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Research Article

Association between Vitamin D levels and Glycemic Control in Sudanese Patients with Type 2 Diabetes

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Abstract
Background: In the past decade, vitamin D has been identified as a risk factor for Type 2 Diabetic Mellitus (T2DM) and linked to reduced insulin secretion and resistance in both experimental and epidemiological research.
Objectives: The research sought to ascertain the correlation between vitamin D insufficiency and type 2 diabetes mellitus (T2DM).
Study Design: This cross-sectional descriptive study included 40 diabetes patients who visited the Abdullah Khalil Diabetes Center at Omdurman Teaching Hospital. The data was collected using a meticulously designed questionnaire. Blood samples were collected for measuring HbA1c and 25-hydroxy vitamin D [25(OH)D]. Variable comparisons were analyzed using t-tests with a significance level of <0.05. Statistical analysis was carried out using SPSS v.26, which included Chi-Square and ANOVA tests.
Results: 70% of the patients were female, with an average age of 50.6 years; 42.5% were classified as overweight and 22.5% as obese. The results indicated that 97.5% of the patients had elevated HbA1c levels, whereas 90% demonstrated diminished 25(OH)D levels. The research identified a notable association between HbA1c, $p = 0.01$), skin pigmentation, $p = 0.02$), and vitamin D deficiency. 85% of the patients had an inadequate consumption of foods rich in vitamin D. The correlation between vitamin D insufficiency and T2DM necessitates the development of an awareness program on vitamin D, which should delineate the recommended daily allowance (RDA), dietary sources rich in and fortified with vitamin D, and appropriate sun exposure guidelines.
Conclusion: The study found a significant link between Vitamin D deficiency and elevated HbA1c levels in individuals with Type 2 diabetes mellitus (T2DM).

Keywords: BMI, HbA1c, Type 2 diabetes (T2DM), and Vitamin D.

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Introduction

Vitamin D deficiency is a prevalent global concern, with significant rates noted among diverse populations, including Saudi Arabian males, female college students in Qatar, and male adolescents in the United Arab Emirates **(Wang *et al*., 2017; Ozfirat and Chowdhury, 2010; El-Kebbi *et al.*, 2021; Alramadan *et al*., 2018; Ali *et al*., 2019)**.

Baz-Hecht and Goldfine (2010) established a correlation between vitamin D deficiency and an elevated risk of type 1 and type 2 diabetes, cardiovascular disease, as well as associated risk factors such as hypertension and obesity. The insufficient research on this subject in Sudan highlights the necessity of exploring the relationship between vitamin D deficiency and T2DM within the Sudanese population.

Prior research indicates a correlation between vitamin D levels and glycemic control in individuals with T2DM. Recommending vitamin D level testing for patients with elevated hemoglobin A1c (HbA1c) may enhance blood glucose regulation **(Buhary et al., 2017)**. Vitamin D sufficiency may confer protection against type 2 diabetes in elderly individuals **(Dalgård *et al*., 2011)**. There are differences between male and female T2DM patients regarding the association of vitamin D deficiency with elevated HbA1c levels **(Zhao *et al*., 2020)**. Lower vitamin D levels in patients with type 2 diabetes mellitus indicate the need for careful supplementation to enhance glycemic control **(Kostoglou *et al*., 2013)**. Vitamin D status is influenced by factors such as sun exposure, clothing choices, and skin pigmentation, alongside noted disparities in diabetes care related to socioeconomic status **(Grintsova et al., 2014)**. Individuals with lower educational attainment necessitate customized risk communication and management strategies in the context of secondary coronary heart disease prevention **(Bruthans et al., 2016). Al-Daghri *et al*., (2023)** identified positive correlations between knowledge and awareness of vitamin D and self-reported physical activity among adults in Saudi Arabia. Certain individuals exhibit low vitamin D levels even with significant sun exposure, suggesting a maximum limit of 60 ng/ml for vitamin D supplementation **(Binkley *et al.*, 2007)**. Skin pigmentation adversely affects vitamin D synthesis as evidenced by studies on UVB exposure **(Libon *et al*., 2013)**. **Looker *et al*. (2001)** documented weight changes preceding and following the onset of T2DM, revealing a propensity for weight loss post-diagnosis. Healthcare inequalities in patients with T2DM were identified based on socioeconomic status and regional deprivation, with lower SES and area deprivation correlating with poorer outcomes and complications **(Grintsova *et al*., 2014)**. This research investigates the association between vitamin D deficiency and T2DM within the Sudanese population.

Material and Methods

Study design, patients, and data collection

This cross-sectional descriptive study encompasses 40 patients with type 2 diabetes, comprising 12 males and 28 females, aged 30 to 78 years, who were referred to the Abdullah Khalil Diabetic Center at Omdurman Teaching Hospital in Omdurman City, Sudan, from July 2022 to December 2022. The participants were randomly selected, with inclusion requirements comprising at least one of the following conditions: 1) Diagnosed with Type 2 Diabetes Mellitus as per the medical record; 2) Currently receiving therapy with oral hypoglycemic agents; 3) Prior laboratory findings included at least one of the following outcomes in accordance with the recommendations set out by the American Diabetes Association: Fasting plasma glucose (FPG) ≥126 mg/dL; random plasma glucose ≥200 mg/dL accompanied by symptoms of polyuria, polydipsia, or weight loss; 2-hour oral glucose tolerance test (OGTT) ≥200 mg/dL or hemoglobin A1c (HbA1c) ≥6.5%. Patients were excluded from the study if they were under 18 years of age, had comorbidities including chronic liver disease, chronic kidney disease, or end-stage renal disease; had bone-mineral disorders such as hyperparathyroidism; were undergoing vitamin D or calcium treatments; were taking medications that could affect vitamin D metabolism; or were pregnant or breastfeeding. A meticulously organized questionnaire was developed to encompass patients' demographic information, medical history, anthropometric measures including weight, height, and body mass index, as well as biochemical data. All participants provided written informed consent after being told of the study's goal and before sampling, and the authors adhered to the ethical principles established in the Declaration of Helsinki. The Ethical Committee Board of Omdurman Islamic University sanctioned this study.

Anthropometric measurements

We utilized the ZT-160 body-weight scale to assess both height and weight. The Body Mass Index (BMI) was computed by dividing weight in kilograms (kg) by height in square meters (m^2), as specified by the World Health Organization **(WHO, 2010)**. The caloric values were determined utilizing the Harris-Benedict equation **(Harris and Benedict, 1918)**. The dietary evaluation method involved estimating nutrient intake through the analysis of food sources and consumption patterns **(Medical Research Council, 2014)**.

Blood collection and sample analysis

Following an overnight fast, 5 ml venous blood samples were obtained from the patients in blank tubes for 25(OH) D analysis and in Ethylenediaminetetraacetic acid (EDTA) tubes for HbA1c measurement. The serum was isolated 2 hours post-collection using centrifugation at 3,000 rpm for 5 minutes, subsequently stored in a refrigerator at -2 to 8 °C, and promptly transported to Al-Riada Modern Medical Laboratory for analysis, adhering to the laboratory methodology and manufacturer's guidelines. Following the preparation of hemolysate, a cobas b 101 system (Roche Diagnostics GmbH) measures the HbA1c concentration with a latex turbidimetric assay. The HbA1c target of 7-8 was established for individuals with T2DM according to the criteria set out by the American College of Physicians **(Qaseem et al., 2018)**. Patients with HbA1c levels below 8% were classified as having good glycemic control, whereas those with HbA1c levels beyond 8% were classified as having poor or uncontrolled glycemic control. The concentration of 25(OH) D was quantified using an automated analyzer (Biosystems BTS-350, USA), utilizing a calibration curve established through a 2-point calibration master curve technique. Patients with 25(OH)D levels exceeding 30 ng/ml were deemed to possess adequate vitamin D levels. Conversely, patients with blood 25(OH) D levels of 20-30 ng/ml or below 20 ng/ml were classified as having insufficient or deficient vitamin D levels, respectively **(Holick, 2009)**.

Statistical analysis

Frequency and percentage were calculated for categorical variables, while mean and standard deviation were used for continuous variables. Variable comparisons were analyzed using t-tests with a significance level of <0.05. Statistical analysis was carried out using SPSS v.26, which included Chi-Square and ANOVA tests.

Results:

Table (1): Demographic distribution of study participants (n = 40)

Gender	**Count**	**Percent (%)**
Male	12	30
Female	28	70
Age group		
30- 49	23	57.5
50-60	8	20
≥ 60 years	9	22.5
Education level		
Illiterate	12	30
Primary	10	25
High school	13	32.5
University	5	12.5
Type of accommodation of the patient		
Houses	38	95
Apartments	2	5
Total	**40**	**100**

As shown in Table 1, the study involved 40 participants, with 70% (n=28) being female and 30% (n=12) male. Demographic information: Age distribution: 57.5% of participants were aged 30-49, 22.5% were over 60, and 20% were between 50-60. Type of accommodation: 95% lived in open houses, while 5% lived in apartments. Average family income: 37.5% had less than 20,000 SDG per month, 22.5% had 20,000-40,000 SDG, 20% had 41,000-60,000 SDG, and only 7.5% had over 100,000 SDG. Educational level: 30% were illiterate, 32.5% had a high school education, 25% completed primary school, and 12.5% were university graduates.

Anthropometric measurements:

Table (2): Anthropometric Measurements of Study Participants (n = 40)

Nutritional status of the patient's (BMI = WHO, 2010)	**Count**	**%**
Normal 18.5 – 24.9	12	30
Class 11 obesity 35 -39.9	9	22.5
Overweight 25 – 29.9	17	42.5
Class 111 obesity > 40	2	5
Total	**40**	**100**
HbA1c laboratory result of the patients	**Count**	**%**
4.5- 6.0 (Normal)	1	2.5
> 6.4 (diabetes)	39	97.5
Total	**40**	**100**
Laboratory results of Alpha 25-hydroxy vitamin D	**Count**	**%**
Less than or equal to 30 (deficient)	36	90
30 – 100	4	10
Total	**40**	**100**

Table 2 shows that 42.5% of participants were overweight, 30% were in a healthy weight range, 22.5% were obese I, and only 5% were obese II. HbA1c Laboratory Results of Patients: - 97.5% of patients have high HbA1c levels, while only 2.5% have normal levels.

Laboratory Results of Alpha 25-hydroxy Vitamin D: Medical results indicate that 90% of patients were vitamin D deficient, while only 10% had normal levels of alpha 25-hydroxy vitamin D.

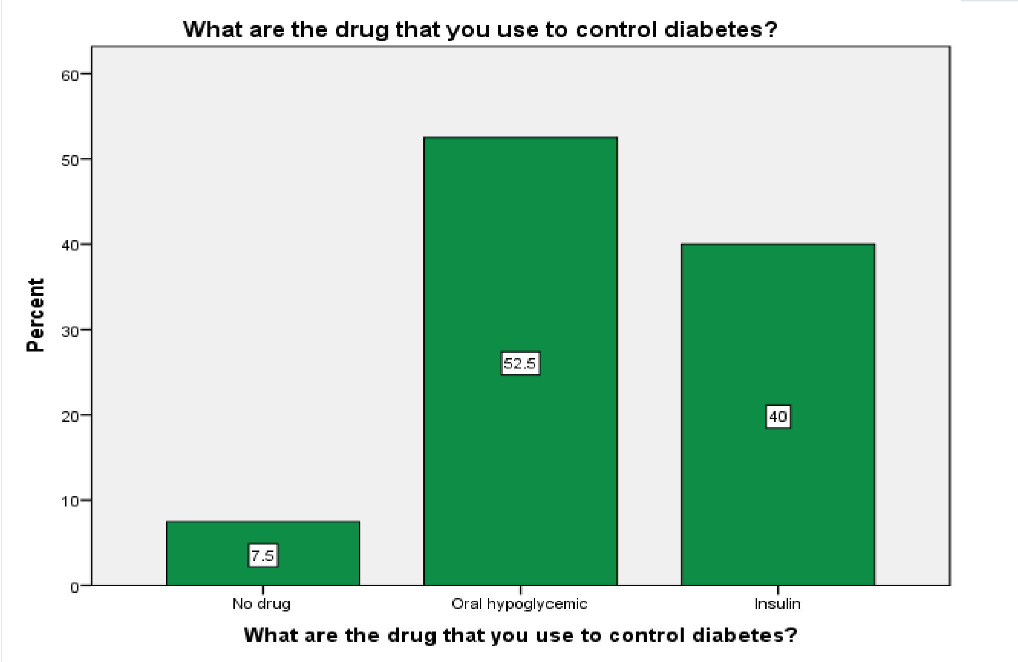

Figure 1: Drugs that patients use to control diabetes:

Figure 1: Medical history of diabetes control drugs used by patients: 52.5% use oral hypoglycemics, 40% use insulin, and 7.5% do not use any medication.

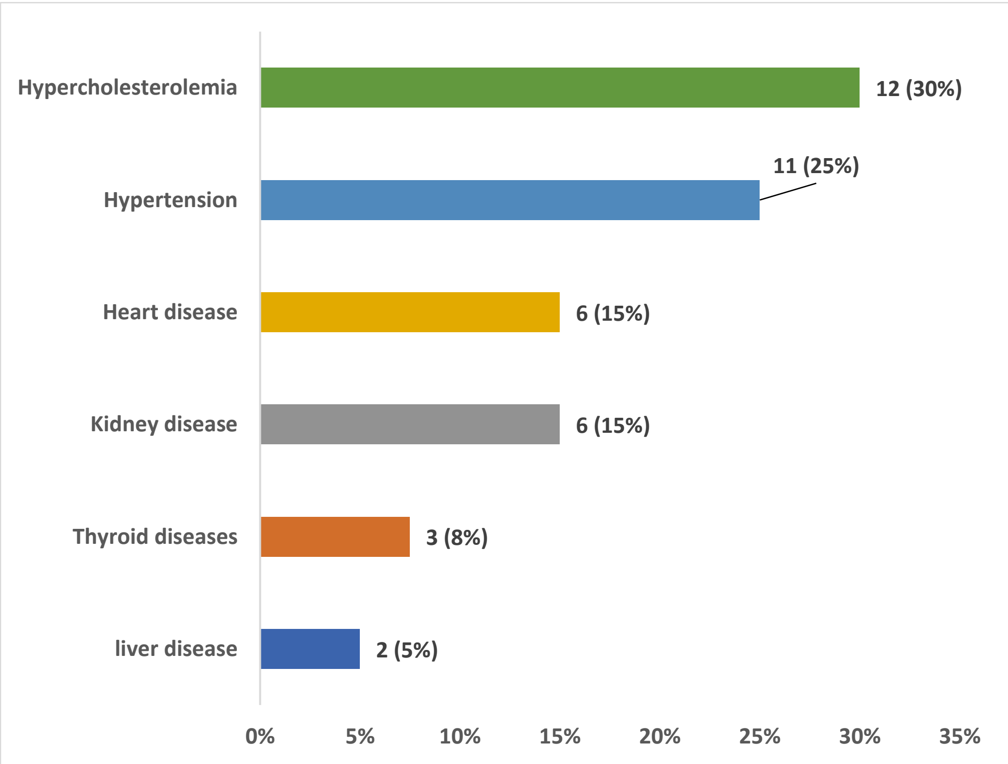

Figure 2: Medical conditions of the patients

Figure 2 shows the distribution of comorbidities among patients: 30% have hypercholesterolemia, 25% have hypertension, 15% have heart disease, 15% have kidney disease, 7% have thyroid disease, and 5% have liver disease.

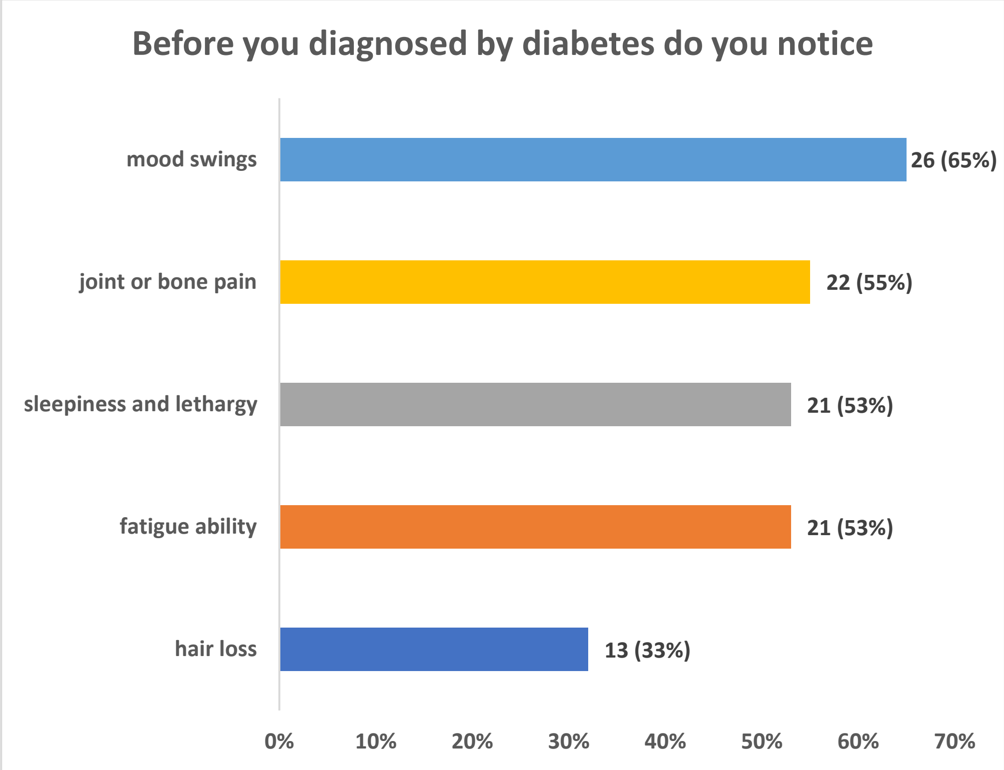

Figure 3: Symptoms of vitamin D deficiency

Figure 3 shows that 60% of patients experienced mood swings, 51% had joint or bone pain, 50% reported fatigue, sleepiness, and lethargy, and approximately one-third experienced hair loss.

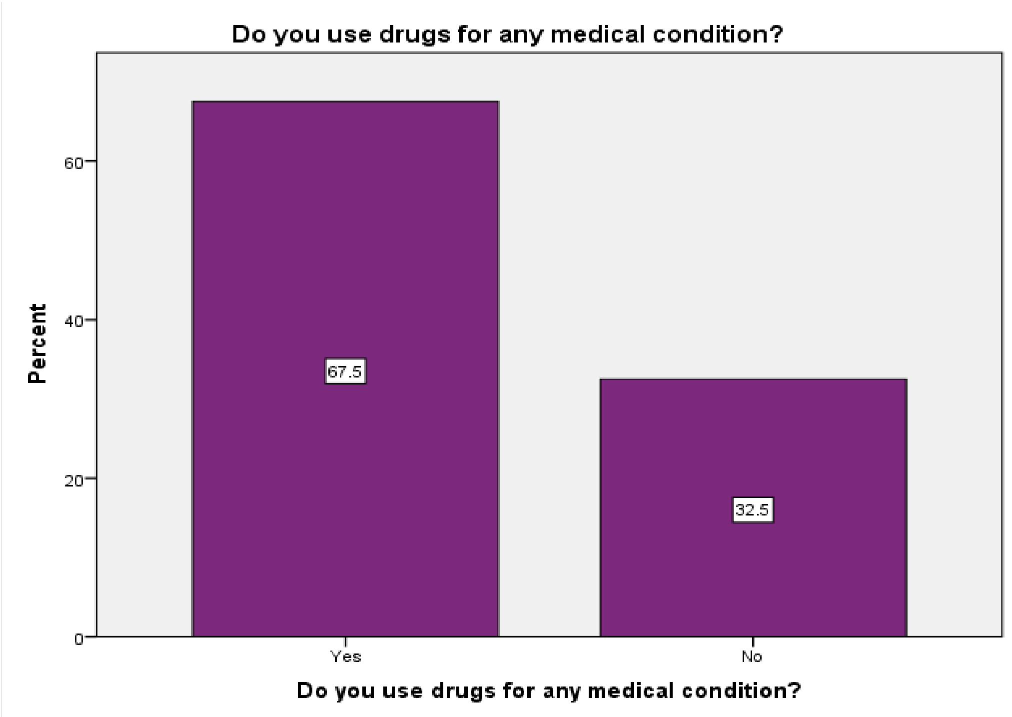

Figure 4: Drugs that used for medical conditions

Figure 4 shows that the majority of the patients (67.5%) use drugs for medical conditions, while the rest (32.5%) do not use drugs.

Table 3: Lifestyle:

Lifestyle:	**N (%)**
Are you exposed to the sun daily?	
Yes	39 (97.5%)
If yes, what is the duration?	
less than 20 minutes	4 (10%)
20-40 minutes	11 (27.5%)
About 1 hour	15 (37.5%)
More than 2 hours	9 (22.5%)
Is there a barrier between the skin and sunlight during exposure?	
Yes	31 (77.5%)
Does your exposure to sunlight start at a certain hour of the day?	
Yes	39 (97.5%)

Table 3 shows that 97% of the patients were exposed to the sun daily, with the highest duration (37%) being about 1 hour. Additionally, 77% of the patients had a barrier between their skin and sunlight during exposure, and almost all patients (97%) started their exposure to sunlight at a specific time of the day.

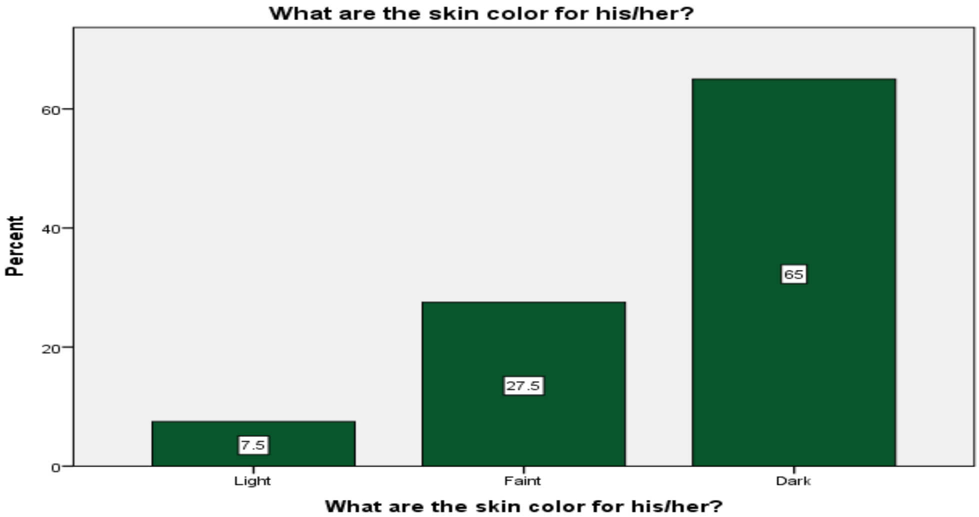

Figure 5: Types of Skin colors of the patient

Figure 5: Represent types of skin color of the patient as follows: the majority of the patients (65%) have a dark skin color, while (27.5%) have faint skin color, whereas the rest that is (7.5%) have light skin color.

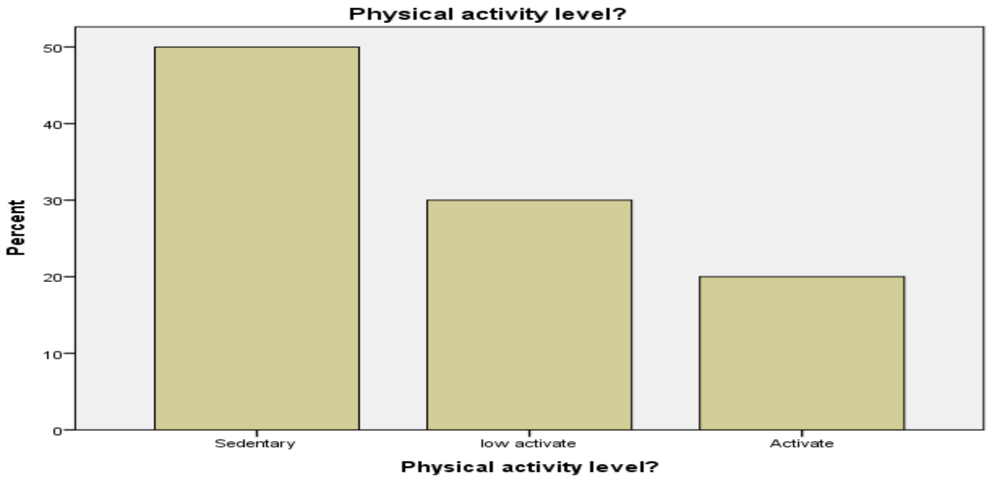

Figure 6: Physical activity level of the patient

As represented in Figure 6: half of the patients (50%) have a sedentary lifestyle, while (30%) have a medium activity level, and (20%) were active.

Table 4: Feeding practice:

Feeding practice:	**N (%)**
How many meals/days do you usually eat	
(1-2) meals	13 (32.5%)
(2-3) Meals	20 (50%)
More than 3meals	7 (17.5%)
Have you ever used a diabetic form of diet?	**40 (100%)**
Yes	27 (67.5%)
No	13(32.5%)
How much milk/milk product do you consume a day	**40 (100%)**
None	11 (27.5%)
1 cup	20 (50%)
2 cup	9 (22.5 %)
Total	**40 (100%)**

Table 4 displays the meal frequency of patients: 50% consumed 2-3 meals per day, 32.5% had 1-2 meals per day, and 17.5% had more than 3 meals per day. 67.5% adhered to a diabetic diet. In terms of milk intake, 50% consumed 1 cup per day, 27.5% never drank milk, and 22.5% consumed 2 cups per day.

Food habits:

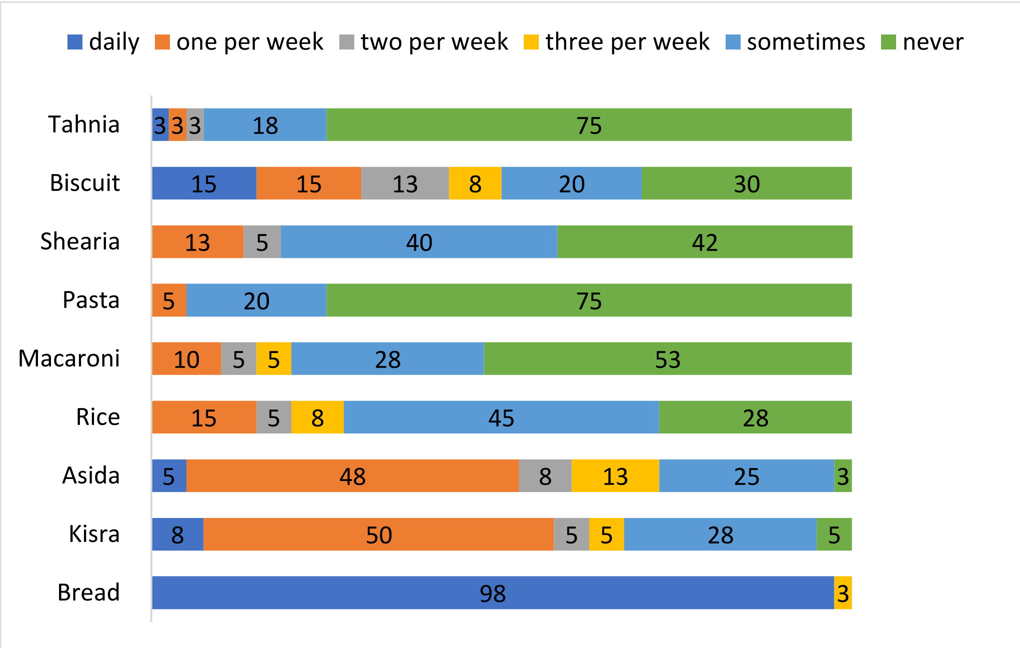

Figure 7: Pattern of carbohydrate intake

Figure 7 illustrates the carbohydrate intake of patients. The majority (98%) consume bread daily, while only 3% eat it three times a week. Half of the patients (50%) eat kisra once a week, with 28% consuming it occasionally, 5% eating it two to three times a week, and 5% never eating it. Only 8% eat kisra daily. Additionally, 45% eat asida once a week, 25% eat it occasionally, and 45% eat rice sometimes, with 28% never consuming it. More than half (53%) never eat macaroni, while 28% eat it daily. The majority (75%) never eat pasta, while 20% consume it daily. About 40% eat shearia daily, with 42% never consuming it. Furthermore, 20% of patients eat biscuits occasionally, while 30% never eat them. Approximately 15% eat biscuits once a week or daily. The majority (75%) never eat tahnia, while 18% consume it occasionally, and 3% eat it daily, once a week, or twice a week.

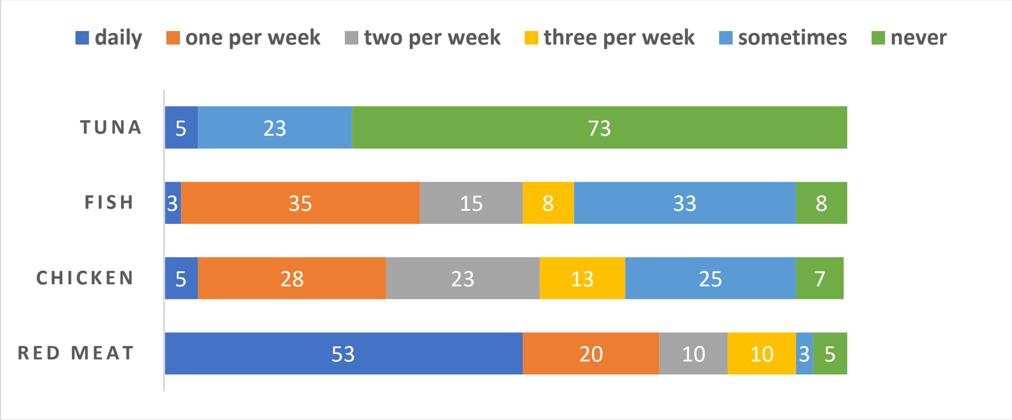

Figure 8: Pattern of animal protein intake

Figure 8 shows the pattern of animal protein intake among patients. More than half (53%) eat red meat daily, while 20% eat it occasionally. Additionally, 10% consume red meat 2-3 times per week. Furthermore, 28% eat chicken once a week, with 25% eating it occasionally and 23% consuming it twice a week. Fish is consumed by 35% of patients once a week, with 33% eating it occasionally. The majority (73%) never eat tuna, while 23% consume it occasionally.

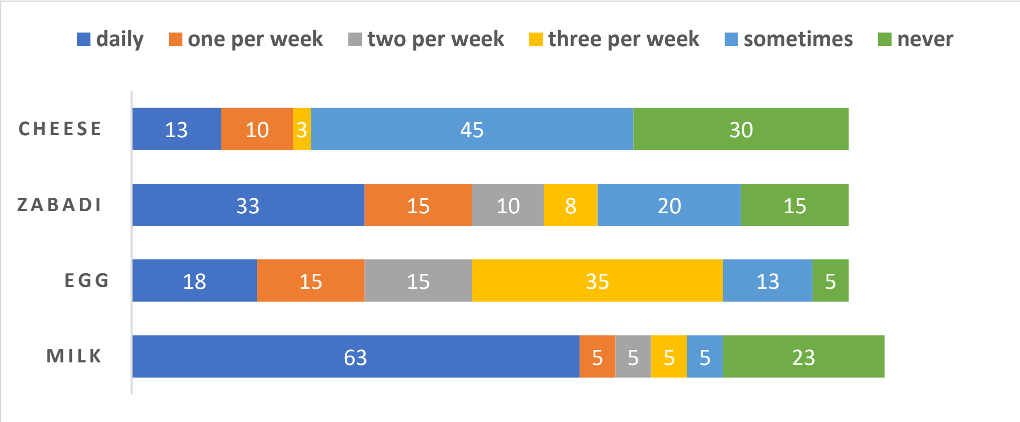

Figure 9: Pattern of dairy product intake

Figure 9 shows the dairy product intake patterns of the patients. 63% drink milk daily, while 5% drink it occasionally. 33% consume zabadi daily, 20% eat it sometimes, and 15% never eat it. 45% eat cheese occasionally, while 30% never eat it. 35% eat an egg three times a week, and 15% eat it once to twice a week.

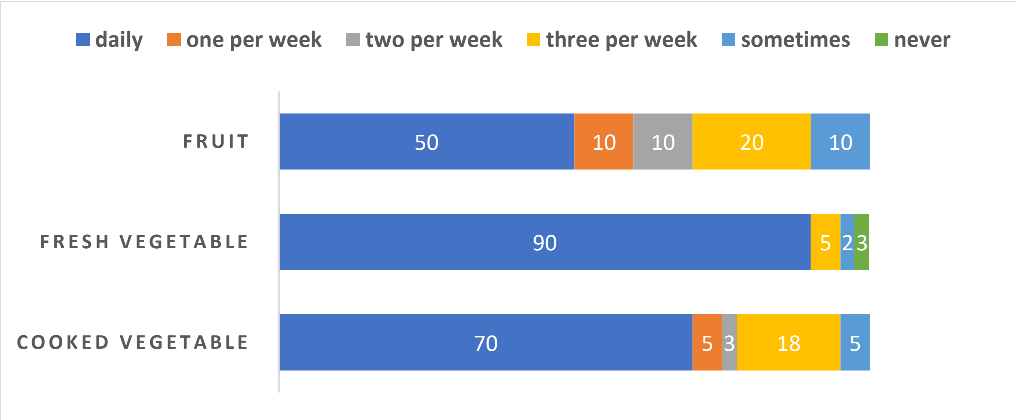

Figure10: Pattern of vegetable and fruit intake

Figure10 illustrates the Pattern of vegetable and fruit intake as follows, the majority (70%) of the patients eat cooked vegetables daily, whereas (18%) eat them three times a week, and almost all of the patients (90%) eat fresh vegetable daily, half of the patient eat fruit daily, while (20%) eat it three times a week.

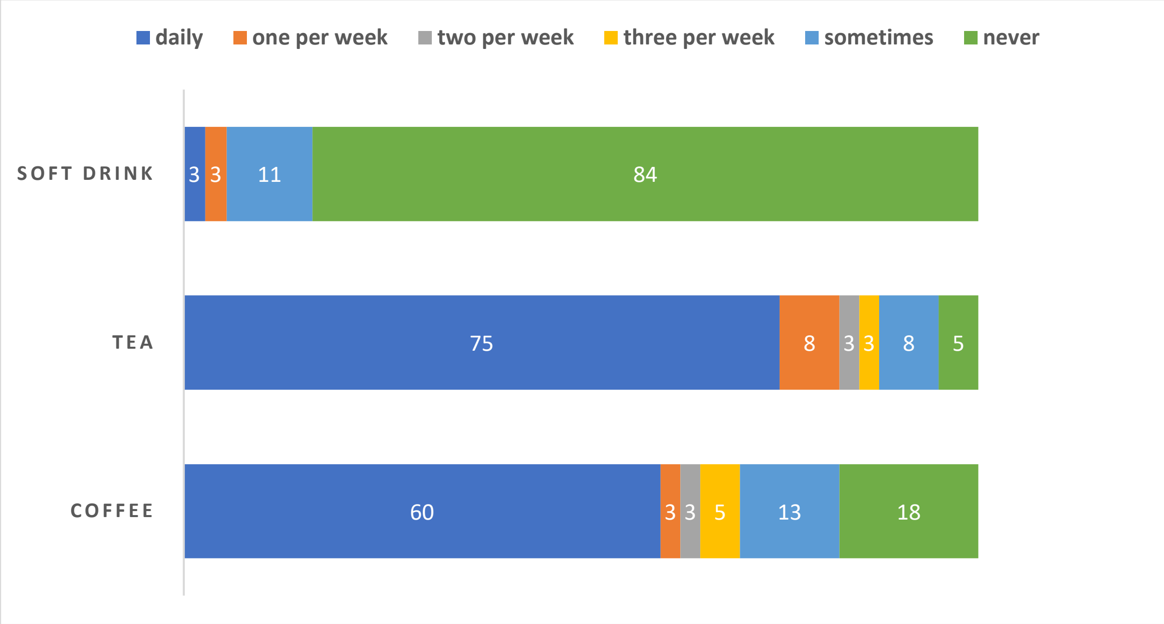

Figure11: Pattern of beverage intake

Figure 11 shows the beverage intake patterns of patients. 60% drink coffee daily, 18% never drink it, and 13% drink it occasionally. 75% drink tea daily, 8% drink it occasionally. 85% never drink soft drinks, while 11% drink them occasionally.

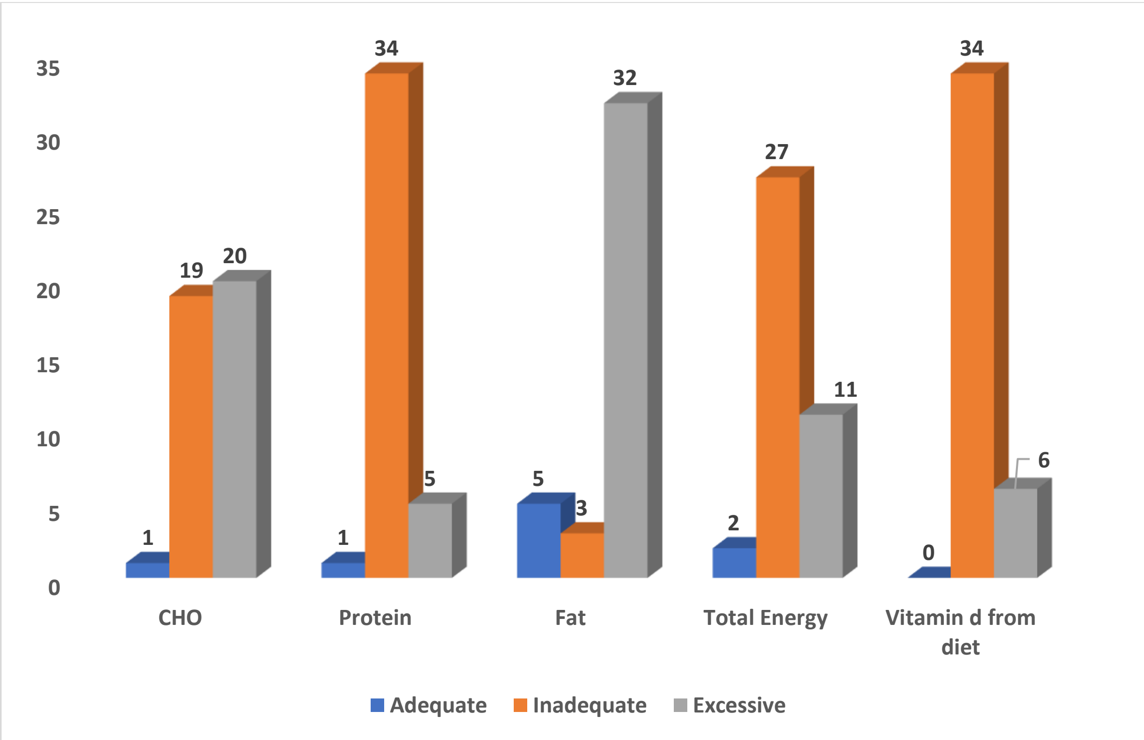

Figure 12: 24 Hours recall

Figure 12 illustrates the food intake pattern of patients over the past 24 hours. Carbohydrate intake was excessive in 50% of patients and inadequate in 47.5%. Protein intake was inadequate in 87.5% and excessive in 12.5%. Fat intake was excessive in 80% and adequate in 12.5%. Total energy intake was inadequate in 67.5% and excessive in 27.5%. Vitamin D intake was insufficient in 85% of patients and excessive in 15%.

The chart in Figure 12 shows the food intake of patients in the last 24 hours. Carbohydrate intake was excessive in 50% of patients and inadequate in 47.5%. Protein intake was inadequate in 87.5% and excessive in 12.5%. Fat intake was excessive in 80% and adequate in 12.5%. Total energy intake was inadequate in 67.5% and excessive in 27.5%. Vitamin D intake was insufficient in 85% of patients and excessive in 15%.

Correlation between Vitamin D and some variables under study:

Table 5: The relation between HbA1c and levels Alpha 25- hydroxy vitamin D

			P .value	
alpha25-hydroxy vitamin D	Between Groups	(Combined)	**0.005**	
		Linear Term	Unweighted	0.024
			Weighted	0.022
			Deviation	0.392
	Within Groups		0.023	
	Total			

There is a correlation between HbA1c and levels of alpha 25-hydroxy vitamin D.

Table 6: The relation between skin color and the levels of Alpha 25-hydroxy vitamin D

Crosstab			
			Total
What is the skin color of his/her?	Light	Count	3
		% within alpha25 hydroxy vitamin D	7.5%
	Faint	Count	11
		% within alpha25 hydroxy vitamin D	27.5%
	Dark	Count	26
		% within alpha25 hydroxy vitamin D	65.0%
Total		Count	40
		% within alpha25 hydroxy vitamin D	100.0%

Chi-Square Tests					
	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	2.393[a]	2	0.302	0.374	
Likelihood Ratio	3.682	2	0.159	0.242	
Fisher's Exact Test	1.695			0.491	
Linear-by-Linear Association	1.985[b]	1	**0.015**	0.242	0.164
N of Valid Cases	40				

There is a correlation between skin color and levels of alpha 25- hydroxy vitamin D.

Discussion:

This study aimed to investigate the association between vitamin D deficiency and type 2 diabetes mellitus at the Abdullah Khalil Diabetic Center in Omdurman Teaching Hospital. Data was collected from 40 patients, with 70% being female and 30% male. The majority of patients (57.5%) were aged between 30- 49 years, 22.5% were above 60 years old, and 20% were between 50-60 years old. A previous Sudanese study on the prevalence, risk factors, and glycemic control of type 2 diabetes mellitus in eastern Sudan reported a mean age of 44.9 years, with 70.3% of participants being women **(Omar *et al.,* 2019)**.

The majority of patients (37.5%) had an income of less than 20,000 SDG, while 20% had an income between 41,000 - 60,000 SDG, which is considered low income according to the World Bank's classification. This indicates that most patients have a low socioeconomic status, which can impact their health. Research has shown that individuals with low socioeconomic status and living in deprived areas are more likely to experience complications and poorer health outcomes **(Grintsova *et al*., 2014)**.

30% of the patients were illiterate, 32.5% had a high school education, 25% had completed primary school, and only 12.5% were university graduates. A study found that better control of chronic diseases was seen in patients with higher education levels, highlighting the need for targeted risk communication and control strategies for patients with lower educational status **(Bruthans *et al.,* 2016).**

In our study, 77% of patients reported using a barrier between their skin and sunlight during exposure, which increases the risk of vitamin D deficiency. This practice involves covering the whole body except for the face and hands. A study in Istanbul found that the prevalence of vitamin D deficiency was 55.0% for covered individuals and 20.0% for uncovered individuals. The study reported a statistically significant association between vitamin D levels and clothing style **(Buyukuslu *et al.,* 2014)**.

Skin color affects vitamin D synthesis, leading to vitamin D deficiency. In a study, 65% of patients with dark skin color had higher vitamin D deficiency compared to those with medium or light skin color (*p-value* = 0.015), indicating a significant relationship between skin color and alpha 25-hydroxy vitamin D levels. This finding supports previous research suggesting that skin pigmentation can negatively influence vitamin D synthesis **(Libon *et al.,* 2013)**.

The study aimed to investigate the relationship between vitamin D deficiency and HbA1c levels. Results showed that a majority of patients exhibited symptoms of vitamin D deficiency, such as mood swings (60%), fatigue (50%), and joint/bone pain (51%). Laboratory tests confirmed that 90% of patients were vitamin D deficient, and 97.5% had high HbA1c levels. The p-value of 0.005 indicated a strong correlation between vitamin D deficiency and HbA1c levels. This finding aligns with previous research that reported significantly higher HbA1c levels in individuals with vitamin D deficiency compared to those with adequate vitamin D levels **(Zhao *et al*., 2020)**.

Most patients (97%) had a higher weight before being diagnosed with diabetes, which aligns with a study showing a progressive increase in weight before diabetes development and a tendency towards weight loss after diagnosis and treatment **(Looker *et al*., 2001)**.

Most patients (52.5%) use oral hypoglycemic drugs, with 42.5% being overweight and 40% using insulin. Weight stability was observed in individuals taking insulin compared to those not on hypoglycemic medication **(Looker *et al*., 2001)**.

In this study, 50% of patients had a sedentary lifestyle, 30% had a moderate activity level, and 20% were active. This lifestyle choice influenced their BMI and vitamin D levels. A study in Saudi Arabia found that physically active individuals had higher awareness of vitamin D and its health benefits compared to those who were less active. The preferred source of vitamin D among physically active individuals was sunlight **(Al-Daghri *et al.*, 2023)**.

The study did not investigate the direct relationship between BMI and type 2 diabetes mellitus in relation to vitamin D deficiency. However, an interesting correlation was found between vitamin D deficiency and HbA1c levels. Previous research has highlighted this correlation **(Zhao. *et al*., 2020)**. While there is no direct link between vitamin D deficiency and BMI, there is a known association between BMI and type 2 diabetes. Being overweight (BMI 25-29.9) and obese (BMI ≥30) are significant health concerns. In this study, 42.5% were overweight, 22.5% were obese I, and 5% were obese II. These conditions are risk factors for various health issues, with type 2 diabetes mellitus being a major concern. Genetic and environmental factors may also contribute to these conditions (**Lagunova *et al*., 2009)**.

High BMI values are associated with an increased risk of developing type 2 diabetes and high HbA1c levels in individuals with type 2 diabetes are significantly correlated with low vitamin D levels **(Zhao *et al*., 2020)**.

The study revealed that 85% of individuals do not consume enough vitamin D, with less than 400 IU in their diet. The Average Requirement (EAR) is 400 IU/day for most people aged one year and older, while the Recommended Dietary Allowance (RDA) is 600 IU/day for individuals over one year, except for those over 70 years old, who should aim for 800 IU/day **(Glendenning. *et al*., 2003)**. Some participants in the study were previously diagnosed with vitamin D deficiency and used supplementation along with dietary changes, resulting in normal HbA1c levels and adequate 25-hydroxy vitamin D. Vitamin D supplementation was shown to enhance islet β cell function and glucose tolerance **(Kadowaki and Norman, 1984)**.

Vitamin D deficiency is linked to various diseases. In this study, 30% of participants had hypercholesterolemia, 25% had hypertension, 15% had heart disease, 15% had kidney problems, 7% had thyroid disease, and 5% had liver disease. These findings align with epidemiological studies that have shown a strong association between 25OHD deficiency and chronic conditions like bone disorders, tumors, cardiovascular diseases, hypertension, diabetes, neuropsychiatric disorders, and autoimmune diseases **(Wang *et al*., 2017)**.

The experiment revealed a correlation between food patterns and BMI. As a dietitian, I can predict a participant's BMI based on their responses to the food frequency questionnaire and 24-hour recall. The study found that a majority of participants had imbalanced diets, with excessive carbohydrate intake in 50% of cases, inadequate protein intake in 87.5% of cases, and excessive fat consumption in 80% of cases, leading to high BMI and health issues. This aligns with previous research indicating that obesity is a growing concern in developed countries and is linked to various health problems. Additionally, there is a connection between overweight/obesity and low vitamin D levels **(Lagunova. *et al*, 2009)**.

Being overweight (BMI 25-29.9) and obese (BMI ≥30) are serious health issues. A majority of patients (85%) had insufficient intake of vitamin D-rich foods such as tuna, fish, eggs, and milk, despite 69% drinking milk daily, 35% consuming eggs three times a week, and 35% eating fish once a week. This indicates a deficiency in quantity rather than quality of food intake, as it does not meet the nutrient requirements.

Conclusion

The results indicate a significant association between Vitamin D deficiency and higher HbA1c levels in patients with Type 2 Diabetes Mellitus (T2DM). Most patients show both low Vitamin D levels and high HbA1c, suggesting that insufficient Vitamin D may contribute to lesser glycemic control. Contributing factors include physical inactivity, inadequate dietary intake of Vitamin D-rich foods, and limited sunlight exposure.

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