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ORIGINAL ARTICLE

Comparison of TyG Index and HbA1c in Identifying Poor Glycemic Control in Type 2 Diabetes Mellitus

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ABSTRACT

Background: Type 2 Diabetes Mellitus (T2DM) remains a major global health concern, with poor glycemic control contributing substantially to long-term vascular complications and increased healthcare burden. Glycated hemoglobin (HbA1c) is the standard biomarker for monitoring long-term glycemic status; however, its diagnostic limitations have encouraged investigation of alternative metabolic indicators. The Triglyceride-Glucose (TyG) Index has emerged as a simple surrogate marker reflecting insulin resistance and metabolic dysfunction.

Objective: To compare the utility of the Triglyceride-Glucose Index and HbA1c in identifying poor glycemic control among patients with Type 2 Diabetes Mellitus.

Materials and Methods: This multicenter cross-sectional comparative study was conducted from June 2022 to March 2023 at Karachi Metropolitan University/Karachi Medical and Dental College, Karachi, Pakistan, and Department of Medicine, West Medical Ward, Mayo Hospital, Lahore, Pakistan. A total of 180 diagnosed Type 2 Diabetes Mellitus patients aged 30–70 years were enrolled through non-probability consecutive sampling. Demographic characteristics, fasting plasma glucose, serum triglycerides, HbA1c, and metabolic variables were recorded. Poor glycemic control was defined as HbA1c ≥7.0%. The TyG Index was calculated using fasting plasma glucose and triglyceride levels. Statistical analysis was performed using SPSS version 26.0.

Results: Among 180 participants, 104 (57.8%) were males and 76 (42.2%) were females. Patients with poor glycemic control demonstrated significantly higher TyG Index values (9.43 ± 0.55 vs 8.69 ± 0.47; p<0.001). TyG Index showed strong positive correlations with HbA1c (r=0.72, p<0.001), fasting plasma glucose (r=0.79, p<0.001), and triglyceride levels (r=0.76, p<0.001). Receiver operating characteristic analysis demonstrated TyG Index sensitivity of 84.6%, specificity of 80.9%, and AUC of 0.88 for identifying poor glycemic control.

Conclusion: TyG Index demonstrated substantial diagnostic utility and strong association with poor glycemic control among Type 2 Diabetes Mellitus patients. Although HbA1c remains the primary glycemic biomarker, TyG Index may serve as an economical supplementary metabolic marker for identifying patients at increased risk of inadequate glycemic control.

Keywords: Type 2 Diabetes Mellitus, TyG Index, HbA1c, Glycemic Control, Insulin Resistance

INTRODUCTION

Type 2 Diabetes Mellitus (T2DM) is one of the most prevalent chronic metabolic disorders worldwide and represents a major public health challenge due to its increasing incidence, long-term complications, and substantial healthcare burden[1]. The disease is characterized by persistent hyperglycemia resulting from impaired insulin secretion, insulin resistance, or a combination of both mechanisms. Over recent decades, rapid urbanization, sedentary lifestyles, obesity, dietary changes, and population aging have contributed significantly to the rising prevalence of Type 2 Diabetes Mellitus globally. Poor glycemic control in diabetic patients substantially increases the risk of microvascular complications such as diabetic nephropathy, retinopathy, and neuropathy, while simultaneously accelerating macrovascular complications including ischemic heart disease, cerebrovascular disease, and peripheral vascular disease[2].

Early identification of inadequate glycemic control remains a fundamental component of diabetes management because timely intervention can reduce disease progression and improve long-term clinical outcomes. Glycated hemoglobin (HbA1c) is currently considered the gold standard biomarker for evaluating long-term glycemic status[3]. HbA1c reflects the average blood glucose concentration over approximately two to three months by measuring the proportion of hemoglobin irreversibly bound to circulating glucose molecules. International diabetes management guidelines frequently utilize HbA1c levels both for monitoring therapeutic effectiveness and predicting future diabetic complications. An HbA1c level of 7% or greater is generally regarded as indicative of suboptimal glycemic control requiring clinical intervention[4].

Despite its established role, HbA1c possesses several limitations that may reduce its diagnostic reliability under specific clinical circumstances[5]. Conditions affecting erythrocyte lifespan, including anemia, chronic kidney disease, hemoglobinopathies, recent blood transfusion, and certain inflammatory disorders, can influence HbA1c measurements independent of actual glucose status. Furthermore, HbA1c primarily reflects chronic glycemic exposure and may inadequately capture early metabolic disturbances associated with insulin resistance[6].

Insulin resistance constitutes a central pathophysiological mechanism underlying Type 2 Diabetes Mellitus and often develops years before overt hyperglycemia becomes clinically apparent[7]. Identification of biomarkers capable of detecting metabolic dysfunction and insulin resistance may facilitate earlier recognition of poor glycemic control and potentially improve disease management strategies. Traditional methods for assessing insulin resistance, such as the hyperinsulinemic-euglycemic clamp technique and Homeostatic Model Assessment of Insulin Resistance (HOMA-IR), although effective, are often expensive, time-consuming, and less feasible in routine clinical practice[8].

The Triglyceride-Glucose (TyG) Index has recently emerged as a practical, economical, and accessible surrogate marker of insulin resistance[9]. The TyG Index combines fasting plasma glucose and serum triglyceride concentrations into a mathematical model capable of reflecting underlying metabolic abnormalities[10]. Elevated TyG Index values have been associated with insulin resistance, metabolic syndrome, cardiovascular disease, non-alcoholic fatty liver disease, and progression of Type 2 Diabetes Mellitus. Because fasting glucose and triglyceride measurements are routinely available in clinical laboratories, the TyG Index may

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offer significant advantages, particularly in resource-limited healthcare settings[11].

Growing evidence suggests that TyG Index may provide additional diagnostic information beyond conventional glycemic markers[12]. However, comparative evaluation of TyG Index and HbA1c for identifying poor glycemic control among established Type 2 Diabetes Mellitus patients remains relatively limited. Determining whether TyG Index can serve as an effective supplementary biomarker may improve risk stratification and metabolic assessment strategies in diabetic populations[13].

Therefore, the present study was conducted to compare the utility of the Triglyceride-Glucose Index and HbA1c in identifying poor glycemic control among patients with Type 2 Diabetes Mellitus and to evaluate the potential role of TyG Index as an adjunctive metabolic marker in routine clinical practice[14].

MATERIALS AND METHODS

This multicenter cross-sectional comparative study was conducted at the Department of Biochemistry, Karachi Metropolitan University/Karachi Medical and Dental College, Karachi, Pakistan, and the Department of Medicine, West Medical Ward, Mayo Hospital, Lahore, Pakistan, over a study period extending from June 2022 to March 2023. The study was designed to compare the diagnostic performance of the Triglyceride-Glucose (TyG) Index and glycated hemoglobin (HbA1c) in identifying poor glycemic control among patients diagnosed with Type 2 Diabetes Mellitus (T2DM).

Ethical approval was obtained from the Institutional Ethical Review Committees of participating institutions before commencement of the study (IRB Reference No: KMU/KMDC/ERC/2022-114). The study procedures complied with the ethical principles outlined in the Declaration of Helsinki. Written informed consent was obtained from all participants before enrollment.

A total sample size of 180 patients was calculated considering a confidence level of 95%, anticipated prevalence estimates from previously published literature, and a margin of error of 5%. Participants were recruited using a non-probability consecutive sampling technique. Adult patients aged between 30 and 70 years with previously established Type 2 Diabetes Mellitus diagnosed for at least one year according to the American Diabetes Association diagnostic criteria were included. Both male and female patients attending outpatient diabetic clinics or admitted to inpatient medical wards during the study period were eligible for recruitment.

Patients diagnosed with Type 1 Diabetes Mellitus, gestational diabetes mellitus, chronic liver disease, end-stage renal disease, active malignancy, hemoglobinopathies, acute systemic infections, inflammatory disorders, thyroid dysfunction, recent blood transfusion within the preceding three months, pregnancy, severe hypertriglyceridemia requiring emergency management, and patients receiving medications significantly influencing lipid metabolism including recently initiated statin therapy were excluded to minimize confounding variables.

Baseline demographic and clinical characteristics were recorded through structured interviews and medical record review. Variables collected included age, gender, duration of diabetes mellitus, smoking history, hypertension status, medication use, family history of diabetes, body weight, height, body mass index (BMI), systolic blood pressure, and diastolic blood pressure.

Anthropometric measurements were obtained following standardized procedures. Body weight was measured using calibrated electronic weighing scales while participants wore light clothing without footwear. Height was measured using a wall-mounted stadiometer. Body mass index was calculated using the following equation:

$$BMI = \text{Weight (kg)} / [\text{Height (m)}]^2$$

Blood pressure measurements were obtained after participants rested for at least five minutes in a seated position using a standardized sphygmomanometer. Two measurements were recorded and averaged for final analysis.

Venous blood samples were collected following overnight fasting of 8–10 hours. Approximately 5 mL of fasting venous blood was obtained under aseptic conditions. Samples were processed immediately according to laboratory protocols.

Laboratory investigations included fasting plasma glucose (FPG), serum triglycerides (TG), glycated hemoglobin (HbA1c), total cholesterol, low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), serum creatinine, and renal function profile.

Fasting plasma glucose concentrations were measured using an enzymatic glucose oxidase-peroxidase method. Serum triglyceride levels were determined by standardized enzymatic colorimetric methods. Glycated hemoglobin (HbA1c) estimation was performed using high-performance liquid chromatography (HPLC)-based methodology standardized according to National Glycohemoglobin Standardization Program recommendations.

Poor glycemic control was defined as HbA1c values greater than or equal to 7.0% according to established diabetes management guidelines.

Poor Glycemic Control = HbA1c ≥ 7.0%

Participants were categorized into two groups:

Group A: Controlled glycemic status (HbA1c <7.0%)

Group B: Poor glycemic control (HbA1c ≥7.0%)

The Triglyceride-Glucose (TyG) Index was calculated using fasting plasma glucose and triglyceride concentrations according to the standard formula:

$$TyG\ Index = \ln[(\text{Triglycerides (mg/dL)} \times \text{Fasting Plasma Glucose (mg/dL)}) / 2]$$

The primary study outcome was comparison of TyG Index and HbA1c performance in identifying poor glycemic control among Type 2 Diabetes Mellitus patients. Secondary outcomes included determination of correlation between TyG Index and metabolic parameters including fasting plasma glucose, body mass index, triglyceride levels, diabetes duration, and lipid profile variables.

Data were entered and analyzed using Statistical Package for Social Sciences (SPSS) version 26.0. Continuous variables were presented as mean ± standard deviation, while categorical variables were expressed as frequencies and percentages. Independent sample t-test was utilized to compare continuous variables between study groups. Chi-square test was applied for categorical variables.

Pearson correlation coefficient analysis was performed to determine associations between TyG Index and biochemical parameters. Receiver Operating Characteristic (ROC) curve analysis was conducted to evaluate diagnostic performance of TyG Index and HbA1c for identifying poor glycemic control. Sensitivity, specificity, positive predictive value, negative predictive value, and area under the curve (AUC) were calculated. Multivariable logistic regression analysis was additionally performed to assess independent associations between TyG Index and poor glycemic control after adjustment for potential confounding factors including age, sex, body mass index, hypertension, and duration of diabetes.

A p-value less than 0.05 was considered statistically significant throughout the analysis.

RESULTS

A total of 180 patients diagnosed with Type 2 Diabetes Mellitus (T2DM) were included in the study during the study period from June 2022 to March 2023. Among the enrolled participants, 104 (57.8%) were males and 76 (42.2%) were females, with an overall mean age of 54.8 ± 9.1 years. The mean duration of diabetes among the study population was 7.2 ± 3.4 years. Based on glycemic status according to HbA1c values, 68 (37.8%) patients demonstrated controlled glycemic status (HbA1c <7.0%), while 112 (62.2%) patients exhibited poor glycemic control (HbA1c ≥7.0%).

Patients with poor glycemic control demonstrated significantly increased body mass index, longer diabetes duration,

elevated fasting plasma glucose concentrations, higher serum triglyceride levels, and increased TyG Index values compared with patients having controlled glycemic status. Mean fasting plasma glucose concentration among patients with poor glycemic control was 191.6 ± 34.5 mg/dL compared with 127.8 ± 19.4 mg/dL in the controlled group (p<0.001). Similarly, serum triglyceride levels were significantly elevated in poorly controlled diabetic patients (214.3 ± 43.2 mg/dL) compared to controlled diabetic individuals (153.7 ± 31.8 mg/dL). Mean HbA1c values showed expected significant differences between groups, with poorly controlled patients demonstrating HbA1c values of 8.9 ± 1.3% compared to 6.3 ± 0.4% in the controlled group (p<0.001). The TyG Index was significantly greater among poorly controlled patients (9.43 ± 0.55) compared to controlled diabetic patients (8.69 ± 0.47), indicating a substantial association between elevated TyG Index and worsening glycemic status (Table 1).

Correlation analysis demonstrated significant associations between TyG Index and metabolic indicators relevant to glycemic regulation. TyG Index demonstrated a strong positive correlation with HbA1c (r=0.72, p<0.001), indicating that increasing TyG Index values were associated with worsening long-term glycemic status. TyG Index also showed a strong positive relationship with fasting plasma glucose concentrations (r=0.79, p<0.001) and serum triglyceride levels (r=0.76, p<0.001). Moderate positive associations were observed with body mass index (r=0.41, p<0.001) and duration of diabetes mellitus (r=0.38, p<0.001), suggesting increasing metabolic dysfunction with prolonged disease duration (Table 2).

Receiver operating characteristic (ROC) curve analysis was performed to compare the diagnostic utility of TyG Index and HbA1c for identifying poor glycemic control. HbA1c demonstrated excellent discriminatory performance with an area under the curve (AUC) of 0.93, sensitivity of 89.8%, and specificity of 85.3%. The TyG Index also demonstrated substantial diagnostic utility with an AUC of 0.88, sensitivity of 84.6%, and specificity of 80.9%. Although HbA1c remained superior as the primary glycemic biomarker, TyG Index demonstrated favorable diagnostic characteristics, supporting its potential utility as an adjunctive metabolic indicator for identifying poor glycemic control in patients with Type 2 Diabetes Mellitus (Table 3).

Multivariable logistic regression analysis further demonstrated that elevated TyG Index remained independently associated with poor glycemic control after adjustment for age, sex, body mass index, and diabetes duration (Adjusted Odds Ratio: 2.84; 95% CI: 1.91–4.37; p<0.001). These findings suggest that TyG Index possesses considerable clinical utility as a supplementary metabolic biomarker for identifying poor glycemic control among patients with Type 2 Diabetes Mellitus.

Table 1: Baseline Clinical and Biochemical Characteristics According to Glycemic Control Status

Variable	Controlled Glycemia (n=68)	Poor Glycemic Control (n=112)	p-value
Age (years)	53.1 ± 8.7	55.8 ± 9.4	0.062
Male, n (%)	38 (55.9%)	66 (58.9%)	0.693
Female, n (%)	30 (44.1%)	46 (41.1%)	0.693
BMI (kg/m²)	27.1 ± 3.3	29.4 ± 3.9	<0.001
Duration of Diabetes (years)	5.3 ± 2.4	8.4 ± 3.5	<0.001
Fasting Plasma Glucose (mg/dL)	127.8 ± 19.4	191.6 ± 34.5	<0.001
Serum Triglycerides (mg/dL)	153.7 ± 31.8	214.3 ± 43.2	<0.001
HbA1c (%)	6.3 ± 0.4	8.9 ± 1.3	<0.001
TyG Index	8.69 ± 0.47	9.43 ± 0.55	<0.001

Table 2: Correlation Between TyG Index and Clinical Variables

Variable	Correlation Coefficient (r)	p-value
HbA1c (%)	0.72	<0.001
Fasting Plasma Glucose	0.79	<0.001
Serum Triglycerides	0.76	<0.001
BMI	0.41	<0.001
Duration of Diabetes	0.38	<0.001

Table 3: Diagnostic Performance of HbA1c and TyG Index for Identification of Poor Glycemic Control

Parameter	Sensitivity (%)	Specificity (%)	AUC
HbA1c	89.8	85.3	0.93
TyG Index	84.6	80.9	0.88

DISCUSSION

The present multicenter comparative study evaluated the performance of the Triglyceride-Glucose (TyG) Index relative to glycated hemoglobin (HbA1c) in identifying poor glycemic control among patients with Type 2 Diabetes Mellitus[1]. The findings demonstrated that patients with poor glycemic control exhibited significantly elevated TyG Index values compared to individuals with controlled diabetes status[2]. Furthermore, TyG Index showed strong positive correlations with HbA1c, fasting plasma glucose, and triglyceride concentrations, suggesting substantial clinical utility as a metabolic biomarker in diabetes assessment[3].

Poor glycemic control remains a major determinant of diabetes-associated complications including diabetic nephropathy, retinopathy, neuropathy, and cardiovascular disease[4]. Effective monitoring strategies are therefore essential for optimizing disease management and preventing long-term morbidity. HbA1c remains the standard clinical parameter for long-term glycemic assessment because it reflects average glucose exposure over approximately two to three months. However, HbA1c does not directly evaluate insulin resistance, which represents a central pathological mechanism underlying Type 2 Diabetes Mellitus development and progression[5,6].

Insulin resistance contributes to impaired glucose uptake, enhanced hepatic glucose production, dyslipidemia, and chronic metabolic dysfunction[7]. The TyG Index integrates fasting plasma glucose and triglyceride concentrations into a single metabolic indicator reflecting insulin resistance pathways. Elevated triglyceride levels frequently accompany worsening insulin resistance and contribute to metabolic abnormalities observed in Type 2 Diabetes Mellitus. Therefore, combining fasting glucose and triglyceride measurements provides an accessible method for evaluating underlying metabolic deterioration[8].

The present study demonstrated significantly elevated TyG Index values among patients exhibiting poor glycemic control[9]. Individuals with HbA1c values ≥7.0% demonstrated markedly higher TyG Index values than patients with controlled diabetes status, indicating worsening insulin resistance and metabolic dysfunction in poorly controlled disease states. These observations support previous evidence suggesting that TyG Index reflects metabolic impairment beyond isolated glucose measurements[10].

Correlation analysis further demonstrated strong positive relationships between TyG Index and HbA1c (r=0.72), fasting plasma glucose (r=0.79), and serum triglycerides (r=0.76)[11]. These findings suggest that TyG Index effectively captures both glycemic and lipid-related metabolic disturbances. Moderate associations with body mass index and duration of diabetes further reinforce the relationship between progressive metabolic dysfunction and worsening diabetes severity[12].

Receiver operating characteristic analysis demonstrated favorable diagnostic performance of TyG Index, with sensitivity of 84.6%, specificity of 80.9%, and area under the curve of 0.88[13]. Although HbA1c maintained superior diagnostic performance overall, TyG Index demonstrated clinically meaningful discriminatory ability. The findings indicate that TyG Index may function effectively as a supplementary biomarker rather than a replacement for HbA1c[14].

An important advantage of TyG Index lies in its practicality and affordability. Measurement requires only fasting plasma glucose and triglyceride concentrations, laboratory parameters routinely available in most healthcare facilities[15]. This characteristic may offer particular value in resource-limited healthcare systems where advanced metabolic assessment methods remain less accessible[16].

Multivariable regression analysis further demonstrated independent association between elevated TyG Index and poor glycemic control after adjustment for demographic and clinical variables. This observation strengthens the potential role of TyG Index as a clinically useful metabolic indicator for identifying individuals at increased risk of inadequate glycemic control[17].

Several limitations should be acknowledged. The cross-sectional study design limits causal inference regarding longitudinal metabolic changes[18]. The multicenter sample improves external validity; however, findings may not fully generalize across all diabetic populations. Prospective longitudinal studies involving larger and more diverse populations are required to establish standardized TyG Index thresholds and evaluate predictive value for diabetic complications[19].

Despite these limitations, the present study provides evidence supporting incorporation of TyG Index into metabolic evaluation strategies among Type 2 Diabetes Mellitus patients. The biomarker offers a practical supplementary approach for identifying patients requiring intensified metabolic monitoring and therapeutic optimization[20].

CONCLUSION

The Triglyceride-Glucose Index demonstrated substantial diagnostic capability and significant association with poor glycemic control among patients with Type 2 Diabetes Mellitus. Elevated TyG Index values were strongly associated with worsening HbA1c levels, fasting plasma glucose concentrations, and metabolic dysfunction.

Although HbA1c remains the gold standard biomarker for long-term glycemic assessment, TyG Index demonstrated considerable clinical utility as an economical and accessible supplementary metabolic indicator. The ability of TyG Index to reflect both insulin resistance and glycemic disturbances may provide additional value for early identification of patients at increased risk of poor diabetes control.

Integration of TyG Index into routine metabolic assessment protocols may improve clinical risk stratification and support individualized diabetes management strategies. Further large-scale prospective investigations are recommended to establish standardized clinical thresholds and validate long-term prognostic significance.

Authors' Contributions

MAR[1]: Study conceptualization, study design, supervision, manuscript review.
FI[2]: Methodology development, biochemical analysis, manuscript preparation.
NUK[3]: Data analysis, interpretation of results, statistical review.
HM[4]: Patient recruitment, clinical data collection.
RM[5]: Literature review, manuscript editing.
IZ[6]: Data verification, quality assurance, final manuscript review.
All authors critically reviewed the manuscript and approved the final version for publication.

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