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RESEARCH ARTICLE

ASSOCIATION BETWEEN VITAMIN D LEVELS AND GLYCEMIC CONTROL AMONG ADULT DIABETIC PATIENTS IN AHSA, SAUDI ARABIA

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Abstract

Background: Vitamin D deficiency is highly prevalent in the Middle East region including Saudi Arabia. Emerging evidence links vitamin D status to glycemic control in diabetes. However, findings on the effects of vitamin D correction on HbA1c levels have been inconsistent.

Objective: To assess the association between vitamin D correction and changes in HbA1c levels among adult diabetic patients in Ahsa, Saudi Arabia.

Methods: The present study used quasi-experimental design, and evaluated 344 patients with vit D deficiency. Patients received vitamin D supplementation, dietary counseling, or sun exposure advice for 6 months. HbA1c was measured at baseline and end-line. Change in HbA1c was compared between intervention groups using statistical analyses.

Results: Improvements in vitamin D levels significantly reduced HbA1c, indicating vitamin D's role in insulin regulation($r = -0.452$, $p < 0.001$). However, direct vitamin D correction showed no statistically significant HbA1c changes (t: 0.898, p 0.37, CI (-0.071 -0.19)), suggesting individualized approaches may be needed. Multiple regression identified significant effects of sickle cell disease(t: 2.615, p =0.005) on glycemic control independent of vitamin D.

Conclusions: While vitamin D may modulate insulin and glycemic control, diabetes management requires comprehensive strategies accounting for individual health profiles. Future research should explore personalized vitamin D interventions in diverse patient subgroups.

Introduction:-

Diabetes mellitus stands as a formidable challenge to global health, with its incidence not merely being a statistic but a harbinger of burgeoning healthcare dilemmas and economic burdens across the world[1]. This metabolic disorder, marked by persistently high levels of blood glucose, arises from either the body's inability to produce enough insulin or its failure to use insulin effectively[2]. The repercussions of diabetes are far-reaching, affecting various organs and leading to serious complications such as cardiovascular diseases, which are the leading cause of death among diabetic patients, kidney failure that necessitates dialysis or transplantation, blindness due to diabetic retinopathy, and lower limb amputations attributable to peripheral neuropathy and vascular disease[3]. The International Diabetes Federation's (IDF) projections serve as a clarion call to the imminent need for robust interventions and

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policies aimed at curtailing this epidemic, enhancing early detection, and optimizing management strategies to avert these life-altering complications[4].

Within the Middle East and North Africa (MENA) region, the diabetes prevalence notably eclipses the global average, underscoring a crisis that is both immediate and escalating. Saudi Arabia, a key nation within this region, exemplifies this public health quandary with one of the highest national rates of diabetes[5,6]. This escalating prevalence is not merely a reflection of global trends but also of region-specific lifestyle changes, including dietary habits and physical inactivity, compounded by genetic predispositions[7]. The impact of diabetes in Saudi Arabia extends beyond the health of individuals to strain the national healthcare system and economy, with significant resources allocated to manage the condition and its complications[8]. This scenario necessitates a concerted effort from policymakers, healthcare professionals, and the community to implement comprehensive diabetes management and prevention strategies, tailored to the cultural and societal context of the MENA region and Saudi Arabia in particular[9]. Addressing these challenges is crucial for improving the quality of life of those affected and for the sustainable development of the region's healthcare infrastructure and economy.
The pivotal role of glycemic control in the management of diabetes cannot be overstated[10].

By maintaining blood glucose levels within recommended ranges, individuals with diabetes can significantly reduce their risk of developing debilitating complications that are often associated with the disease[11]. These complications are broadly categorized into microvascular (such as retinopathy, nephropathy, and neuropathy) and macrovascular (including heart disease, stroke, and peripheral vascular disease) complications[12]. Poor glycemic control exacerbates the risk of these complications, leading to a decline in quality of life, increased healthcare costs, and elevated morbidity and mortality rates[13]. The American Diabetes Association (ADA) underscores the importance of individualized glycemic targets to accommodate the diverse needs and conditions of diabetic patients. Generally, it advocates for an A1C level below 7% for most non-pregnant adults, which has been shown to significantly lower the risk of complications[14]. This recommendation, however, is adjusted based on various factors including age, duration of diabetes, presence of cardiovascular diseases, and the risk of hypoglycemia, ensuring a balanced approach to diabetes management that minimizes risks while optimizing health outcomes[15].

Furthermore, achieving and maintaining glycemic control is a dynamic and complex process that requires a comprehensive management strategy encompassing lifestyle modifications, dietary adjustments, physical activity, and, when necessary, pharmacological intervention[16]. It involves regular monitoring of blood glucose levels to guide the adjustment of treatment modalities in response to fluctuations in glucose levels. Education on self-management practices is also crucial, empowering patients to take an active role in managing their condition[17]. Healthcare professionals play a pivotal role in guiding patients through this process, providing personalized advice and support to navigate the challenges of diabetes management[18]. The emphasis on glycemic control is grounded in evidence-based medicine, highlighting its critical contribution to preventing the progression of diabetes-related complications and improving the overall prognosis of individuals with diabetes[19]. This underscores the significance of ongoing research and innovation in diabetes care, aiming to refine glycemic control strategies and enhance the quality of life for patients living with this chronic condition[20].

Vitamin D stands out in the pantheon of fat-soluble vitamins for its profound effects on various aspects of human health, far beyond its cardinal role in bone health maintenance[20]. It is instrumental in modulating the growth and differentiation of cells, playing a pivotal role in neuromuscular functions, bolstering the immune system, and exerting anti-inflammatory properties[21]. The vitamin's influence on calcium homeostasis and bone metabolism is well-documented, with Vitamin D facilitating the intestinal absorption of calcium and phosphorus, thereby preventing rickets in children and osteomalacia in adults[22]. Recent scientific inquiries have expanded the scope of Vitamin D's benefits, unveiling its involvement in cardiovascular health, cancer prevention, and the modulation of mood disorders. This broad spectrum of actions underscores Vitamin D's vital importance across various physiological processes, highlighting the potential consequences of its deficiency[23].

Emerging evidence has cast a spotlight on Vitamin D's significant yet nuanced role in modulating insulin secretion and sensitivity, bridging the gap between traditional bone health and metabolic disorders such as diabetes[24]. This connection is critical in understanding how Vitamin D influences glycemic control, the cornerstone of diabetes management. Studies suggest that Vitamin D enhances the pancreatic β-cell's function, thus improving insulin secretion[25]. Conversely, Vitamin D deficiency is posited to contribute to an increased risk of insulin resistance, a precursor for type 2 diabetes. This relationship suggests that sufficient levels of Vitamin D could potentially mitigate

the risk of developing diabetes or could be leveraged to improve glycemic control in individuals already managing the disease[26]. Notably, observational studies have linked low Vitamin D levels with poor glycemic control and increased incidence of type 2 diabetes, underscoring the need for further research to elucidate the mechanisms at play and explore Vitamin D's potential as a modifiable risk factor or adjunct therapy in diabetes care[27]. This dual role of Vitamin D, both as a preventive measure against the onset of diabetes and as a possible therapeutic agent in improving outcomes for those with the disease, presents a compelling case for its inclusion in broader diabetes management and prevention strategies[28].However only studies done in Saudi Arabia assessing this association and none of them done in Al Ahsa, knowing the impact of vitamin D correction in this particular population with a low prevalence vitamin d levels is important to understand how much vitamin d correction could affect the management of diabetic patients [49].

Aim of this study is to assess the association between Vitamin D changes in HbA1c levels, alongside overall glycemic control, among adult diabetic patients in Ahsa, Saudi Arabia. Specifically, the study seeks to evaluate how correction of Vitamin D deficiency impacts HbA1c levels and if this correlates with improved glycemic control in this population.

Method:-

Study Design

This research was structured as a retrospective chart review cohort study, specifically employing pre-test and post-test design to assess the effects of Vitamin D improvements on glycemic control, as indicated by HbA1c levels, in diabetic patients attending primary healthcare centers in Al-Ahsa, Saudi Arabia.

Setting and Participantsrecruitments:

Electronic patient files were reviewed on the unified electronic patient follow-up system for all governmental primary health centers in Al-Ahsa

Participants were recruited through a systematic screening process of medical records os patients visiting the primary healthcare centers. The screening process aimed to identify diabetic patients who have complete data and met inclusion criteria.We have a list of 50,000 diabetic patient in Al Ahsa, we reviewed every 19th patient to identify potential participants who met the study's inclusion criteria using a consecutive systematic sampling technique. Hence, 11,000 medical records were reviewed.

Definitions:

We followed the Endocrine Society set the 25(OH)D concentration to define deficiency, insufficiency, sufficiency and possible harm at <20 ng/ml (50 nmol/l), 21–29 ng/ml (52·5–72·5), 30–100 ng/ml (75–250 nmol/l) and >100 ng/ml (>250 nmol/l), respectively [50].So we took less than 30 ng/ml as abnormal and more than 30 ng/ml as normal vitamin d levels.

Definition of normal and abnormal hemoglobin A 1 C is as follows: we define non-diabetic range, the value must be below 6.4 %, while diabetes can be diagnosed with a HbA1c of 6.5% or higher [51].

Inclusion and Exclusion Criteria

Inclusion criteria were:

1. Adults aged 18 years and older with a clinical diagnosis of diabetes mellitus (Type 2).
2. Documented Vitamin D levels were taken more than once within the past 6 months at least 3 months apart and was taken simultaneously with HgA1c levels.
3. Regular attendance at the healthcare center for diabetes management (defined as at least two visits for the last one year).

Exclusion criteria included:

1. Patients with conditions known to affect Vitamin D metabolism or absorption, such as chronic kidney disease, liver cirrhosis, and granulomatous disorders.
2. Pregnant or breastfeeding women, considering the specific nutritional and metabolic considerations in these groups.

Sample Size and Selection

From the initial screening, 344 eligible patients were identified. This sample size was more than the determined based on a power calculation to detect a clinically significant difference in HbA1c levels before and after the Vitamin D correction intervention, with a power of 80% and an alpha level of 0.05. Patients who corrected vitamin D levels (exposed group: P1) = 0.68.Patients who didn't correct vitamin D levels (unexposed group; P2) = 0.52.

These parameters are used to determine the required sample size per group by subjecting them to the following formula:

$$N = \frac{(Z_{\alpha/2} + Z_{\beta})^2 \times \left(P_1 \times (1 - P_1) + P_2 \times (1 - P_2)\right)}{(P_1 - P_2)^2}$$

When substituting z values in the equationthe sample size needed for each group is N ≈ 143 patients. The total number of patients recruited into the study is 2N = 2*143 = 286 patients.

Groups:

The patients were divided into two groups: a group whose vitamin D levels were improved by taking supplements, nutrition, or exposure to the sun, and a group that was unable to improve their vitamin D levels.

Statistical analysis:

This study analyzed data from participants using SPSS software (version 21). we described the characteristics of the groups (cases and controls) by reporting frequencies for categorical data (like gender) and means with standard deviations for continuous data (like age). To compare these groups, we used chi-squared tests for categorical variables and looked for correlations between changes in vitamin D and hemoglobin A1c using Spearman's rank correlation. Finally, we assessed the association between correcting vitamin D levels and hemoglobin A1c with a paired t-test, and employed regression analysis to identify any confounding factors.

Ethical Considerations

The study was conducted in accordance with the Declaration of Helsinki and received approval from the Institutional Review Board (IRB) of the king Fahad Hospital Al Ahsa. All patient information was anonymized, and confidentiality was maintained throughout the study.

Result:-

Table 1 presents the demographic and clinical characteristics of the study population, totaling 344 participants. The majority of participants fell within the age group of 40-59 years (53.5%), with a mean age of 55.52 ± 12.13 years, indicating a predominantly middle-aged cohort. A significant proportion of the participants were female (65.7%), reflecting the gender distribution of the study population.

Comorbidities were common among the participants, with hypertension (HPN) being the most prevalent (62.5%), followed by dyslipidemia (65.7%) and obesity (56.3%). These conditions highlight the common comorbidities associated with diabetes and underscore the complex health profiles of the participants. Other notable comorbidities included hypothyroidism (8.7%), ischemic heart disease (IHD) (15.7%), heart failure (HF) (8.4%), and sickle cell disease (9.0%), with a smaller percentage having chronic kidney failure (CKF) (1.5%). A large majority of the participants (76.2%) were being treated with insulin, indicative of the severity of diabetes management in the cohort. This high rate of insulin usage underscores the advanced nature of diabetes care required for many individuals in this study population.

Table 1:- Demographic data.

Demographic data		N = 344	%
Age groups	20-39	35	10.2
	40-59	184	53.5
	60-79	116	33.7
	80-100	9	2.6

Gender	Male	118	34.3
	Female	226	65.7
Comorbidities	HPN	215	62.5
	HYPOTHYROIDISM	30	8.7
	CKF	5	1.5
	IHD	54	15.7
	HF	29	8.4
	Sickle cell disease	31	9.0 %
	Obesity	192	56.3 %
	Dyslipidemia	226	65.7 %
	Treatment (using of Insulin)	262	76.2 %
Age (mean ±SD)		55.52±12.13	

Table 2 presents the paired-samples T-test results comparing HbA1c levels before and after the Vitamin D correction intervention among the study participants. The mean HbA1c level decreased marginally from 7.17% before the intervention to 7.11% after the intervention, with standard deviations of 1.81 and 1.63, respectively. This slight reduction, however, did not reach statistical significance, as indicated by a p-value of 0.37. The effect size of this change, measured by Cohen's d, was 0.0486, suggesting a small impact of Vitamin D correction on HbA1c levels within the studied population. The 95% confidence interval for the mean difference in HbA1c levels ranged from -0.071 to 0.19, further indicating the change was not statistically significant.

Table 2:- Paired-samples T test results.

		Mean	**SD**	**t**	**P value**	**95% Confidence Interval**		
						Lower	**Upper**	**Effect Size**
HbA1c	Before	7.17	1.81	0.898	0.37	-0.071	0.19	0.0486
	After	7.11	1.63					
	After	28.89	14.11					

Table 3 presents the relationship between changes in Vitamin D levels and differences in HbA1c among groups with varying Vitamin D status adjustments. A significant difference in HbA1c reduction was observed in participants whose Vitamin D levels remained uncorrected but improved naturally (p=0.019), indicating a potential association between spontaneous Vitamin D improvement and glycemic control. However, for participants who underwent Vitamin D correction or had initially high or decreased Vitamin D levels, no significant changes in HbA1c were noted (p=0.614, p=0.847, and p=0.551, respectively).

Table 3:- Relationship between Vitamin D difference and HbA1c Difference for groups of vitamin D improvement.

	HbA1c		**p**
	Improved	**Not improved**	
Vitamin D not corrected	**63**	**92**	**0.019**
Vitamin D corrected	**39**	**31**	**0.614**
Vitamin D vitamin D was high from the beginning	**29**	**30**	**0.847**
Vitamin D dropped	**23**	**19**	**0.551**

Relationship between Vit diff and HbA1c diff

The table illustrates a significant negative correlation (r = -0.452, p < 0.001) between changes in vitamin D levels (Vit D diff) and alterations in glycated hemoglobin levels (HbA1c diff). This indicates that as the difference in vitamin D levels increases or decreases, there is a tendency for the difference in HbA1c levels to decrease or increase, respectively.

Table 4:- Relationship between Vit diff and HbA1c diff.

		Vit D dif
HbA1c diff	**r**	-0.452
	p-value	<0.001

Simple Linear Regression

The presented findings in table 5 reveal a significant relationship between Vitamin D levels and glycemic control, as assessed through HbA1c levels. The results of a simple linear regression analysis demonstrate a moderate positive correlation (R = 0.452) between HbA1c difference and Vitamin D difference, explaining approximately 20.4% of the variance in HbA1c difference. The regression model is statistically significant (F = 15.632, p < 0.001), indicating that the observed association is unlikely to be due to chance. Specifically, for every unit increase in Vitamin D difference, there is an estimated decrease of 0.437 units in HbA1c difference (B = -0.437, p < 0.001). These findings suggest that variations in Vitamin D levels may influence changes in glycemic control.

Table 5:- Simple linear regression results.

Model	**R**	**R^2**	**F**	**Constant**	**B**	**t**	**p**
1	0.452	0.204	15.632	-0.322	-0.437	-9.336	<0.001

Dependent variable: HbA1c diff , Predictor: Vitamin D diff

The regression equation can be written as:

Predicted (HbA1c Diff) = -0.322 – 0.437 (Vitamin D difference)

Table 6 represents the results of multiple linear regression, the overall model fit measures and specific coefficients for each predictor variable are reported. The analysis reveals that the model explains a statistically significant portion of the variance in the dependent variable, HbA1c difference, as indicated by the overall model test (F(10, 312) = 2.001, p = 0.033). Notably, the regression coefficients for certain predictors demonstrate statistical significance in predicting HbA1c difference, including Sickle cell disease (B = 0.66117, SE = 0.25285, t = 2.615, p = 0.005) and the use of insulin treatment (B = -0.312, SE = 0.17689, t = -1.798, p = 0.073). Additionally, a significant negative association is observed between HbA1c difference and the difference in Vitamin D levels (B = -0.012, SE = 0.00443, t = -2.64, p = 0.009). However, several predictors such as Hypertension (HPN) and Chronic Kidney Disease (CKF) do not demonstrate statistically significant associations with HbA1c difference.

Table 6:- Multiple linear regression results.

Model Fit Measures													
				Overall Model Test									
Model		**R**		**R^2**		**F**		**df1**		**df2**		**p**	
1		0.246		0.060		2.001		10		312		0.033	
Dependent variable: HbA1c difference													

Predictors	**B**	**SE**	**t**	**p**	**95% Confidence Interval**	
					Lower	**Upper**
Intercept	-0.15234	0.18672	-0.816	0.415	-0.5196	0.21497
HPN	0.02123	0.16435	0.129	0.897	-0.3021	0.34454
CKF	-0.49748	0.60179	-0.827	0.409	-1.6813	0.68635
IHD	0.22943	0.24966	0.919	0.359	-0.2617	0.72056
HF	0.09326	0.31423	0.297	0.767	-0.5249	0.71142
Sickle	0.66117	0.25285	2.615	0.005	0.1638	1.15857
Obesity	0.20701	0.14837	1.395	0.164	-0.0849	0.49888

Dislipidemia	0.20842	0.16531	1.261	0.208	-0.1168	0.53361
Treatment (using of Insulin)	-0.31804	0.17689	-1.798	0.073	-0.666	0.02994
Diff Vit D	-0.01189	0.00443	-2.231	0.009	-0.0186	-0.00117
HYPOTHYROIDISM	0.02715	0.25556	0.106	0.915	-0.4756	0.52988

Discussion:-

The observed significant reduction in HbA1c levels among participants experiencing natural improvements in vitamin D status in our study underscores the potential role of this nutrient in enhancing glycemic control. This finding is particularly intriguing, suggesting that even without direct intervention, slight increases in vitamin D levels can positively affect blood glucose regulation. This phenomenon may be attributed to vitamin D's known roles in enhancing insulin sensitivity and promoting the efficient function of pancreatic β-cells. The vitamin facilitates calcium influx into pancreatic cells, a crucial process for insulin secretion, and may also influence insulin receptor expression and activity, thus improving glucose metabolism in peripheral tissues[29,30].

Our findings resonate with a body of research that links higher vitamin D levels to improved insulin function and glycemic control. For instance, studies have documented similar associations, suggesting that adequate vitamin D status may be beneficial in managing diabetes more effectively[31,32]. These studies, among others, provide a basis for understanding the positive impact of vitamin D on metabolic health, aligning with the hypothesis that vitamin D supplementation could serve as an adjunct therapy in diabetes management[33]. However, the literature also contains reports of studies where vitamin D supplementation did not significantly impact glycemic control, highlighting the complexity of its role in diabetes management and the possible influence of baseline vitamin D levels, the dose and duration of supplementation, and individual metabolic variations[34,35].

The discrepancies between studies on the impact of vitamin D on glycemic control highlight the need for a nuanced understanding of the relationship between vitamin D status and diabetes management[36]. Factors such as the heterogeneity of study populations, differences in vitamin D dosage, and variability in baseline vitamin D levels across studies could contribute to these inconsistencies[37]. Furthermore, the potential of vitamin D to improve glycemic control may be contingent upon reaching and maintaining optimal serum levels, suggesting that supplementation strategies might need to be personalized to achieve significant clinical benefits[38]. This underlines the importance of further research to elucidate the mechanisms through which vitamin D influences glucose metabolism and to determine the optimal strategies for its use in diabetes care[39].

In examining the outcomes of vitamin D correction strategies within our study, it was noted that there was no statistically significant improvement in HbA1c levels following intervention[40]. This observation challenges the expectation that direct vitamin D supplementation or enhancement through dietary adjustments and increased sun exposure would uniformly facilitate better glycemic control in diabetic patients[41]. The potential factors influencing these outcomes are multifaceted. Baseline vitamin D status, the severity of diabetes at the onset of the study, and the duration of the intervention are critical variables that could significantly impact the efficacy of vitamin D correction[42]. It is possible that patients with severe vitamin D deficiency or more advanced stages of diabetes may require longer or more intensive intervention to see measurable improvements in HbA1c levels. Furthermore, the optimal dose and method of vitamin D supplementation need further investigation to identify the most effective strategies for different patient subgroups[43].

The lack of significant improvement underscores the complexity of managing diabetes, a condition influenced by an interplay of numerous factors beyond simple nutrient supplementation[44]. This complexity necessitates a more tailored approach to treatment, highlighting the importance of personalized medicine in clinical practice. Personalized medicine in the context of vitamin D correction involves considering individual differences in response to supplementation, the presence of comorbidities, lifestyle factors, and genetic predispositions[45]. Such an approach would enable healthcare providers to design more effective, patient-specific strategies for vitamin D correction that align with the patient's overall diabetes management plan. This could include more nuanced dosing strategies, combinations of supplementation with lifestyle interventions, and closer monitoring of vitamin D levels and glycemic control markers over time[46].

The complex nature of diabetes management is underscored by the multifactorial influences on glycemic control, as revealed through multiple regression analyses in our study. These analyses highlight the significant roles that comorbidities and insulin treatment play in determining changes in HbA1c levels, independent of vitamin D status[47]. This finding points to the critical need for a holistic approach in managing diabetes, where the overall health profile and existing comorbid conditions of the patient are taken into account. Recognizing the intricate interplay between various factors, including vitamin D levels, comorbidities, and treatment regimes, can lead to more effective, personalized diabetes management strategies that go beyond mere glycemic control to address the patient's comprehensive health needs[48].

Conclusion:-

In conclusion, our study sheds light on the complex interplay between vitamin D status and glycemic control among adult diabetic patients in Al-Ahsa, Saudi Arabia, underscoring the multifaceted nature of diabetes management. The significant findings of improved glycemic control associated with natural vitamin D level improvements, without direct interventions, highlight the potential role of vitamin D in modulating insulin secretion and sensitivity. However, the absence of significant changes in HbA1c levels following direct vitamin D correction interventions calls for a deeper understanding of the mechanisms at play and suggests the need for a more personalized approach to diabetes management.

The implications of our study extend beyond the clinical realm into public health policy and practice, particularly in regions like the Middle East and North Africa (MENA) where vitamin D deficiency is prevalent. Addressing this deficiency through public health initiatives and incorporating vitamin D screening and supplementation into routine diabetes care could potentially enhance glycemic control, reduce the burden of diabetes complications, and improve the quality of life for those affected. Our findings advocate for a holistic approach to diabetes management that considers the individual's overall health profile, including vitamin D status, to optimize treatment outcomes.

Future research should focus on randomized controlled trials with larger sample sizes and longer follow-up periods to explore the effectiveness of various vitamin D correction strategies in different subsets of the diabetic population. Understanding the indirect effects of vitamin D through its anti-inflammatory and antioxidant properties, as well as its interaction with other lifestyle factors, will be crucial in developing comprehensive diabetes management strategies. Ultimately, by integrating findings from such research into clinical practice, we can move closer to a more effective, personalized approach to diabetes care that addresses not just glycemic control but the overall well-being of individuals living with diabetes.

References:-

1. Naeem Z: Burden of Diabetes Mellitus in Saudi Arabia. Int J Health Sci (Qassim). 2015, 9:V–VI. 10.12816/0024690
2. Banday MZ, Sameer AS, Nissar S: Pathophysiology of diabetes: An overview. Avicenna J Med. 2020, 10:174–88. 10.4103/ajm.ajm_53_20
3. Deshpande AD, Harris-Hayes M, Schootman M: Epidemiology of Diabetes and Diabetes-Related Complications. Phys Ther. 2008, 88:1254–64. 10.2522/ptj.20080020
4. Whiting DR, Guariguata L, Weil C, Shaw J: IDF Diabetes Atlas: Global estimates of the prevalence of diabetes for 2011 and 2030. Diabetes Res Clin Pract. 2011, 94:311–21. 10.1016/j.diabres.2011.10.029
5. Sherif S: Economic development and diabetes prevalence in MENA countries: Egypt and Saudi Arabia comparison. World J Diabetes. 2015, 6:304. 10.4239/wjd.v6.i2.304
6. El-Kebbi IM, Bidikian NH, Hneiny L, Nasrallah MP: Epidemiology of type 2 diabetes in the Middle East and North Africa: Challenges and call for action. World J Diabetes. 2021, 12:1401–25. 10.4239/wjd.v12.i9.1401
7. Kerkadi A, Sadig AH, Bawadi H, et al.: The Relationship between Lifestyle Factors and Obesity Indices among Adolescents in Qatar. Int J Environ Res Public Health. 2019, 16:4428. 10.3390/ijerph16224428
8. Alshahrani JA, Alshahrani AS, Alshahrani AM, Alshalaan AM, Alhumam MN, Alshahrani NZ: The Impact of Diabetes Mellitus Duration and Complications on Health-Related Quality of Life Among Type 2 Diabetic Patients in Khamis Mushit City, Saudi Arabia. Cureus. Published Online First: 27 August 2023. 10.7759/cureus.44216
9. Al Slamah T, Nicholl BI, Alslail FY, Harris L, Melville CA, Kinnear D: Cultural adaptation of self-management of type 2 diabetes in Saudi Arabia (qualitative study). PLoS One. 2020, 15:e0232904. 10.1371/journal.pone.0232904

10. Sugandh F, Chandio M, Raveena F, et al.: Advances in the Management of Diabetes Mellitus: A Focus on Personalized Medicine. Cureus. Published Online First: 18 August 2023. 10.7759/cureus.43697
11. Asif M: The prevention and control the type-2 diabetes by changing lifestyle and dietary pattern. J Educ Health Promot. 2014, 3:1. 10.4103/2277-9531.127541
12. Cade WT: Diabetes-Related Microvascular and Macrovascular Diseases in the Physical Therapy Setting. Phys Ther. 2008, 88:1322–35. 10.2522/ptj.20080008
13. Bin Rakhis SA, AlDuwayhis NM, Aleid N, AlBarrak AN, Aloraini AA: Glycemic Control for Type 2 Diabetes Mellitus Patients: A Systematic Review. Cureus. Published Online First: 21 June 2022. 10.7759/cureus.26180
14. ElSayed NA, Aleppo G, Aroda VR, et al.: 6. Glycemic Targets: Standards of Care in Diabetes—2023. Diabetes Care. 2023, 46:S97–110. 10.2337/dc23-S006
15. Jyotsna F, Ahmed A, Kumar K, et al.: Exploring the Complex Connection Between Diabetes and Cardiovascular Disease: Analyzing Approaches to Mitigate Cardiovascular Risk in Patients With Diabetes. Cureus. Published Online First: 21 August 2023. 10.7759/cureus.43882
16. Shrivastava SR, Shrivastava PS, Ramasamy J: Role of self-care in management of diabetes mellitus. J Diabetes Metab Disord. 2013, 12:14. 10.1186/2251-6581-12-14
17. Ahmad F, Joshi SH: Self-Care Practices and Their Role in the Control of Diabetes: A Narrative Review. Cureus. Published Online First: 5 July 2023. 10.7759/cureus.41409
18. Sørensen M, Groven KS, Gjelsvik B, Almendingen K, Garnweidner-Holme L: The roles of healthcare professionals in diabetes care: a qualitative study in Norwegian general practice. Scand J Prim Health Care. 2020, 38:12–23. 10.1080/02813432.2020.1714145
19. Rodríguez-Gutiérrez R, Montori VM: Glycemic Control for Patients With Type 2 Diabetes Mellitus: Our Evolving Faith in the Face of Evidence. Circ Cardiovasc Qual Outcomes. 2016, 9:504–12. 10.1161/CIRCOUTCOMES.116.002901
20. Ernawati U, Wihastuti TA, Utami YW: Effectiveness of Diabetes Self-Management Education (Dsme) in Type 2 Diabetes Mellitus (T2Dm) Patients: Systematic Literature Review. J Public health Res. 2021, 10:jphr.2021.2240. 10.4081/jphr.2021.2240
21. Rogeri PS, Gasparini SO, Martins GL, et al.: Crosstalk Between Skeletal Muscle and Immune System: Which Roles Do IL-6 and Glutamine Play? Front Physiol. 2020, 11:. 10.3389/fphys.2020.582258
22. Khazai N, Judd SE, Tangpricha V: Calcium and vitamin D: Skeletal and extraskeletal health. Curr Rheumatol Rep. 2008, 10:110–7. 10.1007/s11926-008-0020-y
23. Manson JE, Cook NR, Lee I-M, et al.: Vitamin D Supplements and Prevention of Cancer and Cardiovascular Disease. N Engl J Med. 2019, 380:33–44. 10.1056/NEJMoa1809944
24. Alvarez JA, Ashraf A: Role of Vitamin D in Insulin Secretion and Insulin Sensitivity for Glucose Homeostasis. Int J Endocrinol. 2010, 2010:1–18. 10.1155/2010/351385
25. Wu J, Atkins A, Downes M, Wei Z: Vitamin D in Diabetes: Uncovering the Sunshine Hormone's Role in Glucose Metabolism and Beyond. Nutrients. 2023, 15:1997. 10.3390/nu15081997
26. Lips P, Eekhoff M, van Schoor N, Oosterwerff M, de Jongh R, Krul-Poel Y, Simsek S: Vitamin D and type 2 diabetes. J Steroid Biochem Mol Biol. 2017, 173:280–5. 10.1016/j.jsbmb.2016.11.021
27. Salih YA, Rasool MT, Ahmed IH, Mohammed AA: Impact of vitamin D level on glycemic control in diabetes mellitus type 2 in Duhok. Ann Med Surg. 2021, 64:. 10.1016/j.amsu.2021.102208
28. Nakashima A, Yokoyama K, Yokoo T, Urashima M: Role of vitamin D in diabetes mellitus and chronic kidney disease. World J Diabetes. 2016, 7:89. 10.4239/wjd.v7.i5.89
29. Yousefi Rad E, Djalali M, Koohdani F, et al.: The Effects of Vitamin D Supplementation on Glucose Control and Insulin Resistance in Patients with Diabetes Type 2: A Randomized Clinical Trial Study. Iran J Public Health. 2014, 43:1651–6. 26171357
30. Foroughi M, Maghsoudi Z, Askari G: The effect of vitamin D supplementation on blood sugar and different indices of insulin resistance in patients with non-alcoholic fatty liver disease (NAFLD). Iran J Nurs Midwifery Res. 2016, 21:100. 10.4103/1735-9066.174759
31. Raghuvanshi DS, Chakole S, Kumar M: Relationship Between Vitamins and Diabetes. Cureus. Published Online First: 28 March 2023. 10.7759/cureus.36815
32. Khan Z, Muhammad SA, Carpio J, Yousif Y, Gul A, Hamid S, Gupta A: The Effect of Vitamin D Supplementation on Incidence of Type 2 Diabetes: A Systematic Review. Cureus. Published Online First: 27 March 2023. 10.7759/cureus.36775

33. Argano C, Mirarchi L, Amodeo S, Orlando V, Torres A, Corrao S: The Role of Vitamin D and Its Molecular Bases in Insulin Resistance, Diabetes, Metabolic Syndrome, and Cardiovascular Disease: State of the Art. Int J Mol Sci. 2023, 24:15485. 10.3390/ijms242015485
34. Li X, Liu Y, Zheng Y, Wang P, Zhang Y: The Effect of Vitamin D Supplementation on Glycemic Control in Type 2 Diabetes Patients: A Systematic Review and Meta-Analysis. Nutrients. 2018, 10:375. 10.3390/nu10030375
35. Shaban MM, Sharaa HM, Amer FGM, Shaban M: Effect of digital based nursing intervention on knowledge of self-care behaviors and self-efficacy of adult clients with diabetes. BMC Nurs. 2024, 23:130. 10.1186/s12912-024-01787-2
36. Farahmand MA, Daneshzad E, Fung TT, Zahidi F, Muhammadi M, Bellissimo N, Azadbakht L: What is the impact of vitamin D supplementation on glycemic control in people with type-2 diabetes: a systematic review and meta-analysis of randomized controlled trails. BMC Endocr Disord. 2023, 23:15. 10.1186/s12902-022-01209-x
37. Cao M, He C, Gong M, Wu S, He J: The effects of vitamin D on all-cause mortality in different diseases: an evidence-map and umbrella review of 116 randomized controlled trials. Front Nutr. 2023, 10:. 10.3389/fnut.2023.1132528
38. Nigil Haroon N, Anton A, John J, Mittal M: Effect of vitamin D supplementation on glycemic control in patients with type 2 diabetes: a systematic review of interventional studies. J Diabetes Metab Disord. 2015, 14:3. 10.1186/s40200-015-0130-9
39. Dalgård C, Petersen MS, Weihe P, Grandjean P: Vitamin D Status in Relation to Glucose Metabolism and Type 2 Diabetes in Septuagenarians. Diabetes Care. 2011, 34:1284–8. 10.2337/dc10-2084
40. Madar AA, Knutsen K V, Stene LC, Brekke M, Meyer HE, Lagerløv P: Effect of vitamin D 3 supplementation on glycated hemoglobin (HbA1c), fructosamine, serum lipids, and body mass index: a randomized, double-blinded, placebo-controlled trial among healthy immigrants living in Norway. BMJ Open Diabetes Res Care. 2014, 2:e000026. 10.1136/bmjdrc-2014-000026
41. Aljabri KS, Bokhari SA, Khan MJ: Glycemic changes after vitamin D supplementation in patients with type 1 diabetes mellitus and vitamin D deficiency. Ann Saudi Med. 2010, 30:454–8. 10.4103/0256-4947.72265
42. Md Isa Z, Amsah N, Ahmad N: The Impact of Vitamin D Deficiency and Insufficiency on the Outcome of Type 2 Diabetes Mellitus Patients: A Systematic Review. Nutrients. 2023, 15:2310. 10.3390/nu15102310
43. Randhawa FA, Mustafa S, Khan DM, Hamid S: Effect of Vitamin D supplementation on reduction in levels of HbA1 in patients recently diagnosed with type 2 Diabetes Mellitus having asymptomatic Vitamin D deficiency. Pakistan J Med Sci. 2017, 33:. 10.12669/pjms.334.12288
44. Adu MD, Malabu UH, Malau-Aduli AEO, Malau-Aduli BS: Enablers and barriers to effective diabetes self-management: A multi-national investigation. PLoS One. 2019, 14:e0217771. 10.1371/journal.pone.0217771
45. Goetz LH, Schork NJ: Personalized medicine: motivation, challenges, and progress. Fertil Steril. 2018, 109:952–63. 10.1016/j.fertnstert.2018.05.006
46. Pludowski P: Supplementing Vitamin D in Different Patient Groups to Reduce Deficiency. Nutrients. 2023, 15:3725. 10.3390/nu15173725
47. Almetwazi M, Alwhaibi M, Balkhi B, et al.: Factors associated with glycemic control in type 2 diabetic patients in Saudi Arabia. Saudi Pharm J. 2019, 27:384–8. 10.1016/j.jsps.2018.12.007
48. Basiri R, Seidu B, Rudich M: Exploring the Interrelationships between Diabetes, Nutrition, Anxiety, and Depression: Implications for Treatment and Prevention Strategies. Nutrients. 2023, 15:4226. 10.3390/nu15194226
49. Al-Alyani, H., Al-Turki, H. A., Al-Essa, O. N., Alani, F. M., & Sadat-Ali, M. (2018). Vitamin D deficiency in Saudi Arabians: A reality or simply hype: A meta-analysis (2008-2015). Journal of family & community medicine, 25(1), 1–4. https://doi.org/10.4103/jfcm.JFCM_73_17
50. Holick MF, Binkley NC, Bischoff-Ferrari HA et al. (2011) Evaluation, treatment, and prevention of vitamin D deficiency: an Endocrine Society clinical practice guideline. J Clin Endocrinol Metab 96, 1911–1930.
51. Eyth E, Naik R. Hemoglobin A1C. [Updated 2023 Mar 13]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2024 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK549816/