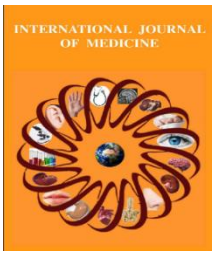

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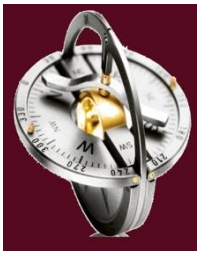

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Original Research

Beyond HbA1c: TyG Index and the Future of Cardiovascular Risk Prediction in Diabetes.

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Abstract

Introduction: Cardiovascular disease remains the leading cause of morbidity and mortality among patients with type 2 diabetes mellitus (T2DM). Although glycated hemoglobin (HbA1c) is the standard marker of glycemic control, it does not adequately reflect insulin resistance. The Triglyceride-Glucose (TyG) index has emerged as a simple surrogate marker of insulin resistance and may provide better cardiovascular risk prediction. The present study evaluated the association of the TyG index with cardiovascular risk factors and compared its predictive performance with HbA1c in patients with T2DM. *Materials and Methods:* This hospital-based observational study was conducted from May 2023 to May 2024 among 100 adult patients with T2DM. Demographic, anthropometric, clinical, and biochemical parameters were recorded. The TyG index was calculated using fasting plasma glucose and triglyceride levels. Participants were categorized according to TyG index values. Correlation analysis, receiver operating characteristic (ROC) curve analysis, and multivariate logistic regression were performed to evaluate the association between the TyG index and cardiovascular risk. *Results:* The mean TyG index was 9.46 ± 0.62, and more than half of the participants had TyG values above 9.2. Higher TyG index categories were significantly associated with hypertension, obesity, dyslipidemia, elevated HbA1c, and increased estimated cardiovascular risk (all $p<0.05$). The TyG index demonstrated significant positive correlations with fasting plasma glucose ($r=0.742$), triglycerides ($r=0.814$), HbA1c ($r=0.532$), and cardiovascular risk score ($r=0.684$). ROC analysis showed that the TyG index (AUC=0.872) outperformed HbA1c (AUC=0.731) in predicting high cardiovascular risk. Multivariate logistic regression identified the TyG index as the strongest independent predictor of cardiovascular risk (Adjusted OR=3.94, $p<0.001$). *Conclusion:* The TyG index is a simple, inexpensive, and reliable marker that demonstrates superior performance over HbA1c for predicting cardiovascular risk in patients with T2DM. Incorporating the TyG index into routine clinical assessment may improve cardiovascular risk stratification and facilitate earlier preventive interventions.

Keywords: *Type 2 diabetes mellitus; Triglyceride-Glucose index; HbA1c; Cardiovascular risk; Insulin resistance.*

Introduction

Type 2 diabetes mellitus (T2DM) is a major global public health challenge and is associated with substantial morbidity and mortality, primarily due to cardiovascular disease (CVD) [1]. Despite significant advances in diabetes management, cardiovascular complications remain the leading cause of death among individuals with T2DM [2]. Early identification of patients at increased cardiovascular risk is therefore essential to facilitate timely preventive interventions and improve long-term clinical outcomes. Although glycated hemoglobin (HbA1c) is the established marker for assessing long-term glycemic control, it does not adequately reflect insulin resistance, which plays a central role in the development of both diabetes and cardiovascular disease [3].

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Insulin resistance contributes to endothelial dysfunction, chronic inflammation, dyslipidemia, and accelerated atherosclerosis, thereby increasing the risk of cardiovascular events in patients with T2DM [4]. The Triglyceride-Glucose (TyG) Index, calculated using fasting plasma glucose and triglyceride levels, has emerged as a simple, inexpensive, and reliable surrogate marker of insulin resistance [5]. Unlike direct methods for measuring insulin resistance, such as the hyperinsulinemic-euglycemic clamp technique, the TyG index can be easily derived from routinely available laboratory parameters, making it a practical tool for clinical use [6].

Growing evidence suggests that the TyG index is associated with metabolic syndrome, coronary artery disease, hypertension, and adverse cardiovascular outcomes [7]. Several studies have demonstrated that a higher TyG index is associated with an increased risk of subclinical atherosclerosis, major adverse cardiovascular events, and cardiovascular mortality, often providing incremental prognostic value beyond conventional glycemic markers [8]. Consequently, the TyG index has gained attention as a promising biomarker for comprehensive cardiovascular risk assessment in individuals with diabetes [9,10].

However, the comparative utility of the TyG index and HbA1c in predicting cardiovascular risk among patients with T2DM remains an area of active investigation, particularly in the Indian population. Identifying a simple and readily available marker that better reflects cardiovascular risk could enhance routine risk stratification and guide targeted preventive strategies. Therefore, the present study aimed to evaluate the association of the Triglyceride-Glucose (TyG) Index with cardiovascular risk factors and to compare its predictive performance with HbA1c for cardiovascular risk assessment in patients with type 2 diabetes mellitus.

Materials and Methods

This hospital-based observational study was conducted in the Department of General Medicine over a period of one year, from May 2023 to May 2024. A total of 100 adult patients with established type 2 diabetes mellitus (T2DM) attending the outpatient and inpatient departments were enrolled after obtaining informed consent. Patients aged ≥18 years with a confirmed diagnosis of T2DM were included in the study. Individuals with type 1 diabetes mellitus, gestational diabetes, acute infectious or inflammatory conditions, chronic liver disease, end-stage renal disease, malignancy, or those receiving medications known to significantly influence lipid metabolism were excluded.

Detailed demographic and clinical information, including age, sex, duration of diabetes, smoking status, family history of cardiovascular disease, and history of hypertension, was recorded using a predesigned case record form. Anthropometric measurements including height, weight, body mass index (BMI), waist circumference, and blood pressure were obtained using standardized techniques. Fasting venous blood samples were collected after an overnight fast of at least 8-10 hours for estimation of fasting plasma glucose, lipid profile (total cholesterol, triglycerides, HDL cholesterol, and LDL cholesterol), and glycated hemoglobin (HbA1c) using standard laboratory methods.

The Triglyceride-Glucose (TyG) Index was calculated for each participant using the formula: TyG Index = ln [fasting triglycerides (mg/dL) × fasting plasma glucose (mg/dL) / 2]. Participants were categorized into TyG index groups for comparative analysis. Cardiovascular risk factors, including obesity, hypertension, dyslipidemia, smoking, and estimated 10-year cardiovascular risk, were assessed and compared across TyG index categories. Correlation analysis was performed to evaluate the relationship between the TyG index and various clinical and biochemical parameters. Receiver operating characteristic (ROC) curve analysis was used to compare the predictive performance of the TyG index, HbA1c, and fasting plasma glucose for identifying individuals at high cardiovascular risk, while multivariate logistic regression analysis was performed to determine independent predictors of cardiovascular risk.

Data were entered into Microsoft Excel and analyzed using IBM SPSS Statistics for Windows, Version 20 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean ± standard deviation, whereas categorical variables were presented as frequencies and percentages. Comparisons between groups were performed using the independent Student's t-test or one-way analysis of variance (ANOVA) for continuous variables and the Chi-square test for categorical variables, as appropriate. Pearson's correlation coefficient was used to assess associations between continuous variables. Logistic regression analysis was performed to estimate adjusted odds ratios with 95% confidence intervals, and ROC curve analysis was used to determine the diagnostic performance of the TyG index. A p-value <0.05 was considered statistically significant throughout the study.

Results

A total of 100 patients with type 2 diabetes mellitus were included in the study. The majority of participants were aged 51-60 years (36.0%), followed by 41-50 years (28.0%) and >60 years (24.0%). Males constituted 58.0% of the study population. Most participants had diabetes for 5-10 years (39.0%), while hypertension was present in 61.0%. Smoking and a family history of cardiovascular disease were observed in 29.0% and 37.0% of participants, respectively (Table 1).

Table 1. Baseline Characteristics of the Study Participants (N = 100)

Variable	Category	n (%)
Age (years)	30-40	12 (12.0)
	41-50	28 (28.0)
	51-60	36 (36.0)
	>60	24 (24.0)
Gender	Male	58 (58.0)
	Female	42 (42.0)
Duration of diabetes	<5 years	31 (31.0)
	5-10 years	39 (39.0)
	>10 years	30 (30.0)
Hypertension	Yes	61 (61.0)
	No	39 (39.0)
Smoking	Yes	29 (29.0)
	No	71 (71.0)
Family history of cardiovascular disease	Yes	37 (37.0)
	No	63 (63.0)

The mean age of the participants was 54.1 ± 10.3 years, with a mean BMI of 28.6 ± 4.2 kg/m². The average fasting plasma glucose and HbA1c were 164.8 ± 46.5 mg/dL and 8.3 ± 1.4%, respectively. The mean triglyceride level was 188.7 ± 61.4 mg/dL, while the mean TyG index was 9.46 ± 0.62, indicating a relatively high burden of insulin resistance in the study population (Table 2).

Table 2. Clinical and Biochemical Characteristics of the Study Participants (N = 100)

Variable	Mean ± SD
Age (years)	54.1 ± 10.3
BMI (kg/m²)	28.6 ± 4.2
Waist circumference (cm)	96.4 ± 10.7
Systolic blood pressure (mmHg)	136.5 ± 16.2

Diastolic blood pressure (mmHg)	84.7 ± 9.8
Fasting plasma glucose (mg/dL)	164.8 ± 46.5
Triglycerides (mg/dL)	188.7 ± 61.4
Total cholesterol (mg/dL)	198.6 ± 41.7
LDL cholesterol (mg/dL)	116.5 ± 34.2
HDL cholesterol (mg/dL)	42.3 ± 8.4
HbA1c (%)	8.3 ± 1.4
TyG Index	9.46 ± 0.62

Based on TyG index values, 36.0% of participants belonged to the 9.21-9.80 category, followed by 24.0% in the 8.8-9.2 category, 22.0% with TyG >9.80, and 18.0% with TyG <8.8. Overall, more than half of the study population had a TyG index above 9.2 (Table 3).

Table 3. Distribution of TyG Index Categories (N = 100)

TyG Index Category	n (%)
<8.8	18 (18.0)
8.8-9.2	24 (24.0)
9.21-9.80	36 (36.0)
>9.80	22 (22.0)

Increasing TyG index categories were significantly associated with a higher prevalence of hypertension, obesity, dyslipidemia, elevated HbA1c, and higher estimated 10-year cardiovascular risk (all $p<0.05$). Although smoking frequency increased across TyG categories, the association was not statistically significant ($p=0.281$). These findings demonstrate a progressive increase in cardiovascular risk factors with rising TyG index (Table 4).

Table 4. Association Between TyG Index Categories and Cardiovascular Risk Factors

Variable	<8.8 (n=18)	8.8-9.2 (n=24)	9.21-9.8 (n=36)	>9.8 (n=22)	χ^2/F	p value
Hypertension, n (%)	6 (33.3)	11 (45.8)	25 (69.4)	19 (86.4)	15.82	<0.001
Obesity (BMI ≥30), n (%)	3 (16.7)	7 (29.2)	17 (47.2)	15 (68.2)	14.67	0.002
Dyslipidemia, n (%)	7 (38.9)	13 (54.2)	28 (77.8)	21 (95.5)	23.84	<0.001
Smoking, n (%)	3 (16.7)	6 (25.0)	11 (30.6)	9 (40.9)	3.82	0.281
HbA1c (%)	7.4 ± 0.7	7.9 ± 0.9	8.5 ± 1.1	9.2 ± 1.3	15.64	<0.001
Estimated 10-year CV Risk (%)	8.6 ± 3.4	12.8 ± 4.8	18.5 ± 6.2	25.7 ± 7.8	41.93	<0.001

The TyG index demonstrated significant positive correlations with BMI, waist circumference, systolic and diastolic blood pressure, fasting plasma glucose, triglycerides, HbA1c, LDL cholesterol, and estimated cardiovascular risk score (all $p<0.05$). A significant negative correlation was observed with HDL cholesterol, while age showed no significant correlation with TyG index ($p=0.064$) (Table 5).

Table 5. Correlation Between TyG Index and Clinical Parameters

Variable	Correlation coefficient (r)	p value
Age	0.186	0.064
BMI	0.468	<0.001
Waist circumference	0.514	<0.001
Systolic blood pressure	0.381	<0.001
Diastolic blood pressure	0.246	0.014
Fasting plasma glucose	0.742	<0.001
Triglycerides	0.814	<0.001
HbA1c	0.532	<0.001
LDL cholesterol	0.301	0.002
HDL cholesterol	−0.344	0.001
Estimated cardiovascular risk score	0.684	<0.001

ROC curve analysis showed that the TyG index had the highest discriminative ability for predicting high cardiovascular risk (AUC=0.872), outperforming fasting plasma glucose (AUC=0.792) and HbA1c (AUC=0.731). At a cut-off value of 9.42, the TyG index achieved a sensitivity of 84.3% and specificity of 80.6%, indicating excellent predictive performance (Table 6).

Table 6. Receiver Operating Characteristic (ROC) Analysis for Predicting High Cardiovascular Risk

Parameter	AUC (95% CI)	Cut-off	Sensitivity (%)	Specificity (%)	p value
TyG Index	0.872 (0.802-0.942)	9.42	84.3	80.6	<0.001
HbA1c	0.731 (0.637-0.825)	8.2%	72.5	66.1	<0.001
Fasting plasma glucose	0.792 (0.709-0.875)	172 mg/dL	76.5	71.0	<0.001

Multivariate logistic regression analysis identified TyG index as the strongest independent predictor of high cardiovascular risk (Adjusted OR=3.94, $p<0.001$). Increasing age, BMI, HbA1c, and hypertension were also independently associated with elevated cardiovascular risk, whereas gender, LDL cholesterol, and smoking were not statistically significant predictors (Table 7).

Table 7. Multivariate Logistic Regression Analysis for Predictors of High Cardiovascular Risk

Variable	Adjusted OR	95% CI	p value
TyG Index	3.94	1.98-7.82	<0.001
HbA1c	1.41	1.03-1.95	0.034
Age	1.05	1.01-1.10	0.018
Male gender	1.29	0.61-2.74	0.503
BMI	1.11	1.02-1.22	0.021
Hypertension	2.16	1.08-4.34	0.029
LDL cholesterol	1.01	0.99-1.02	0.172
Smoking	1.43	0.67-3.07	0.351

Discussion

The present study demonstrated that a higher TyG index was significantly associated with adverse cardiometabolic characteristics, including hypertension, obesity, dyslipidemia, poor glycemic control, and a higher estimated 10-year cardiovascular risk. Furthermore, the TyG index showed strong positive correlations with fasting plasma glucose, triglycerides, HbA1c, and cardiovascular risk score, supporting its role as a surrogate marker of insulin resistance. These findings reinforce the growing evidence that the TyG index reflects both metabolic dysfunction and cardiovascular risk more comprehensively than conventional glycemic markers alone.

Our findings are consistent with those reported by Lertsakulbunlue et al., who evaluated more than 63,000 patients with type 2 diabetes and observed that higher TyG index values were independently associated with increasing predicted 10-year cardiovascular risk, suggesting its usefulness in routine cardiovascular risk stratification among diabetic individuals [11]. Similarly, Moon et al. demonstrated in a large prospective cohort with a median follow-up of 15.6 years that individuals in the highest TyG quartile had a significantly greater risk of developing atherosclerotic cardiovascular disease even after adjustment for conventional cardiovascular risk factors, emphasizing the long-term prognostic value of the TyG index [12].

In the present study, ROC analysis revealed that the TyG index (AUC=0.872) showed superior predictive performance for cardiovascular risk compared with HbA1c (AUC=0.731). Multivariate logistic regression further identified the TyG index as the strongest independent predictor of cardiovascular risk after adjustment for age, BMI, hypertension, and HbA1c. These observations are supported by the systematic review by Tao et al., which concluded that the TyG index is a reliable and inexpensive surrogate marker of insulin resistance with significant diagnostic and prognostic value in cardiovascular disease [13]. Likewise, the meta-analysis by Liu et al. demonstrated that individuals with higher TyG index values had significantly greater risks of coronary artery disease, myocardial infarction, and overall cardiovascular disease, highlighting its incremental predictive value beyond traditional cardiovascular risk factors [14].

Collectively, these findings, together with those of the present study, suggest that the TyG index may serve as a simple, inexpensive, and readily available biomarker for early identification of diabetic patients at increased cardiovascular risk. Incorporating the TyG index into routine diabetes evaluation could complement HbA1c and improve risk stratification, thereby facilitating timely preventive interventions and personalized management strategies.

Conclusion

The present study demonstrated that the Triglyceride-Glucose (TyG) index is strongly associated with adverse cardiometabolic risk factors and exhibits superior predictive performance for cardiovascular risk compared with HbA1c in patients with type 2 diabetes mellitus. Higher TyG index values were significantly associated with hypertension, obesity, dyslipidemia, poor glycemic control, and increased estimated cardiovascular risk, while also emerging as an independent predictor of cardiovascular risk on multivariate analysis. Given its simplicity, low cost, and reliance on routinely available laboratory parameters, the TyG index may serve as a practical adjunct to HbA1c for early cardiovascular risk stratification in clinical practice. Larger multicentric prospective studies are warranted to validate its prognostic utility and establish its role in routine diabetes management.

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