Vitamin D Status and Its Association with Lipid Metabolism and Glycemic Control in Type 2 Diabetes: A Cross-Sectional Study in Tobruk, Libya

(Original Research Article)

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Abstract

Background: Vitamin D deficiency and dyslipidemia are frequently observed in patients with type 2 diabetes mellitus (DM) and may influence glycemic control and cardiovascular risk. This study investigates the association between vitamin D status, glycemic markers, and lipid profiles in DM patients in Tobruk, Libya.

Methods: A cross-sectional study was conducted among 167 participants (both diabetic and non-diabetic). Serum vitamin D, fasting blood glucose (FBG), glycated hemoglobin (HbA1c), and lipid profile parameters (LDL, HDL, total cholesterol, triglycerides) were measured. Statistical analyses included a chi-square test, Pearson correlation, and regression models to assess associations.

Results: Vitamin D deficiency was significantly more prevalent among females (84%) than males (59%) ($p = 0.023$), and among older adults aged 51–78 years (84.9%) ($p = 0.011$). Significant associations were found between vitamin D deficiency and diabetes diagnosis ($p = 0.0012$), elevated FBG ($p = 0.0038$), and HbA1c ($p = 0.014$). Among lipid markers, only LDL cholesterol showed a significant association with vitamin D status ($p = 0.032$). No significant associations were found for total cholesterol ($p = 0.149$), HDL ($p = 0.289$), or triglycerides ($p = 0.903$).

Conclusion: Vitamin D deficiency is highly prevalent among diabetic and older individuals and is significantly associated with poor glycemic control. Elevated LDL cholesterol was the only lipid parameter linked considerably to vitamin D deficiency. Further longitudinal studies are recommended to explore the metabolic implications of vitamin D in DM.

Keywords: type 2 diabetes mellitus (DM), lipid profile, vitamin D, HbA1c, fasting blood sugar (FBS).

1. Introduction:

The International Diabetes Federation reports that diabetes mellitus (DM) affects roughly 537 million adults globally as of 2021. This chronic metabolic disorder has reached epidemic levels. The projection for 2045 indicates that there will be more than 700 million people with diabetes globally [1]. Type 2 diabetes mellitus (DM), which is responsible for more than 90% of all diabetes cases, occurs mostly due to obesity and a sedentary lifestyle [2]. Chronic hyperglycemia in diabetes gradually damages the cardiovascular and other organ systems [3]. Studies suggest that people with diabetes are two to four times more likely to develop cardiovascular diseases (CVD) compared to non-diabetics [4,5]. Furthermore, cardiovascular disease is the leading cause of mortality in diabetic patients. Atherosclerosis is accelerated by factors such as dyslipidemia, chronic inflammation, endothelial dysfunction, and increased CVD risk [6].

In diabetes, dyslipidemia—often called diabetic dyslipidemia—includes:

- Elevated triglycerides (TG).
- Reduced high-density lipoprotein (HDL), also called “good cholesterol”
- Increased dense small LDL or “bad cholesterol” [7,8]

While fasting blood sugar (FBS) and HbA1c remain the primary indicators of glycemic control, the relationship between lipid profile disturbances and dysglycemia remains a topic of controversy. Several studies suggest that low HDL and high triglycerides, although not confirmed as predictive markers, are associated with insulin resistance and suboptimal glycemic control [9]. Additionally, the term glucolipotoxicity describes how lipid dysregulation contributes to the pathogenesis of diabetes [10]. This theory proposes that increased triglycerides and free fatty acids impair insulin action, increase resistance, and damage β-cell function, thereby worsening hyperglycemia [11].

Despite these theoretical links, the correlation between glycemic status and lipid markers varies across studies. Some consider LDL and total cholesterol more predictive of cardiovascular risk than direct diabetes predictors, while others emphasize triglycerides as contributors to metabolic dysfunction [6,8].

Given this uncertainty, the aim of the current study is to:

1. Assess the correlation between lipid markers and glycemic parameters (HbA1c, FBS).
2. Determine whether lipid markers are accurate predictors of diabetes.
3. Evaluate the cardiovascular risk profile of diabetic individuals. Enhancing understanding of these associations can improve early metabolic risk detection and intervention.

2. Materials and Methods:

2.1 Study Design and Participants

This cross-sectional study was conducted between January and March 2023 among individuals attending various public and private clinics in Tobruk City, Libya. A total of 167 participants were enrolled, including both diabetic and non-diabetic individuals, based on the diagnostic criteria of the American Diabetes Association (ADA) [3].

2.2 Biochemical Analysis

Fasting venous blood samples were collected from participants. Laboratory assessments followed standardized methods used in previous studies:

- HbA1c (%): Quantified by high-performance liquid chromatography (HPLC)
- Fasting blood glucose (mg/dL): Glucose oxidase-peroxidase method
- Vitamin D (ng/mL): Measured using ELISA-based immunoassay
- Total cholesterol and LDL (mg/dL): Enzymatic colorimetry assay
- HDL: Direct immunoinhibition technique

- Triglycerides: Glycerol phosphate oxidase method.

2.3 Statistical Analysis.

Statistical analyses were performed using IBM SPSS version 25 (Armonk, NY, USA). The study was powered at 95% to detect significant associations between vitamin D status and glucose/lipid profiles based on the sample size. Categorical variables were described as frequencies and percentages. Pearson's chi-square test was used to assess associations between categorical variables (e.g., vitamin D status vs. glycemic or lipid categories). A p-value < 0.05 was considered statistically significant.

2.4 Ethical Considerations

Ethical approval was obtained from both private and public clinic administrations. Patient confidentiality was ensured by assigning coded identifiers to de-identified medical records, without any personal information.

3. The results:

3.1 Association Between Vitamin D Status and the Demographic Characteristics.

The demographic characteristics of the study population are summarized in Table 1. A total of 167 participants were included in the analysis. Chi-square test (at $p < 0.05$) was used to assess the association between vitamin D status (categorized as normal, insufficient, and deficient) and demographic variables: age groups and gender.

Table 1. *Demographic characteristics of the study population and their association with vitamin D status* ***(N = 167)****.*

Category	Normal Vit D (Group 1) n=20 12 %	Insufficient Vit-D (Group 2) n=27 16 %	Deficient Vit-D (Group 3) n=120 72 %	P-Value
Gender				**0.023**
Male (N=80)	16 (20%)	17 (21%)	47 (59%)	
Female (N=87)	4 (5%)	10 (11%)	73 (84%)	
Age Category				**0.011**
15–30 (N=32)	9 (28.1%)	8 (25.0%)	15 (46.9%)	
31–50 (N=62)	7 (11.3%)	14 (22.6%)	41 (66.1%)	
51–78 (N=73)	3 (4.1%)	8 (11.0%)	62 (84.9%)	

There were notable disparities in vitamin D status based on gender, as detailed in Table 1. Among participants with normal vitamin D levels, males accounted for 20%, while females accounted for only 5%. Similarly, in the insufficient group, 21% were males compared to 11% females. However, in the deficiency group, a significantly greater proportion of females (84%) had vitamin D deficiency compared to males (59%). A statistically significant association was found between gender and vitamin D status (p = 0.023), suggesting that vitamin D deficiency is more prevalent among females than males. This difference may be influenced by factors such as sun exposure, clothing habits, dietary differences, and hormonal or physiological variations [12].

Similarly, age category showed a strong correlation with vitamin D status (p = 0.011). Participants aged 15–30 years had the highest proportion of normal vitamin D levels (28.1%),

while the 51–78 age group had the highest prevalence of vitamin D deficiency (84.9%). A clear increasing trend in vitamin D deficiency was observed with age: older individuals were more likely to be vitamin D deficient than younger ones. This pattern may be attributed to aging-related changes such as reduced dietary intake, decreased skin synthesis of vitamin D, and lower outdoor activity. These findings are visually summarized in Figure 1.

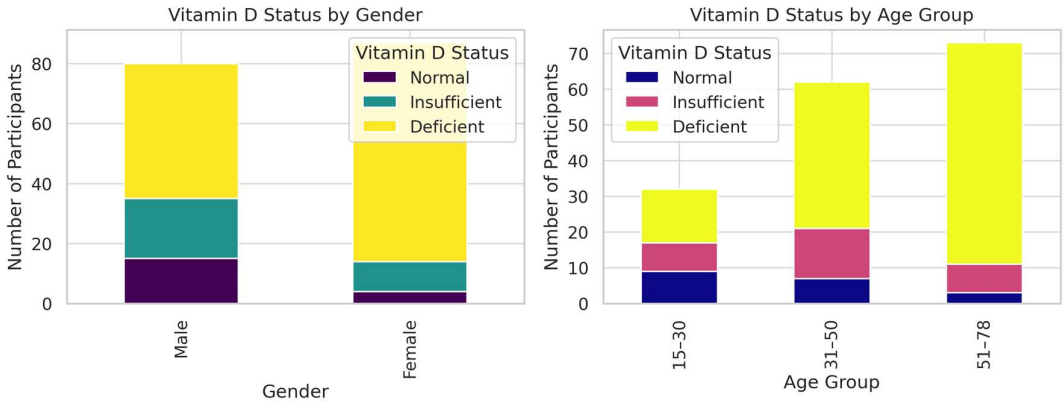

Figure 1. *Distribution of vitamin D status (normal, insufficient, deficient) among study participants by gender (left) and age group (right). A significantly higher prevalence of vitamin D deficiency was observed in females compared to males (p = 0.023) and among older participants compared to younger groups (p = 0.011). These findings suggest age and gender are important factors associated with vitamin D deficiency in the study population (N = 167).*

3.2 Association Between Vitamin D Status and Diabetic Markers.

Table 2 presents the association between vitamin D status and key diabetic parameters, including diabetes diagnosis, fasting blood glucose levels, and HbA1c categories. A statistically significant association was found between vitamin D status and diabetes diagnosis (p = 0.0012). Among individuals diagnosed with diabetes, vitamin D deficiency was far more prevalent (60%) compared to those without diabetes (40%). Conversely, normal

vitamin D levels were more frequently observed in non-diabetics (90%) than in diabetics (10%).

A significant relationship was found between fasting blood glucose levels and vitamin D status (p = 0.0038). Participants with normal glucose levels had the highest proportion of normal vitamin D status (90%), while vitamin D deficiency was most prevalent among those with diabetic-range glucose values (49%)

In terms of HbA1c levels, a significant association was also observed (p = 0.014). Vitamin D deficiency increased with worsening HbA1c control, reaching 33% in the pre-diabetic group and 40% in the diabetic group. No diabetic participants had normal vitamin D levels.

These findings suggest that vitamin D deficiency is associated with poor glycemic indicators, confirming previously documented correlations between lower vitamin D status and poor glycemic control [2,15,16].

Table 2: *Association between vitamin D groups and the diabetes status of the patients (N=167).*

Category	Normal Vit D (Group 1, n=20)	Insufficient Vit-D (Group 2, n=27)	Deficient Vit-D (Group 3, n=120)	p-value
Diabetes status				**0.0012**
Diabetic	2 (10%)	10 (37%)	72 (60%)	
Non-diabetic	18 (90%)	17 (63%)	48 (40%)	
Fasting Blood Glucose				**0.0038**
Normal (70–99 mg/dl)	18 (90%)	14 (52%)	31 (26%)	
Pre-diabetic (100–125)	2 (10%)	12 (44%)	30 (25%)	

Diabetic (>126 mg/dl)	0 (0.0%)	1 (4%)	59(49%)	
HbA1c level (%)				**0.014**
Normal (<5.7%)	14 (70%)	13 (48%)	32 (27%)	
Pre-diabetic (5.7–6.4%)	6 (30%)	11 (41%)	40 (33%)	
Diabetic (≥6.5%)	0 (0.0%)	3 (11%)	48 (40%)	

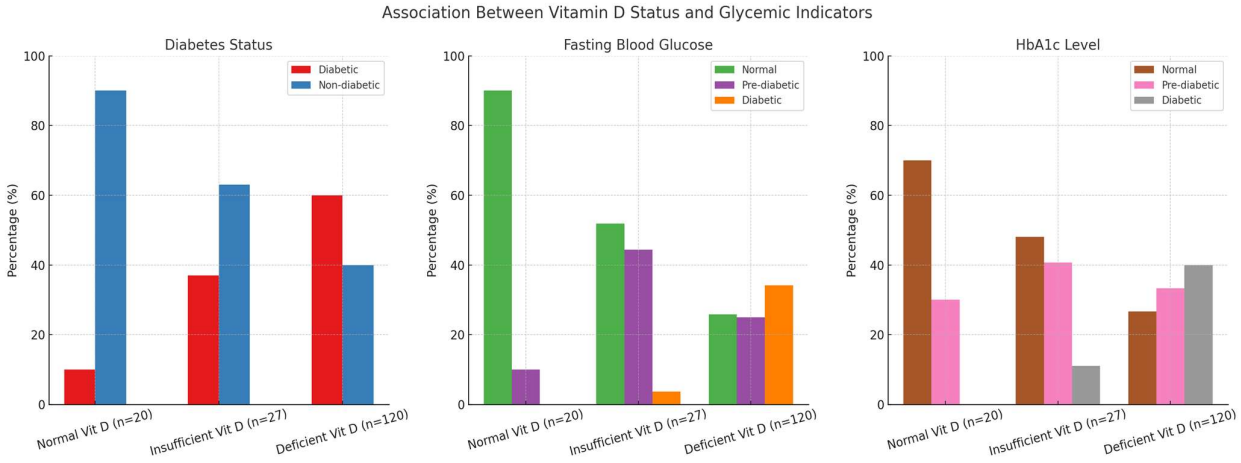

Figure 2: *Association between Vitamin D status and diabetic indicators. This composite figure shows the distribution of Vitamin D status (normal, insufficient, and deficient) concerning: (A) diagnosis of diabetes mellitus, (B) fasting blood glucose levels, and (C) HbA1c categories. Vitamin D deficiency was more prevalent among individuals with diabetes and prediabetes. Statistically significant associations were observed for: diabetes status (p = 0.0012), fasting blood glucose (p = 0.0038), and HbA1c levels (p = 0.014).*

3.3 Association Between Vitamin D Status and Lipid Profile Indices.

According to Table 3, the relationship between vitamin D status and lipid profile indices, total cholesterol, LDL, HDL (gender-specific), and triglycerides, was assessed across three vitamin D groups: **normal**, **insufficient**, and **deficient**.

Table 3: *Association between vitamin D groups and the lipid profile of the patients (N=167).*

Category	Normal (Group 1) n=20	Insufficient (Group 2) n=27	Deficient (Group 3) n=120	p-value
Total Cholesterol (mg/dL)				**0.149**
Normal (<200)	6 (30%)	7 (26%)	13 (11%)	
Borderline (200–239)	2 (10%)	1 (4%)	6 (5%)	
High (>240)	12 (60%)	19 (70%)	101 (84%)	
LDL (mg/dL)				**0.032**
Optimal (<100)	8 (40%)	10 (37%)	31 (26%)	
Borderline (100–159)	4 (20%)	1 (4%)	6 (5%)	
High (>160)	8 (40%)	16 (59%)	83 (69%)	
HDL (mg/dL)				**0.289**
Normal (female) >50	8 (40%)	16(59%)	67(56%)	
Low (female) <50	4 (20%)	2(8%)	11(9%)	
Normal (male) >40	6 (30%)	6(22%)	22(18%)	
Low (male) <40	2 (10%)	3(11%)	20(17%)	
Triglycerides (mg/dL)				**0.903**
Normal (<150)	6 (30%)	7 (26%)	22 (18%)	
Borderline (150–199)	2 (10%)	3 (11.1%)	17 (14%)	
High (>200)	12 (60%)	17 (63.0%)	81 (68%)	

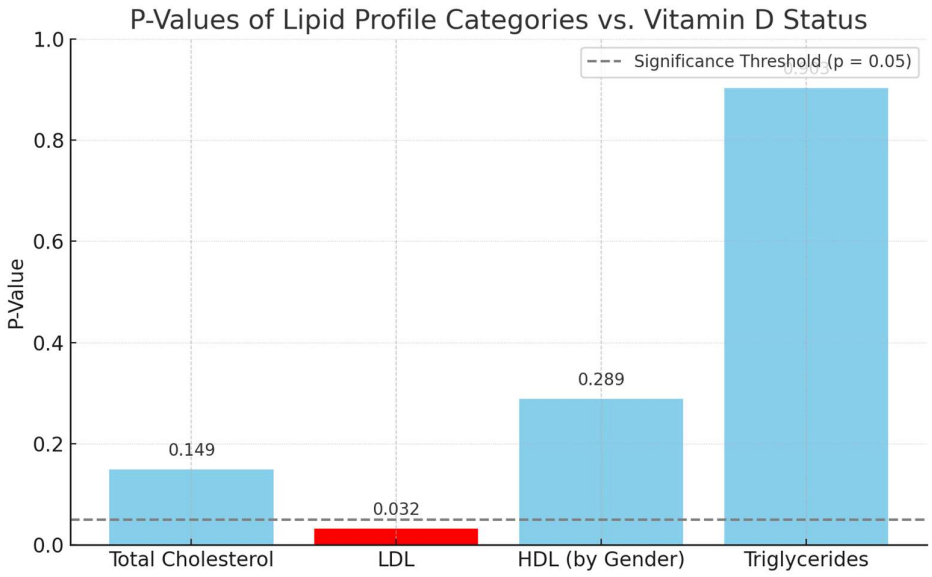

Figure 3: *Bar chart showing the statistical significance (p-values) of associations between Vitamin D status and lipid profile parameters (total cholesterol, LDL, HDL by gender, and triglycerides). The dashed line represents the significance threshold (p = 0.05). Only LDL showed a statistically significant association (p = 0.032).*

A statistically significant association was observed between vitamin D status and LDL cholesterol levels (p = 0.032). Among participants with high LDL levels (>160 mg/dL), the majority (n = 83) were vitamin D deficient. In contrast, optimal LDL levels (<100 mg/dL) were more common in the normal (n = 8) and insufficient (n = 10) vitamin D groups. This indicates a trend toward higher LDL levels in individuals with lower vitamin D status. This partial correlation is consistent with mixed results in recent meta-analyses describing variable lipid outcomes following vitamin D supplementation [6,7,17]. However, other parameters showed no statistically significant association between vitamin D status and total cholesterol levels (p = 0.149). Although the majority of individuals with high total cholesterol (>240 mg/dL) were vitamin D deficient (n = 84%), this pattern did not reach statistical significance.

Fewer individuals with normal vitamin D levels (n = 6) or insufficient vitamin D levels (n = 7) had total cholesterol in the normal range (<200 mg/dL). In addition, there was no significant association between vitamin D status and HDL levels (p = 0.289). Both male and female participants with normal HDL levels were distributed across all vitamin D categories. While 67 females with normal HDL (>50 mg/dL) and 22 males with normal HDL (>40 mg/dL) were vitamin D deficient, these proportions were not statistically different from those in the other vitamin D groups. Specifically, there was no statistically significant relationship found between vitamin D status and triglyceride levels (p = 0.903). A large proportion of individuals with high triglycerides (>200 mg/dL) were vitamin D deficient (n = 81), but similar trends were observed across all vitamin D groups, with no significant differences detected. These findings are in line with randomized controlled trials and observational studies published between 2020 and 2022 that reported inconsistent effects of vitamin D supplementation on lipid markers such as HDL, triglycerides, and total cholesterol [3,24].

4. Discussion:

This study highlights a high prevalence of vitamin D deficiency, particularly among females and older adults, consistent with previous evidence linking deficiency to reduced dermal synthesis, limited sun exposure, and lifestyle factors [12].

A significant association was observed between vitamin D deficiency and markers of glycemic control, including diabetes status, elevated fasting glucose, and increased HbA1c. These findings align with prior studies suggesting a relationship between low serum 25(OH)D and insulin resistance or risk of type 2 diabetes [13,14]. While vitamin D supplementation has shown potential benefits in improving glycemic markers in deficient individuals, its effect on insulin sensitivity remains uncertain [15,16].

Regarding lipid profile, a significant association was found only with elevated LDL cholesterol. This supports existing literature indicating that vitamin D deficiency may contribute to dyslipidemia, particularly increased LDL levels [18,19]. Although supplementation may offer modest lipid-lowering effects, results across studies remain inconsistent [21–23].

No associations were observed with total cholesterol, HDL, or triglycerides, possibly due to unaccounted confounders such as diet, genetic variation, or inflammation [12].

5. Conclusion:

This study demonstrates a significant association between vitamin D deficiency and both type 2 diabetes mellitus and elevated LDL cholesterol levels. Vitamin D-deficient individuals showed higher rates of diabetes, impaired glycemic control, and dyslipidemia, particularly elevated LDL. These findings highlight the potential role of vitamin D in glucose and lipid metabolism. Routine screening and correction of vitamin D deficiency may aid in managing metabolic risk factors. However, further randomized controlled trials are needed to clarify the therapeutic impact of supplementation.

6. Study Recommendations:

- Prioritize HbA1c and fasting blood glucose (FBS) as reliable markers for diagnosing and monitoring diabetes mellitus.
- Include LDL and triglyceride assessments routinely in diabetic patients to evaluate cardiovascular risk.
- Consider LDL and triglycerides as secondary indicators of metabolic dysfunction, especially in cases of insulin resistance or obesity.
- Screen vitamin D status in patients with diabetes or high metabolic risk;

supplementation may be beneficial but requires further validation.

- Future research should integrate broader metabolic markers (e.g., BMI, insulin resistance indices, inflammation) to better understand the interaction between vitamin D, glycemic control, and lipid metabolism.

7. Study Limitations:

- The cross-sectional design limits causal inference; longitudinal or interventional studies are needed to establish directionality.
- Key metabolic variables such as BMI, insulin resistance (e.g., HOMA-IR), and inflammatory markers were not assessed, limiting the metabolic context.
- The study population was confined to Tobruk City, which may reduce generalizability due to regional genetic, dietary, and lifestyle differences.

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