Eskisehir Med J. 2026; 7(3): 285-292
doi: 10.48176/esmj.2026.277

Original Article

THE RELATIONSHIP BETWEEN THE TRIGLYCERIDE-GLUCOSE INDEX AND INSULIN RESISTANCE, INFLAMMATION, IRON METABOLISM AND MICRONUTRIENT PROFILE IN INDIVIDUALS WITH OBESITY

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ABSTRACT

Introduction: The aim of this study was to compare metabolic parameters, inflammatory markers, indicators of iron metabolism and micronutrient levels among groups of obese individuals categorised according to the Triglyceride-Glucose (TyG) index, and to assess the relationship between the TyG index and these parameters.

Methods: The data of 110 obese individuals with a BMI ≥ 30 kg/m² who presented at Eskişehir City Hospital were retrospectively analysed. Patients were divided into two groups according to the TyG index (Group 1: TyG < 8.85, n=48; Group 2: TyG ≥ 8.85, n=62). Demographic, anthropometric and laboratory data were compared. The diagnostic performance of the TyG index in predicting insulin resistance (HOMA-IR > 2.5) was assessed using ROC analysis.

Results: In Group 2, BMI (37.8±4.5 vs. 32.4±2.1 kg/m²), waist circumference (114.2±12.6 vs. 98.6±8.4 cm), HOMA-IR (5.12±1.64 vs. 2.38±0.72), CRP (5.9±1.8 vs. 2.2±0.9 mg/L), ferritin (128±34 vs. 45±12 ng/mL) and uric acid (6.4±1.2 vs. 4.8±0.8 mg/dL) were significantly higher; serum iron (58±22 vs. 85±18 µg/dL), vitamin D (14.2±6.1 vs. 22.4±8.6 ng/mL), vitamin B12 (228±74 vs. 312±88 pg/mL), folate (7.2±2.6 vs. 9.8±3.1 ng/mL) and magnesium (1.75±0.3 vs. 2.08±0.2 mg/dL) were found to be significantly low. The strongest positive correlations with TyG were observed with HOMA-IR (r=+0.67) and CRP (r=+0.61). In the ROC analysis, the AUC value of the TyG index for predicting insulin resistance was 0.85 (p<0.001), and the optimal cut-off value was determined to be 8.85 (sensitivity 76.8%, specificity 81.2%). In the gender-based subgroup analysis, elevated uric acid levels were more pronounced in men (p=0.003 for interaction).

Conclusion: The TyG index is a comprehensive metabolic marker that reflects insulin resistance, alongside inflammation, iron metabolism disorders and micronutrient deficiencies, in obese individuals. The use of the TyG index in the metabolic risk assessment of obese individuals may provide clinical benefits, particularly in the early detection of functional iron deficiency and micronutrient deficiencies.

Keywords: Obesity, Triglyceride-Glucose Index, Insulin Resistance, Ferritin, Vitamin D, Vitamin B12, Folate, Magnesium

INTRODUCTION

Obesity is one of the most significant global public health issues today, and its prevalence has increased markedly in recent years. According to World Health Organisation data, more than one billion people worldwide are living with obesity (1), and obesity is a major risk factor for cardiovascular disease, type 2 diabetes, certain types of cancer and premature mortality (2). Insulin resistance is one of the key pathophysiological mechanisms underlying obesity-related metabolic complications. However, the euglycaemic-hyperinsulinaemic clamp technique, the gold standard method for assessing insulin resistance, cannot be widely used in everyday clinical practice. Consequently, in recent years, the Triglyceride-Glucose (TyG) index, calculated from fasting triglyceride and glucose levels, has attracted attention as a practical and low-cost indicator of insulin resistance (3,4). Various studies have demonstrated that the TyG index is associated with the development of type 2 diabetes, metabolic syndrome and cardiovascular disease (5,6).

Obesity is also characterised by chronic low-grade inflammation. Pro-inflammatory cytokines released from adipose tissue disrupt insulin signalling, thereby contributing to the development of metabolic disorders. In this process, increases in inflammatory markers such as C-reactive protein (CRP), the neutrophil-to-lymphocyte ratio (NLR) and ferritin may be observed (7,8). Similarly, a recent study observed a tendency for CRP levels to rise as obesity class increased; however, this association was not found to be statistically significant (9). Chronic inflammation associated with obesity can increase hepcidin synthesis and disrupt iron homeostasis via various pro-inflammatory cytokines, particularly interleukin-6. As a result, functional iron deficiency—characterised by a decrease in serum iron levels despite normal or elevated ferritin levels—may develop (10,11).

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Submission Date: 22.06.2026 **Acception Date:** 04.08.2026
Cite as: Kaya ZI, SaGdıç A, Çoban HH, et al. The Relationship Between the Triglyceride-Glucose Index and Insulin Resistance, Inflammation, Iron Metabolism and Micronutrient Profile in Individuals with Obesity. Eskisehir Med J. 2026; 7(3): 285-292. doi: 10.48176/ esmj.2026.277

Furthermore, deficiencies in vitamin D, magnesium, vitamin B12 and folate are common in obese individuals. It is known that vitamin D and magnesium play an important role in insulin sensitivity and glucose metabolism (12,13). Similarly, it has been reported that low levels of vitamin B12 and folate may be associated with hyperhomocysteinemia, endothelial dysfunction and an increased metabolic risk (14,15). However, there are limited studies that jointly assess the relationship between the TyG index and inflammation, iron metabolism and micronutrient status in obese individuals.

The aim of this study was to compare metabolic parameters, inflammatory markers, indicators of iron metabolism and micronutrient levels among groups of obese individuals classified according to the TyG index, and to assess the relationship between the TyG index and these parameters.

METHODS

Study Design and Participants

This retrospective cross-sectional study was conducted using the records of obese individuals who presented to the Department of Internal Medicine and the Obesity Centre at XXXX Hospital. The study included individuals aged 18 years and over with a body mass index (BMI) of ≥ 30 kg/m². Patients with missing clinical or laboratory data were excluded from the study. Approval for the study was obtained from the Eskisehir City Hospital Clinical Research Ethics Committee (Decision No: 2026/413).

Records of the participants' age, sex, height, body weight and body mass index were retrospectively assessed. Laboratory data were obtained from the electronic patient record system. The following parameters, measured as part of routine clinical practice, were recorded: fasting plasma glucose, fasting insulin, HbA1c, total cholesterol, LDL-cholesterol, HDL-cholesterol, triglycerides, aspartate aminotransferase (AST), alanine aminotransferase (ALT), uric acid, C-reactive protein (CRP), ferritin, iron, vitamin B12, folate, 25-hydroxyvitamin D and magnesium levels were recorded.

Inclusion criteria: aged 18 years or over, body mass index (BMI) ≥ 30 kg/m², and having complete results for all tests requested during routine clinical follow-up (fasting glucose, insulin, lipid profile, CRP, ferritin, iron, vitamin B12, folate, 25-hydroxyvitamin D, magnesium). The exclusion criteria are as follows: being under 18 years of age; (2) having a BMI < 30 kg/m²; having an active infectious disease; having a diagnosis of a chronic inflammatory disease (rheumatoid arthritis, inflammatory bowel disease, systemic lupus erythematosus, etc.); having a diagnosis of malignancy or currently undergoing active chemotherapy or radiotherapy; having chronic kidney disease (stages 3–5) or undergoing dialysis treatment; having liver cirrhosis or decompensated liver disease; being on iron replacement therapy or taking vitamin B12, folate, vitamin D or magnesium supplements (within the last 3 months); taking lipid-lowering medication (statins, fibrates, etc.) or antidiabetic medication (metformin, insulin, etc.), being pregnant or breastfeeding, or having incomplete clinical or laboratory data.

Index Calculations

HOMA-IR = Fasting insulin (μU/mL) × Fasting plasma glucose (mg/dL) / 405 (16).

The triglyceride-glucose (TyG) index was calculated using the following formula: TyG = ln [Fasting triglycerides (mg/dL) × Fasting plasma glucose (mg/dL) / 2] (17).

The optimal cut-off value of the TyG index for predicting clinical insulin resistance (defined as HOMA-IR > 2.5) was determined using Receiver Operating Characteristic (ROC) curve analysis based on the Youden index ($Sensitivity + Specificity - 1).

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics for Windows (Version 26.0, IBM Corp., Armonk, NY, USA) software (18). The normality of continuous variables was assessed using the Shapiro-Wilk test. To ensure descriptive and comparative clarity across subgroups, all continuous variables were presented as mean ± standard deviation. Comparisons between two independent groups were performed using the independent samples t-test or the Mann–Whitney U test, where appropriate. Linear relationships between variables were evaluated using Pearson correlation analysis for normally distributed variables and Spearman correlation analysis for non-normally distributed variables.The diagnostic accuracy of the TyG index in predicting insulin resistance (HOMA-IR > 2.5) and its optimal cut-off value were determined using Receiver Operating Characteristic (ROC) analysis, with the Area Under the Curve (AUC) calculated. In the ROC analysis, the Youden Index (Sensitivity + Specificity – 1) was used to determine the optimal cut-off value. A p-value of <0.05 was considered statistically significant.

RESULTS

Demographic and Anthropometric Characteristics

The mean age of the 110 obese patients included in the study was 45.2 ± 11.4 years, and 62 per cent (n=68) were women. No statistically significant difference was observed between the groups in terms of age and gender distribution ($p > 0.05$). However, in Group 2, BMI (37.8 ± 4.5 vs. 32.4 ± 2.1 kg/m², $p < 0.001$), waist circumference (114.2 ± 12.6 vs. 98.6 ± 8.4 cm, $p < 0.001$), systolic blood pressure (138 ± 15 vs. 122 ± 12 mmHg, $p = 0.004$) and diastolic blood pressure (85 ± 11 vs. 79 ± 9 mmHg, $p = 0.008$) were found to be significantly higher. The anthropometric data are summarised in Table 1.

Metabolic Parameters

In Group 2, fasting glucose (112 ± 18 vs. 94 ± 10 mg/dL, $p < 0.001$), triglycerides (218 ± 42 vs. 124 ± 28 mg/dL, $p < 0.001$), total cholesterol (214 ± 34 vs. 186 ± 28 mg/dL, $p = 0.002$), LDL-C (142 ± 30 vs. 115 ± 22 mg/dL, $p = 0.028$) and HOMA-IR (5.12 ± 1.64 vs. 2.38 ± 0.72, $p < 0.001$); HDL-C, on the other hand, was found to be significantly lower (39 ± 5 vs. 48 ± 6 mg/dL, $p = 0.015$). Uric acid levels were also markedly higher in Group 2 (6.4 ± 1.2 vs. 4.8 ± 0.8 mg/dL, $p = 0.012$). The metabolic parameters are presented in Table 2.

Inflammatory Markers and Micronutrients

When inflammation markers were assessed, NLR (3.12 ± 0.8 vs. 1.88 ± 0.4, $p < 0.001$), CRP (5.9 ± 1.8 vs. 2.2 ± 0.9 mg/L, $p < 0.001$) and ferritin (128 ± 34 vs. 45 ± 12 ng/mL, $p < 0.001$) were found to be significantly higher in Group 2; serum iron (58 ± 22 vs. 85 ± 18 μg/dL, $p < 0.001$), on the other hand, was found to be significantly lower. This finding, reflecting low serum iron alongside the concurrent elevation of ferritin and CRP, supports the diagnosis of functional iron deficiency.

In the micronutrient assessment, Group 2 showed lower levels of vitamin D (14.2 ± 6.1 vs. 22.4 ± 8.6 ng/mL, $p < 0.001$) (Figure 1), vitamin B12 (228 ± 74 vs. 312 ± 88 pg/mL, $p = 0.008$), folate (7.2 ± 2.6 vs. 9.8 ± 3.1 ng/mL, $p = 0.012$) and magnesium (1.75 ± 0.3 vs. 2.08 ± 0.2 mg/dL, $p = 0.024$) were found to be significantly lower in Group 2. All these parameters are presented in a comparative table in Table 3.

Table 1. Demographic and Anthropometric Characteristics of the Patients

Parametre	All Patients (n=110)	Group 1 (TyG < 8.85, n = 48)	Group 2 (TyG ≥ 8.85, n = 62)	p
Age (years)	45.2±11.4	44.1±10.8	46.4±12.1	0.312
Gender – Female, n (%)	68 (62%)	30 (62.5%)	38 (61.3%)	0.845
Height (cm)	166.3±8.4	167.2±8.1	165.6±8.8	0.310
Weight (kg)	92.6±14.2	88.4±11.6	96.1±15.4	0.004
BMI (kg/m²)	33.4±4.8	32.4±2.1	37.8±4.5	<0.001
Waist circumference (cm)	107.2±13.6	98.6±8.4	114.2±12.6	<0.001
Systolic BP (mmHg)	131±15	122±12	138±15	0.004
Diastolic BP (mmHg)	82±10	79±9	85±11	0.008

BMI: Body Mass Index; BP: Blood Pressure. Data are presented as mean ± standard deviation or number (%). Independent samples t-test was used for continuous variables and chi-square test for categorical variables.

Table 2. Comparison of Metabolic Parameters According to TyG Groups

Parameter	Group 1 (n=48)	Group 2 (n=62)	P Value
Fasting Glucose (mg/dL)	94±10	112±18	<0.001
Triglycerides (mg/dL)	124±28	218±42	<0.001
TyG Index	8.31±0.28	9.18±0.44	<0.001
Total Cholesterol (mg/dL)	186±28	214±34	0.002
LDL-C (mg/dL)	115±22	142±30	0.028
HDL-C (mg/dL)	48±6	39±5	0.015
Uric Acid (mg/dL)	4.8±0.8	6.4±1.2	0.012
Fasting Insulin (µU/mL)	10.2±3.1	18.6±5.4	<0.001
HOMA-IR	2.38±0.72	5.12±1.64	<0.001

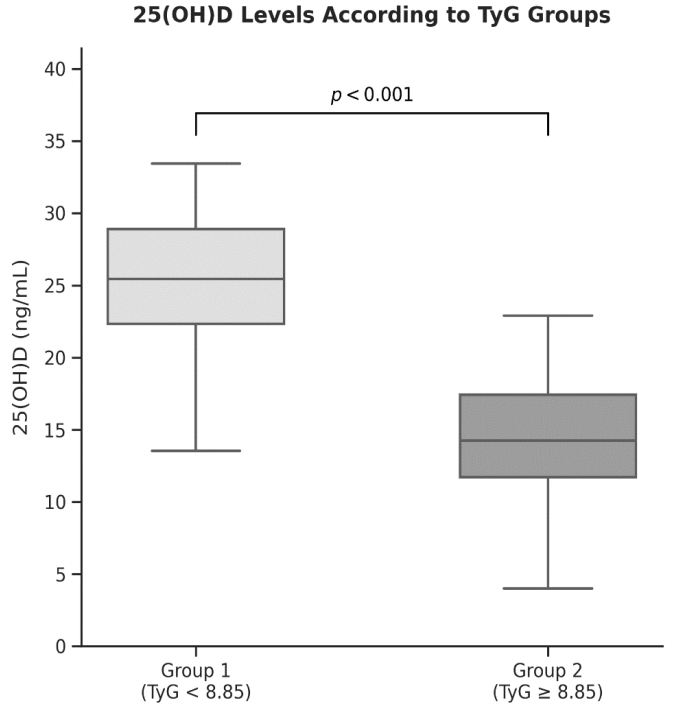
TyG: Triglyceride-Glucose Index; HOMA-IR: Homeostatic Model Assessment-Insulin Resistance; LDL-C: Low-Density Lipoprotein Cholesterol; HDL-C: High-Density Lipoprotein Cholesterol. Data are presented as mean ± standard deviation. Independent samples t-test was used for group comparisons.

Table 3. Comparison of Inflammatory Markers and Micronutrient Levels According to TyG Groups

Parameter	Group 1 (n=48)	Group 2 (n=62)	p Value
NLR	1.88±0.4	3.12±0.8	<0.001
CRP (mg/L)	2.2±0.9	5.9±1.8	<0.001
Ferritin (ng/mL)	45±12	128±34	<0.001
Serum Iron (µg/dL)	85±18	58±22	<0.001
Magnesium (mg/dL)	2.08±0.2	1.75±0.3	0.024
Vitamin D (25-OH) (ng/mL)	22.4±8.6	14.2±6.1	<0.001
Vitamin B12 (pg/mL)	312±88	228±74	0.008
Folate (ng/mL)	9.8±3.1	7.2±2.6	0.012

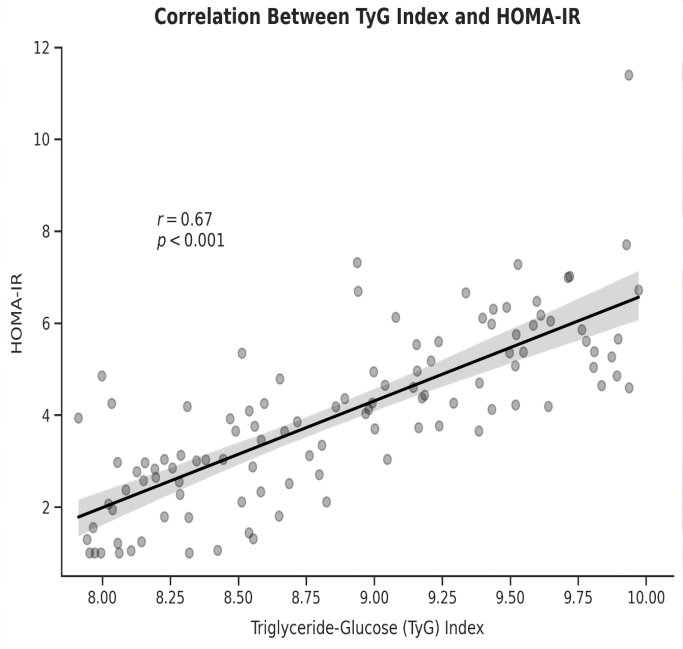
NLR: Neutrophil-to-Lymphocyte Ratio; CRP: C-Reactive Protein; Vitamin D: 25-hydroxyvitamin D. Data are presented as mean ± standard deviation. Independent samples t-test was used for group comparisons.

Figure 1. Comparison of serum 25-hydroxyvitamin D [25(OH)D] levels between Triglyceride–Glucose (TyG) index subgroups.



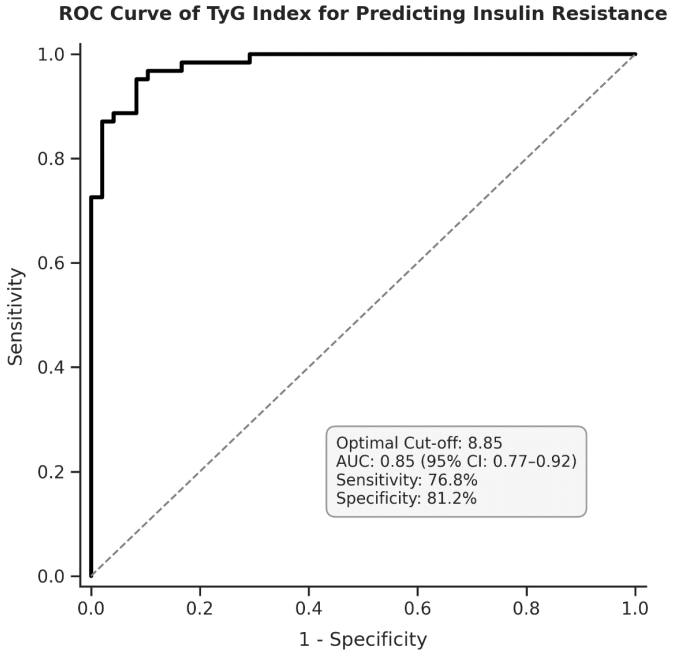
Boxplots illustrate that participants with higher metabolic risk (Group 2: TyG ≥ 8.85) had significantly lower serum 25(OH)D levels than those with lower metabolic risk (Group 1: TyG < 8.85) (p < 0.001). The horizontal line within each box indicates the median, the box represents the interquartile range (IQR), and the whiskers extend to 1.5 × IQR.

Figure 2. Scatter plot illustrating the association between the Triglyceride–Glucose (TyG) index and Homeostatic Model Assessment of Insulin Resistance (HOMA-IR).



A significant positive correlation was observed (r = 0.67, p < 0.001). The solid line represents the fitted linear regression line, and the shaded area indicates the 95% confidence interval.

Figure 3. Receiver operating characteristic (ROC) curve evaluating the diagnostic performance of the Triglyceride–Glucose (TyG) index for identifying clinical predicting insulin resistance defined by HOMA-IR >2.5



The TyG index demonstrated good discriminative ability, with an area under the curve (AUC) of 0.85 (95% confidence interval [CI]: 0.77–0.92; p < 0.001). The optimal cut-off value, determined using the Youden index, was 8.85, corresponding to a sensitivity of 76.8% and a specificity of 81.2%. The diagonal dashed line represents the line of no discrimination (AUC = 0.50).

Correlation Analysis

The results of the analysis between the TyG index and other parameters are presented in Table 4. The strongest positive correlation with TyG was found to be with HOMA-IR (r = +0.67, p < 0.001) (Figure 2), followed by CRP (r = +0.61, p < 0.001), ferritin (r = +0.58, p < 0.001) and waist circumference (r = +0.54, p < 0.001). Among the negative correlations, serum iron (r = −0.44) and vitamin D (r = −0.43) stood out. Considering the magnitude of the correlation coefficients, it was observed that the strongest associations were with HOMA-IR, CRP and ferritin, whilst the associations with folate (r = −0.26) and vitamin B12 (r = −0.29), although statistically significant, remained at a weak level.

Gender-Based Subgroup Analysis

The gender-based subgroup analysis revealed some marked differences between women and men. In men, uric acid levels were significantly higher in Group 2 (7.4 ± 1.3 vs. 5.8 ± 0.8 mg/dL); this difference was statistically significantly more pronounced than the increase observed in women (5.8 ± 1.0 vs. 4.2 ± 0.6 mg/dL) (p = 0.003). Vitamin D levels were lower in Group 2 for both sexes, without a significant sex-group interaction (p = 0.412). However, a significant sex-group interaction was observed for triglyceride levels, with a more pronounced increase in men (p = 0.046). In this analysis, conducted using two-way ANOVA, the main effect of the TyG group was found to be significant for all parameters (p < 0.05); the main effect of sex was significant for uric acid (p < 0.001) and HDL-C (p = 0.018), but not significant for the other parameters. The results of the subgroup analysis are presented in Table 5.

Table 4. Spearman Correlation Analysis Between TyG Index and Metabolic, Inflammatory, and Micronutrient Parameters

Parameter	r	p Değeri
CRP (mg/L)	+0.61	<0.001
Ferritin (ng/mL)	+0.58	<0.001
NLR	+0.52	<0.001
Uric Acid (mg/dL)	+0.48	0.001
HOMA-IR	+0.67	<0.001
Waist circumference (cm)	+0.54	<0.001
Serum Iron (µg/dL)	−0.44	<0.001
Magnesium (mg/dL)	−0.31	0.024
Vitamin D (ng/mL)	−0.43	<0.001
Vitamin B12 (pg/mL)	−0.29	0.008
Folate (ng/mL)	−0.26	0.012

NLR: Neutrophil-to-Lymphocyte Ratio
HOMA-IR:Homeostatic Model Assessment-Insulin Resistance
r: Spearman correlation coefficient. According to the magnitude of correlation coefficients, the strongest associations were observed with HOMA-IR (r=+0.67), CRP (r=+0.61), and ferritin (r=+0.58), whereas weaker associations were found with magnesium (r=-0.31), vitamin B12 (r=-0.29), and folate (r=-0.26).

Table 5. Sex-Based Subgroup Analysis: Selected Parameters According to TyG Groups

Parameter	Female Group 1 (n=30)	Female Group 2 (n=38)	Male Group 1 (n=18)	Male Group 2 (n=24)	p*
TyG Index	8.28±0.26	9.14±0.42	8.36±0.31	9.24±0.47	0.210
BMI (kg/m²)	32.1±2.0	37.4±4.2	32.9±2.3	38.4±4.9	0.194
Waist circumference (cm)	97.2±7.8	112.4±11.8	101.2±9.2	117.6±13.8	0.082
Triglycerides (mg/dL)	119±26	208±40	131±30	231±45	0.046
HDL-C (mg/dL)	51±6	42±5	43±5	34±4	0.012
Vitamin D (ng/mL)	21.6±8.2	13.8±5.8	23.8±9.2	14.8±6.6	0.412
Uric Acid (mg/dL)	4.2±0.6	5.8±1.0	5.8±0.8	7.4±1.3	0.003
NLR	1.92±0.4	3.08±0.8	1.82±0.4	3.18±0.9	0.614

Two-way ANOVA, p value for sex-TyG group interaction. Data are presented as mean ± standard deviation. The main effect of TyG group w as significant for all parameters (p<0.05); the main effect of sex was significant for uric acid (p<0.001) and HDL-C (p=0.018), and non-signifi cant for other parameters.

Diagnostic Performance of the TyG Index in Predicting Insulin Resistance

In this study, the diagnostic accuracy of the TyG index in predicting clinical insulin resistance (HOMA-IR > 2.5) in obese individuals was assessed using ROC curve analysis (Figure 3). The analysis revealed that the Area Under the Curve (AUC) value for the TyG index was 0.85, which was found to be highly statistically significant (95% Confidence Interval [CI]: 0.77–0.92; p < 0.001). The optimal cut-off value for the TyG index in distinguishing insulin resistance was determined to be 8.85 using the Youden Index. At this cut-off value, the sensitivity of the TyG index was confirmed to be 76.8 per cent, whilst its specificity was 81.2 per cent.

DISCUSSION

Obesity is a complex metabolic condition that affects multiple systems via chronic low-grade inflammation and insulin resistance associated with adipose tissue dysfunction. In this

study, the association of the TyG index with insulin resistance, inflammation, iron metabolism, uric acid levels and micronutrient profile was evaluated; furthermore, its performance in predicting insulin resistance was analysed. The findings suggest that the TyG index may be associated with a broader spectrum of metabolic dysfunction beyond glucose and lipid metabolism.

Whilst the hyperinsulinaemic-euglycaemic clamp method is the gold standard for assessing insulin resistance, it is not feasible in clinical practice. Consequently, HOMA-IR is a widely used surrogate measure (16). However, HOMA-IR may be affected by variations in insulin measurements.

The strong positive correlation observed in our study between the TyG index and HOMA-IR ($r = +0.67$, $p < 0.001$) suggests that the TyG index may reflect a metabolic state associated with insulin resistance. This finding is consistent with studies in the literature reporting an association between the TyG index and

insulin resistance (3,4). The TyG index has also been found to be associated with metabolic comorbidities (diabetes and cardiovascular disease) in COVID-19 intensive care patients, a finding that supports the index's potential to reflect metabolic disorders across different clinical presentations (19).

In the ROC analysis, the TyG index demonstrated a good level of discriminatory performance in predicting insulin resistance (HOMA-IR > 2.5), with an AUC value of 0.85. The optimal cut-off value of 8.85, determined using the Youden Index, can be considered a potential threshold for clinical classification, with acceptable sensitivity (76.8%) and specificity (81.2%). However, the cut-off values recommended for the TyG index in the literature show heterogeneity across populations. For example, whilst some studies of Asian origin report lower cut-off values (8.50–8.65) for insulin resistance, the higher cut-off value of 8.85 observed in our cohort may be attributable to the higher mean BMI (33.4 kg/m^2) and greater visceral adiposity burden in our population. Although population-based data on TyG cut-off values in the Turkish population remain limited, a recent large-scale study from the TEKHAP cohort, comprising nearly 1,900 Turkish adults, reported a lower ROC-derived TyG cut-off of 8.45 (AUC 0.740) for predicting insulin resistance defined by HOMA-IR (20). The comparatively higher cut-off value (8.85) identified in our cohort may reflect the fact that our sample consisted exclusively of individuals with obesity (BMI ≥ 30 kg/m²), whereas the TEKHAP cohort represented a general adult population with a broader BMI range; this difference in the underlying population's metabolic risk profile likely accounts for a higher optimal threshold in our more severely obese cohort.

The finding that BMI and waist circumference were significantly higher in the high TyG group supports the link between visceral adiposity and insulin resistance. It is known that free fatty acids released from visceral adipose tissue may contribute to hepatic insulin resistance (21). The finding that CRP and NLR levels were elevated, whilst serum iron was low and ferritin levels were high in the high TyG group, is consistent with the inflammatory response associated with obesity. This indicates a profile characteristic of functional iron deficiency.

During the inflammatory process, an increase in hepcidin synthesis mediated by IL-6 may lead to iron sequestration by reducing iron efflux via ferroportin (22,23). This mechanism is also supported by studies showing that, even in obese individuals with normal acute-phase markers, an increased body mass index is associated with elevated NLR and ferritin levels, and is linked to insulin resistance (24). Whilst in the traditional clinical approach, elevated ferritin levels may be interpreted as indicative of abundant tissue iron stores or iron overload, this increase in obese individuals should be interpreted, in conjunction with low serum iron levels, as a pseudo-acute phase reaction secondary to systemic inflammation rather than a genuine increase in iron stores. Indeed, contrary to some dissenting views in the literature, the strong positive correlation between ferritin and CRP ($r = +0.61$) observed in our study clinically validates this hypothesis. It has been reported in the literature that obesity and inflammation are associated with iron metabolism disorders, which may be partially reversed by weight loss (25).

In our study, the elevated serum uric acid levels observed in the high TyG group are consistent with the known association between insulin resistance and uric acid metabolism. It has been shown that insulin resistance can lead to hyperuricaemia by reducing renal urate excretion (26). The observation of a more pronounced elevation in uric acid levels in men ($p=0.003$ for interaction) suggests that oestrogen's uricosuric effect may play a protective role in women (27). This supports the clinical significance of gender-related metabolic differences. The literature reports an association between the TyG index and cardiometabolic risk and uric acid levels, and it has been shown that these parameters together may increase the risk of endothelial dysfunction (28).

The finding of lower levels of vitamin D, B12, folate and magnesium in the high TyG group suggests that micronutrient deficiencies associated with obesity may occur alongside metabolic disorders. The sequestration of vitamin D in adipose tissue and its reduced bioavailability may explain the low levels observed in obese individuals. It has also been reported to play a role in insulin secretion and inflammatory processes (29). It is known that magnesium plays a role in insulin receptor signalling and that its deficiency may adversely affect glucose metabolism (30). Although there are some isolated studies in the literature arguing that micronutrient deficiencies do not worsen due to high macronutrient intake in obese individuals, in our study, as the TyG index (glycolipid load) leads to a significant decline in vitamin B12 and folate levels, supports the view that this deficiency is directly triggered by poor dietary quality and malabsorption. Deficiencies in B12 and folate, in turn, are associated with cardiometabolic risk via homocysteine metabolism (31). These findings suggest that assessing micronutrient status as a component of the metabolic profile may be clinically beneficial.

This study demonstrates that the TyG index is a comprehensive metabolic marker that may be associated with inflammation, iron metabolism, uric acid levels and micronutrient profile, alongside insulin resistance, in obese individuals. The high AUC value obtained in the ROC analysis supports the notion that the TyG index could serve as a potential tool for distinguishing metabolic risk. However, due to the cross-sectional design of the study, it is not possible to establish a causal relationship, and the findings should be interpreted solely at the level of association.

CONCLUSION

This study has demonstrated that the TyG index is associated with insulin resistance, inflammation, iron metabolism and micronutrient profile in obese individuals, and that the index possesses acceptable diagnostic performance in predicting insulin resistance. A high TyG index is accompanied by a decrease in serum iron, alongside elevated levels of CRP, ferritin and NLR; this supports the picture of functional iron deficiency associated with

obesity. Similarly, levels of vitamin D, B12, folate and magnesium were found to be significantly lower in the high TyG group, and it was observed that these micronutrient deficiencies paralleled metabolic dysfunction. In the ROC analysis, the TyG index had an AUC value of 0.85 and demonstrated a sensitivity of 76.8 per cent and a specificity of 81.2 per cent at a cut-off value of 8.85, suggesting that the index could serve as a practical and low-cost tool for metabolic risk screening in obese individuals.

Among the strengths of our study is the fact that the TyG index was not considered in isolation but in conjunction with multidimensional parameters such as inflammation, iron metabolism and micronutrient status. Furthermore, the identification of gender-specific differences in metabolic parameters through gender-based subgroup analysis enhances the study's original value.

However, our study has certain limitations. Firstly, the study has a retrospective and cross-sectional design. Consequently, the relationships between the parameters measured by the TyG index do not indicate causality and can only be interpreted at the level of correlation. Secondly, the sample size (n=110) is relatively small, and the study was conducted at a single centre. This limits the generalisability of the findings to different populations. Thirdly, lifestyle factors such as patients' dietary habits, levels of physical activity and tobacco and alcohol use could not be included in the analyses as they were missing from the records. It is known that these factors may influence both the TyG index and micronutrient levels. Fourthly, the hyperinsulinaemic-euglycaemic clamp technique—the gold standard method—was not used; instead, a surrogate measure such as HOMA-IR was employed to assess insulin resistance. Finally, no detailed subgroup analysis was performed according to obesity classes, and clinically significant variables such as the duration of obesity could not be assessed.

Despite these limitations, our study provides significant evidence that the TyG index can be used as a comprehensive marker in the metabolic assessment of obese individuals, reflecting not only insulin resistance but also inflammatory processes and micronutrient deficiencies. In future studies, it would be beneficial to investigate the predictive value of the TyG index for clinical outcomes using prospective designs and larger sample sizes.

Based on these findings, we practically recommend incorporating the TyG index into routine clinical metabolic assessment protocols for individuals with obesity. Utilizing this low-cost and accessible index can serve as a comprehensive screening tool, allowing clinicians to timely detect not only insulin resistance but also concurrent functional iron deficiency and micronutrient exhaustion.

Ethics Committee Approval: Approval for the study was obtained from the Eskişehir City Hospital Non-Interventional Clinical Research Ethics Committee (Decision No: 2026/413), and the study was conducted in accordance with the principles of the Declaration of Helsinki.

Financial Disclosure: No funding was taken for the study.

Conflict of Interest: The authors have no declarations of conflicts of interest.

Informed Consent: Consent forms were not obtained due to the retrospective design.

Authorship Contributions: Concept: ZIK, AS, HHÇ; Design: ZIK,AS; Supervision: ZIK,AS,HHÇ; Materials: ZIK, AS, HMÖ, RK; Data Collection or Processing: ZIK, AS, HMÖ, RK; Analysis or Interpretation: ZIK, HHÇ, AS; Literature Review: ZIK, SD, HMÖ, HHÇ, AY ; Writing: ZIK, AS; Critical Review: ZIK, HHÇ, AS.

Acknowledgments: The authors used artificial intelligence tools for grammatical language editing to improve fluency and readability. The authors reviewed and take responsibility for the final intellectual content.

* This study was previously presented as an abstract at the 5th National Congress of Internal Medicine Specialists, held between 14–17 May 2026 in Antalya, Türkiye.

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