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Original Research Article

Association Between Vitamin D Status and Glycaemic Control in Patients with Type 2 Diabetes Mellitus

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Abstract

Background: Vitamin D deficiency has been increasingly recognized as a potential contributor to impaired glucose metabolism and poor glycaemic control in patients with type 2 diabetes mellitus (T2DM). However, the relationship between vitamin D status and glycaemic control remains inconsistent across different populations.
Objectives: To evaluate the association between serum vitamin D levels and glycaemic control in patients with T2DM and to determine whether vitamin D deficiency is associated with adverse metabolic parameters.
Methods: This hospital-based cross-sectional observational study included 150 adults with T2DM. Demographic, clinical, and biochemical data were recorded. Serum 25-hydroxyvitamin D [25(OH)D], fasting blood glucose (FBS), postprandial blood glucose (PPBS), glycated haemoglobin (HbA1c), and lipid profile were measured. Patients were categorized into vitamin D deficient (<20 ng/mL) and sufficient (≥20 ng/mL) groups. Continuous variables were compared using the independent samples t-test or Mann–Whitney U test, while categorical variables were analysed using the Chi-square test. Pearson correlation and multivariable logistic regression were performed to evaluate the association between vitamin D status and glycaemic control.
Results: Vitamin D deficiency was observed in 62.7% of participants. Patients with vitamin D deficiency had significantly higher HbA1c (9.02 ± 1.48% vs. 7.74 ± 1.19%; p<0.001), FBS (182.6 ± 46.3 vs. 145.2 ± 39.5 mg/dL; p<0.001), and PPBS (262.7 ± 63.4 vs. 214.8 ± 54.1 mg/dL; p<0.001) than those with sufficient vitamin D levels. Vitamin D levels demonstrated a significant inverse correlation with HbA1c (r = −0.48, p<0.001). After adjustment for confounding variables, vitamin D deficiency remained an independent predictor of poor glycaemic control (adjusted OR 3.64; 95% CI: 1.74–7.63; p<0.001).
Conclusion: Vitamin D deficiency was highly prevalent among patients with T2DM and was significantly associated with poorer glycaemic control and an adverse metabolic profile. Routine assessment of vitamin D status may aid in identifying patients at risk of poor metabolic control. Further prospective studies are warranted to determine whether correction of vitamin D deficiency improves long-term glycaemic outcomes.
Keywords: Type 2 diabetes mellitus; Vitamin D deficiency; Glycaemic control; HbA1c; Hyperglycaemia; 25-hydroxyvitamin D; Insulin resistance.

Introduction

Type 2 diabetes mellitus (T2DM) is one of the most prevalent non-communicable diseases worldwide and represents a major public health challenge because of its rapidly increasing incidence and its association with significant morbidity and mortality [1]. According to the International Diabetes Federation (IDF), approximately 589 million adults aged 20–79 years were living with diabetes globally

in 2024, with nearly 90–95% having T2DM. This number is projected to rise to 853 million by 2050. India bears one of the largest global burdens, with more than 101 million adults affected, emphasizing the need for effective strategies to improve glycaemic control and reduce diabetes-related complications [2].

T2DM is characterized by insulin resistance, progressive pancreatic β-cell dysfunction, and impaired insulin secretion, resulting in chronic hyperglycaemia. Persistent hyperglycaemia contributes to the development of microvascular complications, including retinopathy, nephropathy, and neuropathy, as well as macrovascular complications such as coronary artery disease, stroke, and peripheral arterial disease. Glycated haemoglobin (HbA1c), reflecting average blood glucose levels over the previous 8–12 weeks, is the most reliable indicator of long-term glycaemic control. Current guidelines recommend maintaining HbA1c below 7% in most adults with T2DM to minimize the risk of complications [3,4].

Vitamin D, traditionally recognized for its role in calcium homeostasis and bone metabolism, has gained attention for its extraskeletal effects, particularly in glucose metabolism. Vitamin D receptors and the enzyme 1α-hydroxylase are expressed in pancreatic β-cells, skeletal muscle, adipose tissue, and immune cells, suggesting an important role in insulin secretion and insulin sensitivity. Experimental studies indicate that vitamin D enhances insulin synthesis, improves peripheral insulin sensitivity, regulates intracellular calcium required for insulin release, and reduces inflammatory pathways associated with insulin resistance [5,6].

Vitamin D deficiency is a major global health concern, affecting nearly one billion people worldwide. Despite abundant sunlight, hypovitaminosis D is highly prevalent in India, with reported rates ranging from 50% to 90%. Factors such as darker skin pigmentation, obesity, ageing, limited outdoor activity, urbanization, dietary insufficiency, and cultural clothing practices contribute to this high prevalence. The coexistence of widespread vitamin D deficiency and increasing T2DM prevalence has raised interest in their potential relationship [7,8].

Several observational studies have demonstrated an inverse association between serum 25-hydroxyvitamin D [25(OH)D] levels and HbA1c, fasting and postprandial blood glucose, insulin resistance, and adverse lipid profiles, suggesting poorer metabolic control among vitamin D-deficient individuals. However, evidence from randomized controlled trials remains inconsistent, with some studies reporting improved glycaemic control after vitamin D supplementation, while others found no significant benefit after adjustment for confounding factors [9–13]. Serum 25(OH)D is the accepted marker of vitamin D status, with concentrations <12 ng/mL indicating deficiency, 12–20 ng/mL inadequacy, and ≥20 ng/mL sufficiency according to the Institute of Medicine [14].

Although international evidence continues to grow, data evaluating the association between vitamin D status and glycaemic control among Indian patients with T2DM, particularly from Bihar and eastern India, remain limited. Regional variations in nutrition, lifestyle, socioeconomic status, and sunlight exposure may influence both vitamin D status and glycaemic outcomes. Therefore, the present study was undertaken to evaluate the association between serum vitamin D levels and glycaemic control among patients with type 2 diabetes mellitus.

Methodology:

This was a hospital-based, observational, cross-sectional study conducted in the Department of General Medicine

Study Population

The study included adult patients diagnosed with type 2 diabetes mellitus who fulfilled the eligibility criteria and were recruited consecutively during the study period. A total of 150 patients were enrolled in the study.. A total of 150 patients with type 2 diabetes mellitus were included using consecutive sampling, which was considered adequate to evaluate the association between serum vitamin D status and glycaemic control.

Inclusion Criteria

Patients fulfilling all of the following criteria were included:

- Age ≥18 years.
- Previously diagnosed or newly diagnosed type 2 diabetes mellitus according to the American Diabetes Association (ADA) diagnostic criteria.
- Patients willing to provide written informed consent.
- Patients who underwent serum vitamin D estimation and HbA1c measurement during the study period.
- Exclusion Criteria
- Patients meeting any of the following criteria were excluded:
- Type 1 diabetes mellitus.
- Gestational diabetes mellitus.
- Pregnancy or lactation.
- Chronic liver disease.
- Chronic kidney disease (Stage IV or V).
- Malabsorption syndromes.

- Known disorders affecting vitamin D metabolism such as hyperparathyroidism or granulomatous diseases.
- Current use of vitamin D or calcium supplementation within the preceding three months.
- Patients receiving corticosteroids, anticonvulsants, or other medications known to interfere with vitamin D metabolism.
- Patients with acute severe illness, active infection, malignancy, or unwilling to participate.

Data Collection

After obtaining written informed consent, demographic and clinical information was collected using a predesigned case record form. Details including age, sex, duration of diabetes, body mass index (BMI), smoking status, alcohol consumption, comorbidities, current antidiabetic treatment, and associated medical illnesses were recorded. A detailed clinical examination was performed for every participant.

Clinical Assessment

Height and weight were measured using standardized instruments, and body mass index was calculated as weight (kg) divided by height squared (m^2). Blood pressure was measured using a calibrated sphygmomanometer after at least five minutes of rest in the sitting position. The average of two readings was recorded.

Laboratory Investigations

After overnight fasting, approximately 8–10 mL of venous blood was collected from each participant under aseptic precautions.

The following investigations were performed:

- Fasting blood glucose (FBS)
- Postprandial blood glucose (PPBS)
- Glycated haemoglobin (HbA1c)
- Serum 25-hydroxyvitamin D [25(OH)D]
- Total cholesterol
- Triglycerides
- High-density lipoprotein cholesterol (HDL-C)
- Low-density lipoprotein cholesterol (LDL-C)
- Very-low-density lipoprotein cholesterol (VLDL-C), where applicable

Fasting and postprandial plasma glucose levels were measured using the glucose oxidase-peroxidase method on an automated biochemistry analyser. HbA1c was estimated using high-performance liquid chromatography (HPLC), standardized according to the National Glycohemoglobin Standardization Program (NGSP). Serum 25-hydroxyvitamin D concentrations were measured using chemiluminescent immunoassay (CLIA). Lipid profile parameters were analysed using enzymatic colorimetric methods on an automated analyser following standard laboratory procedures.

Definition of Variables

Glycaemic Control

Glycaemic control was assessed using HbA1c levels.

- Good glycaemic control: HbA1c <7%
- Poor glycaemic control: HbA1c ≥7%
- Vitamin D Status
- Serum vitamin D status was categorized according to the Institute of Medicine (IOM) recommendations:
- Vitamin D deficiency: <12 ng/mL
- Vitamin D inadequacy: 12–20 ng/mL
- Vitamin D sufficiency: ≥20 ng/mL
- For comparative analysis, participants were also categorized into:
- Low vitamin D group: <20 ng/mL
- Adequate vitamin D group: ≥20 ng/mL

Outcome Measures

Primary Outcome

- Association between serum vitamin D status and glycaemic control as assessed by HbA1c.
- Secondary Outcomes
- Comparison of fasting blood glucose between vitamin D groups.
- Comparison of postprandial blood glucose between vitamin D groups.
- Comparison of lipid profile parameters between vitamin D groups.
- Determination of the prevalence of vitamin D deficiency among patients with type 2 diabetes mellitus.
- Correlation between serum vitamin D concentration and HbA1c.

Statistical Analysis

Data were entered into Microsoft Excel and analysed using Statistical Package for the Social Sciences (SPSS) software version 26.0 (IBM Corp., Armonk, NY, USA).Continuous variables were tested for normality using the Shapiro–Wilk test. Normally distributed variables were expressed as mean ± standard deviation (SD), whereas non-normally distributed variables were expressed as median with interquartile range (IQR). Categorical variables were summarized as frequency and percentage.

Comparisons between two independent groups were performed using the independent samples t-test for normally distributed continuous variables and the

Mann–Whitney U test for non-normally distributed variables. Categorical variables were compared using the Chi-square test or Fisher's exact test, as appropriate.

The relationship between serum vitamin D levels and HbA1c, fasting blood glucose, postprandial blood glucose, and lipid parameters was evaluated using Pearson's correlation coefficient for normally distributed variables or Spearman's rank correlation coefficient for non-parametric data.Multivariable linear regression analysis was performed to determine whether serum vitamin D concentration was independently associated with HbA1c after adjustment for potential confounding variables including age, sex, body mass index, duration of diabetes, and other clinically relevant covariates.A two-tailed p-value <0.05 was considered statistically significant.

Results:

A total of 150 patients with type 2 diabetes mellitus were enrolled in the study. The mean age of the study population was 56.8 ± 10.9 years, with a median age of 57 years (IQR: 49–64 years; range: 31–82 years). Males constituted 92 (61.3%) participants, while 58 (38.7%) were females. The majority of patients belonged to the 51–60 years age group (34.7%), followed by the 61–70 years age group (28.0%) (Table 1).

Table 1. Baseline Demographic Characteristics of the Study Population (N = 150)

Variable	Value
Age (years), mean ± SD	56.8 ± 10.9
Median (IQR)	57 (49–64)
Range	31–82
<40 years	12 (8.0%)
41–50 years	28 (18.7%)
51–60 years	52 (34.7%)
61–70 years	42 (28.0%)
>70 years	16 (10.6%)
Male	92 (61.3%)
Female	58 (38.7%)
BMI (kg/m²), mean ± SD	27.6 ± 4.3
Median BMI (IQR)	27.2 (24.6–30.1)
Duration of diabetes (years), mean ± SD	8.4 ± 5.2
Median duration (IQR)	7 (4–12)

Hypertension was the most common comorbidity, affecting 101 (67.3%) patients, followed by dyslipidaemia (84; 56.0%), obesity (52; 34.7%), coronary artery disease (33; 22.0%), and chronic kidney disease (21; 14.0%). The majority of participants (70.0%) were receiving oral hypoglycaemic agents, whereas 30.0% required insulin therapy.

Table 2. Clinical Characteristics

Variable	n (%)
Hypertension	101 (67.3)
Dyslipidaemia	84 (56.0)
Coronary artery disease	33 (22.0)
Chronic kidney disease	21 (14.0)
Obesity	52 (34.7)
Smoking	38 (25.3)
Alcohol consumption	29 (19.3)
Oral hypoglycaemic drugs	105 (70.0)
Insulin therapy	45 (30.0)

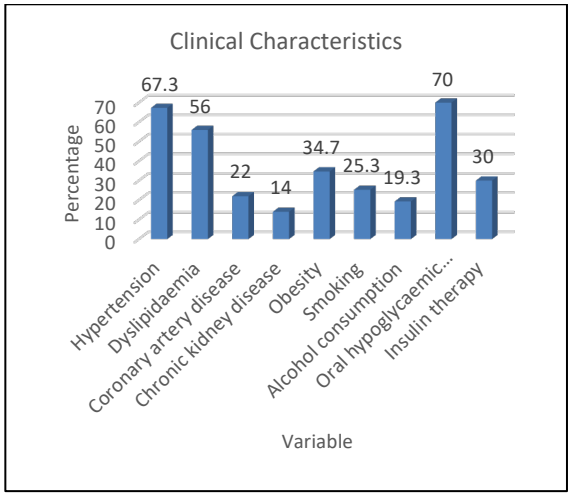

Figure 1. Clinical Characteristics

The mean HbA1c was 8.54 ± 1.63%, with a median value of 8.3% (IQR: 7.4–9.5%). The mean fasting blood glucose (FBS) was 168.4 ± 48.7 mg/dL, while the mean postprandial blood glucose (PPBS) was 244.9 ± 68.2 mg/dL. The median serum vitamin D concentration was 18.2 ng/mL (IQR: 12.6–25.8 ng/mL).

Table 3. Glycaemic and Biochemical Parameters

Variable	Mean ± SD	Median (IQR)
HbA1c (%)	8.54 ± 1.63	8.3 (7.4–9.5)
FBS (mg/dL)	168.4 ± 48.7	162 (135–198)
PPBS (mg/dL)	244.9 ± 68.2	236 (196–286)
Vitamin D (ng/mL)	19.8 ± 8.4	18.2 (12.6–25.8)

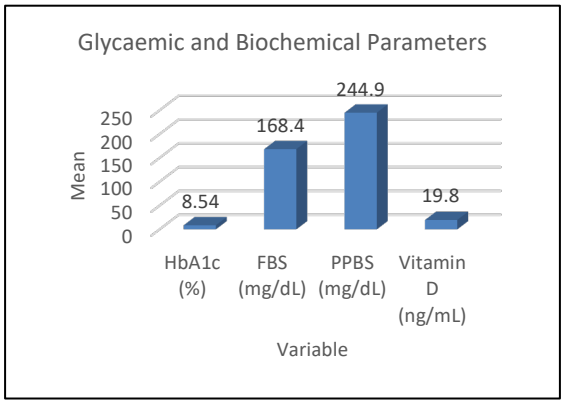

Figure 2. Glycaemic and Biochemical Parameters

Vitamin D deficiency (<20 ng/mL) was observed in 94 (62.7%) patients, while 56 (37.3%) had adequate vitamin D levels.Among the vitamin D deficient patients, 49 (52.1%) had severe deficiency (<12 ng/mL), whereas 45 (47.9%) had insufficiency (12–19.9 ng/mL).

Table 4. Vitamin D Status

Category	n (%)
Severe deficiency (<12 ng/mL)	49 (32.7)
Insufficiency (12–19.9 ng/mL)	45 (30.0)
Sufficient (≥20 ng/mL)	56 (37.3)

Patients with low vitamin D levels (<20 ng/mL) had significantly higher HbA1c, fasting blood glucose, postprandial blood glucose, triglycerides, and LDL cholesterol compared with patients having adequate vitamin D levels (≥20 ng/mL). HDL cholesterol was significantly lower in the vitamin D deficient group.Independent samples t-test was used for normally distributed variables, while the Mann–Whitney U test was used for non-normally distributed variables.

Table 5. Comparison Between Vitamin D Groups

Variable	<20 ng/mL (n=94)	≥20 ng/mL (n=56)	p-value	Test
Age (years)	57.6 ± 10.7	55.4 ± 11.2	0.228	Independent t-test
BMI (kg/m²)	28.2 ± 4.4	26.7 ± 4.1	0.041	Independent t-test
Duration of DM (years)	9.2 ± 5.4	7.1 ± 4.8	0.023	Independent t-test
HbA1c (%)	9.02 ± 1.48	7.74 ± 1.19	<0.001	Independent t-test
FBS (mg/dL)	182.6 ± 46.3	145.2 ± 39.5	<0.001	Independent t-test
PPBS (mg/dL)	262.7 ± 63.4	214.8 ± 54.1	<0.001	Independent t-test

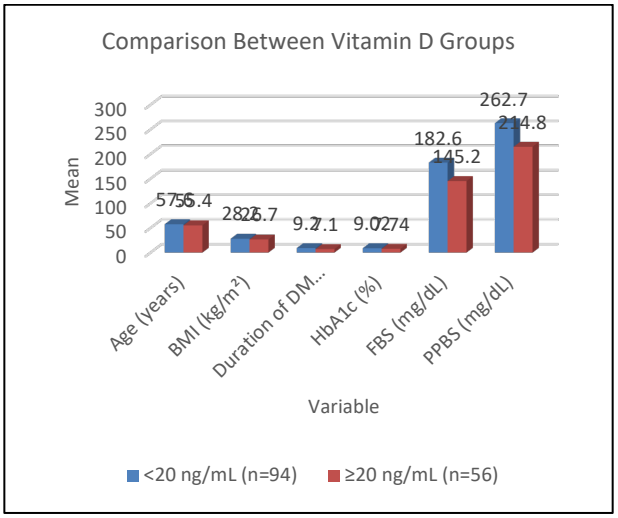

Figure 3. Comparison Between Vitamin D Groups

The vitamin D deficient group demonstrated significantly higher total cholesterol, LDL cholesterol, and triglyceride levels, whereas HDL cholesterol was significantly lower.

Table 6. Lipid Profile Comparison

Parameter	<20 ng/mL	≥20 ng/mL	p-value	Test
Total cholesterol	208.4 ± 38.2	184.6 ± 31.5	<0.001	t-test
Triglycerides	201.8 ± 74.6	164.7 ± 58.3	0.002	t-test
LDL	132.6 ± 30.4	112.8 ± 25.1	<0.001	t-test

HDL	39.8 ± 7.2	45.3 ± 6.8	<0.001	t-test

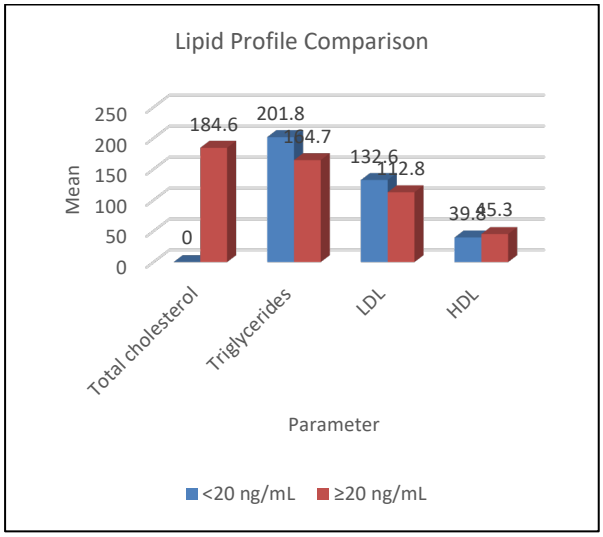

Figure 4. Lipid Profile Comparison

Pearson correlation analysis demonstrated a significant inverse correlation between serum vitamin D concentration and HbA1c ($r = -0.48$, $p < 0.001$). Significant negative correlations were also observed between vitamin D levels and fasting blood glucose, postprandial blood glucose, total cholesterol, LDL cholesterol, and triglycerides. A positive correlation was observed with HDL cholesterol.

Table 7. Correlation Between Vitamin D and Clinical Parameters

Variable	Correlation (r)	p-value
HbA1c	−0.48	<0.001
FBS	−0.41	<0.001
PPBS	−0.44	<0.001
Total cholesterol	−0.33	<0.001
LDL	−0.37	<0.001
Triglycerides	−0.29	0.001
HDL	+0.32	<0.001

Statistical test: Pearson correlation coefficient.

After adjustment for age, sex, body mass index, duration of diabetes, hypertension, and dyslipidaemia, vitamin D deficiency remained an independent predictor of poor glycaemic control (HbA1c ≥7%).

Table 8. Multivariable Logistic Regression for

Variable	Adjusted OR	95% CI	p-value
Vitamin D <20 ng/mL	3.64	1.74–7.63	<0.001
Duration of diabetes >10 years	2.18	1.08–4.38	0.029
BMI ≥30 kg/m²	1.92	1.01–3.65	0.046
Hypertension	1.71	0.89–3.27	0.108
Dyslipidaemia	1.59	0.82–3.07	0.171
Age ≥60 years	1.38	0.71–2.67	0.339

Statistical analysis: Binary logistic regression.

Discussion

The present study evaluated the association between serum vitamin D status and glycaemic control among patients with type 2 diabetes mellitus (T2DM). The major findings were that vitamin D deficiency (<20 ng/mL) was highly prevalent (62.7%), vitamin D-deficient patients had significantly poorer glycaemic control with higher HbA1c, fasting blood glucose (FBS), and postprandial blood glucose (PPBS), exhibited a more adverse lipid profile, showed a moderate inverse correlation between serum vitamin D and HbA1c, and vitamin D deficiency remained an independent predictor of poor glycaemic control after adjustment for potential confounders. These findings support growing evidence linking vitamin D deficiency with impaired metabolic control in T2DM [15].

Vitamin D deficiency has become a common nutritional disorder among individuals with T2DM. In the present study, nearly two-thirds of patients had serum vitamin D levels below 20 ng/mL. This prevalence is consistent with the systematic review by Md Isa et al. [15], which concluded that vitamin D deficiency is highly prevalent in patients with

T2DM and is associated with obesity, hypertension, dyslipidaemia, diabetic complications, and poor glycaemic control. Similarly, a recent BMJ Open systematic review and meta-analysis reported a high global prevalence of vitamin D deficiency among patients with T2DM across diverse populations, emphasizing its importance as a metabolic comorbidity [16].

A key finding of our study was that vitamin D-deficient patients had significantly higher HbA1c levels than those with adequate vitamin D (9.02 ± 1.48% vs. 7.74 ± 1.19%; $p<0.001$). Comparable findings were reported by Jamali et al. [17], who demonstrated a significant inverse relationship between serum vitamin D and HbA1c. Likewise, Md Isa et al. [15] observed that most observational studies consistently reported poorer glycaemic control among vitamin D-deficient individuals. These findings are biologically plausible because vitamin D receptors are present in pancreatic β-cells and insulin-sensitive tissues, where vitamin D enhances insulin secretion, improves insulin sensitivity, regulates intracellular calcium, and reduces inflammation contributing to insulin resistance [15].

In addition to higher HbA1c, vitamin D-deficient patients in our study had significantly elevated fasting and postprandial glucose levels. Similar observations were reported in the meta-analysis by Farahmand et al. [18], which showed that vitamin D supplementation resulted in modest but significant improvements in fasting plasma glucose and HbA1c, particularly among individuals with baseline vitamin D deficiency. However, the authors noted that treatment effects varied according to baseline vitamin D status, obesity, supplementation dose, and study duration [18].

An adverse lipid profile was also observed among vitamin D-deficient patients, with significantly higher total cholesterol, LDL cholesterol, and triglycerides, together with lower HDL cholesterol. These findings are consistent with Md Isa et al. [15], who identified dyslipidaemia as a frequent metabolic abnormality associated with vitamin D deficiency in T2DM. Vitamin D deficiency may contribute to altered lipid metabolism through impaired insulin sensitivity, inflammatory pathways, and adipocyte dysfunction, thereby increasing cardiovascular risk.

Our study further demonstrated a moderate inverse correlation between serum vitamin D and HbA1c ($r = -0.48$, $p<0.001$), comparable to the findings of Jamali et al. [17], who also reported a significant negative correlation between these parameters. Multivariable analysis confirmed vitamin D deficiency as an independent predictor of poor glycaemic control after adjustment for conventional risk factors. Although observational studies consistently support this association, Md Isa et al. [15] emphasized that evidence from randomized controlled trials remains heterogeneous, and causality has not yet been established. Nevertheless, the high prevalence of vitamin D deficiency and its association with poor glycaemic control suggest that assessment of vitamin D status may serve as a useful adjunct in the comprehensive management of patients with T2DM, while vitamin D supplementation should complement, rather than replace, standard diabetes care [18].

Conclusion

The present study demonstrated that vitamin D deficiency is highly prevalent among patients with type 2 diabetes mellitus and is significantly associated with poor glycaemic control. Patients with deficient vitamin D levels had higher HbA1c, fasting and postprandial blood glucose levels, together with a more adverse lipid profile compared with those having adequate vitamin D status. Serum vitamin D concentrations showed a significant inverse correlation with glycaemic indices, and vitamin D deficiency emerged as an independent predictor of poor glycaemic control after adjustment for potential confounding factors. These findings suggest that assessment of vitamin D status may serve as a useful adjunct in the comprehensive evaluation of patients with T2DM. Although the observational nature of the study precludes establishing causality, routine screening for vitamin D deficiency and appropriate correction in deficient individuals may contribute to improved metabolic management. Further large-scale prospective studies and randomized controlled trials are warranted to determine whether vitamin D supplementation can lead to sustained improvements in glycaemic control and reduce long-term diabetes-related complications.

Limitations

his single-centre cross-sectional study with a relatively small sample size cannot establish causality and may limit the generalizability of the findings. Additionally, potential confounders such as sunlight exposure, dietary vitamin D intake, seasonal variation, and supplementation were not fully assessed, and the lack of follow-up precluded evaluation of long-term outcomes.

Ethical approval

Ethical approval for this study was obtained from the Institutional Ethics Committee prior to the commencement of the study. The study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki and applicable institutional guidelines.

Informed Consent

Written informed consent was obtained from all participants prior to their enrolment in the study.

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Conflict of Interest Declaration

The authors declare no conflict of interest.

Data Availability Statement

All data generated or analysed during this study are available from the corresponding author upon reasonable request.

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