Role of Vitamin D Receptor in Prediabetes

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Abstract:
Background: Recent epidemiological evidence points towards the potential association of vitamin D insufficiency with adverse metabolic risk and in the pathogenesis of cancer, cardiovascular diseases, type 2 diabetes and other diseases. Vitamin D exerts its action in a variety of cell types through vitamin D receptors. No reports are available in the literature regarding vitamin D and vitamin D receptor status in prediabetics. The present study was planned to compare serum 25-hydroxy vitamin D [25(OH)D] and vitamin D receptor (VDR) protein levels in prediabetic cases and normoglycemic controls.

Methods: The present study was conducted in 80 persons who were divided into two groups, Study group (n= 40) comprised of diagnosed cases of prediabetes and control group (n=40) comprised of healthy normoglycemic controls. Serum 25-hydroxy vitamin D [25(OH)D] was analyzed by radioimmunoassay (RIA). Serum vitamin D receptor (VDR) protein was analyzed by sandwich enzyme immunoassay (ELISA).

Results: Serum 25(OH) vitamin D levels were significantly decreased in prediabetic cases as compared to normoglycemic controls \( p<0.001 \). Serum Vitamin D receptor protein levels were highly significantly decreased in prediabetic cases as compared to normoglycemic controls \( p<0.00 \). Serum 25(OH)D levels showed a highly significant positive correlation with serum VDR levels in both the groups \( p<0.001 \) at both levels.

Conclusion: The findings of the present study indicate that vitamin D and VDR can serve as a possible screening marker and target for modulation of the management and alleviating the progress and complications of diabetes.

Keywords: Vitamin D, Vitamin D receptor, Prediabetes, Normoglycemia, Hyperglycemia, Marker.

1. INTRODUCTION

Vitamin D deficiency has been linked to impaired glucose tolerance and type 2 DM in humans. Vitamin D has been proposed to play an important role and to be a risk factor in the development of insulin resistance and pathogenesis of type 2 DM by affecting either insulin sensitivity or β cell function or both [1]. Vitamin D exerts its action in a variety of cell types through vitamin D receptors.

Only 1,25(OH)\(_2\)D form of vitamin D is metabolically active and this molecule exerts its effects by activating the nuclear vitamin D receptor (VDR). The binding of 1,25(OH)\(_2\)D to VDR leads to the transcription of genes regulated by 1,25(OH)\(_2\)D. It is well established that pancreatic β cells express VDR. Johnson et al. have demonstrated the presence of VDR on pancreatic β cells in the islets of Langerhans [2]. Molecular evidence have found that pancreatic β cells express both cytosolic/nuclear VDR, thus enhancing β cells function [3]. Several studies have demonstrated a link between VDR gene polymorphisms and type 2 diabetes, although the findings differ from one population to another [3, 4].

Recent epidemiological evidence points to a potential association of vitamin D insufficiency with adverse metabolic risk and in the pathogenesis of cancer, cardiovascular diseases, type 2 diabetes and other diseases [5]. No reports are available in the literature regarding vitamin D receptor status in...
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2. MATERIALS AND METHODS

The present study was a case control study conducted in the Departments of Biochemistry and Endocrinology and Medicine, Pt. B.D. Sharma PGIMS, Rohtak, Haryana from December 2017 to November 2018 and most of them belonged to Rohtak district and Haryana state at large. The study included 80 persons (in age group: 30-55 years) who were divided into two groups by randomization. Study group (n=40) comprised of diagnosed cases of prediabetes and control group (n=40) comprised of healthy normoglycemic controls. Sample size was calculated according to the formula [6].

Subjects were selected as per American Diabetes Association (ADA) criteria. Subjects aged ≥18 years, irrespective of their gender, with impaired fasting glucose (IFG) of 100-125 mg/dL and/or impaired glucose tolerance (IGT) of 140-199 mg/dL and/or HbA1c between 5.7-6.4% were included in the study as prediabetic cases.

Pregnant women, women who were breast feeding, critically ill patients, patients with diabetes, tuberculosis, renal/hepatic impairment, malabsorption syndrome, cardiovascular disease, hypoglycemia, history of cancer, underweight, subjects taking drugs known to alter glucose tolerance, taking vitamin D supplementation for last one year, steroids, oral contraceptive pills, beta blockers, phenytoin and diuretics or fasting serum calcium, Arsenazo method; for serum phosphorus, colorimetric method; for serum uric acid, enzymatic method; for serum creatinine, Jaffe’s Kinetic dehydrogenase method; for serum cholesterol, CHOD-PAP method; for serum triglycerides >400 mg/dL (in both the groups) were excluded from the study.

Approval for the study was taken from the Ethical committee of the institution and written informed consent was taken from all the subjects. No new procedures were performed in these persons and standard treatment protocols were followed and ethical guidelines of Helsinki declaration were followed.

Five ml venous sample was drawn, and serum was separated by centrifugation. For blood urea, urease glutamate dehydrogenase method; for serum creatinine, Jaffe’s Kinetic method; for serum uric acid, enzymatic method; for serum calcium, Arsenazo method; for serum phosphorus, colorimetric without precipitation; for serum AST and ALT, UV Kinetic method; for serum ALP, PNP-AMP kinetic method; for serum bilirubin, Evelyn- Malloy method; for serum triglycerides, enzymatic method; for serum cholesterol, CHOD-PAP method; for blood sugar, GOD-POD method; for serum HDL, direct method were used in autoanalyzer (make: RX Suzuki Randox laboratories ltd., County Antrim town, United Kingdom).

Samples were taken after overnight fasting of 8-10 hours and in the morning, study samples were drawn at 8-9 am. Serum 25-hydroxy vitamin D [25(OH)D] was analyzed by radioimmunoassay (RIA) from Beckman Coulter [7]. Serum vitamin D receptor (VDR) protein was analyzed by sandwich enzyme immunoassay (ELISA) from Elabscience [8]. With 95% confidence interval, the population means for vitamin D in cases was between 22.2 and 26.8; and for vitamin D in controls was between 28.4 and 34 (based on 40 samples in each group). With 95% confidence interval, the population means for VDR in cases was between 2.63 and 3.57; and for VDR in controls is between 12.5 and 15.8 (based on 40 samples).

Statistical Package for Social Sciences (SPSS) version 23 was used for analysis, data was normalized and two tailed Pearson correlation test between variables was applied. Data so obtained were expressed as mean with standard deviation (Mean± SD), student’s t-test, chi square (χ²) test and regression analysis were carried out; significance was considered as p<0.05.

3. RESULTS

The mean age was comparable in two groups, in the study group, it was 40.9±10.43 years as compared to 38.72 ± 12.10 years in the control group. There were 42.5% females and 57.5% males in the control group.

Serum calcium levels were significantly lower in prediabetic group as compared to normoglycemic controls [p=0.05(0.040)]. Mean values of blood urea, serum creatinine, ALT, AST, ALP levels were higher in prediabetic cases as compared to normoglycemic controls [p<0.05 at all levels], (Table 1).

| Parameter       | Prediabetic Group | Normoglycemic Controls | p-value |
|-----------------|-------------------|------------------------|---------|
| Blood Urea      | 25.1±5.2          | 27.8±4.1               | <0.001  |
| Serum Creatinine| 1.2±0.3           | 1.0±0.2                | <0.001  |
| ALT             | 30.8±6.4          | 25.2±5.1               | <0.001  |
| AST             | 37.1±7.8          | 32.5±6.0               | <0.001  |
| ALP             | 1.5±0.3           | 1.2±0.2                | <0.001  |

Mean values of serum triglyceride, serum cholesterol, LDL and VLDL were significantly higher in prediabetic cases as compared to normoglycemic controls [p<0.001]. Serum Vitamin D receptor protein levels were highly significantly decreased in prediabetic cases as compared to normoglycemic controls [p<0.001(2.66 x 10^-3)], (Table 3), (Fig. 1).

A significant positive correlation was noted between serum 25(OH)D levels and serum VDR levels in both the groups [r = 0.83 vs r = 0.88 respectively; p=2.16x10^-14 vs p=3.71x10^-14 at both levels]. No significant correlation could be found between vitamin D and fasting blood sugar and 2 hours plasma glucose after 75 grams glucose load in prediabetes cases, though it was negative [r= -0.085, r= -0.073 respectively, p=0.59, p=0.65 respectively, p<0.05 at both levels].

4. DISCUSSION

Prediabetes can develop at any age, but the risk of prediabetes is thought to rise after the age of 45 years. This may be due to inactivity, poor diet and a loss of muscle mass, which typically declines with age. But, now a days, prediabetes and diabetes are becoming more common in children and adolescents due to an increase in fast food consumption and decrease in physical activity, which leads to overweight and obesity.

In the present study, 25 (62.5%) prediabetic cases were in the age group of 40 to 59 years and 15 (37.5%) cases were below the age of 40 years. Whereas, 19 (47.5%) normoglycemic controls were in the age group of 40 to 59 years and
plays a critical role in the acceleration of macrovascular atherosclerosis and contribute to the excess risk of CVD. In the present study, mean values of serum triglyceride, serum cholesterol, LDL and VLDL were significantly higher in prediabetic cases as compared to normoglycemic controls \(\{p<0.043, p=0.021, p=0.032, p=0.034\}\) respectively, \(p<0.05\) at all levels\]. (Table 2). The findings of the present study are in agreement with the previous studies [16 - 18].

Among many non-calcemic functions are the induction of differentiation in Peripheral Blood Mononuclear Cells (PBMCs) and antiproliferative effects in many cancers, as well as its immunosuppressive properties; vitamin D also acts as a necessary adjunct for insulin secretion [4]. Some of the immune non-classical actions of vitamin D point towards its role in the pathogenesis of type 2 DM through down-regulation of cytokines (IL-6). Vitamin D can modulate insulin secretion and also possesses pleiotropic effects on the pathogenesis of diabetes mellitus [19].

Serum 25(OH) vitamin D levels significantly decreased in prediabetic cases as compared to normoglycemic controls \(\{p<0.001\}\) in the present study. Lower serum vitamin D levels affect glucose homeostasis and parathyroid hormone concentrations in patients with prediabetes. Gupta et al. reported low 25(OH)D levels in prediabetic patients [20].

Twenty-eight cases (70\%) showed vitamin D inadequacy (<30 ng/mL) whereas 18 (45\%) controls had vitamin D inadequacy. The odds ratio for developing prediabetes in people with vitamin D inadequacy was 2.85 (95\% CI: 1.13-7.15, \(p<0.05\) (0.025). The findings of the present study are in agreement with other studies [21].

1,25(OH)2D, an active vitamin D metabolite, binds to vitamin D receptor (VDR) in the intestinal cell and stimulates active calcium transport from the intestine to the circulation.

Vitamin D exerts action in a variety of cell types through vitamin D receptor. Serum vitamin D receptor protein levels significantly decreased in prediabetic cases as compared to normoglycemic controls \(\{p<0.001\}\) in the present study. No reports are available regarding vitamin D receptor protein in prediabetes. A significant positive correlation was noted between serum 25(OH)D levels and serum VDR levels in both the groups \(\{p<0.001\} at both levels\].

### Table 1. Routine investigations in both the groups [MEAN±SD]

| Parameter (Normal Range) | Cases (n=40) Mean ± SD (Range) | Controls (n=40) Mean ± SD (Range) | \(p\) Value |
|--------------------------|-------------------------------|---------------------------------|-------------|
| Hb (12-15.5 gm/dL in females, 13.5-17.5 gm/dL in males) | 12.69 ± 1.80\(^{†}\) (9.2-16.1) | 13.06 ± 2.6 (9.2-16.7) | 0.45 |
| Blood urea (10-50 mg/dL) | 25.85 ± 9.20\(^{†}\) (15-58) | 24.02 ± 7.04 (14-52) | 0.32 |
| Serum creatinine (0.5-0.9 mg/dL in females, 0.6-1.1 mg/dL in males) | 0.91 ± 0.22\(^{†}\) (0.5-1.6) | 0.84 ± 0.17 (0.6-1.4) | 0.11 |
| Serum uric acid (2.4-5.7 mg/dL in females, 3.4-7.0 mg/dL in males) | 4.65 ± 1.34\(^{†}\) (2.8-9.2) | 4.47 ± 1.28 (2.0-6.9) | 0.55 |
Table 1. Lipid profile in both the groups

| Parameter (Normal Range) | Cases (n=40) Mean ± SD (Range) | Controls (n=40) Mean ± SD (Range) | p Value |
|---------------------------|---------------------------------|---------------------------------|---------|
| ALT/SGPT (upto 40 U/L)    | 40.05 ± 17.77† (15-83)          | 38.12 ± 17.55 (15-74)           | 0.62    |
| AST/SGOT (upto 40 U/L)    | 40.3 ± 17.9† (19-84)            | 34.3 ± 12.81 (15-66)            | 0.088   |
| Serum ALP (30-90 U/L)     | 77.97 ± 19.65† (27-109)        | 76.15 ± 17.50 (39-105)         | 0.66    |
| Serum bilirubin (upto 1.0 mg/dL) | 0.69 ± 0.22† (0.4-1.2) | 0.65 ± 0.16 (0.4-1.1)          | 0.46    |
| Serum calcium (8.1-10.4 mg/dL) | 9.54 ± 0.84* (8.0-11.2)       | 9.91 ± 0.70 (7.9-11.5)         | 0.040   |
| Serum phosphorus (2.7-4.5 mg/dL) | 3.61 ± 0.60† (2.4-5.2)       | 3.58 ± 0.54 (2.3-4.8)           | 0.80    |

Table 2. Lipid profile in both the groups

| Parameter (Normal Range) | Cases (n=40) Mean ± SD (Range) | Controls (n=40) Mean ± SD (Range) | p Value |
|---------------------------|---------------------------------|---------------------------------|---------|
| Serum triglyceride (upto 150 mg/dL) | 145.3 ± 54.50* (51-246)       | 118.9 ± 60.77 (35-261)          | 0.043   |
| Serum cholesterol (upto 200 mg/dL) | 189.95 ± 41.82* (92-255)      | 170.22 ± 32.83 (99-230)         | 0.021   |
| Serum HDL (40-60 mg/dL)     | 45.15 ± 9.96† (23-59)          | 45.12 ± 8.33 (22-59)            | 0.99    |
| Serum LDL (upto 160 mg/dL)  | 121.87 ± 38.85* (47-182)      | 105.47 ± 27.60 (46-157)         | 0.032   |
| Serum VLDL (16-32 mg/dL)    | 23.07 ± 7.26* (13-42)         | 19.82 ± 6.23 (11-33)            | 0.034   |

* p<0.05 when compared to controls
† Not significant (p>0.05) as compared to controls

Fig. (1). Correlation between serum 25(OH) vitamin D and serum VDR levels in both groups
Table 3. Serum 25(OH) vitamin D levels and Vitamin D Receptor Protein (VDR) Levels in both the groups [MEAN ± SD, ng/mL]

| Parameter (Normal Range) | Cases (n=40) | Controls (n=40) |
|-------------------------|-------------|----------------|
| Serum 25(OH)D (30-100 ng/mL) | 24.51 ± 7.48** | 31.19 ± 9.12 |
| Range | 9.4-39.3 | 17.7-55.0 |
| Serum VDR (ng/mL) | 3.10 ± 1.51** | 14.12 ± 5.34 |
| Range | 0.74-6.71 | 5.89-25.89 |

*p<0.001 when compared to controls

Vitamin D and its receptor complex play a key role in regulating the β cell insulin secretion. In the present study, a negative correlation was observed between vitamin D and fasting blood sugar and 2 hours plasma glucose after 75 grams glucose load in prediabetes cases, but the difference was statistically insignificant. Forouhi et al. demonstrated a negative correlation between insulin resistance and 25(OH)D levels [22]. During the early phase of prediabetes, pancreatic insulin release is impaired and together with increased serum insulin levels it accelerate the development of insulin resistance and overt diabetes in prediabetic patients. Recent studies support a role for vitamin D as a vascular protective agent against the effects of advanced glycation end products, which mediate the devastating consequences of diabetes on cardiac complications [19].

Few observational studies have suggested that low blood 25-hydroxyvitamin D levels are associated with the risk of type 2 diabetes. However, this is still not known whether vitamin D supplementation lowers the risk of diabetes. Conflicting reports are available in the literature [23 - 25].

Pittas et al. in their Vitamin D and Type 2 Diabetes (D2d) trial to test whether vitamin D supplementation (dose of 4000 IU per day) reduces the risk of type 2 diabetes among adults, reported that this supplementation did not lower the risk of diabetes than placebo in their study population [20]. Also, another study reported no differences between placebo and vitamin D supplementation groups in terms of fasting plasma glucose, 2-h glucose, or insulin secretion and sensitivity or percent developing diabetes or returning to normal glucose tolerance [21]. In contrast, one study has reported that vitamin D supplementation in prediabetes subjects significantly lowered FPG, 2-h plasma glucose and A1C levels [22]. These differences could be due to ethnic population differences in the relationship between vitamin D and glucose metabolism. No study is available regarding the effect of vitamin D supplementation on vitamin D receptor in prediabetes.

CONCLUSION

The findings of the present study indicate that vitamin D and VDR can serve as a possible screening marker and target for modulation the management and alleviating the progress and complications of diabetes. In the future, vitamin D supplementation may have a role in the diagnosis of impending diabetes, and prevention of complications of prediabetes.

Further work is needed to define the mechanisms by which such variations in VDR synthesis lead to variation in cellular function and to determine whether such variation is abolished by adequate vitamin D repletion.

Identifying people with prediabetes and creating awareness on the prevention of diabetes by lifestyle modification and development of cost-effective strategy to prevent or delay, the progression of the prediabetic stage to diabetic stage is the need of the hour for prevention of diabetes in a country like India, which experiencing the epidemiological transition of chronic non-communicable diseases.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Ethics approval for the study was taken from the institutional ethical committee of the Pt. B.D.Sharma PGIMS/ UHS. Rohtak. The ethical code number is IEC/17/488.

HUMAN AND ANIMAL RIGHTS

No animals were used in this research. All human research procedures followed were in accordance with the ethical standards of the committee responsible for human experimentation (institutional and national), and with the Helsinki Declaration of 1975, as revised in 2013.

CONSENT FOR PUBLICATION

Written informed consent was taken from all the subjects.

AVAILABILITY OF DATA AND MATERIALS

The data sets analyzed during the current study are available from the corresponding author upon request.

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None.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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REFERENCES

[1] Deleskog A, Hilding A, Brismar K, Hamsten A, Efendic S, Ostenson CG. Low serum 25-hydroxyvitamin D level predicts progression to type 2 diabetes in individuals with prediabetes but not with normal glucose tolerance. Diabetologia 2012; 55(6): 1668-78. [http://dx.doi.org/10.1007/s00125-012-2529-x] [PMID: 22426800]
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[1] Johnson JA, Grande JP, Roche PC, Kumar R. Immunohistochemical localization of the 1,25(OH)2D3 receptor and calbindin D28k in human and rat pancreas. Am J Physiol 1994; 267(3 Pt 1): E356-60. [PMID: 7943215]

[2] Nemere I, Schwartz Z, Pedrozo H, Sylvia VL, Dean DD, Boyan BD. Identification of a membrane receptor for 1,25-dihydroxyvitamin D3 which mediates rapid activation of protein kinase C. J Bone Miner Res 1998; 13(9): 1353-9. [http://dx.doi.org/10.1053/jbmr.1998.13.9.1353] [PMID: 9738506]

[3] Ogunkolade BW, Boucher BJ, Phahl JM, et al. Vitamin D receptor (VDR) mRNA and VDR protein levels in relation to vitamin D status, insulin secretory capacity, and VDR genotype in Bangladeshi Asians. Diabetes 2002; 51(7): 2294-300. [http://dx.doi.org/10.2337/diabetes.51.7.2294] [PMID: 12086963]

[4] Zeitzmann A. Vitamin D in preventive medicine: are we ignoring the evidence? Br J Nutr 2003; 89(5): 552-72. [http://dx.doi.org/10.1079/BIN2003837] [PMID: 12720576]

[5] Charan J, Biswas T. How to calculate sample size for different study designs in medical research? Indian J Psychol Med 2013; 35(2): 121-6. [http://dx.doi.org/10.4103/0253-7176.116232] [PMID: 24049221]

[6] Hollis BW, Napoli JL. Improved radioimmunoassay for vitamin D and its use in assessing vitamin D status. Clin Chem 1985; 31(11): 1815-9. [http://dx.doi.org/10.1093/clinchim/31.11.1815] [PMID: 4053331]

[7] Veldman CM, Cantorna MT, DeLuca HF. Expression of a 1,25-dihydroxyvitamin D(3) receptor in the immune system. Arch Biochem Biophys 2000; 374(2): 334-8. [http://dx.doi.org/10.1006/abbi.1999.1605] [PMID: 10666315]

[8] Ngo ST, Steyn P, McCombe PA. Gender differences in autoimmune disease. Front Neuroendocrinol 2014; 35(3): 347-69. [http://dx.doi.org/10.1016/j.yfrne.2014.04.004] [PMID: 24793874]

[9] Muthunarayanan L, Ramraj B, Russel JK. Prevalence of prediabetes and its associated risk factors among rural adults in Tamil Nadu. Arch Med Health Sci 2015; 3: 178-84. [http://dx.doi.org/10.4103/0253-7176.116232] [PMID: 24049221]

[10] Muthunarayanan L, Ramraj B, Russel JK. Prevalence of prediabetes and its associated risk factors among rural adults in Tamil Nadu. Arch Med Health Sci 2015; 3: 178-84. [http://dx.doi.org/10.4103/0253-7176.116232] [PMID: 24049221]

[11] Saijadi F, Mohammadifard N, Kelishadi R, Ghaderian N, Alikhahi H, Maghrun M. Clustering of coronary artery disease risk factors in patients with type 2 diabetes and impaired glucose tolerance. East Mediterr Health J 2008; 14(5): 1080-9. [PMID: 19161080]

[12] Anjana RM, Pradeep R, Deepa M, et al. ICMR–INDIAB Collaborative Study Group. Prevalence of diabetes and prediabetes (impaired fasting glucose and/or impaired glucose tolerance) in urban and rural India: phase I results of the Indian Council of Medical Research–India DIABetes (ICMR–INDIAB) study. Diabetologia 2011; 54(12): 3022-7. [http://dx.doi.org/10.1007/s00125-011-2291-5] [PMID: 21959057]

[13] Balagopal P, Kamalmuna N, Patel TG, Misra R. A community-based diabetes prevention and management education program in a rural village in India. Diabetes Care 2008; 31(6): 1097-104. [http://dx.doi.org/10.2337/dc07-1680] [PMID: 18316397]

[14] Akter S, Rahman MM, Abe SK, Sultana P. Prevalence of diabetes and prediabetes and their risk factors among Bangladeshi adults: A nationwide survey. Bull World Health Organ 2014; 92(3): 204-213, 213A. [http://dx.doi.org/10.2347/BLT.13.128371] [PMID: 24700980]

[15] Pittas AG, Lau J, Hu FB, Dawson-Hughes B. The role of vitamin D and calcium in type 2 diabetes. A systematic review and meta-analysis. J Clin Endocrinol Metab 2007; 92(6): 2017-29. [http://dx.doi.org/10.1010/jc.2007-0298] [PMID: 17389701]

[16] Rahbar S. An abnormal hemoglobin in red cells of diabetics. Clin Chim Acta 1968; 22(2): 296-8. [http://dx.doi.org/10.1016/0009-8981(68)90372-0] [PMID: 5687098]

[17] Kansal S, Kamble TK. Lipid profile in prediabetes. J Assoc Physicians India 2016; 64(3): 18-21. [http://dx.doi.org/10.27731552]

[18] Miyazaki Y, Furugen M, Akasaka H, Saitoh S, Miura T. Atherogenic lipids profile relates to postprandial hyperglycemia and hyperinsulinemia due to whole body insulin resistance in prediabetic subjects. JDM 2012; 2: 272-8. [http://dx.doi.org/10.4236/jdm.2012.22044]

[19] Mackaway AMH, Badawi MEH. Association of vitamin D and vitamin D receptor gene polymorphisms with chronic inflammation, insulin resistance and metabolic syndrome components in type 2 diabetic Egyptian patients. Metu Gene 2014; 2: 540-56. [http://dx.doi.org/10.1016/j.mgen.2014.07.002] [PMID: 25600437]

[20] Pittas AG, Dawson-Hughes B, Sheehan P, et al. D2d Research Group. Vitamin D supplementation and prevention of type 2 diabetes. N Engl J Med 2019; 381(6): 520-30. [http://dx.doi.org/10.1056/NEJMoa1900906] [PMID: 31173679]

[21] Davidson MB, Duran P, Lee ML, Friedman TC. High-dose vitamin D supplementation in people with prediabetes and hypovitaminosis D. Diabetes Care 2013; 36(2): 260-6. [http://dx.doi.org/10.2337/dc12-1204] [PMID: 23033239]

[22] Kuchay MS, Laway BA, Bashir MI, Wani AI, Misgar RA, Shah ZA. Effect of Vitamin D supplementation on glycemic parameters and progression of prediabetes to diabetes: A 1-year, open-label randomized study. Indian J Endocrinol Metab 2015; 19(3): 387-92. [http://dx.doi.org/10.4103/2230-8210.152783] [PMID: 25923296]

[23] Gupta AK, Brashier MM, Johnson WD. Low vitamin D levels, prediabetes and prehypertension in healthy African American adults. Nutr Metab Cardiovasc Dis 2012; 22(10): 877-82. [http://dx.doi.org/10.1016/j.numecd.2012.01.006] [PMID: 22494807]

[24] Sahasrabudhe AV, Pinale SU, Gupta M, Chari S, Sagdeo M. Study of vitamin D levels and its correlation with insulin resistance. Natl J Physiol Pharmocol 2017; 7: 963-7. [http://dx.doi.org/10.5455/njpp.2017.7.030942402017]

[25] Forouhi NG, Luan J, Cooper A, Boucher BJ, Wareham NJ. Baseline serum 25-hydroxy vitamin D is predictive of future glycemnic status and insulin resistance: The Medical Research Council Ely Prospective Study 1990-2000. Diabetes 2008; 57(10): 2619-25. [http://dx.doi.org/10.2337/db08-0593] [PMID: 18591391]