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Triglyceride Glucose Index and Related Parameters as Alternative Indicators of Metabolic Syndrome: Hospital-Based Cross-Section Study

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ABSTRACT

Background: Insulin resistance (IR) is a main risk factor for metabolic syndrome (MetS), type 2 diabetes, and cardiovascular disease (CVD). The triglyceride glucose (TyG) index and TyG-related metrics, such as TyG-BMI or TyG-WC are effective for identifying IR and MetS.

Methods: This cross-sectional study included 120 patients who attended Benha University Hospital Clinics and 60 healthy volunteers. To diagnose MetS, the International Diabetes Federation (IDF) criteria was used. TyG index, TyG-BMI, and TyG-WC were estimated for every subject.

Results: Patients with Mets showed significantly higher TYG index, TYG-WC, and TYG-BMI compared to controls. ROC analysis revealed that TYG-WC index and TYG-BMI cut-off values of 422.6 (81.7% sensitivity and 83.3% specificity) and 111.12 (83.3% sensitivity and 83.3% specificity) could be excellent predictive test of MetS with AUC of 0.907 & 0.909 respectively. TYG index predicted metabolic syndrome with cut-off value of 4.65 (AUC = 0.819) (sensitivity and specificity of 75% and 76.7% respectively). Regarding forecasting IR, the TYG index exhibited a threshold of 4.73, achieving a sensitivity of 77.3% and a specificity of 81.6%. In the case of TYG-WC, the cutoff point was 465.04, yielding a sensitivity of 84.2% and a specificity of 81.8%. TYG-BMI, on the other hand, displayed a threshold value of 117.89, accompanied by a sensitivity of 89.5% and a specificity of 77.3%.

Conclusion: Although TYG-BMI and TYG-WC were more effective in evaluating IR and MetS, TYG index is still an easy way to identify IR and MetS**.**

Keywords: Insulin resistance, Metabolic syndrome, TYG index**.**

INTRODUCTION

Metabolic syndrome (MetS) represents the combined presence of risk factors associated with cardiovascular disease (CVD) and diabetes. These include central obesity, hypertension, hypertriglyceridemia, dysglycemia, and low levels of HDL cholesterol [1]. IR is recognised as a key risk factor for metabolic syndrome, type 2 diabetes, and CVD [2]. Additionally, it has been determined that IR is a defining characteristic and a key underlying mechanism of the metabolic syndrome [3]. IR is defined as an inadequate physiological response to the actions of insulin on peripheral tissues. This results in reduced glucose utilization in muscles and fat, along with heightened gluconeogenesis in the liver. These mechanisms contribute to metabolic and hemodynamic irregularities commonly associated with metabolic syndrome [4]. In the past, tests like the pancreatic suppression tests, the minimal model approximation of glucose metabolism (MMAMG), and the hyperinsulinemic euglycemic clamp technique (HIEG clamp) were initially employed to evaluate insulin resistance [5, 6].

However, these procedures are intrusive, intricate, pricey, and challenging to apply in clinical settings [7]. Using insulin concentration and fasting blood glucose, indicators that evaluate insulin resistance indirectly have been created in 1985, including the homeostasis model for IR (HOMA-IR) [8]. It is found that the triglyceride glucose (TyG) index, a straightforward measurement that combines triglyceride (TG) and fasting plasma glucose, is effective for identifying people with IR and MetS. Numerous studies have examined metrics, including TyG-BMI or TyG-WC, which combine TyG index and obesity indices for IR or diabetes and concluded that they are more effective than TyG index alone in evaluating IR and MetS [3]. We intended to assess the relevance of TYG, TYG-WC, and TYG-BMI concerning their relationship with metabolic syndrome. Furthermore, we aimed to determine the predictive capability of these parameters for identifying metabolic syndrome and insulin resistance in individuals visiting Benha University Hospital Clinic in Egypt.

PATIENTS AND METHOD

This was a cross sectional study involving 120 patients ≥ 18 years old who attended Benha University Hospital Clinics for checkup or follow up their diabetes, hypertension and dyslipidemia from December 2022 to January 2023.

Exclusion criteria: Subjects with systemic disease, diabetes complications and cardiovascular diseases or malignancy.

In addition, 60 individuals, age and sex matched, as healthy volunteers. The participants' diagnoses were made following the criteria outlined by the International Diabetes Federation (IDF) for identifying metabolic syndrome. This necessitated the existence of at least three of the five risk variables, which included elevated triglycerides (with the use of triglyceride-lowering medication as an alternative indicator) at a level of ≥150 mg/dL (1.7 mmol/L), low levels of high-density lipoprotein cholesterol (HDL-C) (with the use of HDL-C-lowering medication as an alternative indicator)

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below 40 mg/dL (1.0 mmol/L) for males and below 50 mg/dL (1.3 mmol/L) for females, high blood pressure (with the use of antihypertensive medication in patients with a history of hypertension as an alternative indicator), where systolic blood pressure (SBP) was ≥130 and/or diastolic blood pressure (DBP) was ≥ 85 mm Hg, elevated fasting plasma glucose (FPG) of ≥100 mg/dL (with the use of glucose-lowering medications as an alternative indicator), and waist circumference of ≥ 94 cm and ≥ 80 cm for men and women, respectively, (according to values specific to the Middle East and Mediterranean populations for defining metabolic syndrome) [1]. Demographic information, including age, gender, body mass index (BMI), SBP, DBP, and waist circumference (WC) were collected.

Laboratory analysis and calculations:

To analyze plasma glucose and lipids, aseptic venous samples were collected following an overnight fast using aseptic procedures. The Clinical Pathology Department of Benha University Hospital measured FPG, fasting insulin (FI), total cholesterol (TC), triglycerides (TG), and HDL-C, in accordance with laboratory standards. Utilizing the Friedwald equation, low-density lipoprotein cholesterol (LDL-C) was computed. The following formula was used to compute HOMA-IR: fasting insulin (micro/L) fasting glucose (mg/dl)/405, with a normal range of 0.5-1.4. A person is doing well if his insulin sensitivity is less than 1.0. Insulin resistance began to emerge at or above 1.9. When the result exceeds 2.9, insulin resistance is present [9]. Triglycerides and glucose (TyG) index, TyG-waist circumference (TyG-WC), and TyG-body mass index (TyG-BMI) were calculated for each individual using the following equations:

TyG = Ln [fasting triglycerides (mg/dL) × fasting glucose (mg/dL)]/2 [10].

TyG-WC = TyG index × WC [2], and TyG-BMI = TyG index × BMI.

Statistical analysis

Collected data were analyzed using SPSS version 20. Values were expressed as percentages and means ± SD. Separate ROC curves were generated for TYG index, TYG-WC, and TYG-BMI. The best cut-off and diagnostic indices were determined. The MedCalc software, version 7.50 (Mariakerke, Belgium**)** was used for the ROC curve analysis.

RESULTS

120 patients (40 % males vs 60 % females) **(Table 1)** as well as 60 healthy control, constituted our study subjects. In patients with MetS, a non-significant difference was detected between both genders regarding age, BMI, WC , SPB, DBP, FPG, TC, LDL-C, HDL-C, TG, HOMA-IR, TYG index, TYG-WC and TYG-BMI **(Table 2)**.

The mean patients' age was 42.12 ± 10.40 years while that of control group was 38.83 ± 16.01 years with non-significant different between both groups **(Table 3)**. FPG and lipid profile were significantly higher in patient with MetS compared to control. Patients with metS had significantly higher ($p < 0.001$) TYG index (4.8± 0.21) compared to control (4.61±0.07). TYG-WC (466.91±50.06) and TYG-BMI (122.75± 12.43) indices were substantially higher in patients with MetS compared to control (381.74±35.72) and (103.34±7.91) respectively. ROC curve analysis revealed that TYG-WC index cut-off value of 422.6 could be excellent predictive test of MetS patients with 81.7% sensitivity and 83.3% specificity (AUC, 0.907). ROC curve analysis revealed that TYG-BMI cut-off value of 111.12 could be excellent predictive test of MetS patients with 83.3% sensitivity and 83.3% specificity (AUC, 0.909) (TABLE 4).

Meanwhile, TYG index predicted metabolic syndrome with cut-off value of 4.65 (AUC = 0.819) with sensitivity and specificity of 75% and 76.7% respectively. Regarding forecasting IR, the TYG index exhibited a threshold of 4.73, achieving a sensitivity of 77.3% and a specificity of 81.6%. In the case of TYG-WC, the cutoff point was 465.04, yielding a sensitivity of 84.2% and a specificity of 81.8%. TYG-BMI, on the other hand, displayed a threshold value of 117.89, accompanied by a sensitivity of 89.5% and a specificity of 77.3% **(Tables 4 & 5)**. AUC of 0.891 and 0.873 for TYG-BMI and TYG-WC, respectively, were better for prediction of IR than TYG alone (AUC, 0.791) **(Figures 1 & 2)**.

Table (1): Descriptive data of patients with MetS group

	mean (S.D.)
Age (years)	42.12 (10.4)
Gender ratio (F/M)	72/48
BMI (Kg\m2)	25.51 (1.9)
SBP (mmHg)	137.1 (10.5)
DBP (mmHg)	86.67 (9.97)
Waist circumference(cm)	97.05 (8.05)
HOMA-IR	3.32 (0.62)
TYG	4.8 (0.21)
TYG-WC	466.91
TYG-BMI	(50.06)
	122.75
	(12.43)
Laboratory data, mean (S.D.)	
FPG (mg\dl)	132.55
	(43.95)
FI (mU/ L)	13.6 (1.86)
TG (mg\dl)	129.72
	(30.13)
TC (mg\dl)	182.50
	(37.34)
LDL (mg\dl)	122.87 (26.6)
HDL (mg\dl)	48 (7.67)

Table (2): Clinical and laboratory characteristics of males and females in patients with MetS

	Female (n=72)		Male (n=48)		t test	p-value
	mean	S.D.	mean	S.D.		
Age (years)	42.31±10.45		41.83 ±10.54		0.1	0.9
BMI (Kg\m2)	25.30±1.85		25.83 ±1.97		1.1	0.3
SBP (mmHg)	138.69±11.32		134.67 ±8.70		1.5	0.1
DBP (mmHg)	87.67± 11.61		85.17 ±6.78		0.9	0.3
Waist circumference (cm)	95.64 ± 9.37		99.17 ±4.98		1.9	0.06
FPG (mg\dl)	132.11 ±6.62		133.21 ±4.58		0.1	0.9
TC (mg\dl)	184.34 ±8.04		179.49 ±6.88		0.5	0.6
TG (mg\dl)	129.81 ±31.83		129.58 ±28.07		0.1	0.9
LDL (mg\dl)	124.20 ±26.71		120.88 ±26.87		0.5	0.6
HDL (mg\dl)	48.03 ±7.88		47.96 ±7.52		0.1	0.9
FI (mU/ L)	13.46 ±1.95		13.80 ±1.74		0.7	0.5
HOMA-IR	3.28 ±0.64		3.39 ±0.61		0.7	0.5
TYG	4.81 ±0.21		4.80 ±0.19		0.2	0.8
TYG-WC	460.65 ±55.60		476.30 ±39.64		1.2	0.2
TYG-BMI	121.85±12.20		124.10 ±12.91		0.7	0.5

Table (3): Laboratory features, TYG index, TYG-WC, TYG-BMI of patients with MetS Vs. control group

		Cases (n=120)		Control (n=60)		t test	p-value
Sex: Female	(N) (%)	72	60.0%	26	43.3%	2.2	0.1
Male	(N) (%)	48	40.0%	34	56.7%		
Age (years)	Mean ± SD	42.12 ±10.40		38.83 ±16.01		1.02	0.3
FPG (mg\dl)		132.55 ± 4.95		88.93± 3.87		7.6	<0.001*
TC (mg\dl)		182.40±37.34		149.50±13.73		6.1	<0.001*
TG (mg\dl)		129.72± 30.13		113.23 ±14.58		3.5	<0.001*
LDL (mg\dl)		122.87 ±26.60		106.63 ±11.94		3.9	<0.001*
HDL (mg\dl)		48.00 ± 7.67		54.63 ± 7.77		3.8	<0.001*
FI (mU/ L)		13.60 ± 1.86		7.76 ± 1.29		17.3	<0.001*
HOMA-IR		3.32 ± 0.62		1.69 ± 0.32		16.5	<0.001*
TYG		4.80 ± 0.21		4.61 ± 0.07		6.7	<0.001*
TYG-WC		466.91 ± 50.06		381.74 ±35.72		9.3	<0.001*
TYG-BMI		122.75 ± 12.43		103.34 ± 7.91		8.9	<0.001*

Table (4): ROC curve analysis for the studied parameters to predict metabolic syndrome

Variable (baseline)	AUC	Cut-off value	Sensitivity	Specificity	PPV	NPV
TYG index	0.819	>4.65	75	76.7	90	60.5
TYG-WC	0.907	>422.6	81.7	83.3	90.7	69.4
TYG-BMI	0.909	>111.12	83.3	83.3	90.9	71.4

Table (5): ROC curve analysis for the studied parameters to predict Insulin Resistance in metabolic syndrome cases

Variable (baseline)	AUC	Cut-off value	Sensitivity	Specificity	PPV	NPV
TYG	0.791	4.73	81.6	77.3	86.1	70.8
TYG-WC	0.873	465.04	84.2	81.8	88.9	75
TYG-BMI	0.891	117.89	89.5	77.3	87.2	80.9

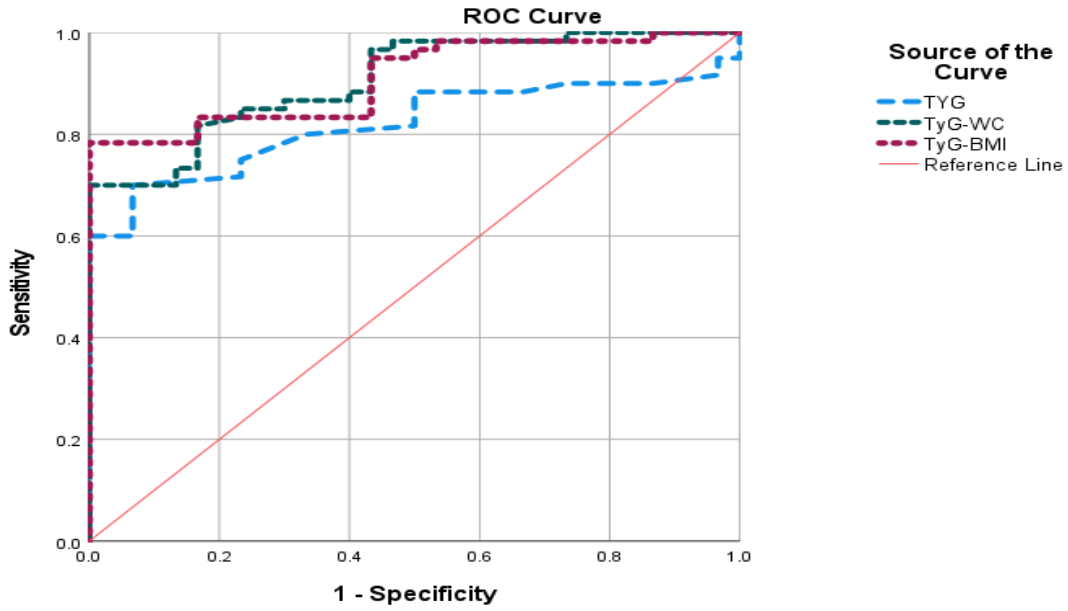

Figure (1): ROC analysis for the studied parameters to predict metabolic syndrome.

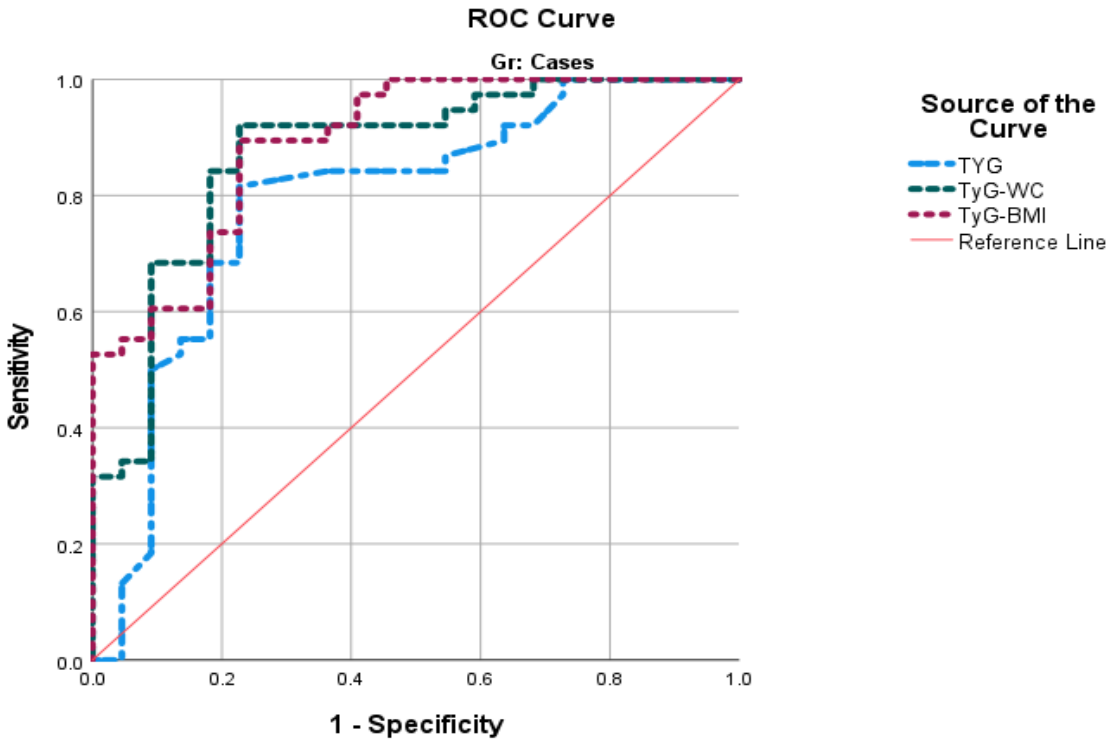

Figure (2): ROC curve analysis for the studied parameters to predict Insulin Resistance in metabolic syndrome cases.

DISCUSSION

TyG index is significantly linked with MetS identification and outperformed HOMA-IR. TyG-related factors, such as TyG-WC and TyG-BMI enhanced the identification of individuals with IR [11]. MetS is believed to be caused by IR, which is defined by reduced tissue sensitivity to circulating insulin [12]. In this study, three new MetS parameters we evaluated and compared, including TyG index, TyG-BMI, and TyG-WC. Additionally, we determined the cut off value of these indices in prediction of patients with MetS and IR. Mean TYG index was significant higher in patients with MetS (4.80 ± 21) compared to control group (4.61 ± 0.07) ($p<0.001$). The AUC of TYG index was 0.819 for prediction of MetS, with cut-off value > 4.65 (Sensitivity of 75% and specificity of 76.7%), while the cut-off value for prediction of IR was 4.73 with sensitivity of 81.6 and specificity of 77.3 %. Previous result showed that TYG index cut-off value for prediction of IR was 4.65 (Sensitivity of 84 % and specificity of 45%) [13]. Another study showed TYG index cut off value of 4.78 (Sensitivity of 75.9 % and specificity of 71.9%) for prediction of IR [14]. In addition, cut-off values for TYG index were 4.69 and 4.49 in another 2 studies with sensitivity of 73.8 % & 82.6 and specificity of 75.6 & 82.1% respectively [15, 16]. It is important to mention that the above studies used HOMA-IR as reference for insulin resistance definition. In a Brazilian study, the TyG index in MetS patients had an AUC and Youden's cut-off point of 0.873 and Ln 4.52, respectively. The sensitivity and specificity were 75.75% and 84.30%, respectively [10].

The United States National Health and Nutrition Examination Survey (1999–2016) data of 11,378 individuals found that the cut-off value for the TyG index to predict IR is 4.665 for males and 4.575 for females [17]. Meanwhile, another study demonstrated the TyG index at a range of 7.8–11.0 for patients with MetS [18]. Mean TyG index 8.4 ± 0.7), and it is effective in identifying MetS [11]. The cut-off values with the IDF definition for MetS were 8.65, 8.65, 8.15, and 8.55, respectively [19]. The Korean National Health and Nutrition Examination Survey from 2007 to 2010 with a total of 11,149 respondents determined that the mean TYG index for patients with IR was 8.76 ± 0.60 [2]. The manner in which the TyG index is computed provides a plausible explanation for such discrepancies. Two formulas were mentioned in previous studies: first formula was: Ln [fasting triglycerides (mg/dL) × fasting glucose (mg/dL)]/2 [10]. The second formula was: Ln [fasting triglycerides (mg/dL) × fasting glucose (mg/dL)/2] [20], for this reason the finding of higher value for TYG index in some studies.

Our study revealed that mean TG level was 129.72 ± 30.13 mg/dl. The means of WC & BMI in patients with MetS were 97.05 ± 8.05 cm and 25.51 ± 1.9 kg/m^2 respectively. In addition, mean FPG was 132.55 ± 43.95 mg/dl. Occurrence of IR in hypertriglyceridemia can be explained as follows: In cases of obesity, there can be an excess of lipid intake that surpasses the adipose tissue's ability to store it. This surplus can lead to the build-up of lipids in non-typical locations like the liver and muscles [21]. Thus, a substantial amount of these fatty acids enters the mitochondria [22]. Triglyceride accumulation in liver and muscle, caused by insufficient fatty acids oxidation in the mitochondria, has a role in developing IR [23]. In this state, the efficiency of insulin is compromised, as it is unable to attach to its receptor. Consequently, this results in a decrease in the production of hepatic glycogen and a reduced uptake of glucose by muscle tissues [24]. The conflict between glucose and fatty acids for oxidation and absorption leads to disrupted glucose metabolism due to the prioritization of fatty acid oxidation [23]. Moreover, among people with visceral obesity, the increase in triglyceride levels may be associated with insulin resistance, emphasizing the substantial influence of triglycerides on the onset of insulin resistance. This highlights the scientific rationale for regarding triglycerides as a factor in detecting insulin resistance [13].

Earlier research has established a clear link between the TyG index and insulin resistance, along with associated health issues. As an example, individuals with elevated TyG index scores exhibited greater prevalence of type 2 diabetes. Moreover, recent findings have revealed a direct correlation between the TyG index and the incidence of cardiovascular events, providing additional support for a potential connection with this metabolic anomaly [25].

When comparing the TyG index with the HIEC as the gold standard test, various studies found that the TyG index cutoff values ranging from 4.55 to 5.88. These studies demonstrated a sensitivity of more than 67% and a specificity that fell within the range of 32.5% to 85%. These studies collectively involved 678 participants. On the contrary, when examining the HOMA-IR, cutoff values were documented in five studies, ranging from 4.55 to 4.78. Across these studies, there was a considerable variation in sensitivity, with values ranging from 73% to 90%, as well as in specificity, which ranged from 45% to 99%. There was significant variation in the cut-off values used for HOMA-IR to define insulin resistance, which limited comparability between the studies. Lower diagnostic accuracy for TyG was observed in studies using HOMA-IR as the gold standard than studies using HIEC [10].

We proposed several conceivable mechanisms to explain why a higher TyG index may be linked to an elevated risk of cardiovascular disease (CVD). These mechanisms include more pronounced underlying metabolic dysfunction, resulting in more significant fluctuations in the levels of key biomarkers such as blood pressure, fasting glucose, and lipids. Additionally, a higher TyG index could be associated

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with increased lipolysis and altered lipid exchange, endothelial dysfunction, an enhanced inflammatory response, and arterial plaques formation. These factors collectively contribute to the increased risk of CVD [26].

Our study revealed no significant difference in mean TG level between females and males (129.81 ± 31.83 and129.58 ± 28.07 respectively) (p=0.9). In MetS patients, there was no significant difference in WC between females (95.64 ± 9.37 cm) and males (99.17 ± 4.98 cm). There was no significant difference between females (25.30 ± 1.85 kg/m^2) and males (25.83 ± 1.97kg/m^2) concerning BMI. We found mean FPG was 132.55 ± 43.95 mg/dl without significant difference between females (132.11 ± 46.62 mg/dl), and males (133.21 ± 40.58 mg/dl). However, Korean National Health and Nutrition Examination Survey revealed that males were significantly higher than females concerning WC, BMI, FPG, TG and HOMA-IR [2]. In contrast, data from the National Health and Nutrition Examination Survey (NHANES) revealed inconsistent results concerning WC and BMI among different population for example; Non-Hispanic Black Females had significantly higher WC than males while Korean and Mexican American males had significantly higher WC in comparison with females. In the same study, non-Hispanic White showed non-significant difference in WC between males and females. For BMI, Mexican American and non-Hispanic White showed non-significant different between males and females. However, non-Hispanic Black females had significantly higher BMI.

In addition, males showed significant higher FPG in males than females in all study populations. TG level showed inconsistent results regarding sex in each study population [19]. Our study showed non-significant difference regarding TYG index between males and females, similar to Korean population in **Moon *et al.*** [19] study. Multiple clinical definitions have been suggested for the metabolic syndrome. This has led to considerable uncertainty among doctors about the identification of people with the illness, for this reason the definition of MetS is population- and country-specific [1]. This explains why there is heterogeneity in TYG index, TYG-WC, and TYG-BMI cut off values. The current study demonstrated the cut-off value for TYG-WC > 422.6 for detecting MetS patients (Sensitivity of 81.7% & specificity of 83.3%), and for TYG-BMI >111.12 (Sensitivity of 83.3 % & specificity of 83.3 %). The cut-off values were as follows: TyG-BMI: 135.5 for males and 135.5 for females; TyG-WC: 461.5 for males and 440.5 for females [17].

Taiwo H. Raimi [11] concluded that the product of TyG index and anthropometric indices (TyG-waist to height ratio (TyG-WHtR), TyG-WC, and TyG-BMI) enhanced MetS identification and prediction. Korean National Health and Nutrition Examination Survey concluded that TyG-BMI was found to be superior to other parameters; TyG index, TyG-WC, and TyG-WHtR for IR prediction [2]. In our study, obesity indices in terms of TYG-WC and TYG-BMI were more effective than TyG index alone in evaluating patients with MetS evidenced by high AUC of 0.907 and 0.909 for TYG-WC and TYG-BMI respectively than 0.819 for TYG index. Furthermore, AUC of 0.873 and 0.891 for TYG-WC and TYG-BMI respectively were better than 0.791 for TYG index for detecting patients with IR. Regarding practicality, glucose and triglyceride measurements are routine biochemical tests frequently employed in primary healthcare settings. As a result, the TyG index presents a viable substitute for detecting insulin resistance. Regarding using the TyG index to differentiate between those with and without insulin resistance and metabolic Syndrome (MetS), varying outcomes were observed. In addition, it was known that criteria of diagnosis of MetS in different population, specifically WC, were not consistent and there is heterogeneity about the cut-off value.

CONCLUSION

Obesity indices such as TYG-BMI and TYG-WC were more effective in evaluating patients with IR and MetS compared to TyG index alone. TYG index is still an easy way to identify IR and MetS due to the availability of plasma glucose and TG in primary health care centres.

Limitations of the study: This study was conducted in a cross-sectional manner with a limited sample size, which means we cannot definitively establish a direct cause-and-effect relationship based solely on our findings. Furthermore, the variations in the methods used to calculate the TyG index pose a potential limitation, as they make it challenging to compare our data with that from existing literature.

Data availability: Upon a reasonable request, the corresponding author could provide the data sets used in the course of this research.

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Ethics approval: This retrospective study adhered to the ethical standards of the institutional and national research committee, and followed the Helsinki declaration. The study protocol received approval from the Ethics Committee of Benha Faculty of Medicine, Benha University, Egypt (Reference Code: RC;9-11-2022).

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REFERENCES

1. **Alberti K , Eckel R , Grundy S *et al.*(2009):** International Diabetes Federation Task Force on Epidemiology and Prevention, National Heart, Lung, and Blood Institute, American Heart Association.Circulation, 120 (16): 1640–1645. https://doi.org/10.1161/CIRCULATIONAHA.109.192644
2. **Lim J, Kim J, Koo S *et al.* (2019):** 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, 14(3): e0212963. https://doi.org/10.1371/journal.pone.0212963
3. **Bonora B, Marescotti M, Marcuzzo G *et al.* (2015):** Synergistic interactions among metabolic syndrome components and homeostasis model assessment of insulin resistance in a middleaged general population over time. Metab Syndr Relat Disord., 13: 171-8.
4. **Lee J, Kim B, Kim W *et al.* (2021):** Lipid indices as simple and clinically useful surrogate markers for insulin resistance in the U.S. population. Scientific reports, 11 (1): 2366. https://doi.org/10.1038/s41598-021-82053-2
5. **DeFronzo R , Tobin J , Andres R (1979):** Glucose clamp technique: A method for quantifying insulin secretion and resistance. Am. J. Physiol., 237: E214-223.
6. **Bergman R , Prager R, Volund A *et al.* (1987):** Equivalence of the insulin sensitivity index in man derived by the minimal model method and the euglycemic glucose clamp. J. Clin. Investig., 79: 790–800.
7. **Du T, Yuan G, Zhang M *et al.* (2014):** Clinical usefulness of lipid ratios, visceral adiposity indicators, and the triglycerides and glucose index as risk markers of insulin resistance. Cardiovascular diabetology, 13: 146. https://doi.org/10.1186/s12933-014-0146-3
8. **Matthews D , Hosker J , Rudenski A *et al.* (1985):** Homeostasis model assessment: insulin resistance and beta-cell function from fasting plasma glucose and insulin concentrations in man. Diabetologia, 28 (7): 412–419. https://doi.org/10.1007/BF00280883
9. **Roitberg G, Dorosh Z, Sharkhun O (2015):** A new method for screening diagnosis of insulin resistance. Bulletin of Experimental Biology and Medicine, 158 (3): 397– 400.
10. **Ferreira J , Zandonade E, de Paula Alves B *et al.* (2021):** Cutoff point of TyG index for metabolic syndrome in Brazilian farmers. Archives of endocrinology and metabolism, 65 (6): 704–712. https://doi.org/10.20945/2359-3997000000401
11. **Raimi T , Dele-Ojo B , Dada S *et al.* (2021):** Triglyceride-Glucose Index and Related Parameters Predicted Metabolic Syndrome in Nigerians. Metabolic syndrome and related disorders, 19 (2): 76–82. https://doi.org/10.1089/met.2020.0092
12. **Alberti K, Zimmet P (1998):** Definition, diagnosis and classification of diabetes mellitus and its complications. Part 1: Diagnosis and classification of diabetes mellitus provisional report of a WHO consultation. Diabet Med., 15: 539–553.
13. **Simental-Mendía L , Rodríguez-Morán M, Guerrero-Romero F (2008):** The product of fasting glucose and triglycerides as surrogate for identifying insulin resistance in apparently healthy subjects. Metabolic syndrome and related disorders, 6 (4): 299–304. https://doi.org/10.1089/met.2008.0034
14. **Mazidi M, Kengne A , Katsiki N *et al.* (2018):** Lipid accumulation product and triglycerides/glucose index are useful predictors of insulin resistance. Journal of diabetes and its complications, 32 (3): 266–270. https://doi.org/10.1016/j.jdiacomp.2017.10.007
15. **Lojko D, Owecki M, Suwalska A (2019):** "Impaired glucose metabolism in bipolar patients: the role of psychiatrists in its detection and management," International Journal of Environmental Research and Public Health, 16 :7.
16. **Salazar J, Bermudez V, Calvo M *et al.* (2017):** Optimal cutoff for the evaluation of insulin resistance through triglyceridеglucose index: a cross-sectional study in a Venezuelan population.F1000Research, 6: 1337
17. **Lee J, Kim B, Kim W *et al.* (2021):** Lipid indices as simple and clinically useful surrogate markers for insulin resistance in the U.S. population. Scientific reports, 11 (1): 2366. https://doi.org/10.1038/s41598-021-82053-2
18. **Jiang M, Li X, Wu H *et al.* (2022):** Triglyceride-Glucose Index for the Diagnosis of Metabolic Syndrome: A Cross-Sectional Study of 298,652 Individuals Receiving a Health Check-Up in China. https://doi.org/10.1155/2022/3583603
19. **Moon S, Park J , Ahn Y (2017):** The Cut-off Values of Triglycerides and Glucose Index for Metabolic Syndrome in American and Korean Adolescents. Journal of Korean medical science, 32 (3): 427–433.https://doi.org/10.3346/jkms.
20. **Guerrero-Romero F, Simental-Mendía L , González-Ortiz M *et al.* (2010):** The product of triglycerides and glucose, a simple measure of insulin sensitivity. Comparison with the euglycemic-hyperinsulinemic clamp. The Journal of clinical endocrinology and metabolism, 95 (7): 3347–3351. https://doi.org/10.1210/jc.2010-0288
21. **Ertunc M, Hotamisligil G (2016):** Lipid signaling and lipotoxicity in metaflammation: indications for metabolic disease pathogenesis and treatment. J Lipid Res., 57 (12): 2099-114.
22. **Engin A (2017):** What is lipotoxicity? Adv Exp Med Biol., 960: 197-220.
23. **Hegarty B, Furler S, Ye J *et al.* (2003):** The role of intramuscular lipid in insulin resistance. Acta Physiol Scand., 178 (4): 373-83.
24. **Toro-Huamanchumo C, Urrunaga-Pastor D, Guarnizo-Poma M *et al.* (2019):** Metabolic Syndrome Research Group. Triglycerides and glucose index as an insulin resistance marker in a sample of healthy adults. Diabetes Metab Syndr., 13 (1): 272-7.
25. **Sánchez-García A, Rodríguez-Gutiérrez R, Mancillas-Adame L *et al.* (2020):** Diagnostic Accuracy of the Triglyceride and Glucose Index for Insulin Resistance: A Systematic Review. https://doi.org/10.1155/2020/4678526
26. **Li H, Zuo Y, Qian F *et al.* (2022):** Triglyceride-glucose index variability and incident cardiovascular disease: a prospective cohort study. Cardiovascular diabetology, 21 (1): 105. https://doi.org/10.1186/s12933-022-01541-5.