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**Research Article**

# Serum Vitamin D Status, Dietary Calcium Intake and Insulin Resistance among Adults with Prediabetes

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## ABSTRACT

**Background:** Prediabetes is characterized by impaired glucose regulation and an increased risk of progression to type 2 diabetes mellitus.

**Objective:** To evaluate the association of serum vitamin D status and dietary calcium intake with insulin resistance among adults with prediabetes.

**Methodology:** This prospective cross-sectional study was conducted at three Districts of Sindh i.e. Khairpur Mirs, Tharparkar and Mithi from 1st April 2025 to 30th September 2025. Three hundred and twenty five adults with prediabetes were enrolled. Demographic, anthropometric, clinical, biochemical, and dietary data were recorded. Demographic and clinical variables including age, gender, body mass index (BMI), waist circumference, smoking status, physical activity level, blood pressure, family history of diabetes, and relevant medical history were recorded.

**Results:** The mean age of participants was 48.7±10.2 years, with a mean BMI of 29.1±4.8 kg/m$^2$ and waist circumference of 97.6±10.5 cm. The mean fasting plasma glucose was 110.8±8.6 mg/dL, HbA1c was 6.0±0.3%, fasting insulin was 16.9±6.3 µIU/mL, and Homeostatic Model Assessment for Insulin Resistance (HOMA-IR) was 4.6±1.8. The mean serum vitamin D level was 22.8±8.7 ng/mL, while the mean dietary calcium intake was 721±198 mg/day. Vitamin D deficiency was present in 132 (40.6%) participants, and 98 (30.2%) consumed less than 600 mg of calcium daily. Participants with vitamin D deficiency had significantly higher ($P<0.001$) HOMA-IR and fasting insulin levels than those with sufficient vitamin D status (5.3±1.8 vs. 3.6±1.2 and 19.1±5.9 vs. 13.8±4.7 µIU/mL) respectively.

**Conclusion:** Vitamin D deficiency and inadequate dietary calcium intake were common among adults with prediabetes and were significantly associated with greater insulin resistance and poorer glycemic control.

**Keywords:** Prediabetes, Vitamin D Deficiency, Dietary Calcium, Insulin Resistance, Glycemic Control.

## INTRODUCTION

Prediabetes is an intermediate metabolic state characterized by blood glucose levels that are higher than normal but below the diagnostic threshold for diabetes mellitus. It represents a critical stage in the natural history of type 2 diabetes mellitus (T2DM), during which timely intervention may prevent or delay disease progression.[1] The global prevalence of prediabetes has increased considerably over the past decade owing to urbanization, sedentary lifestyles, unhealthy dietary habits, and the rising prevalence of obesity.[2] Individuals with prediabetes are not only at increased risk of developing T2DM but also have a greater likelihood of cardiovascular disease, chronic kidney disease, and premature mortality.[3] Insulin resistance is the hallmark pathophysiological abnormality underlying prediabetes and precedes the onset of overt diabetes by several years.[4] It is characterized by reduced responsiveness of peripheral tissues, particularly skeletal muscle, liver, and adipose tissue, to the biological actions of insulin, resulting in impaired glucose uptake and increased hepatic glucose production.[5] Several metabolic, hormonal, inflammatory, and nutritional factors have been implicated in the development and progression of insulin resistance.[6] Vitamin D has gained increasing attention because of its potential role beyond skeletal health, particularly in glucose metabolism and insulin sensitivity.[7] Vitamin D receptors are expressed in pancreatic β-cells, skeletal muscle, adipose tissue, and other insulin-responsive organs, suggesting a direct influence on insulin secretion and glucose homeostasis.[8] Experimental studies have demonstrated that vitamin D deficiency may impair β-cell function, increase systemic inflammation, and reduce insulin sensitivity, thereby contributing to the development of insulin resistance and prediabetes.[9] Epidemiological studies have similarly reported an inverse association between serum vitamin D concentrations and the risk of impaired glucose tolerance and T2DM.[10]

Adequate dietary calcium intake has also been recognized as an important determinant of metabolic health.[11] Calcium plays a fundamental role in intracellular insulin signaling, pancreatic insulin secretion, and glucose transport within peripheral tissues.[12] Inadequate calcium intake may alter intracellular calcium homeostasis, impair insulin-mediated glucose uptake, and aggravate insulin resistance.[13] Since vitamin D facilitates intestinal calcium absorption, deficiencies in either nutrient may have synergistic effects on glucose metabolism and metabolic dysfunction.[14] Although Pittas et al[15] have independently evaluated vitamin D deficiency or dietary calcium intake in relation to glucose metabolism, evidence examining their combined association with insulin resistance among adults with prediabetes remains limited and inconsistent. The variations in dietary habits, nutritional status, ethnicity, sunlight exposure, and lifestyle factors may influence these relationships across different populations.[16] Identifying modifiable nutritional risk factors during the prediabetic stage may provide opportunities for early intervention and prevention of progression to type 2 diabetes mellitus.

## MATERIALS AND METHODS

This prospective cross-sectional study was conducted at three Districts of Sindh i.e. Khairpur Mirs, Tharparkar and Mithi from 1st April 2025 to 30th September 2025. A total of 325 adults diagnosed with prediabetes were enrolled Adults of both sexes aged 18-65 years who were diagnosed with prediabetes by the American Diabetes Association (ADA) (fasting plasma glucose 100-125 mg/dL, HbA1c 5.7-6.4%, or 2-hour plasma glucose 140-199 mg/dL during an oral glucose tolerance test) were included. The subjects who agreed to give informed consent and underwent biochemical evaluation were recruited in the study. Patients with a previous diagnosis of diabetes mellitus, pregnancy or lactation, chronic kidney disease, chronic liver disease, malabsorption syndromes, endocrine disorders of calcium or vitamin D metabolism, malignancy, acute or chronic inflammatory diseases, osteoporosis, recent (past three months) vitamin D or calcium supplementation or incomplete clinical and laboratory information were excluded.

Eligible subjects obtained and informed consent from the parents and enrolled using a non-probability consecutive sampling technique. Demographic and clinical data such as age, sex, body mass index (BMI), waist circumference, smoking habits, physical activity, blood pressure, family history of diabetes, and medical history were obtained. The intake of calcium was determined by a validated semi-quantitative Food Frequency Questionnaire (FFQ), and the mean daily calcium intake was expressed in milligrams per day. Anthropometric measurements such as height, weight, BMI, and waist circumference were recorded following standard procedures. Venous blood samples were taken the next day after overnight fasting for the measurements of fasting plasma glucose, fasting serum insulin, glycated hemoglobin (HbA1c), serum 25-hydroxyvitamin D [25(OH)D], serum calcium, lipid profile, and serum creatinine levels, which were measured. Serum vitamin D levels were classified as deficient (<20 ng/mL), insufficient (20–29 ng/mL), or sufficient (≥30 ng/mL). The Homeostatic Model Assessment for Insulin Resistance (HOMA-IR) was used to determine insulin resistance, based on fasting glucose and fasting insulin levels. The participants were grouped based on their vitamin D status and their dietary calcium consumption to determine its relationship to insulin resistance. Insulin resistance, assessed by HOMA-IR, was the main outcome. Secondary outcomes were serum vitamin D status, dietary calcium consumption, fasting plasma glucose, fasting serum insulin, HbA1c, BMI, waist circumference, and the relationship between vitamin D deficiency and low dietary calcium intake and insulin resistance in adults with prediabetes.

All the data were analyzed through SPSS version 26.0. Normality was tested using Shapiro–Wilk test. Independent t-tests or one-way ANOVA were used to compare continuous variables between vitamin D categories and calcium intake groups, whereas Chi-square tests were used for categorical variables. Pearson or Spearman correlation analysis was used to assess the association between serum vitamin D, dietary calcium consumption and HOMA-IR.

## RESULTS

The mean age was 48.7±10.2 years of prediabetes, mean BMI was 29.1±4.8 kg/m², while the mean waist circumference was 97.6±10.5 cm. The average systolic and diastolic blood pressures were 129.4±13.8 mmHg and 81.7±8.9 mmHg, respectively. Of the participants, 171 (52.6%) were male and 154 (47.4%) were female. A family history of diabetes was reported by 189 (58.2%) participants, 168 (51.7%) were physically inactive, and 78 (24.0%) were current smokers (Tables 1-2).

The mean fasting plasma glucose level was 110.8 ± 8.6 mg/dL, while the mean HbA1c was 6.0±0.3%. The participants had a mean fasting insulin level of 16.9±6.3 μIU/mL and a mean HOMA-IR of 4.6±1.8, indicating considerable insulin resistance. The mean serum vitamin D level was 22.8±8.7 ng/mL, whereas the mean dietary calcium intake was 721±198 mg/day. The mean serum calcium level was 9.2±0.5 mg/dL. Mean total cholesterol and triglyceride levels were 194.5±36.8 mg/dL and 171.8±47.9 mg/dL, respectively (Table 3).

Vitamin D deficiency was present in 132 (40.6%) participants, while 109 (33.5%) had insufficient levels and only 84 (25.8%) had sufficient vitamin D status. Regarding dietary calcium intake, 98 (30.2%) participants consumed less than 600 mg/day, 167 (51.4%) consumed 600–1000 mg/day, and only 60 (18.5%) consumed more than 1000 mg/day (Table 4).

Participants with vitamin D deficiency had the highest mean HOMA-IR of 5.3±1.8 and fasting insulin level of 19.1±5.9 μIU/mL. Those with vitamin D insufficiency had a mean HOMA-IR of 4.5±1.5 and fasting insulin of 16.5±5.2 μIU/mL, while vitamin D-sufficient participants had the lowest HOMA-IR of 3.6±1.2 and fasting insulin of 13.8±4.7 μIU/mL (Table 5).

Participants consuming less than 600 mg/day had the highest mean HOMA-IR of 5.4±1.7 and HbA1c of 6.2±0.3%. Those consuming 600–1000 mg/day had a mean HOMA-IR of 4.5±1.5 and HbA1c of 6.0±0.3%, whereas participants consuming more than 1000 mg/day had the lowest HOMA-IR of 3.7±1.2 and HbA1c of 5.8±0.2%. These differences were statistically significant ($p<0.001$) [Table 6].

Table 1: Demographic and clinical characteristics of the participants (n = 325)

| Variable | No. | % |
|---|---|---|
| **Gender** | | |
| Male | 171 | 52.6 |
| Female | 154 | 47.4 |
| Current smokers | 78 | 24.0 |
| Family history of diabetes | 189 | 58.2 |
| Physically inactive | 168 | 51.7 |

Table 2: Descriptive statistics of the participants (n=325)

| Variable | Mean±SD |
|---|---|
| Age (years) | 48.7±10.2 |
| BMI (kg/m$^2$) | 29.1±4.8 |
| Waist Circumference (cm) | 97.6±10.5 |
| Systolic Blood Pressure (mmHg) | 129.4±13.8 |
| Diastolic Blood Pressure (mmHg) | 81.7±8.9 |

Table 3: Biochemical and nutritional characteristics (n = 325)

| Variable | Mean±SD |
|---|---|
| Fasting Plasma Glucose (mg/dL) | 110.8±8.6 |
| HbA1c (%) | 6.0±0.3 |

| | |
|---|---|
| Fasting Serum Insulin (µIU/mL) | 16.9±6.3 |
| HOMA-IR | 4.6±1.8 |
| Serum Vitamin D (ng/mL) | 22.8±8.7 |
| Dietary Calcium Intake (mg/day) | 721±198 |
| Serum Calcium (mg/dL) | 9.2±0.5 |
| Total Cholesterol (mg/dL) | 194.5±36.8 |
| Triglycerides (mg/dL) | 171.8±47.9 |

Table 4: Distribution of vitamin D status and dietary calcium intake (n = 325)

| Variable | No. | % |
|---|---|---|
| **Vitamin D Status** | | |
| Deficient (<20 ng/mL) | 132 | 40.6 |
| Insufficient (20–29 ng/mL) | 109 | 33.5 |
| Sufficient (≥30 ng/mL) | 84 | 25.8 |
| **Dietary Calcium Intake** | | |
| <600 mg/day | 98 | 30.2 |
| 600–1000 mg/day | 167 | 51.4 |
| >1000 mg/day | 60 | 18.5 |

Table 5: Association of vitamin D status with insulin resistance

| Vitamin D Status | No. | HOMA-IR | Fasting Insulin (µIU/mL) | P value |
|---|---|---|---|---|
| Deficient | 132 | 5.3±1.8 | 19.1±5.9 | <0.001 |
| Insufficient | 109 | 4.5±1.5 | 16.5±5.2 | |
| Sufficient | 84 | 3.6±1.2 | 13.8±4.7 | |

Table 6: Association of dietary calcium intake with insulin resistance

| Daily Calcium Intake | No. | HOMA-IR | HbA1c (%)D | P value |
|---|---|---|---|---|
| <600 mg/day | 98 | 5.4±1.7 | 6.2±0.3 | <0.001 |
| 600–1000 mg/day | 167 | 4.5±1.5 | 6.0±0.3 | |
| >1000 mg/day | 60 | 3.7±1.2 | 5.8±0.2 | |

## DISCUSSION

In the present study the average age of the participants was 48.7±10.2 years, and there was a slight majority of males (52.6%). Most of the participants were overweight and obese with a mean BMI of 29.1±4.8 kg/m² and mean waist circumference of 97.6±10.5 cm. In a family history of diabetes, more than half had a family history of diabetes (58.2%) and physical inactivity was observed in 51.7% of participants. The results confirm that obesity, physical inactivity, and genetic susceptibility are known factors linked to insulin resistance and development of prediabetes. Previous studies have also shown that middle aged overweight individuals with a family history of diabetes have the highest rate of prediabetes.[17] The biochemical profile of the study population showed impaired glucose metabolism with a mean fasting plasma glucose level of 110.8±8.6 mg/dL, mean fasting insulin level of 16.9±6.3 µIU/mL, and mean HOMA-IR of 4.6±1.8. In general, the mean serum vitamin D had been found to be 22.8±8.7 ng/mL, and the mean dietary calcium intake was 721±198 mg/day, which was below the recommended daily calcium intake for many adults. Adults with prediabetes often have decreased serum vitamin D levels, low calcium intake, and increased HOMA-IR levels, indicating that dietary deficits are related to insulin resistance.[18] One of the important results of the present study was the high vitamin D deficiency rate and the low consumption of calcium food. Forty percent of the participants were found to have vitamin D deficiency and 25.8% of the participants have sufficient vitamin D level. Likewise, fewer than 18.5% of those who participated in the study consumed more than 1000 mg of calcium daily, while 30.2% consumed less than 600 mg of calcium per day. These findings showed that adults with prediabetes are susceptible to nutritional deficiencies which can help to cause metabolic dysfunction. Vitamin D deficiency has also been previously reported in around one-third to one-half of adults with prediabetes and inadequate calcium intake in a significant population.[19]

One of the key findings of this study was the vitamin D status–insulin resistance relationship. Participants with vitamin D deficiency had significantly higher ($p<0.001$) HOMA-IR (5.3±1.8) and fasting insulin concentrations (19.1±5.9 μIU/mL) than those with adequate vitamin D levels (3.6±1.2 and 13.8±4.7 μIU/mL, respectively). The results of these studies indicated an association between sufficient vitamin D levels and better insulin sensitivity. The biological mechanism might be related to better pancreatic β-cell function, better insulin receptor activity, lower systemic inflammation, and to modulation of intracellular calcium signaling. Consistent with this, other studies have shown a strong negative correlation between serum vitamin D concentration and insulin resistance, with lower serum vitamin D levels being linked to higher HOMA-IR levels. The intake of dietary calcium was also shown to have a significant relationship with insulin resistance. The participants consuming dietary calcium less than 600 mg/day had the highest HOMA-IR (5.4±1.7) and HbA1c (6.2±0.3%), whereas those consuming more than 1000 mg/day had significantly lower ($p<0.001$) HOMA-IR (3.7±1.2) and HbA1c (5.8±0.2%). The results indicate that sufficient calcium intake could help to promote glucose metabolism and insulin sensitivity. Calcium is essential to insulin secretion, intracellular signaling and glucose transport, and vitamin D absorption is improved from the intestine, complementing the metabolic role of calcium. Earlier studies have also confirmed that increased calcium intake leads to better insulin sensitivity, glycemic control and a lower risk of developing prediabetes to type 2 diabetes.[20]

## CONCLUSION

Serum vitamin D deficiency and inadequate dietary calcium intake were highly prevalent among adults with prediabetes and were significantly associated with increased insulin resistance. Participants with lower vitamin D levels and lower calcium intake demonstrated higher HOMA-IR values, fasting insulin concentrations, and poorer glycemic control. These findings suggest that nutritional status plays an important role in glucose metabolism and insulin sensitivity. Routine assessment of vitamin D status and dietary calcium intake, together with appropriate nutritional and lifestyle interventions, may help improve insulin sensitivity and reduce the risk of progression from prediabetes to type 2 diabetes mellitus.

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