Assessment of Vitamin D Deficiency Prevalence among Type 2 Diabetes Mellitus Patients in a South Indian Tertiary Care Hospital

Kalimuthu Senthilkumar[1], Sachu Philip[2], Natarajan Elango Nandhini[2], Lalamiya Abdul Rahiman Baba[3], Shanmugasundaram Ravichandran[2*]

[1]Central Research Laboratory, Swamy Vivekanandha Medical College Hospital and Research Institute, Elayampalayam, Namakkal, Tamil Nadu, India
[2]Department of Biochemistry, Swamy Vivekanandha Medical College Hospital and Research Institute, Elayampalayam, Namakkal, Tamil Nadu, India
[3]Department of Pathology, Swamy Vivekanandha Medical College Hospital and Research Institute, Elayampalayam, Namakkal, Tamil Nadu, India

Abstract

Vitamin D deficiency has become a global health issue and is associated with the multifactorial clinical manifestations of diabetes. The objective of this study is to analyze vitamin D deficiency in T2DM patients in association with biochemical parameters and thyroid-stimulating hormone (TSH). This study was a cross-sectional study in a tertiary care hospital conducted after the Institutional Ethical Committee (IEC) approval. The available descriptive data of patients, such as age, gender, biochemical parameters, TSH, and glycated hemoglobin (HbA1c), were collected. Vitamin D was measured using the enzyme-linked immunosorbent assay (ELISA) method. The descriptive parameters were statistically analyzed using chi-square analysis. The results comprise 322 T2DM patients, with 187 males and 135 females. Vitamin D status levels were observed to have severe deficiency < 10 ng.mL^{-1} (23.6%), deficiency >10-20 ng.mL^{-1} (42.2%), insufficient >20-29 ng.mL^{-1} (22.7%), and sufficient > 30 ng.mL^{-1} (11.5%). The male and female patients with vitamin D status were significantly ($p<0.001$) different between groups. No significant ($p = 0.122$) association was observed between HbA1c and vitamin D. The high status of vitamin D deficiency with high glycemic levels is associated with poor diabetic control. Therefore, patients require awareness about their vitamin D status; with a proper diet, adequate exposure to sunlight, and exercise can help them improve their health.

Keywords: Cholesterol, HbA1c, TSH, Type 2 diabetes mellitus, Vitamin D.

INTRODUCTION

Diabetes mellitus (DM) is a common disease, and its prevalence is continuously increasing worldwide. It is expected that, by 2030, the global diabetes population will be 562 million [1]. The global diabetes statistics report shows that 463 million people have diabetes, and 374 million have a prediabetic condition called Impaired Glucose Tolerance (IGT). These estimated numbers will increase by up to 51% to 700 million patients with diabetes and 548 million patients with IGT by 2045 [2]. Vitamin D deficiency is a documented health issue worldwide [3], mainly associated with rickets and fractures. In addition, low vitamin D (hypovitamin) levels have been measured as a factor responsible for the onset and development of DM. Studies have shown that elevated vitamin D levels are widespread in patients with DM [4]. Vitamin D plays several roles in central homeostatic regulations, including cellular growth, bone metabolism, immunity, neuromuscular function, and inflammation. Low levels of vitamin D in the serum make an individual prone to multiple health complications, including multiple sclerosis, respiratory, infectious, autoimmune disorders, cardiometabolic diseases, and cancer, among others [5]. A diverse longitudinal cohort study identified a connection between vitamin D and the risk of developing Type 2 Diabetes Mellitus (T2DM) [6]. In a women's health study, vitamin D intake was associated with a decreased risk of developing T2DM with a lower intake [7] of vitamin D.

Vitamin D insufficiency affects almost 1 billion people worldwide [5]. The prevalence of vitamin D deficiency is higher in healthcare systems worldwide and is increasingly associated with multifactorial clinical manifestations. However, observational longitudinal studies, as well as the systematic review and meta-analysis, indicated that vitamin D deficiency may increase the risk of complications in DM [8-10].

Therefore, the increased prevalence of vitamin D causes huge problems for healthcare systems worldwide. A randomized controlled trial

*Correspondence address:
Dr.S. Ravichandran
Email : dr.s.ravichand@gmail.com
Address : Professor and Head, Department of Biochemistry, Swamy Vivekanandha Medical College Hospital and Research Institute, Elayampalayam, Tiruchengode, Namakkal – 637 205. Tamil Nadu, India.

suggested that for prediabetes and vitamin D deficiency, high-dose vitamin D supplementation improves insulin sensitivity and reduces the risk of diabetes [11]. Thus, differences in the results and inherent restrictions of the studies have sparked debate regarding the relationship between vitamin D deficiency and T2DM. Cellular and molecular experimental studies have elucidated the potential etiological actions underlying the association between vitamin D deficiency and T2DM [12]. A recent study found that about 134 (70.2%) patients had vitamin D deficiency [13]. However, epidemiological findings must be more conclusive if they need further validation for molecular studies. Due to the controversy and persistence, further research is needed to determine the relationship between T2DM and vitamin D. This is the first research study on the prevalence of vitamin D in the rural populations at Swamy Vivekanandha Medical College Hospital and Research Institute (SVMCHRI). The present study investigates vitamin D deficiency among T2DM patients in a South Indian tertiary care hospital using biochemical parameters and thyroid-stimulating hormone (TSH).

MATERIAL AND METHOD

Study Design

The cross-sectional study was conducted at the Central Laboratory, Department of Biochemistry, and Central Research Laboratory of SVMCHRI, Namakkal, India. This research study was approved by the Institutional Ethical Committee (IEC-SVMCHRI), with the approved letter No. SVMCHRI/IEC/2023/005. Informed consent was obtained from all patients. Patients with confirmed T2DM were enrolled in the study.

Sample Size Analysis

The sample size was calculated based on a previous study [13]. A total of 322 patients were enrolled in our research study using the following sample size calculation formula:

$$n = Z^2 \times p(1 - p) \div d^2$$

Description:

p = Prevalence of vitamin D deficiency = 70.2% [13]
d = allowance error = 5
Z = 1.96 (95% Confidence interval)
Total sample size: 322

Inclusion and Exclusion Criteria

Patients aged ≥18 to 80 years with a definite T2DM diagnosis were included in this study. The exclusion of patients included type 1 diabetes mellitus and pregnant and lactating females.

Data Collection

The patient's blood samples were collected, and the isolated serum was stored at -80°C to analyze vitamin D levels. The selected T2DM patients, along with their available descriptive variable parameters (age and sex) and biochemical parameters such as fasting plasma glucose (FBS), postprandial glucose (PPBS), triglycerides (TGL), total cholesterol, high-density lipoprotein (HDL) cholesterol, glycated hemoglobin (HbA1c), urea, and creatinine using a Vitros slide method with respective calibrator kit an autoanalyzer (Vitros chemistry 5.1/FS, Japan). The quantitative measurement of thyroid-stimulating hormone (TSH) used a one-step immunometric sandwich assay design automated Immunodiagnostic Systems (Vitros ECi/ECiQ/ 3600, Japan).

The serum vitamin D concentration was analyzed by a quantitative micro Enzyme-Linked ImmunoSorbent Assay (ELISA) according to the kit protocol for the quantitative detection of 25-OH vitamin D (total) in human serum (Jmithra, India). Briefly, 25µL of serum, standards (1-6), and controls were added to the respective wells, and 100 µL of the assay diluent was added. Then, 50 µL of vitamin D biotin conjugate was mixed thoroughly in all wells. The plate was incubated at 37°C for 45 minutes, and then the vitamin D biotin conjugate (50 µL) was incubated at 37°C for 15 minutes. The wells were washed three times with a wash buffer solution. 100 µL of enzyme conjugate was added, incubated for 15 min at room temperature, and washed thrice. A 100 µL working substrate was added and kept in the dark for 15 min, and then a 50 µL stop solution was added. The plate was read at 450 and 630 nm using an ELISA reader. Serum vitamin D levels were used for the study: > 30 sufficient; 21-29 insufficiency; 10-20 deficiency; and < 10 severe deficiency.

Data Analysis

Statistical analyses were performed using two-tailed tests for male and female variances. All variables, such as patient demographic data, HbA1c, and vitamin D, were performed by descriptive analysis based on the frequency and percentage distribution. Biochemical parameters such as FBS, PPBS, urea, creatinine, total cholesterol, HDL-cholesterol, TGL, and TSH levels are shown as means and standard deviations (SD). The Pearson X^2 test for small frequency distributions was used to test the relationship between vitamin D levels and T2DM in the

ISSN. 2087-2852
E-ISSN. 2338-1655

demographic data. A p-value less than 0.05 was considered statistically significant in cross-tab analysis using SPSS Statistics version 15 (IBM, Armonk, NY). All figures were generated using GraphPad Prism 8, and correlation analysis was used to determine the correlation between vitamin D and HbA1c levels.

RESULTS

A total of 322 T2DM patients were included in this study. The mean age of the total patients was 51.74 ± 10.88 years. The study comprised 135 (41.9%) females and 187 (58.1%) males. The majority of the participants' age distributions among the totals were 42 (13%) of 18-40, 216 (67.1%) of 41-60, and 64 (19.9%) of 61-80, respectively (Fig. 1A and 1B). Vitamin D levels were found in T2DM patients as severe deficiency < 10 ng ml^{-1} 76 (23.6%), deficiency 10-20 ng ml^{-1} 136 (42.2%), insufficient 21-29 ng ml^{-1} 73 (22.7%), and sufficient > 30 ng ml^{-1} 37 (11.5%), respectively (Figure 2).

The concentration of vitamin D (mean ± SD) between males and females was significantly different in the Pearson chi-square test ($p<0.05$; *P = 0.001) (Table 1). However, the age groups between 18-40, 41-60, and 61-80 were insignificant (p=0.08). Overall, vitamin D deficiency determined by the patient's data is presented in Table 1. The mean age of males and females was 52.27 ± 10.26 and 50.99 ± 11.69, respectively. The mean values for vitamin D in males were 19.27±12.11 and females 15.01±9.42, respectively. The HbA1c mean value was 9.81±2.13 for male and 10.63±2.45 for female patients. The means of all parameters are listed in Table 2.

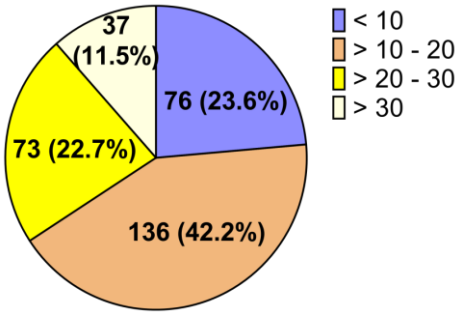

Figure 2. Prevalence of vitamin D level distribution in type 2 diabetes mellitus (T2DM) patients in a tertiary care hospital in south India.
Vitamin D levels (ng.mL^{-1}):
< 10 severe deficiency; >10-20 deficiency; >20-30 insufficiency; > 30 sufficient.

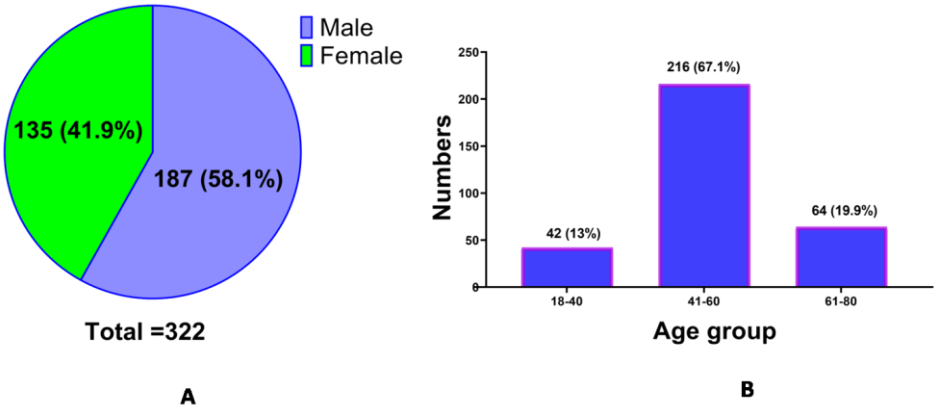

Figure 1. Total number of patients and age distribution, A) Total number of patients with male and female population in percentage, B) Age distribution of the patients from total numbers.

Table 1. Distribution vitamin D deficiency by gender and age in type 2 diabetes mellitus (T2DM) patients.

Vitamin D	Severe deficiency (< 10 ng.mL^{-1})	Deficiency (> 10 – 20 ng.mL^{-1})	Insufficiency (> 20 – ng.mL^{-1})	Sufficient (> 30 ng.mL^{-1})	Statistical significance p value
Variables	**n (%)**	**n (%)**	**n (%)**	**n (%)**	
Total Numbers (n=322)	76 (23.60)	136 (42.2)	73 (22.7)	37 (11.5)	
Male (n=187)	37 (19.8)	69 (36.9)	52 (27.8)	29 (15.5)	0.001*
Female (n= 135)	39 (28.9)	67 (49.6)	21 (15.6)	8 (5.9)	
18-40 (n=42)	11 (26.2)	24 (57.1)	5 (11.9)	2 (4.8)	0.08
> 40 -60 (n=216)	56 (25.9)	83 (38.4)	52 (24.1)	25 (11.6)	
> 60 -80 (n=64)	9 (14.1)	29 (45.3)	16 (25.0)	10 (15.6)	

Notes: Pearson chi-square test *p < 0.05 (significant). Asymptomatic significance (2-sided).

ISSN. 2087-2852
E-ISSN. 2338-1655

Table 2. Mean and standard deviation (SD) of the male and female patient age, vitamin D, HbA1c, biochemical parameters, and thyroid stimulating hormone (TSH) in T2DM.

Parameters	Male		Female	
	n	Mean ± SD	n	Mean ± SD
Age	187	52.27 ± 10.26	135	50.99 ± 11.69
FBS (mg.dL^{-1})	185	189.40 ± 70.16	132	173.97 ± 63.85
PPBS (mg.dL^{-1})	146	292.18 ± 91.16	105	262.26 ± 84.08
Vitamin D (ng.mL^{-1})	187	19.27 ± 12.11	135	15.01 ± 9.42
HbA1c (%)	47	9.81 ± 2.13	32	10.63 ± 2.45
Cholesterol (mg.dL^{-1})	131	186.95 ± 44.14	74	187.39 ± 39.75
Triglycerides (mg.dL^{-1})	128	191.80 ± 100.39	72	195.61 ± 112.98
HDL (mg.dL^{-1})	127	40.65 ± 8.08	71	42.56 ± 8.48
Urea (mg.dL^{-1})	88	25.92 ± 15.20	50	23.88 ± 10.06
Creatinine (mg.dL^{-1})	93	1.01 ± 0.91	51	0.68 ± 0.33
TSH (µIU.mL^{-1})	62	6.26 ± 19.46	53	3.45 ± 4.16

Notes: n =total number, SD = Standard Deviation

In the present study, the distribution of HbA1c (n = 79) in patients with diabetes was in the range of 6-8% for 19 (24.1%) patients and had higher levels of >8% in 60 (75.9%) patients (Fig. 3A). From the HbA1c (n = 79), vitamin D levels were distributed in severe deficiency 26 (32.90%), deficiency 31 (39.20%), insufficiency 11 (13.90%), and sufficient 11 (13.90%) (Fig. 3B). HbA1c distribution range and vitamin D levels were observed, and it was found that in the 6-8% range of HbA1C, the levels of vitamin D were severe deficiency in 5 (6.3%), deficiency in 8 (10.1%), insufficiency in 3 (3.8%), and sufficient in 3 (3.8%) patients respectively. In >8% of HbA1C, the levels of vitamin D were found to be in severe deficiency 21 (26.6%), deficiency 23 (29.1%), insufficiency 8 (10.1%), and sufficient 8 (10.1%) (Fig. 3C). The present study also correlated vitamin D and HbA1c found no significant relationship between vitamin D and HbA1c levels (p = 0.129) (Fig. 3D).

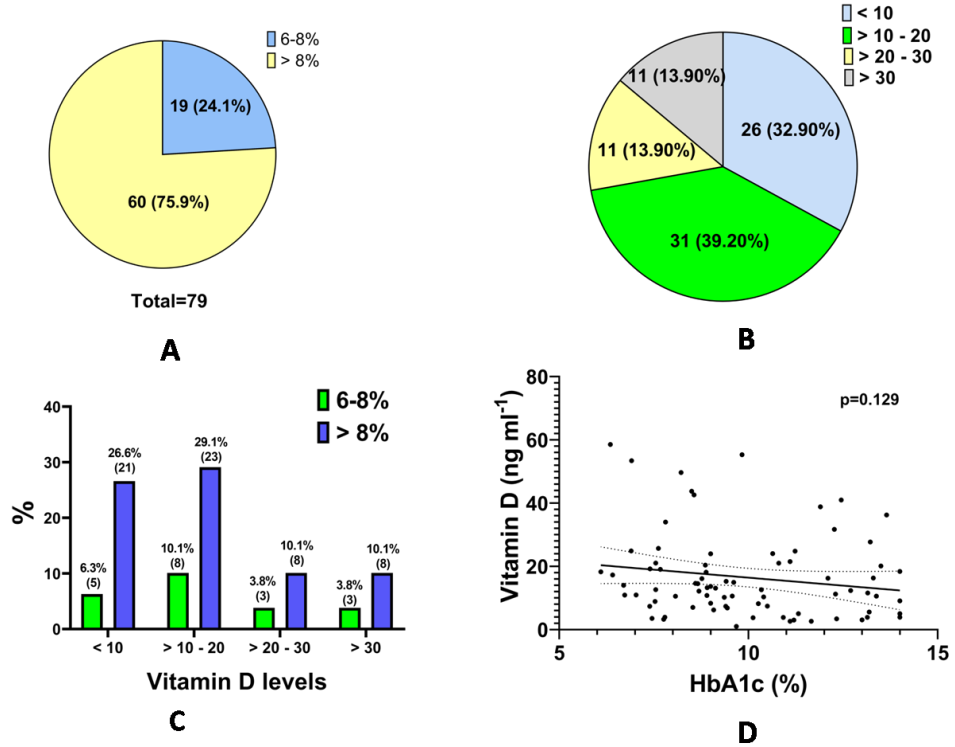

Figure 3. Association of HbA1c levels with vitamin D and correlation (n-79) in type2 diabetic (T2DM) patients. A) HbA1c distribution in type2 diabetes mellitus patients (T2DM), B) Status of vitamin D distribution in HbA1c, C) The association of HbA1c with vitamin D levels, D) Correlation of HbA1c and vitamin D. The correlation between vitamin D and HbA1c was not significant (p=0.129). Vitamin D levels (ng.mL^{-1}): > 30 sufficient; >20-30 insufficiency, >10-20 deficiency; and < 10 severe deficiency.

ISSN. 2087-2852
E-ISSN. 2338-1655

Table 3. Vitamin D deficiency and sufficiency distribution in HbA1c, biochemical parameters, and thyroid stimulating hormone (TSH) distribution in patients with T2DM.

Vitamin D				**Deficiency (< 30 ng.mL^{-1})**	**Sufficiency (> 30 ng.mL^{-1})**
Parameters	**Total number of patients (n)**	**Parameters Range**	**Number of patients (n)**	**n**	**n**
HbA1c (%)	79	6 – 8	19	16	3
		> 8	60	52	8
Cholesterol (mg.dL^{-1})	203	< 200	120	107	13
		> 200	83	78	5
Triglycerides (mg.dL^{-1})	200	< 150	81	74	7
		150 - < 200	44	41	3
		> 200	75	67	8
High-density lipoprotein Cholesterol (mg.dL^{-1})	188	> 40	104	98	6
		< 40	84	73	11
Urea (mg.dL^{-1})	138	< 45	130	114	16
		> 45	8	8	0
Creatinine (mg.dL^{-1})	142	< 1.3	132	117	15
		> 1.3	10	9	1
TSH (µIU.mL^{-1})	115	0.5 - 5.0	91	82	9
		< 0.5	10	10	0
		> 5.5	14	12	2

The biochemical parameters, HbA1c and TSH levels, and insufficient and deficient vitamin D levels are shown in Table 3. In T2DM patients, high-glycemic (HbA1c) levels (>8%) were observed in 60 of 79 patients. Of the 60 high-glycemic patients, 52 had vitamin D deficiency, and 8 had sufficient vitamin D (Table 3). Hypercholesterolemia was found in 83 patients and 120 normal cases out of 203 total patients. Seventy-eight patients had vitamin D deficiency and high cholesterol levels, while 107 had normal cholesterol. There was no association between normal and high cholesterol levels and vitamin D deficiency. The other biochemical parameters and TSH levels in patients with vitamin D deficiency are shown in Table 3.

DISCUSSION

Serum total vitamin D deficiency (%) was higher in T2DM patients. In this hospital-based study of 322 patients, vitamin D levels was about 76 (23.6%) had severe deficiency, 136 (42.2%) had deficiency, 73 (22.7%) had insufficient, and 37 (11.5%) had sufficient. Numerous diseases, including DM, are linked to vitamin D deficiency [12]. There is debate about whether diseases and vitamin deficiency are causal or confounding. The connection between insulin resistance and vitamin D deficiency is due to increased levels of inflammation markers [14]. In our study, vitamin D deficiency levels were significantly ($p < 0.001$) different between male and female patients. A study reported that 98.4% of T2DM patients have vitamin D deficiency [15]. It was also found that approximately 75% of female diabetic patients had vitamin D deficiency compared to male diabetic patients.

A cross-sectional analytical study conducted by Vijay, 2023, in the urban health training center of Dr. D.Y. Patil Medical College, Pune, India, stated that vitamin D deficiency was found in 86 (74.14%) of 116 patients with diabetes. Of these 63 males and 53 females, 71.43% and 77.36% had lower vitamin D levels, respectively [16]. This study also recommends a regular dose of vitamin D for patients with diabetes, which will help prevent further complications. A recent retrospective cross-sectional study from the King Faisal University Health Centre, Saudi Arabia, included 191 T2DM patients with 134 (70.2%) deficiency, 53 (27.7%) insufficiency in vitamin D, and 4 (2.1%) with a normal vitamin D. The mean age was 56.1 ± 11.4 years (range: 21-85 years) for the patients [13]. In our study, the total mean age was 51.74±10.88. The mean age of males and females was 52.27±10.26 and 50.99±11.69, respectively.

A study by Prasad, 2022, found that among the diabetic population, vitamin D deficiency was 78.2% in Karnataka, India [17]. A study from the northern part of India discovered that 91.1% of patients with diabetes were deficient in vitamin D. New-onset diabetes mellitus was newly diagnosed in these patients [18]. Many studies stated above, including our research study,

ISSN. 2087-2852
E-ISSN. 2338-1655

pointed out that the prevalence of vitamin D deficiency is significantly higher in T2DM in India and worldwide. The current study observed high glycemic levels in patients with vitamin D deficiency, and cholesterol, triglyceride, HDL, urea, and creatinine were also altered. Hypo- and hyperthyroid patients were also found to have diabetes with vitamin D deficiency. High cholesterol and hypertension, two non-communicable diseases, were mostly observed in India. Our study found no association between vitamin D deficiency with hypercholesterol and normal cholesterol levels. As a result, predicting the relationship between hypertension and vitamin D levels is difficult.

Al Ghadeer, 2022, found that poor diabetic control patients had more vitamin D deficiency with HbA1c greater than 5.9% [13]. In this study, patients with poor diabetes control had the highest level of vitamin D deficiency (52 out of 60 cases). Therefore, vitamin D plays a definitive role in T2DM in the overall population and can be explained by the link between vitamin D deficiency and insulin resistance in patients with DM.

A previous cohort follow-up study of 9841 patients observed low plasma vitamin D levels and a correlated higher risk of T2DM [19]. Studies have also speculated on the molecular effects of the sunshine hormone vitamin D on secretion, insulin sensitivity, and immunity. Observational and interventional human studies have recommended diabetes treatment with vitamin D [20]. Therefore, increasing lifestyle wakefulness, better diet management, effective sunlight requirements, and exercise can help prevent non-communicable diseases. Moreover, studies must be performed to understand the pathophysiology, which can provide an idea of how to avoid diseases in the developmental stage. The limitation of this study was that it did not include all the descriptive biochemical parameters, HbA1c and TSH, for all patients because the data were collected from the patient's investigations.

CONCLUSION

The present study found that most patients with vitamin D deficiency or insufficiency in T2DM have been linked to high glycemic control. This study supports the idea that vitamin D deficiency in T2DM may provide evidence to inform the public about health efforts to reduce the prevalence of diabetes and can be helpful in diabetic treatment. Simultaneously increasing evidence will address vitamin D deficiency and its multidimensional consequences on health.

Acknowledgements

The authors express their thanks to Dr.K.Prakasam, Medical Director, Swamy Vivekanandha Medical College Hospital and Research Institute (SVMCHRI), Namakkal, Tamil Nadu, India, for encouraging research activities and support. The authors also express sincere thanks to our SVMCHRI Management and the Dean, SVMCHRI, for their encouraging support of the research initiatives. We also thank Dr.S.Kavinkumar, Assistant Professor, Department of Community Medicine, SVMCHRI, for helping the sample size calculation.

REFERENCES

[1] Olokoba, A.B., O.A. Obateru, L.B. Olokoba. 2012. Type 2 diabetes mellitus: a review of current trends. *Oman Med. J.* 27(4). 269-273. DOI: 10.5001/omj.2012.68.

[2] Saeedi, P., I. Petersohn, P. Salpea, B. Malanda, S. Karuranga, N. Unwin. 2019. Global and regional diabetes prevalence estimates for 2019 and projections for 2030 and 2045: Results from the International Diabetes Federation Diabetes Atlas, 9th Edition. *Diabetes Res Clinic Practice*. 157. 1-10. DOI: 10.1016/j.diabres.2019.107843.

[3] Holick, M.F. 2006. High prevalence of vitamin D inadequacy and implications for health. *Mayo Clinic Proceedings*. 81(3). 353-373. DOI: 10.4065/81.3.353.

[4] Husemoen, L.L.N., B.H. Thuesen, M. Fenger, T. Jorgensen, C. Glumer, J. Svensson. 2012. Serum 25 (OH) D and type 2 diabetes association in a general population: a prospective study. *Diabetes Care*. 35(8). 1695-1700. DOI: 10.2337/dc11-1309.

[5] Pfotenhauer, K.M., J.H. Shubrook. 2017. Vitamin D deficiency, its role in health and disease, and current supplementation recommendations. *J. Osteopathic Med*. 117(5). 301-305. DOI: 10.7556/jaoa.2017.055.

[6] Mitri, J., M. Muraru, A.G. Pittas. 2011. Vitamin D and type 2 Diabetes: a systematic review. *Europe J. Clinical Nutr.* 65(9). 1005-1015. DOI: 10.1038/ejcn.2011.118.

[7] Liu, S., Y. Song, E.S. Ford, J.E. Manson, J.E. Buring, P.M. Ridker. 2005. Dietary calcium, vitamin D, and the prevalence of metabolic syndrome in middle-aged and older US women. *Diabetes care*. 28(12). 2926-2932. DOI: 10.2337/diacare.28.12.2926.

ISSN. 2087-2852
E-ISSN. 2338-1655

[8] Lucato, P., M. Solmi, S. Maggi, A. Bertocco, G. Bano, C. Trevisan, E. Manzato. 2017. Low vitamin D levels increase the risk of type 2 diabetes in older adults: A systematic review and meta-analysis. *Maturitas.* 100. 8-15. DOI: 10.1016/j.maturitas.2017.02. 016.

[9] Luo, B.A, F. Gao, L.L. Qin. 2017. The association between vitamin D deficiency and diabetic retinopathy in type 2 diabetes: a meta-analysis of observational studies. *Nutrients*. 9(3). 1-12. DOI: 10.3390/nu9030 307.

[10] Marcus, H., M. Varma, S.M. Sekhar. 2021. Association of serum vitamin D status with development of type 2 diabetes: A retrospective cross-sectional study. *Clin. Nutr. Open Sci*. 36. 1-13.

[11] Niroomand, M., A. Fotouhi, N. Irannejad, F. Hosseinpanah. 2018. Does high-dose vitamin D supplementation impact insulin resistance and risk of development of diabetes in patients with pre-diabetes? A double-blind randomized clinical trial. *Diabetes Res Clinical Practice*. 148. 1-9. DOI: 10.1016/j.diabres.2018.12.008.

[12] Berridge, M.J. 2017. Vitamin D deficiency and diabetes. *Biochem J.* 474(8). 1321-1332. DOI: 10.1042/bcj20170042.

[13] Al Ghadeer, H.A., M.S. AlRamadan, M.M. Al Amer, M.J. Alshwaf, F. J. Alali, A.A. Bubshait, *et al.* 2022. Vitamin D serum levels in type 2 diabetic patients: a cross-sectional study. *Cureus*. 14(2). 42-44.

[14] Kolb, H., T. Mandrup-Poulsen. 2005. An immune origin of type 2 diabetes? *Diabetologia*. 48(6). 1038-1050. DOI: 10.1007/s00125-005-1764-9.

[15] Al-Zahrani, M.K. 2018. The prevalence of vitamin D deficiency in type 2 diabetic patients. *J. Heal Sci*. 1(1). 18-22.

[16] Vijay, G.S., S. Ghonge, S.M. Vajjala, D. Palal. 2023. Prevalence of vitamin D deficiency in type 2 diabetes mellitus patients: A cross-sectional study. *Cureus*. 15(5). 1-12. DOI: 10.7759/cureus.38952.

[17] Prasad, B.R., T. Imran, R. Ahmed, S. Me, P. Kumar, C. Chaitra. 2022. Influence of serum levels of vitamin D on insulin resistance in patients with type II diabetes mellitus. *J. Association Physic India*. 70(7). 11-12. DOI: 10.5005/japi-11001-0045.

[18] Daga, R.A., B.A. Laway, Z.A. Shah, S.A. Mir, S.K. Kotwal, A.H. Zargar. 2012. High prevalence of vitamin D deficiency among newly diagnosed youth-onset diabetes mellitus in north India. *Arquivos Brasileiros de Endocrinologia & Metabologia*. 56(7). 423-428. DOI: 10.1590/s0004-27302012 000700003.

[19] Afzal, S., S.E. Bojesen, B.G. Nordestgaard. 2013. Low 25-hydroxyvitamin D and risk of type 2 diabetes: a prospective cohort study and metaanalysis. *Clinical Chem*. 59(2). 381-391. DOI: 10.1373/clinchem.2012.193003.

[20] Wu. J., A. Atkins, M. Downes, Z. We. 2023. Vitamin D in diabetes: Uncovering the sunshine hormone's role in glucose metabolism and beyond. *Nutrients*. 15(8). 1-15. DOI: 10.3390/nu15081997.

ISSN. 2087-2852
E-ISSN. 2338-1655