing the diagnostic value of all indices for predicting metabolic syndrome.

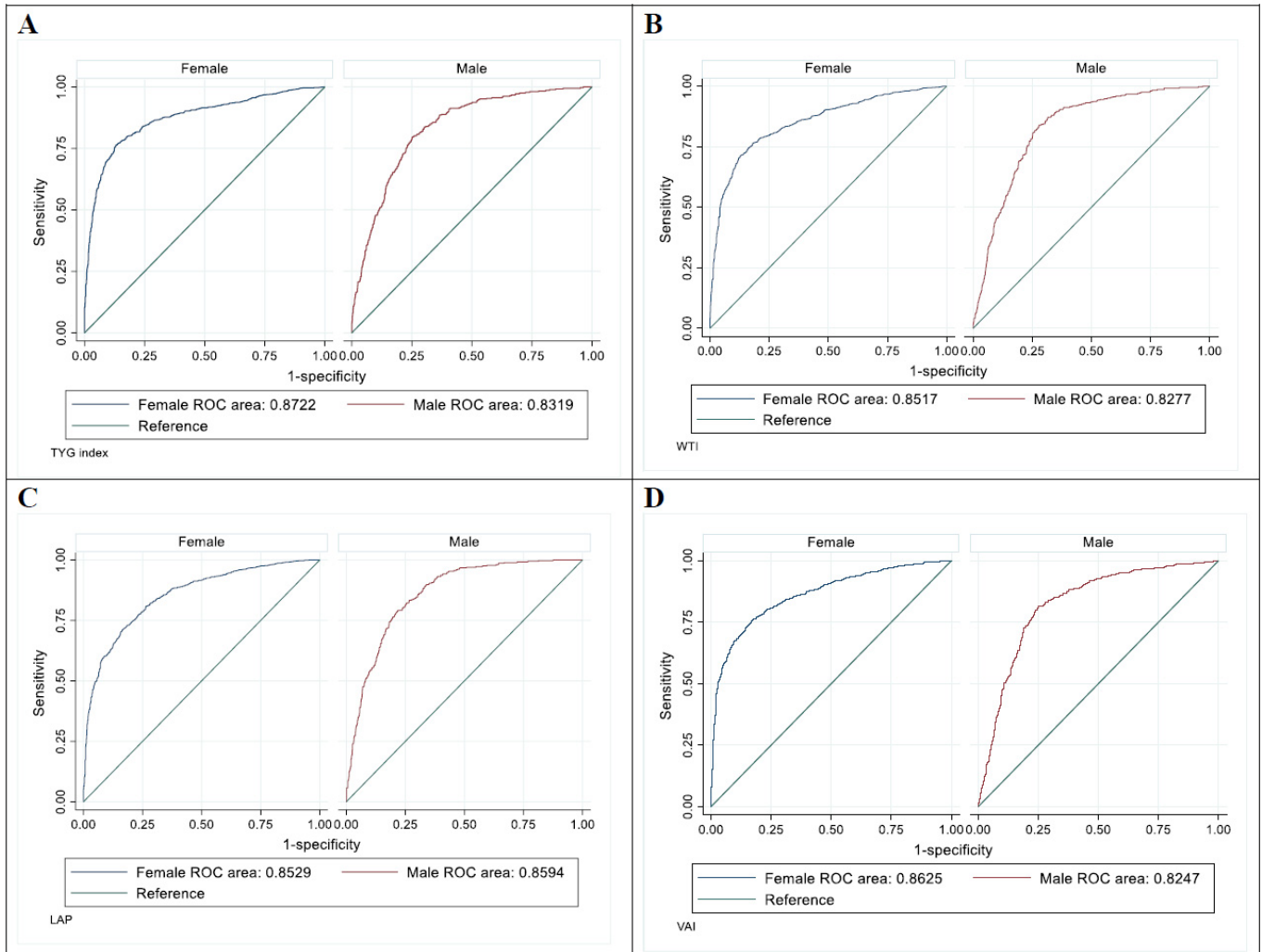


Fig. (2). ROC curves for assessing the diagnostic value of various indices for predicting metabolic syndrome based on sex. **(A)** TYG (Triglyceride-Glucose) Index: ROC curves for females (AUC = 0.8722) and males (AUC = 0.8319). **(B)** WTI (Waist Triglyceride Index): ROC curves for females (AUC = 0.8517) and males (AUC = 0.8277). **(C)** LAP (Lipid Accumulation Product): ROC curves for females (AUC = 0.8629) and males (AUC = 0.8594). **(D)** VAI (Visceral Adiposity Index): ROC curves for females (AUC = 0.8625) and males (AUC = 0.8247).

Table 4. Diagnostic performance of anthropometric indices for predicting metabolic syndrome, including AUC, sensitivity, specificity, and youden index.

Variable	AUC	95% CI	p-value	Sensitivity	Specificity	Youden Index
All participant						
TyG index	0.83	0.81 - 0.84	<0.0001	78.65	76.56	0.55
TyG -BMI	0.81	0.80 - 0.82	<0.0001	78.56	70.23	0.48
TyG -WC	0.84	0.82 - 0.85	<0.0001	71.19	80.30	0.51
TyG - WHpR	0.83	0.82 - 0.84	<0.0001	75.46	75.75	0.51
TyG - WHtR	0.86	0.85 - 0.87	<0.0001	84.56	72.23	0.56
VAI	0.84	0.83 - 0.86	<0.0001	76.00	80.78	0.56
LAP	0.85	0.84 - 0.86	<0.0001	81.17	74.07	0.55
WTI	0.82	0.80 - 0.83	<0.0001	75.98	76.95	0.52
Male						

Variable	AUC	95% CI	p-value	Sensitivity	Specificity	Youden Index
TyG index	0.83	0.81 - 0.84	<0.0001	79.62	74.79	0.54
TyG -BMI	0.86	0.84 - 0.87	<0.0001	84.20	71.68	0.55
TyG -WC	0.90	0.88 - 0.91	<0.0001	79.29	85.04	0.64
TyG - WHpR	0.86	0.84 - 0.88	<0.0001	80.93	78.17	0.59
TyG - WHtR	0.89	0.88 - 0.91	<0.0001	86.65	76.79	0.63
VAI	0.82	0.80 - 0.84	<0.0001	81.37	74.85	0.56
LAP	0.85	0.84 - 0.87	<0.0001	79.18	78.13	0.57
WTI	0.82	0.80 - 0.84	<0.0001	83.92	71.91	0.55
Female						
TYG index	0.87	0.85 - 0.88	<0.0001	76.12	87.01	0.63
TYG-BMI	0.76	0.74 - 0.78	<0.0001	75.86	65.44	0.41
TYG-WC	0.81	0.79 - 0.82	<0.0001	67.17	79.27	0.46
TYG- WHpR	0.84	0.82 - 0.85	<0.0001	71.72	81.66	0.53
TYG- WHtR	0.81	0.79 - 0.83	<0.0001	79.69	67.95	0.47
VAI	0.86	0.84 - 0.87	<0.0001	75.43	83.22	0.58
LAP	0.85	0.83 - 0.86	<0.0001	71.18	83.48	0.54
WTI	0.85	0.83 - 0.86	<0.0001	71.41	86.95	0.58

4. DISCUSSION

The objective of this study was to investigate the connection between the TyG index (generated using triglycerides and glucose levels) and the presence of metabolic syndrome (MetS) and to assess the diagnostic accuracy of the TyG index and similar tools. From the Dehghan cohort data, it was discovered by researchers that MetS was present in 35.19% of participants. Among the entire group, the TyG-WHtR index scored the highest AUC of 0.86, along with 84.56% sensitivity and 72.23% specificity. Among men, the TyG-WC index had the top AUC of 0.90, along with a sensitivity of 79.29% and specificity of 85.4%. On the other hand, the TyG index by itself was the top performer in women, achieving an AUC of 0.87, sensitivity of 76.12%, and specificity of 87.1%. These results indicate that the combination of anthropometric indices and the TyG index is more effective for diagnosis in the overall and male populations, whereas the TyG index on its own is more valuable for diagnosing females. After accounting for potential factors that could affect the results, the TyG index exhibited the highest OR among women, affirming its better overall performance.

The increasing prevalence of Metabolic Syndrome (MetS) in Iran aligns with global trends and is largely driven by urbanization, lifestyle changes, and dietary shifts over the past few decades [3, 24, 25]. Studies suggest that the prevalence of MetS in Iran has been rising steadily since the early 2000s, with significant increases observed in urban populations [25]. Unfortunately, detailed incidence data over time is limited, but longitudinal studies such as the Tehran Lipid and Glucose Study (TLGS) have documented this upward trend [26-29]. This highlights the urgent need for effective diagnostic tools to identify and manage MetS in high-risk populations.

The variation in diagnostic accuracy could be attributed to differences in body fat distribution between sexes and the potential impact of visceral fat on MetS

development, along with hormonal and metabolic disparities between males and females. Recent studies have highlighted the protective role of gluteal-femoral fat against metabolic disorders, including insulin resistance, type 2 diabetes, and cardiovascular diseases [30]. This underscores the importance of considering fat distribution patterns when evaluating MetS risk.

Our results align with similar studies that have indicated the TyG index and related tools can serve as better predictors for MetS compared to other indices. For instance, in the total population of this study, the AUC for the TyG Index was 0.83, which is consistent with studies on different populations in Pakistan (Khan *et al.*, 2018) [31], South Korea (Lee *et al.*, 2015) [32], and Nigeria (Raimi *et al.*, 2021) [33], further demonstrating the high diagnostic power of this index across diverse populations. The study by Lee *et al.* (2015) [32] in the South Korean population, which compared the TyG Index results between female and male populations, not only showed remarkable similarity to our findings but also demonstrated slightly higher values in the female population. This observation further corroborates the higher diagnostic power of the TyG Index, particularly in the female population, as observed in our study.

Given the cultural and legal restrictions on alcohol consumption in Iran, it was not included as a covariate in this study. As a result, non-alcoholic fatty liver disease (NAFLD) observed in our population is likely unrelated to alcohol use and is instead driven by metabolic factors such as insulin resistance, obesity, and dyslipidemia. This distinction is critical, as NAFLD in Iran is primarily a consequence of metabolic abnormalities rather than alcohol-related liver damage [34, 35].

It is important to note that insulin resistance (IR) plays a crucial role in the development of MetS and is one of its primary causes. The TyG index, derived from fasting triglyceride and glucose levels, has been shown to be a reliable marker for IR. By providing an inexpensive alternative to more invasive and costly methods like the

hyperinsulinemic-euglycemic glucose clamp technique or HOMA-IR, the TyG index can facilitate the assessment of IR and aid in the early detection and management of MetS, particularly in resource-limited settings [7, 31, 33, 36-38].

While the TyG Index exhibited high diagnostic power, it ranked fifth compared to anthropometric indices in the total population in our study. This finding is consistent with the study by Lim *et al.* (2019) [38], which reported similar results. Additionally, in a study by Raimi *et al.* (2021) on the Nigerian population [33], the highest AUC in the total population was associated with the TyG-WHtR index, supporting our observation that the combination of the TyG index with anthropometric indices has higher diagnostic power compared to the TyG index alone. This relationship between anthropometric characteristics and the occurrence of MetS is plausible, as abdominal adiposity, a key component of MetS [39, 40], comprises both subcutaneous and visceral fat [41]. The visceral fat component, due to its higher production of inflammatory cytokines, adipokines, and free fatty acids, is more closely associated with cardiovascular diseases and insulin resistance, which are crucial components of MetS [42, 43]. Although the TyG-WC index had the highest AUC in the male population, and the TyG-WHtR index ranked second, after adjustment for potential confounding variables, the highest OR in the male population was observed for the TyG-WHtR index. Considering this, it can be inferred that the TyG-WHtR index is ultimately the best diagnostic index for both the male and total populations. The reason behind this result can be explained by the fact that both waist circumference (WC) and waist-to-height ratio (WHtR) are measures of abdominal fat accumulation, which is a crucial factor contributing to the development of MetS. The superior performance of WHtR over WC may be attributed to its consideration of an individual's height in addition to their waist circumference, providing a more accurate assessment of abdominal obesity [44, 45].

LIMITATIONS AND FUTURE DIRECTIONS

Despite the valuable insights obtained from this study, several limitations must be acknowledged. First, the study population consisted predominantly of Kurdish individuals residing in western Iran, which may limit the generalizability of the findings to other ethnic or geographic groups. Future studies should include more diverse populations to validate the applicability of the TyG index across different demographics. Second, the cross-sectional design of the study precludes causal inferences, and longitudinal studies are needed to assess the predictive power of the TyG index for long-term health outcomes, such as cardiovascular disease and type 2 diabetes. Third, the lack of complete data on medication use or self-administered drugs that could influence MetS components introduces potential confounding factors. Finally, while the TyG index demonstrated high diagnostic accuracy, its performance may vary depending on the criteria used to define MetS (*e.g.*, WHO vs. IDF definitions). Addressing these limitations in future

research will strengthen the evidence base and improve the clinical utility of the TyG index.

CONCLUSION

In conclusion, this cross-sectional analysis from the Dehgolan Prospective Cohort Study (DehPCS) demonstrates the diagnostic utility of the TyG index and its anthropometric variants for detecting Metabolic Syndrome (MetS). The TyG index exhibited high diagnostic accuracy, particularly in females, achieving an AUC of 0.87. Incorporating anthropometric measures further enhanced diagnostic performance, with the TyG-WHtR index (AUC 0.86) and TyG-WC index (AUC 0.90) showing the highest diagnostic value in the total and male populations, respectively. These findings highlight the potential of the TyG index, both as a standalone tool and when combined with anthropometric parameters, as a cost-effective screening method for early detection of MetS.

The study underscores the importance of considering sex-specific differences in diagnostic accuracy, as the TyG index alone performed better in women, while indices incorporating waist circumference or waist-to-height ratio were superior in men. This variation likely reflects differences in body fat distribution and metabolic profiles between genders. Additionally, the results align with prior studies conducted in diverse populations, reinforcing the generalizability of the TyG index as a reliable marker for insulin resistance and MetS.

Despite these promising findings, several limitations must be acknowledged. First, the study was conducted in a Kurdish population, which may limit the generalizability of the results to other ethnic groups. Second, the cross-sectional design precludes causal inferences, and longitudinal studies are needed to validate these findings over time. Third, the lack of data on medication use or self-administered drugs that could influence MetS components introduces potential confounding factors. Future research should address these gaps by conducting prospective cohort studies in diverse populations, incorporating detailed medication histories, and exploring the predictive power of the TyG index for long-term health outcomes such as cardiovascular disease and type 2 diabetes.

In clinical practice, the TyG index represents a promising, accessible biomarker for risk stratification and management of MetS, especially in resource-limited settings where more invasive or costly methods like HOMA-IR are not feasible. Its simplicity, low cost, and high diagnostic accuracy make it a valuable tool for early identification and intervention. However, further validation across diverse populations and healthcare systems is warranted to establish its broader applicability. By integrating the TyG index into routine clinical assessments, healthcare providers can enhance early detection and management of MetS, ultimately reducing the global burden of this prevalent metabolic disorder.

AUTHORS CONTRIBUTIONS

Authors M. Afshar, M. Afraie, FM and YM designed the study. M. Afshar, FM and YM participated in the conception of the study. M. Afraie, M Azami, KZ, FM and YM managed and conducted the statistical analyses and interpreted the data. M. Afshar prepared the first draft and FM and YM revised it to make the final manuscript. All authors approved the final manuscript.

LIST OF ABBREVIATIONS

MetS	= Metabolic Syndrome
TyG	= Triglyceride-Glucose
WHO	= World Health Organization
IR	= Insulin Resistance
DehPCS	= Dehgolan Prospective Cohort Study
PERSIAN	= Prospective Epidemiological Research Studies in Iran
ROC	= Receiver Operating Characteristic
AUC	= Area Under the Curve
BMI	= Body Mass Index
WC	= Waist Circumference
WHpR	= Waist-to-Hip Ratio
WHtR	= Waist-to-Height Ratio
VAI	= Visceral Adiposity Index
LAP	= Lipid Accumulation Product
WTI	= Waist-Triglyceride Index
HDL	= High-Density Lipoprotein
LDL	= Low-Density Lipoprotein
FPG	= Fasting Plasma Glucose
TG	= Triglycerides
OR	= Odds Ratio
CI	= Confidence Interval
HOMA-IR	= Homeostatic Model Assessment of Insulin Resistance

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The protocol and ethical considerations were formally reviewed and approved by the Ethics Committee of Kurdistan University of Medical Sciences under the approval code IR.MUK.AEC.1403.018.

HUMAN AND ANIMAL RIGHTS

No animals were used in this research. All procedures performed in studies involving human participants were in accordance with the ethical standards of institutional and/or research committee and with the 1975 Declaration of Helsinki, as revised in 2013.

CONSENT FOR PUBLICATION

All participants provided written, informed consent prior to enrollment, affirming their voluntary participation and understanding of the study's objectives, procedures, and potential risks/benefits.

STANDARDS OF REPORTING

STROBE guidelines were followed.

AVAILABILITY OF DATA AND MATERIALS

The data and supportive information are available within the article.

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CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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REFERENCES

- [1] Fornari Laurindo L, Minniti G, José Tofano R, Quesada K, Federighi Baisi Chagas E, Maria Barbalho S. Detection of metabolic syndrome using insulin resistance indexes: A cross-sectional observational cohort study. *Endocrines* 2023; 4(2): 257-68. <http://dx.doi.org/10.3390/endocrines4020021>
- [2] Couto AN, Pohl HH, Bauer ME, Schwanke CHA. Accuracy of the triglyceride-glucose index as a surrogate marker for identifying metabolic syndrome in non-diabetic individuals. *Nutrition* 2023; 109: 111978. <http://dx.doi.org/10.1016/j.nut.2023.111978> PMID: 36842288
- [3] Noubiap JJ, Nansseu JR, Lontchi-Yimagou E, *et al.* Global, regional, and country estimates of metabolic syndrome burden in children and adolescents in 2020: A systematic review and modelling analysis. *Lancet Child Adolesc Health* 2022; 6(3): 158-70. [http://dx.doi.org/10.1016/S2352-4642\(21\)00374-6](http://dx.doi.org/10.1016/S2352-4642(21)00374-6) PMID: 35051409
- [4] Santos-Moreno P, Rodríguez-Vargas GS, Martínez S, Ibatá L, Rojas-Villarraga A. Metabolic abnormalities, cardiovascular disease, and metabolic syndrome in adult rheumatoid arthritis patients: Current perspectives and clinical implications. *Open Access Rheumatol* 2022; 14: 255-67. <http://dx.doi.org/10.2147/OARRR.S285407> PMID: 36388145
- [5] Silveira Rossi JL, Barbalho SM, Reverete de Araujo R, Bechara MD, Sloan KP, Sloan LA. Metabolic syndrome and cardiovascular diseases: Going beyond traditional risk factors. *Diabetes Metab Res Rev* 2022; 38(3): e3502. <http://dx.doi.org/10.1002/dmrr.3502> PMID: 34614543
- [6] Alberti KGMM, Eckel RH, Grundy SM, *et al.* Harmonizing the metabolic syndrome. *Circulation* 2009; 120(16): 1640-5. <http://dx.doi.org/10.1161/CIRCULATIONAHA.109.192644> PMID: 19805654
- [7] 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. <http://dx.doi.org/10.1007/s11010-022-04494-1> PMID: 35710684
- [8] Angoorani P, Heshmat R, Ejtahed HS, *et al.* Validity of triglyceride-glucose index as an indicator for metabolic syndrome in children and adolescents: The CASPIAN-V study. *Eat Weight*

- Disord 2018; 23(6): 877-83.
<http://dx.doi.org/10.1007/s40519-018-0488-z> PMID: 29453589
- [9] Kang B, Yang Y, Lee EY, *et al.* Triglycerides/glucose index is a useful surrogate marker of insulin resistance among adolescents. *Int J Obes* 2017; 41(5): 789-92.
<http://dx.doi.org/10.1038/s41325-017-14> PMID: 28104918
- [10] Aslan Çin NN, Yardımcı H, Koç N, Uçaktürk SA, Akçil Ok M. Triglycerides/high-density lipoprotein cholesterol is a predictor similar to the triglyceride-glucose index for the diagnosis of metabolic syndrome using international diabetes federation criteria of insulin resistance in obese adolescents: A cross-sectional study. *J Pediatr Endocrinol Metab* 2020; 33(6): 777-84.
<http://dx.doi.org/10.1515/jpem-2019-0310> PMID: 32447329
- [11] Singh B, Saxena A. Surrogate markers of insulin resistance: A review. *World J Diabetes* 2010; 1(2): 36-47.
<http://dx.doi.org/10.4239/wjdv.v1.i2.36> PMID: 21537426
- [12] Tabassum M, Mozaffar M, Rahman MM, Huda RM. Triglycerides and glucose index as potential marker of metabolic syndrome. *IJHHS* 2020; 5(1): 85-9.
<http://dx.doi.org/10.31344/ijhhs.v5i1.239>
- [13] Araújo SP, Juvanhol LL, Bressan J, Hermsdorff HHM. Triglyceride glucose index: A new biomarker in predicting cardiovascular risk. *Prev Med Rep* 2022; 29: 101941.
<http://dx.doi.org/10.1016/j.pmedr.2022.101941> PMID: 36161140
- [14] Zhang X, Zhang T, Sen H, Jia S, Zhang Z, Ye R, *et al.* Association of metabolic syndrome with TyG index and TyG-related parameters in an urban Chinese population: A 15-year prospective study. *Diabetol Metab Syndr* 2022; 14: 1.
- [15] Wu TD, Fawzy A, Brigham E, *et al.* Association of triglyceride-glucose index and lung health. *Chest* 2021; 160(3): 1026-34.
<http://dx.doi.org/10.1016/j.chest.2021.03.056> PMID: 33839084
- [16] Moradpour F, Ghaderi E, Moradi G, *et al.* The Dehghan Prospective Cohort Study (DehPCS) on non-communicable diseases in a Kurdish community in the west of Iran. *Epidemiol Health* 2021; 43: e2021075.
<http://dx.doi.org/10.4178/epih.e2021075> PMID: 34607397
- [17] Tabatabaei-Malazy O, Saeedi Moghaddam S, Rezaei N, *et al.* A nationwide study of metabolic syndrome prevalence in Iran; a comparative analysis of six definitions. *PLoS One* 2021; 16(3): e0241926.
<http://dx.doi.org/10.1371/journal.pone.0241926> PMID: 33657130
- [18] Okamura T, Hashimoto Y, Hamaguchi M, Obora A, Kojima T, Fukui M. The visceral adiposity index is a predictor of incident nonalcoholic fatty liver disease: A population-based longitudinal study. *Clin Res Hepatol Gastroenterol* 2020; 44(3): 375-83.
<http://dx.doi.org/10.1016/j.clinre.2019.04.002> PMID: 32434704
- [19] Nusranto R, Ayundini G, Kristanti M, *et al.* Visceral adiposity index and lipid accumulation product as a predictor of type 2 diabetes mellitus: The Bogor cohort study of non-communicable diseases risk factors. *Diabetes Res Clin Pract* 2019; 155: 107798.
<http://dx.doi.org/10.1016/j.diabres.2019.107798> PMID: 31330161
- [20] Ahn N, Baumeister SE, Amann U, *et al.* Visceral adiposity index (VAI), lipid accumulation product (LAP), and product of triglycerides and glucose (TyG) to discriminate prediabetes and diabetes. *Sci Rep* 2019; 9(1): 9693.
<http://dx.doi.org/10.1038/s41598-019-46187-8> PMID: 31273286
- [21] Liu PJ, Lou HP, Zhu YN. Screening for metabolic syndrome using an integrated continuous index consisting of waist circumference and triglyceride: A preliminary cross-sectional study. *Diabetes Metab Syndr Obes* 2020; 13: 2899-907.
<http://dx.doi.org/10.2147/DMSO.S259770> PMID: 32884316
- [22] Alberti KGMM, Zimmet P, Shaw J. The metabolic syndrome—A new worldwide definition. *Lancet* 2005; 366(9491): 1059-62.
[http://dx.doi.org/10.1016/S0140-6736\(05\)67402-8](http://dx.doi.org/10.1016/S0140-6736(05)67402-8) PMID: 16182882
- [23] Simmons RK, Alberti KGMM, Gale EAM, *et al.* The metabolic syndrome: Useful concept or clinical tool? report of a WHO expert consultation. *Diabetologia* 2010; 53(4): 600-5.
<http://dx.doi.org/10.1007/s00125-009-1620-4> PMID: 20012011
- [24] Jahangiry L, Khosravi-far L, Sarbakhsh P, Kousha A, EntezarMahdi R, Ponnet K. Prevalence of metabolic syndrome and its determinants among Iranian adults: Evidence of IraPEN survey on a bi-ethnic population. *Sci Rep* 2019; 9(1): 7937.
<http://dx.doi.org/10.1038/s41598-019-44486-8> PMID: 31138853
- [25] Nikbakht HA, Rezaianzadeh A, Seif M, Ghaem H. Prevalence of metabolic syndrome and its components among a population-based study in south of Iran, PERSIAN Kharamah cohort study. *Clin Epidemiol Glob Health* 2020; 8(3): 678-83.
<http://dx.doi.org/10.1016/j.cegh.2020.01.001>
- [26] Azizi F, Mirmiran P, Momenan AA, *et al.* The effect of community-based education for lifestyle intervention on the prevalence of metabolic syndrome and its components: Tehran lipid and glucose study. *Int J Endocrinol Metab* 2013; 11(3): 145-53.
<http://dx.doi.org/10.5812/ijem.5443> PMID: 24348586
- [27] Azizi F, Salehi P, Etemadi A, Zahedi-Asl S. Prevalence of metabolic syndrome in an urban population: Tehran lipid and glucose study. *Diabetes Res Clin Pract* 2003; 61(1): 29-37.
[http://dx.doi.org/10.1016/S0168-8227\(03\)00066-4](http://dx.doi.org/10.1016/S0168-8227(03)00066-4) PMID: 12849921
- [28] Azizi F, Madjid M, Rahmani M, Emami H, Mirmiran P, Hadjipour R. Tehran Lipid and Glucose Study (TLGS): Rationale and design. *IJEM* 2000; 2(2): 77-86.
- [29] Azizi F. Tehran lipid and glucose study: A national legacy. *Int J Endocrinol Metab* 2018; In Press(In Press) (Suppl.): e84774.
<http://dx.doi.org/10.5812/ijem.84774> PMID: 30584440
- [30] Trouwborst I, Jardon KM, Gijbels A, *et al.* Body composition and body fat distribution in tissue-specific insulin resistance and in response to a 12-week isocaloric dietary macronutrient intervention. *Nutr Metab* 2024; 21(1): 20.
<http://dx.doi.org/10.1186/s12986-024-00795-y> PMID: 38594756
- [31] Khan SH, Sobia F, Niazi NK, Manzoor SM, Fazal N, Ahmad F. Metabolic clustering of risk factors: Evaluation of Triglyceride-glucose index (TyG index) for evaluation of insulin resistance. *Diabetol Metab Syndr* 2018; 10(1): 74.
<http://dx.doi.org/10.1186/s13098-018-0376-8> PMID: 30323862
- [32] Lee S, Han K, Yang H, Kim H, Cho J, Kwon H, *et al.* A novel criterion for identifying metabolically obese but normal weight individuals using the product of triglycerides and glucose. *Nutr Diabetes* 2015; 5(4): e149.
<http://dx.doi.org/10.1038/nutd.2014.46> PMID: 25915739
- [33] Raimi TH, Dele-Ojo BF, Dada SA, *et al.* Triglyceride-glucose index and related parameters predicted metabolic syndrome in Nigerians. *Metab Syndr Relat Disord* 2021; 19(2): 76-82.
<http://dx.doi.org/10.1089/met.2020.0092> PMID: 33170086
- [34] Zarean E, Goujani R, Rahimian G, Ahmadi A. Prevalence and risk factors of non-alcoholic fatty liver disease in southwest Iran: A population-based case-control study. *Clin Exp Hepatol* 2019; 5(3): 224-31.
<http://dx.doi.org/10.5114/ceh.2019.87635> PMID: 31598559
- [35] Alavian SM, Mohammad-Alizadeh AH, Esna-Ashari F, Ardalan G, Hajarizadeh B. Non-alcoholic fatty liver disease prevalence among school-aged children and adolescents in Iran and its association with biochemical and anthropometric measures. *Liver Int* 2009; 29(2): 159-63.
<http://dx.doi.org/10.1111/j.1478-3231.2008.01790.x> PMID: 18492015
- [36] Tahapary DL, Pratisthita LB, Fitri NA, *et al.* Challenges in the diagnosis of insulin resistance: Focusing on the role of HOMA-IR and Triglyceride/glucose index. *Diabetes Metab Syndr* 2022; 16(8): 102581.
<http://dx.doi.org/10.1016/j.dsx.2022.102581> PMID: 35939943
- [37] Son DH, Lee HS, Lee YJ, Lee JH, Han JH. Comparison of triglyceride-glucose index and HOMA-IR for predicting prevalence and incidence of metabolic syndrome. *Nutr Metab Cardiovasc Dis* 2022; 32(3): 596-604.
<http://dx.doi.org/10.1016/j.numecd.2021.11.017> PMID: 35090800
- [38] Lim J, Kim J, Koo SH, Kwon GC. Comparison of triglyceride glucose index, and related parameters to predict insulin resistance in Korean adults: An analysis of the 2007-2010 Korean national health and nutrition examination survey. *PLoS One* 2019;

- 14(3): e0212963.
<http://dx.doi.org/10.1371/journal.pone.0212963> PMID: 30845237
- [39] Lee PF, Ho CC, Kan NW, *et al.* The association between physical fitness performance and abdominal obesity risk among Taiwanese adults: A cross-sectional study. *Int J Environ Res Public Health* 2020; 17(5): 1722.
<http://dx.doi.org/10.3390/ijerph17051722> PMID: 32155732
- [40] Alser M, Naja K, Elrayess MA. Mechanisms of body fat distribution and gluteal-femoral fat protection against metabolic disorders. *Front Nutr* 2024; 11: 1368966.
<http://dx.doi.org/10.3389/fnut.2024.1368966> PMID: 38590830
- [41] McLaughlin T, Lamendola C, Liu A, Abbasi F. Preferential fat deposition in subcutaneous versus visceral depots is associated with insulin sensitivity. *J Clin Endocrinol Metab* 2011; 96(11): E1756-60.
<http://dx.doi.org/10.1210/jc.2011-0615> PMID: 21865361
- [42] Boden G, Shulman GI. Free fatty acids in obesity and type 2 diabetes: Defining their role in the development of insulin resistance and β -cell dysfunction. *Eur J Clin Invest* 2002; 32(s3) (Suppl. 3): 14-23.
<http://dx.doi.org/10.1046/j.1365-2362.32.s3.3.x> PMID: 12028371
- [43] Kwon H, Pessin JE. Adipokines mediate inflammation and insulin resistance. *Front Endocrinol* 2013; 4: 71.
<http://dx.doi.org/10.3389/fendo.2013.00071> PMID: 23781214
- [44] Zhang Z, Deng J, He L, Ling W, Su Y, Chen Y. Comparison of various anthropometric and body fat indices in identifying cardiometabolic disturbances in Chinese men and women. *PLoS One* 2013; 8(8): e70893.
<http://dx.doi.org/10.1371/journal.pone.0070893> PMID: 23951031
- [45] Yang H, Xin Z, Feng JP, Yang JK. Waist-to-height ratio is better than body mass index and waist circumference as a screening criterion for metabolic syndrome in Han Chinese adults. *Medicine* 2017; 96(39): e8192.
<http://dx.doi.org/10.1097/MD.00000000000008192> PMID: 28953680

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