Iraqi Journal of Science, 2026, Vol. xx, No. x, pp: xx
DOI: 10.24996/ijs.2026.67.9.5

ISSN: 0067-2904

Effect of Glycemic Control on Lipid Profile Liver and Kidney Function in a Sample of Iraqi Patients with Type 2 Diabetes

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Received: 10/6/2025 Accepted: 23/11/2025 Published: xx

Abstract

This cross-sectional study examined how glycemic control affected lipid profile, as well as liver and kidney functions in 95 patients (51 males and 44 females) with type 2 diabetes (T2DM) with no complications. The patients were divided into two groups, based on their glycated hemoglobin (HbA1C) levels. The majority of the well-controlled group were males (68.89%), while the majority of the poorly-controlled glycemic group were females (60%). The relationship between glycemic control and various biochemical parameters was examined using Pearson correlation analysis. The results have shown that poor glycemic control was highly related to dyslipidemia, elevated liver enzymes, and impaired kidney functions. Large effect sizes were observed for triglycerides (TG; Cohen's d = 2.69;95% CI:2.14-3.25), very low-density lipoprotein-cholesterol (VLDL-C; Cohen's d = 3.10: 95% CI: 2.51-3.69), alanine aminotransferase (ALT; Cohen's d = 1.51;95% CI:1.06-1.97), alkaline phosphatase (ALP; Cohen's d = 0.725;95% CI: 0.309-1.14), and creatinine (Cohen's d = 1.25; 95% CI: 0.806-1.69). Strong positive association was found between HbA1c and various indices, which include the triglyceride/fasting blood glucose index (TyG; $r = 0.824$, $p = 0.0001$), TG/HDL-C ratio ($r = 0.818$, $p = 0.0001$), atherogenic index of plasma (AIP; $r = 0.809$, $p = 0.0001$), but only weakly to moderately with R-factor ($r = 0.317$, $p = 0.002$). On the other hand, HbA1c levels were negatively correlated with the AST/ALT ratio ($r = -0.444$, $p = 0.0001$) and the estimated glomerular filtration rate (eGFR; $r = -0.294$, $p = 0.005$). These results emphasize the significance of maintaining ideal blood glucose levels to avoid or delay T2DM complications.

Keywords: Glycemic control, Atherogenic index of plasma, Glomerular filtration rate

تأثير السيطرة على مستوى السكر في الدم على الدهون ووظائف الكبد والكلى في عينة من المرضى العراقيين المصابين بداء السكري من النوع الثاني

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الخلاصة

تناولت هذه الدراسة المقطعية الى فحص تأثير ضبط سكر الدم على ملف الشحميات، ووظائف الكبد والكلى لدى 95 مريضًا (44 أنثى و51 ذكرًا) مصابين بداء السكري من النوع الثاني (T2DM) دون مضاعفات. قُسّم المرضى إلى مجموعتين بناءً على مستويات السكر التراكمي (HbA1c). كانت الغالبية في مجموعة الضبط الجيد من الذكور (68.89%)، بينما كانت الغالبية في مجموعة الضبط السيئ من الاناث (60%). تم فحص العلاقة بين ضبط السكر ومختلف المعايير الكيموحيوية باستخدام تحليل ارتباط بيرسون. أظهرت النتائج ان ضبط السكر السيء كان مرتبطاً بشكل كبير باضطراب الدهون، وارتفاع إنزيمات الكبد، وضعف وظائف الكلى. لوحظت احجام تأثير كبيرة في الدهون الثلاثية (TG; Cohen's=2.69;95% CI:2.14−3.25) والبروتين الدهني ذو الكثافة المنخفضة جدا (VLDL−C; Cohen's d = 3.10: 95% CI: 2.51−3.69) وناقلة امين الالانين (ALT; Cohen's= 1.51;95% CI:1.06−1.97) والفوسفاتاز القلوي (ALP; Cohen's d =0.725;95% CI: 0.309−1.14) والكرياتينين (Cohen's d = 1.25; 95% CI: 0.806−1.69). ارتبط HbA1c ارتباطاً قويا بمؤشر الدهون الثلاثيةا سكر الدم الصائم (r = 0.824، p = 0.0001)، وبمؤشر الدهون الثلاثية إلى الكوليسترول الجيد (r = 0.818، p = 0.0001)، ومؤشر تصلب الشرايين في البلازما (r = 0.809، p = 0.0001)، لكن بشكل ضعيف الى متوسط مع عامل R (r = 0.317، p = 0.002). في المقابل، ارتبطت مستويات HbA1c سلبًا بنسبة AST/ALT (r =− 0.444، p = 0.001) وبمعدل الترشيح الكبيبي (r = −0.294، p = 0.005)، تؤكد هذه النتائج على أهمية الحفاظ على مستويات مثالية لسكر الدم لتجنب او تأخير مضاعفات داء السكري من النوع الثاني.

1. Introduction

Type 2 diabetes mellitus (T2DM) is one of the most prevalent chronic diseases in the world, which is associated with a high incidence of complications such as retinopathy, nephropathy, and neuropathy [1-2]. According to the International Diabetes Federation, 853 million individuals, or one in eight adults, will have diabetes by 2050, a 46% increase [3]. While in Iraq, the World Health Organization reports that more than 13.9% of adults in Iraq have diabetes, and many are still ignorant of their condition [4]. T2DM prevalence is rising constantly; this has led to numerous studies aimed at better understanding the disease [5-7]. Good glycemic control plays a critical role in minimizing the complications of diabetes and enhancing patients' quality of life [8]. Also, blood glucose levels have a crucial part in the development and progression of the same complications related to diabetes. The hemoglobin A1c (HbA1c) test measures average blood glucose level for the past three months. This quantifies the proportion of glycated hemoglobin. In general, good glycemic control in diabetic patients is indicated by the maintenance of HbA1c levels under 6.5% [8-9]. Recently, several studies have shown a strong relationship between good glycemic control regulation and improvements in lipid profile and the functional state of vital organs [9-11].

This relationship needs further exploration, particularly in Iraq, where type 2 diabetes is on the rise. So, to explore the role of the effect of glycemic control in minimizing diabetes-related complications, the aim of the present study is to assess the effect of glycemic control on lipid profile and liver and kidney function in a sample of Iraqi patients diagnosed with type 2 diabetes.

2. Material and methods

2.1. Studied groups

This study was conducted from November 2024 to February 2025 on 95 patients (51 males and 44 females) with T2DM without complications, attending Endocrinology Outpatient Clinic, Baghdad Teaching Hospital, Medical City, Baghdad, Iraq.

The sample size of 95 was determined according to practicality considerations and the available patient population during the study duration. A post hoc power analysis was performed using G*Power (version 3.1.9.7) showed that with this sample size, the study had over 80% power to detect moderate correlations ($r \geq 0.28$) at $\alpha = 0.05$. This confirms that the sample size was adequate to detect clinically meaningful associations.

All patients had been previously diagnosed with diabetes by consultant physicians based on the criteria established by the American Diabetes Association (ADA) Professional Practice Committee [12]. Patients with Type 1 diabetes mellitus (T1DM), thyroid dysfunction, T2DM with complications, those receiving insulin therapy, metabolic syndrome, non-alcoholic fatty disease (NAFLD), alcohol use, smoking or taking medications that affect liver, kidney, or lipid function (e.g., statin, antihypertensives) were excluded, as these factors could significantly influence glycemic control and biochemical parameters. The study protocol was approved by the Ethics Committee of the College of Science, University of Baghdad, Iraq (Reference No. CSEC/1024/0078 on October 30, 2024).

2.2 Blood sample collection

Venous blood samples were collected from each participant after a 12-hour fasting period: one sample in an EDTA tube for HbA1c measurement, and another in a serum-separating tube (SST) at room temperature. Serum was obtained by centrifuging the clotted blood at 1200 × g for ten minutes.

The clear serum was then stored at -20 °C until analysis of the various study parameters.

2.3 Laboratory methods

The i-ChromaTM HbA1c kit was used to measure the HbA1c levels in the blood, it employs fluorescence immunoassay technology. The kidney function measurements are not affected with this method because it acts independently of both the Jaffe and enzymatic methods. The assays were conducted following the manufacturer's instructions.

To guarantee the accuracy and reliability of the measurement, standardized control samples were used for quality control.

The corresponding estimated average glucose (eAG) in mg/dL was calculated using the equation proposed by Nathan *et al*. (2008), Eq. (1) [13]:

$$\text{eAG (mg/dL)} = (28.7 \times \text{HbA1c}) - 46.7 \quad (1)$$

Serum levels of fasting blood glucose (FBG), lipid profile components including: triglycerides (TG), total cholesterol (TC), and high-density lipoprotein cholesterol (HDL-C) as well as Liver function tests [alanine aminotransferase (ALT), aspartate aminotransferase (AST), and alkaline phosphatase (ALP)] and kidney function tests [uric acid, urea, and creatinine] were measured by the colorimetric method using commercial kits from Spinreact (Spain). Very low-density lipoprotein cholesterol (VLDL-C) and low-density lipoprotein cholesterol (LDL-C) were calculated using the Friedewald equation (1972), Eq. (2,3) [14].

$$\text{LDL} - \text{C (mg/dL)} = \text{TC} - \text{HDL} - \text{C} - (\text{TG} / 5) \quad (2)$$

$$\text{VLDL} - \text{C (mg/dL)} = \text{TG} / 5 \quad (3)$$

The Atherogenic Index of Plasma (AIP) was calculated (as the base-10 logarithm), as proposed by Dobiásová (2000), Eq. (4) [15-16]:

$$\mathrm{AIP} = \log 10\,[\mathrm{TG\ (mg/dL)} / \mathrm{HDL-C\ (mg/dL)}] \quad (4)$$

The Triglyceride-FBG index (TyG index) was calculated (as the natural logarithm), as formulated by Guerrero-Romero *et al.* (2010), Eq. (5) [17]:

$$\mathrm{TyG\ index} = \ln[\mathrm{TG\ (mg/dL)} \times \mathrm{FBG\ (mg/dL)} / 2] \quad (5)$$

The R-factor, used to differentiate patterns of liver injury (hepatocellular, cholestatic, or mixed), was calculated using the following equation, Eq. (6) [18]:

$$\mathrm{R-factor} = (\mathrm{ALT} / \mathrm{ALT.ULN}) / (\mathrm{ALP} / \mathrm{ALP.ULN}) \quad (6)$$

Although the R-factor is primarily used in drug-induced liver injury (DILI), in the present study it was employed as an auxiliary index to characterize the pattern of liver enzyme alterations in diabetes. It was not intended as a diagnostic tool for DILI but as an analytical method to explore hepatocellular, cholestatic, or mixed changes. The upper limit of normal (ULN) for ALT is 40 U/L and for ALP is 120 U/L, and these values were used in the calculation of the R-factor.

Estimated glomerular filtration rate (GFR) was calculated using the 2021 CKD-EPI creatinine equation developed by Inker *et al.,* which excludes race as a variable, Eq. (7) [19]:

$$\mathrm{eGFR(ml/min/1.73m^2)} = 142 \times \min(\mathrm{Scr}/\kappa, 1)^{\alpha} \times \max(\mathrm{Scr}/\kappa, 1)^{(-1.200)} \times 0.9938^{\mathrm{Age\ (years)}} \times \mathrm{Multiplier} \quad (7)$$

Where Scr = serum creatinine (mg/dL), κ (kappa) = 0.7 for females, 0.9 for males, α (alpha) = –0.241 for females, –0.302 for males, Multiplier = (1.012 if female, 1.0 if male).

2.4 Statistical analysis

Data were statistically analyzed using IBM SPSS Statistics for Windows, version 26. Data are presented as mean ± standard deviation (SD). The Shapiro–Wilk test was used to assess the normality of the data. Student's t-test was used to compare the mean values among the two groups. In addition to *P*- values, effect sizes were calculated for each comparison, including Cohen's d with 95% confidence intervals (CI) providing a quantitative measure of the magnitude of differences between groups. Effect sizes were calculated using the online tool Psychomerrica (available at: Computation of different effect sizes like d, f, r and transformation of different effect sizes: Psychometrica). Although Hedges' g was also calculated to correct for the slightly unequal sample sizes (n = 45 vs, n = 50), the values were nearly identical to Cohen's d; therefore, only Cohen's d is presented in the table for simplicity. Pearson correlation analysis was performed to assess the strength and direction of linear relationships between continuous variables, with correlation coefficients (*r*) and their corresponding *P*-values reported. A *p*-value of less than 0.05 was considered statistically significant.

3. Results

3.1 Demographic characteristics

Table 1 presents the demographic characteristics of the participants along with their HbA1c levels. The study included 95 individuals diagnosed with T2DM. The mean age of the participants was 52.21±5.19 years, and 53.68 % were male. The mean serum HbA1c level was

7.59 ± 1.47 %. Female and male participants had no significant differences in mean age or HbA1c levels ($p > 0.05$).

Table 1: Demographic characteristics and their HbA1c values of the participants.

Characteristic	Total: (females + males)	Females	Males	*P*-value
Number (%)	95	44 (46.32%)	51(53.68 %)	-
Age (years)	52.21±5.19	53.07±5.12	51.41±5.17	0.133
HbA1c (%)	7.59±1.47	7.29±1.13	7.88±1.69	0.057

According to the guidelines of the American Diabetes Association (ADA) [8,20, 21], patients with T2DM were categorized into two groups based on their glycated hemoglobin (HbA1c) levels: those with well-controlled (HbA1c ≤ 7.0%) and those with poor glycemic control (HbA1c > 7.0%). The classification is summarized in Table 2.
To examine the impact of HbA1c levels on lipid profile, liver and kidney function parameters in the sera of these patients, individuals with well-controlled group (HbA1c ≤ 7.0%) were utilized in the current study as the control group.

The results presented in Table 2 indicate that 52.63% (n = 50) of the 95 patients with T2DM showed poor glycemic control (HbA1c > 7.0%), with females comprising 60% of this group. In contrast, 47.37% (n = 45) of the patients demonstrated well-controlled (HbA1c ≤ 7.0%), with males comprising 68.89 % of this group. Patients in the poor glycemic control group had a mean age of 52.18 ± 5.31 years, compared to 52.24 ± 5.14 years in the well-controlled group. This difference was not statistically significant ($p = 0.955$).

Table 2: Baseline characteristics and serum HbA1c level in studied groups.

Characteristic	Well-controlled group	Poor glycemic control group	*P*-value
Participants, n (%)	45 (47.37%)	50 (52.63)	-
Female, n (%)	14 (31.11 %)	30 (60 %)	-
Male, n (%)	31 (68.89 %)	20 (40%)	-
Age (years)	52.24±5.14	52.18±5.31	0.955
Duration of Diabetes (years)	5.3 ± 3.1	6.1 ± 3.3	0.52
HbA1c (%)	6.39 ± 0.25	8.83 ± 1.15	0.0001**

**: indicates a highly significant difference ($p<0.01$)

When comparing estimated average glucose (eAG) (225.4 ± 32.55 vs 149.93 ± 9.02: Cohen's d = 3.16, 95% CI: 2.56-3.76; $P = 0.0001$) and FBG levels (179.30 ± 25.99 vs 113.36 ± 10.46: Cohen's d = 3.33, 95% CI: 2.71-3.95; $P = 0.0001$) between patients with good and poor glycemic control, both glycemic markers were significantly higher in the poor glycemic control group compared to the well-controlled group (Figure 1).

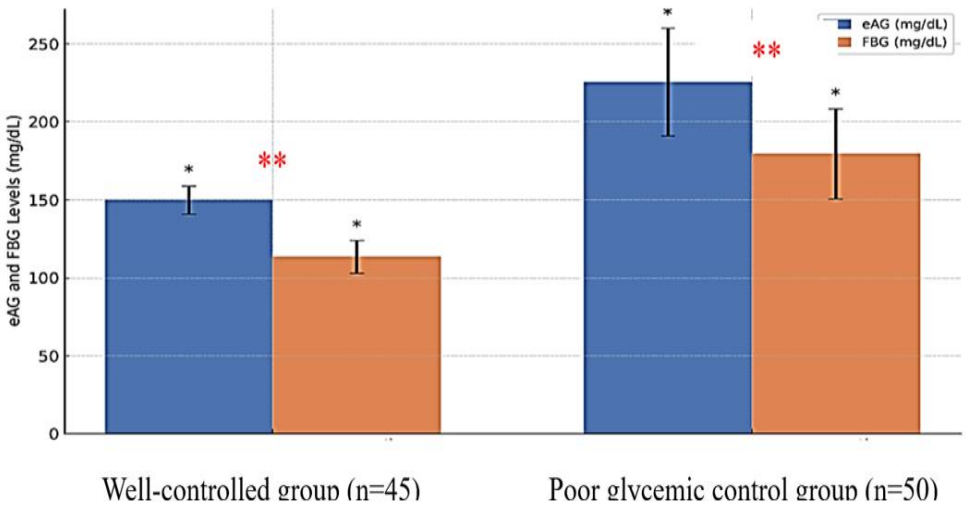

Figure 1: Mean ± SD levels of estimated average glucose (eAG) and fasting blood glucose (FBG) in patients with T2DM, based on glycemic control status, **: indicates a highly significant difference (P<0.01).

3.2 Lipid Profile parameters

TG, and VLDL-C levels were significantly higher in poor glycemic control group compared to the well-controlled group, showing very large effect sizes (Cohen's d = 2.69, 95% CI: 2.14-3.25 and 3.10, 95% CI: 2.51-3.69, respectively: P = 0.0001). High-density lipoprotein cholesterol was significantly lower in the poor glycemic control group (Cohen's d = 0.824; 95% CI: 0.405-1.24; P = 0.001), as shown in Table 3. In contrast, TC and LDL-C showed small effect sizes (Cohen's d = 0.344 and 0.235, respectively) and not statistically significant (P = 0.108 and 0.285). These findings indicate that poor glycemic control is associated with marked alteration in TG, VLDL-C, and HDL-C, while TC and LDL-C remain largely unaffected.

Table 3: Lipid profile parameters in studied groups

Parameters (Mean ± SD)	Well-controlled group (n=45)	Poor glycemic control group (n=50)	Cohen's d (95% CI)	*P*-value
TC (mg/dl)	185.5± 33.15	197.81+38.15	0.344 (-0.06-0.75)	0.108
TG (mg/dl)	114.01± 20.31	247.72± 67.27	2.69 (2.14-3.25)	0.0001**
HDL-C (mg/dl)	43.34± 8.07	37.66± 5.46	0.824 (0.405-1.24)	0.001**
LDL-C (mg/dl) (calculated)	118.91± 37.52	110.74± 31.70	0.235 (-0.64-0.17)	0.285
VLDL-C (mg/dl) (calculated)	23.16± 4.48	48.52± 10.66	3.10 (2.51-3.69)	0.0001**

**: indicates a highly significant difference (p<0.01)

As shown in Figure. 2, lipid-related cardiovascular risk markers were significantly elevated in patients with poor glycemic control compared to those with well-controlled. The TyG index was markedly higher in the poor glycemic control group (5.33 ± 0.15) than in the well-controlled group (4.74 ± 0.10; Cohen's d = 4.63, 95% CI: 3.86-5.4; P = 0.0001). Similarly, the TG/HDL-C ratio was significantly elevated in the poor glycemic control group (6.65 ± 1.30 vs 2.71 ± 0.52: Cohen's d = 3.98, 95% CI: 3.29-4.67; P = 0.0001). Additionally, the AIP was

significantly higher in patients with poor glycemic control (0.815 ± 0.098) compared to the well-controlled group (0.421 ± 0.08: Cohen's d = 4.41, 95% CI: 3.66-5.15; *P* = 0.0001).

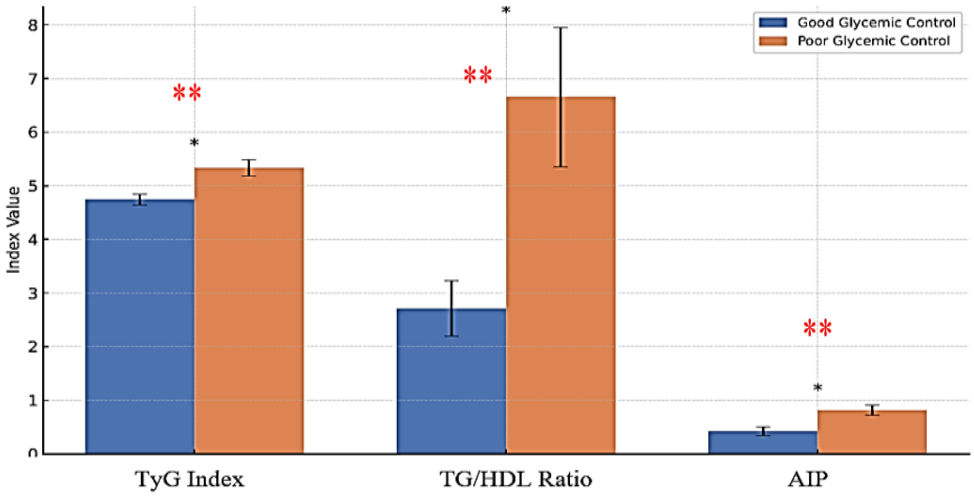

Figure 2: Mean ± SD levels of Calculated Lipid-Related Index Values [Triglyceride-FBG index (TyG index), triglyceride-to-HDL-C (TG/HDL) ratio, and atherogenic index of plasma (AIP)] in patients with T2DM, based on glycemic control status, **: indicates a highly significant difference (*P*<0.01).

3.3 Liver Functions parameters

The results in Table 4 show that patients with poor glycemic control had significantly elevated levels of ALT (36.82±7.14 vs 26.89± 5.93 U/L: Cohen's d = 1.51, 95% CI: 1.06-1.97; *p* = 0.0001) and ALP (36.82±7.14 vs 26.89± 5.93 U/L: Cohen's d = 0.725, 95% CI: 0.309-1.14; *P* = 0.003) compared to those with well-controlled (*p* = 0.0001, and 0.003, respectively). However, no significant difference was observed in AST levels between the groups (*P* = 0.675). Additionally, the results demonstrated a significantly higher AST/ALT ratio in individuals with well-controlled (0.96 ± 0.20) compared to those with poor glycemic control (0.67 ± 0.13: Cohen's d = 1.72, 95% CI: 1.25-2.19; *P* = 0.0001).

Also, individuals with poor glycemic control showed a higher mean R-factor (1.31 ± 0.15) compared to those with well-controlled (1.12 ± 0.33; Cohen's d = 0.74, 95% CI: 0.33-1.16; *p* = 0.001), as shown in Figure -3.

Table 4: Liver enzyme activities in studied groups.

Parameters (Mean ± SD)	Well-controlled group (n=45)	Poor glycemic control group (n=50)	Cohen's d (95% CI)	*P*-value
ALT (U/L)	26.89± 5.93	36.82±7.14	1.51 (1.06-1.97)	0.0001**
AST (U/L)	24.82± 5.83	24.28± 5.78	0.093 (-0.495-0.309)	0.675
ALP (U/L)	73.94± 12.34	83.28± 13.42	0.725 (0.309-1.14)	0.003**

**: indicates a highly significant difference (*p*<0.01)

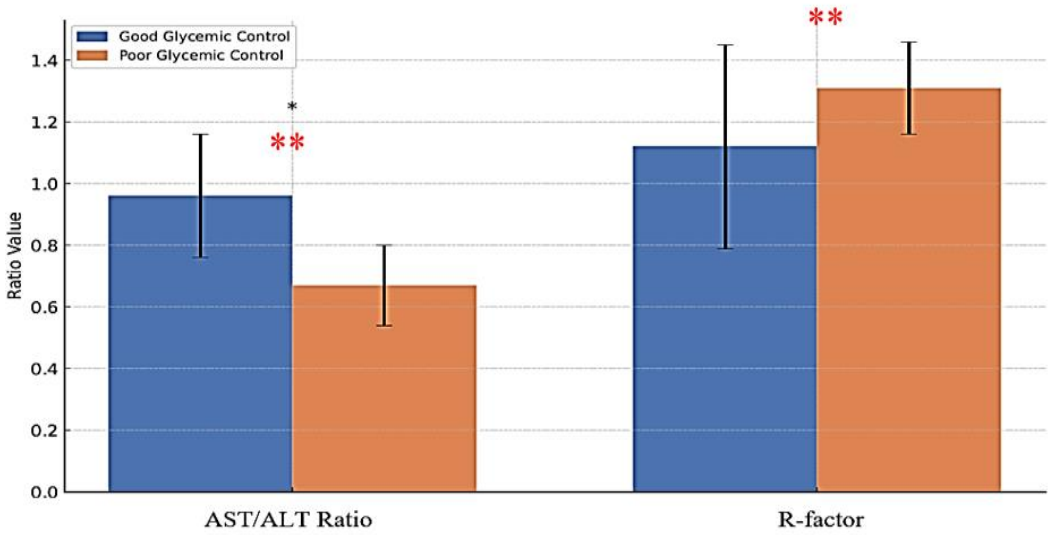

Figure 3: Mean ± SD levels of AST/ALT Ratio and R-factor in patients with T2DM, based on glycemic control status, **: indicates a highly significant difference (P<0.01).

3.4 Kidney Functions parameters

Regarding kidney function, creatinine levels were significantly higher in patients with poor glycemic control (0.93± 0.13 mg/dl) compared to those with well-controlled (0.78± 0.11 mg/dl, P = 0.0001), with a large effect size (Cohen's d = 1.25; 95% CI:0.806-1.69; P = 0.0001). In contrast, no significant differences were observed in uric acid and urea levels between the groups (P = 0.858 and P = 0.081, respectively) as shown in Table 5.

Table 5: Kidney functions parameters in studied groups

Parameters (Mean ± SD)	Well-controlled group (n=45)	Poor glycemic control group (n=50)	Cohen's d (95% CI)	*P*-value
Uric Acid (mg/dl)	5.09± 0.79	5.05+0.84	-0.049 (-0.451-0.353)	0.858
Urea (mg/dl)	30.23± 4.67	32.25± 5.07	0.414 (0.008-0.821)	0.081
Creatinine (mg/dl)	0.78± 0.11	0.93± 0.13	1.25 (0.806-1.69)	0.0001**

**: indicates a highly significant difference (p<0.01)

In addition, the results indicated that participants with well-controlled had a significantly higher mean eGFR (100.02 ± 9.46 mL/min/1.73 m²) compared to those with poor glycemic control (87.68 ± 13.04 mL/min/1.73 m²; Cohen's d = 1.08; 95%CI: 0.653-1.514; p = 0.0001) as shown in Figure 4.

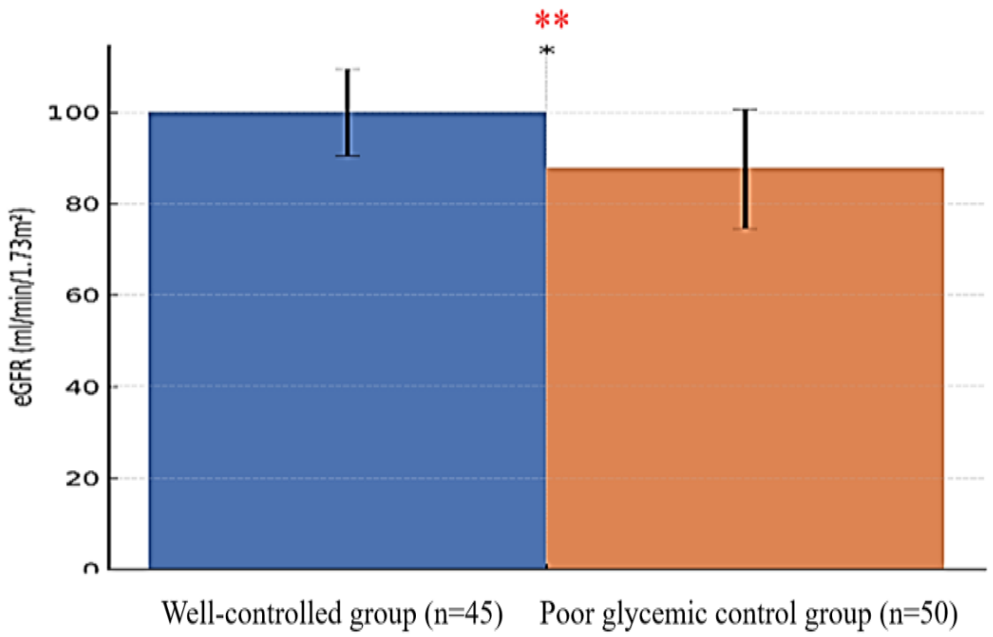

Figure 4: Mean ± SD levels of Glomerular Filtration Rate (GFR) in patients with T2DM, based on glycemic control status, **: indicates a highly significant difference (P<0.01).

3.5 Correlation Analysis

To examine the relationship between biochemical parameters, including lipid profile liver and kidney function indices, with HbA1c levels in patients with T2DM, a Pearson correlation analysis was performed.

As shown in Figure 5, HbA1c levels were correlated with calculated lipid-related indices (P < 0.05), and Pearson's correlation coefficient showed that this correlation was positive between HbA1c and the TyG index (r =0.824, p =0.0001), the TG/HDL ratio (r =0.818, p =0.0001), and the AIP (r =0.809, p =0.0001).

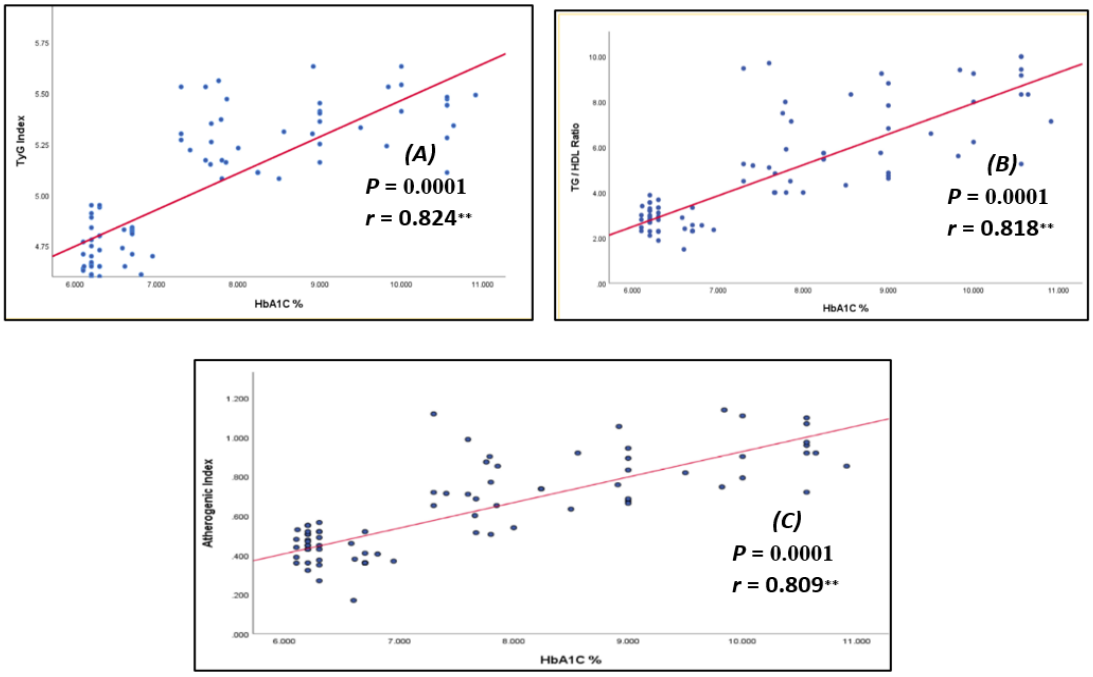

Figure 5: Correlations between HbA1c levels and the A: TyG index, B: TG/HDL ratio, and C: AIP in patients with T2DM.

For the liver function indices; Figure 6 shows a positive correlation between HbA1c levels and R-factor (r= 0.317, p= 0.002), while a negative correlation between HbA1c levels and AST/ALT ratio$r$= -0.444, p= 0.0001) was found.
Also, the results for the kidney function; Figure 7 shows a negative correlation between HbA1c and eGFR (r = -0.294, p = 0.005), this signifies a significant link between glycemic control and changes in both liver enzyme activity and kidney function.

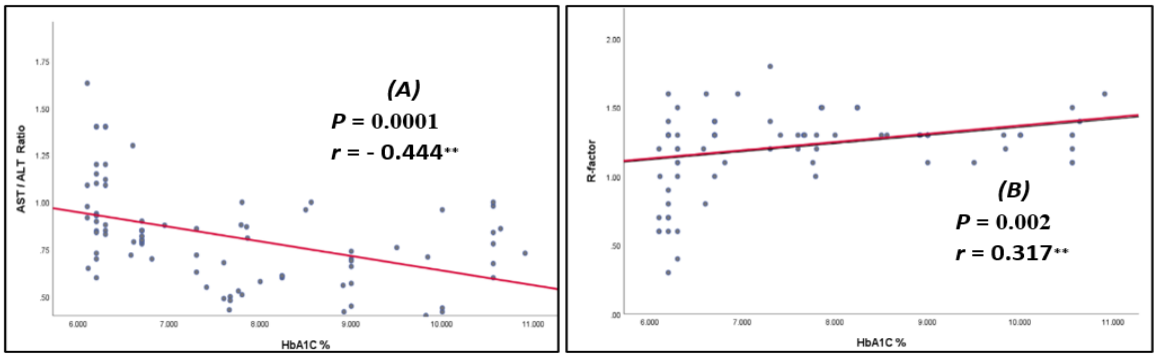

Figure 6: Correlations between HbA1c and the A: AST/ALT ratio and B: R-factor in patients with T2DM.

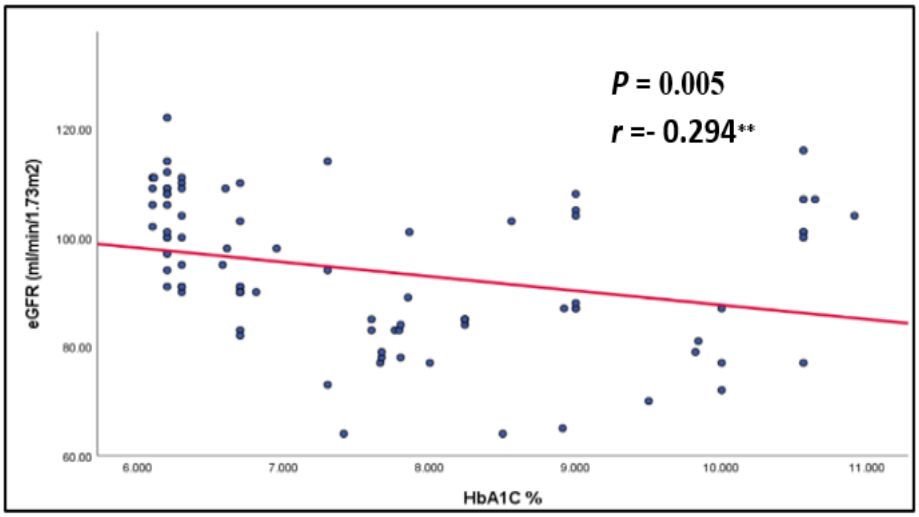

Figure 7: Correlations between HbA1c and the eGFR in patients with T2DM.

4. Discussion

The results of the present study showed that the majority of the poorly-controlled glycemic group (HbA1c > 7.0%) were females (60%), signifying that poor glycemic control may be linked to gender.
This agrees with previous studies suggesting that women (especially postmenopausal women) may have critical glycemic effects [22-24] which may due to hormonal changes, lower insulin sensitivity [25], and psychosocial or behavioral factors such as stress, decreased physical activity, and lower treatment regimens adherence [26].
Also, the results showed that poor glycemic control patients had much higher levels of both eAG and FBG compared to good glycemic control patients. This highlights the important aspect of maintaining optimal glycemic control to manage diabetes and to avoid its microvascular and macrovascular complications which include retinopathy, nephropathy, neuropathy and cardiovascular disease [27-28]. This agrees with Nathan *et al.* (2008) and Ram *et al.* (2021),

both of which showed a significant association between HbA1c and eAG, confirming that eAG is a dependable indicator of long-term glycemic status [13, 29].
Regarding lipid metabolism, the findings showed increased TG and VLDL-C, and decreased HDL-C, which are consistent with atherogenic dyslipidemia, in poor glycemic control patients. This leads to increased risk of cardiovascular diseases and it agrees with findings from Iraq [30], Saudi Arabia [31], and Jordan [32]. This signifying the necessity of effective glycemic control in lowering dyslipidemia and related cardiovascular diseases in T2DM patients.

Also, regarding insulin resistance, the TyG index is considered a reliable and cost-effective marker due to its dependence on routinely measured TG and FBG levels [33]. In addition to that index, both the TG/HDL-C ratio and AIP (log [TG/HDL-C]) are also being recognized as reliable indices for insulin resistance and cardiovascular risk [16].
Moreover, a positive correlation between HbA1c and these indices (Figure 5) display that poor glycemic control is related to atherogenic lipid profiles which are commonly associated with insulin resistance and adverse metabolic results [34].

As shown in Figure 2, poor glycemic control patients also displayed much higher values of these indices compared to well-controlled patients. Suggesting that optimal glycemic control may lower TyG, TG/HDL-C ratio, and AIP values, regulate lipid parameters, improve insulin sensitivity, and reduce cardiovascular risk [35 – 36].
Regarding hepatic involvement, the liver enzymes (ALT, ALP) were increased and the AST/ALT ratio was decreased, this indicates an early hepatocellular involvement and possible risk of non-alcoholic fatty liver disease. Even though the R-factor remained under 2, its relative increase indicates subtle hepatocellular changes. This agrees with studies that has linked insulin resistance and hyperglycemia to hepatic fat accumulation, oxidative stress, and inflammation, which may lead to progressive liver dysfunction [18, 24].

Renal changes were also observed as increased serum creatinine and decreased GFR among poor glycemic control patients which signifying the risk of diabetic nephropathy. This agrees with previous study that showed long period of hyperglycemia may led to a faster renal failure through mechanisms such as glomerular hyperfiltration, endothelial dysfunction, and increased oxidative stress [37].

In comparison with previous studies conducted in Iraq, which focused on individual parameters, such as lipid alterations [38-39] or renal function [40], our study gives a comprehensive and more integrated view through evaluation of lipid, hepatic, and renal parameters, and at the same time, presenting advanced indices (TG/HDL-C ratio, ALP, TyG index, R-factor, and AST/ALT ratio), this study also shows the predictive potential of subtle biochemical changes, even when within normal ranges, to identify early stages of diabetes and its complications. Therefore, our study emphasizes its clinical significance by providing a multidimensional view of glycemic control and systemic involvement in Iraqi patients with T2DM. Also, dietary adherence, physical activity, and medication adherence, are important factors as they may have affected the observed associations. Recent studies show that poor adherence to these factors is common and is associated with worse glycemic control while good adherence improves glycemic control [41-42]. Even though these were not directly involved in this study, they could partially explain individual variations and should be considered in future research.

5. Conclusion

In conclusion, to avoid or delay diabetes-related complications, it is necessary to have good glycemic control. This study shows that good glycemic control patients tend to have better metabolic and biochemical profiles, including liver and kidney function markers. Also, this study emphasizes the importance of a complete diabetes management, which should include regular blood glucose monitoring, lipid, liver, and kidney parameters. Furthermore, this study assesses not only conventional metabolic and organ function parameters, but also specific indices such as TyG and AIP. These indices can be used by clinicians to help in predicting early metabolic abnormalities, optimizing patient care, and reducing the risk of long-term complications more effectively, even in settings with limited resources.

Acknowledgments

The author acknowledges the great assistance offered by the staff of the Endocrinology Outpatient Clinic at Medical City in Baghdad for their assistance with sample collection.

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