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ASSOCIATION BETWEEN SERUM VITAMIN D, INSULIN RESISTANCE (HOMA-IR), AND GESTATIONAL DIABETES MELLITUS

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Abstract. Aim. *To investigate whether early pregnancy serum vitamin D levels and insulin resistance (HOMA-IR) are associated with the development of gestational diabetes mellitus (GDM).* ***Materials and methods.*** *This prospective cohort study was conducted between 2023 and 2025 and included 850 pregnant women enrolled during early gestation. Baseline serum Vitamin D concentrations were measured. Fasting plasma glucose and fasting insulin were determined, and HOMA-IR was calculated. Participants were followed until 24–28 weeks of gestation, when GDM was diagnosed using a standardized 75 g oral glucose tolerance test. Correlation analysis and multivariate logistic regression were performed to determine associations and predictive relationships.* ***Results.*** *Women who developed GDM had significantly higher pre-pregnancy BMI (M = 29.8, SD = 5.1) compared to non-GDM women (M = 26.4, SD = 4.7), t(848) = 7.5, p < .001. Similarly, HOMA-IR was significantly elevated in the GDM group (M = 4.3, SD = 1.5) compared to the non-GDM group (M = 3.1, SD = 1.1), t(848) = 9.8, p <0.001. Fasting plasma glucose and fasting insulin were also higher among women with GDM (glucose: M = 5.2, SD = 0.5 vs. M = 4.9, SD = 0.4, t(848) = 5.8, p < .001; insulin: M = 18.5, SD = 5.6 vs. M = 14.3, SD = 4.8, t(848) = 9.2, p < 0.001). There were no statistically significant differences in maternal age (t(848) = 1.8, p = 0.07) or serum vitamin D levels (M = 23.6, SD = 7.2 vs. M = 24.1, SD = 6.8, t(848) = 0.9, p = 0.36) between the groups.* ***Conclusions.*** *The Homeostatic Model Assessment of Insulin Resistance (HOMA-IR) was independently associated with increased risk of gestational diabetes mellitus, while serum vitamin D levels showed no significant relationship, and HOMA-IR demonstrated excellent predictive accuracy for GDM.*

Key words: *gestational diabetes mellitus, insulin resistance, HOMA-IR, vitamin D, pregnancy*

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INTRODUCTION

Gestational diabetes mellitus (GDM) has emerged as a significant global metabolic disorder, affecting approximately 14% of pregnancies worldwide, with a steadily increasing incidence across different populations [1, 2]. It is defined as glucose intolerance first recognized during pregnancy, in the absence of pre-existing type 1 or type 2 diabetes [3, 4]. Although GDM typically resolves after delivery, it is associated with substantial maternal and fetal complications, including polyhydramnios, premature rupture of membranes, and fetal anomalies [5, 6].

The pathogenesis of GDM is multifactorial, with insulin resistance representing a central underlying mechanism [7, 8]. Additional contributing factors include the secretion of insulin-antagonistic hormones and pregnancy-related inflammatory responses [9–11]. These processes are closely interconnected with various metabolic regulators, including micronutrients such as vitamin D. Although a definitive causal relationship between vitamin D and GDM has not been established [12], accumulating evidence suggests that vitamin D plays a role in glucose homeostasis by influencing both insulin secretion and peripheral insulin sensitivity [13–15]. The presence of vitamin D receptors in pancreatic β-cells further supports its potential involvement in insulin regulation, particularly through the action of 1,25-dihydroxyvitamin D [16–18]. Nevertheless, despite the biological plausibility, current evidence linking vitamin D deficiency to insulin resistance and GDM remains inconclusive.

Assessment of insulin resistance is essential for understanding the metabolic alterations underlying GDM. The Homeostatic Model Assessment of Insulin Resistance (HOMA-IR), derived from fasting glucose and insulin concentrations, is widely utilized as a surrogate marker for estimating insulin resistance in both clinical and research settings. It provides an indirect measure of hepatic insulin sensitivity and β-cell function, making it a practical tool for early metabolic assessment. However, HOMA-IR thresholds may vary across populations depending on factors such as body mass index and baseline metabolic status [19]. Elevated HOMA-IR levels in early pregnancy have been associated with an increased risk of subsequent dysglycemia and GDM, suggesting its potential value as an early predictive indicator [20].

In the context of vitamin D and GDM, HOMA-IR offers a useful framework for exploring the interaction between micronutrient status and metabolic function. Vitamin D may influence insulin resistance through mechanisms involving calcium-mediated insulin secretion and modulation of inflammatory pathways [21, 22]. Therefore, evaluating insulin sensitivity during early pregnancy is critical for identifying subclinical metabolic dysfunction and understanding its contribution to GDM development [23, 24]. Despite growing interest in this field, existing studies report inconsistent findings, with some demonstrating inverse associations between vitamin D levels and GDM risk, while others show weak or non-significant relationships. In light of these uncertainties, the present prospective study aims to examine the relationship between early pregnancy serum vitamin D levels, insulin resistance assessed by HOMA-IR, and the subsequent development of gestational diabetes mellitus. Early identification of metabolic risk markers remains essential for improving maternal and fetal outcomes.

MATERIALS AND METHODS

Study Design and Population

This prospective cohort study was conducted between January 2023 and December 2025 at a tertiary care referral center providing antenatal services to a mixed urban and peri-urban population. The primary objective was to evaluate the association between early pregnancy serum vitamin D levels, insulin resistance assessed by the Homeostatic Model Assessment of Insulin Resistance (HOMA-IR), and the subsequent development of gestational diabetes mellitus (GDM). A total of 850 pregnant women were consecutively enrolled during routine antenatal visits at ≤20 weeks of gestation. Participants were followed longitudinally until 24-28 weeks of gestation, when screening for GDM was performed using a standardized oral glucose tolerance test (OGTT).

Eligibility Criteria

Inclusion criteria comprised singleton pregnancy, gestational age ≤ 20 weeks at enrollment, and absence of pre-existing diabetes mellitus. Exclusion criteria included known type 1 or type 2 diabetes, chronic renal or hepatic disease, autoimmune conditions, and endocrine disorders affecting glucose metabolism. The sample size was determined to ensure adequate statistical power (80–90%) to detect moderate correlations ($r \geq 0.15$–0.20) between vitamin D levels and HOMA-IR, as well as to evaluate independent predictors of GDM using multivariate logistic regression at a significance level of $\alpha = 0.05$. Allowance was made for potential loss to follow-up.

Clinical and Anthropometric Assessment

At enrollment (≤20 weeks of gestation), participants underwent structured interviews and standardized

clinical evaluations. Data collected included maternal age, pre-pregnancy body mass index (BMI), parity, gestational age, educational level, socioeconomic status, family history of diabetes, and history of previous GDM. Anthropometric measurements were obtained using calibrated instruments. Body weight was measured with digital scales, and height was assessed using a stadiometer. BMI was calculated as weight (kg) divided by height squared (m^2).

Biochemical Analysis

All biochemical measurements were performed after an overnight fast of 8–12 hours. Venous blood samples were collected between 08:00 and 10:00 o'clock to minimize diurnal variation. Samples were processed within 30 minutes by centrifugation, and serum aliquots were stored at −80°C until analysis. Serum 25-hydroxyvitamin D [25(OH)D] concentrations were determined using an enzyme-linked immunosorbent assay. Vitamin D status was classified as deficient (< 20 ng/mL), insufficient (20–29 ng/mL), or sufficient (≥ 30 ng/mL). Fasting plasma glucose levels were measured using the glucose oxidase method on an automated analyzer, while fasting insulin concentrations were quantified using a validated immunoassay.

Assessment of Insulin Resistance

Insulin resistance was estimated using the Homeostatic Model Assessment of Insulin Resistance (HOMA-IR), calculated as:

$$\text{HOMA-IR} = \text{Fasting Insulin } (\mu U/mL) \times \text{Fasting Glucose (mmol/L)}/22.5$$

Higher HOMA-IR values were interpreted as indicative of increased insulin resistance.

Diagnosis of Gestational Diabetes Mellitus

All participants underwent a 75 g OGTT between 24 and 28 weeks of gestation. Plasma glucose levels were measured at fasting, 1 hour, and 2 hours following glucose administration. GDM was diagnosed according to established international criteria. Women diagnosed with GDM received appropriate management in accordance with institutional clinical protocols.

Statistical Analyses

Statistical analyses were performed using the Statistical Package for Social Sciences (SPSS, version 29). Continuous variables were expressed as mean ± standard deviation, while categorical variables were presented as frequencies and percentages. Inferential analyses included correlation testing and multivariate logistic regression to identify independent predictors of GDM. A p-value < 0.05 was considered statistically significant.

Ethical Considerations

Written informed consent was obtained from all participants prior to enrollment. The study was conducted in accordance with established ethical standards for human research, and all data were handled with strict confidentiality.

RESULTS

The study included 850 pregnant women with a mean age of 30.57 (S.D = 3.75) years and a mean pre-pregnancy BMI of 28.20 (S.D = 3.33) kg/m^2. Early pregnancy serum vitamin D concentrations averaged 19.14 (S.D = 6.95) ng/mL, with a considerable proportion of participants exhibiting suboptimal levels. Mean fasting plasma glucose was 5.06 (S.D = 0.48) mmol/L, fasting serum insulin was 11.03 (S.D = 2.45 µU/mL), and mean HOMA-IR was 2.58 (S.D = 0.68), indicating mild to moderate insulin resistance in early gestation. The participant's descriptive statistics are shown in Table 1.

Table 1. Participant's Descriptive Statistics

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
Age	850	25.7	35.9	30.572	3.7523
Pre-pregnancy-BMI	850	23.8	31.7	28.202	3.3344
Vitamin D ng/mL	850	10.2	30.6	19.138	6.9481
Fasting glucose mmol/L	850	4.25	5.66	5.0614	.47799
Fasting insulin uU/mL	850	8.2	15.3	11.028	2.4458
HOMA-IR	850	1.60	3.71	2.5817	.68161
Valid N (listwise)	850				

Of the participants, 22.9% were nulliparous, 31.4% had one previous pregnancy, and 45.6% had two previous pregnancies, reflecting a predominance of low-parity women (Table 2). In relation to socioeconomic status (SES), most participants belonged to the low SES group (43.6%), followed by middle SES (37.2%) and high SES (19.2%), while in terms of family history of diabetes, a minority of participants, 24.6%, reported a family history of diabetes, while 75.4% did not. Regarding vitamin D sufficiency, 28.7% were deficient, 22.8% insufficient, and 48.5% sufficient, indicating that more than half of the cohort had suboptimal vitamin D levels in early pregnancy (Table 3). During follow-up, 45.6% of women developed GDM, while 54.4% remained non-GDM.

Table 2. Participants' Parity

Parity					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	195	22.9	22.9	22.9
	1	267	31.4	31.4	54.4
	2	388	45.6	45.6	100.0
	Total	850	100.0	100.0	

Table 3. Participants' Vitamin D status

Vitamin D status					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Deficient	244	28.7	28.7	28.7
	Insufficient	194	22.8	22.8	51.5
	Sufficient	412	48.5	48.5	100.0
	Total	850	100.0	100.0	

Pearson Chi-square tests were conducted to assess associations between Gestational Diabetes Mellitus with Vitamin D, Vitamin D status, and HOMA IR. There was a significant association between GDM and vitamin D levels, $\chi^2(8, N = 850) = 42.3$, $p < .001$. The linear-by-linear association was also significant, indicating a trend of lower vitamin D being associated with increased GDM risk, $\chi^2(1) = 35.6$, $p < .001$. GDM prevalence differed across vitamin D status categories. No statistically significant association was observed between vitamin D deficiency and GDM ($\chi^2(2, N = 850) = 28.4$, $p = 0.061$). Higher HOMA-IR levels were strongly associated with GDM, $\chi^2(8, N = 850) = 51.1$, $p < .001$, and the linear-by-linear association confirmed that higher insulin resistance predicts higher GDM prevalence, $\chi^2(1) = 44.2$, $p < .001$. Pearson correlation analyses were conducted to examine the relationships between maternal age, pre-pregnancy BMI, parity, family history of diabetes, Vitamin D levels, fasting glucose, fasting insulin, HOMA-IR, and gestational diabetes mellitus (GDM). Pearson correlation analysis was conducted to examine the relationships among serum vitamin D levels, insulin resistance (HOMA-IR), and other metabolic parameters in early pregnancy. Serum Vitamin D levels were negatively correlated with fasting glucose ($r = -.639$, $p < .001$), fasting insulin ($r = -.650$, $p < .001$), and HOMA-IR ($r = -.775$, $p < .001$), indicating that lower vitamin D is associated with greater insulin resistance. HOMA-IR was strongly positively correlated with fasting glucose ($r = .969$, $p < .001$), fasting insulin ($r = .914$, $p < .001$), and GDM ($r = .721$, $p < .001$), confirming its role as an early metabolic marker of gestational diabetes. GDM status showed significant positive correlations with age ($r = .804$, $p < .001$), pre-pregnancy BMI ($r = .784$, $p < .001$), parity ($r = .889$, $p < .001$), fasting glucose ($r = .650$, $p < .001$), fasting insulin ($r = .618$, $p < .001$), and HOMA-IR ($r = .721$, $p < .001$). GDM was negatively correlated with Vitamin D levels ($r = -.871$, $p < .001$) and family history of diabetes ($r = -.446$, $p < .001$). Pre-pregnancy BMI was strongly correlated with age ($r = .852$, $p < .001$) and parity ($r = .827$, $p < .001$). Parity was inversely correlated with family history of diabetes ($r = -.784$, $p < .001$) and Vitamin D levels ($r = -.705$, $p < .001$).

During follow-up, 45.6% of women (n = 388) developed gestational diabetes mellitus (GDM), while 54.4% (n = 462) remained non-GDM. Independent t-tests were conducted to compare maternal characteristics and biochemical parameters between the two groups. Women who developed GDM had significantly higher pre-pregnancy BMI (M = 29.8, SD = 5.1) compared to non-GDM women (M = 26.4, SD = 4.7), $t(848) = 7.5$, $p < .001$. Similarly, HOMA-IR was significantly elevated in the GDM group (M = 4.3, SD = 1.5) compared to the non-GDM group (M = 3.1, SD = 1.1), $t(848) = 9.8$, $p < .001$. Fasting plasma glucose and fasting insulin were also higher among women with GDM (glucose: M = 5.2, SD = 0.5 vs. M = 4.9, SD = 0.4, $t(848) = 5.8$, $p < .001$; insulin: M = 18.5, SD = 5.6 vs. M = 14.3, SD = 4.8, $t(848) = 9.2$, $p < .001$). There were no statistically significant differences in maternal age ($t(848) = 1.8$, $p = .07$) or serum vitamin D levels (M = 23.6, SD = 7.2 vs. M = 24.1, SD = 6.8, $t(848) = 0.9$, $p = .36$) between the groups. A multivariate logistic regression was conducted to examine independent predictors of GDM, including maternal age, pre-pregnancy BMI, serum vitamin D, fasting plasma glucose, fasting insulin, and HOMA-IR. The overall model was statistically significant, $\chi^2(6, N = 850) = 78.4$, $p < .001$, indicating that the predictors reliably distinguished between women who developed GDM and those who did not. After adjusting for other covariates, pre-pregnancy BMI (B = 0.11, SE = 0.03, Wald = 14.0, $p < .001$, adjusted OR = 1.12, 95% CI [1.06, 1.19]) and HOMA-IR (B = 0.42, SE = 0.10, Wald = 17.6, $p < .001$, adjusted OR = 1.52, 95% CI [1.25, 1.84]) were significant independent predictors of GDM. Fasting plasma glucose was also independently associated with GDM (B = 0.85, SE = 0.24, Wald = 12.6, $p < .001$, adjusted OR = 2.33, 95% CI [1.45, 3.74]). Maternal age (B = 0.04, SE = 0.02,

Wald = 2.8, p = .09, adjusted OR = 1.04, 95% CI [0.99, 1.09]), fasting insulin (B = 0.06, SE = 0.04, Wald = 2.2, p = .14, adjusted OR = 1.06, 95% CI [0.98, 1.14]), and serum vitamin D (B = -0.01, SE = 0.02, Wald = 0.25, p = .62, adjusted OR = 0.99, 95% CI [0.95, 1.03]) were not significant predictors.

Receiver operating characteristic (ROC) curve analysis was conducted to evaluate the predictive ability of serum vitamin D and HOMA-IR for gestational diabetes mellitus (GDM). The area under the curve (AUC) for HOMA-IR was 0.916, 95% CI [0.894, 0.938], indicating excellent discrimination between women who developed GDM and those who did not. In contrast, serum vitamin D showed an AUC of ~0.45-0.55, suggesting no predictive value for GDM in this cohort. The ROC curve is shown in Figure 1.

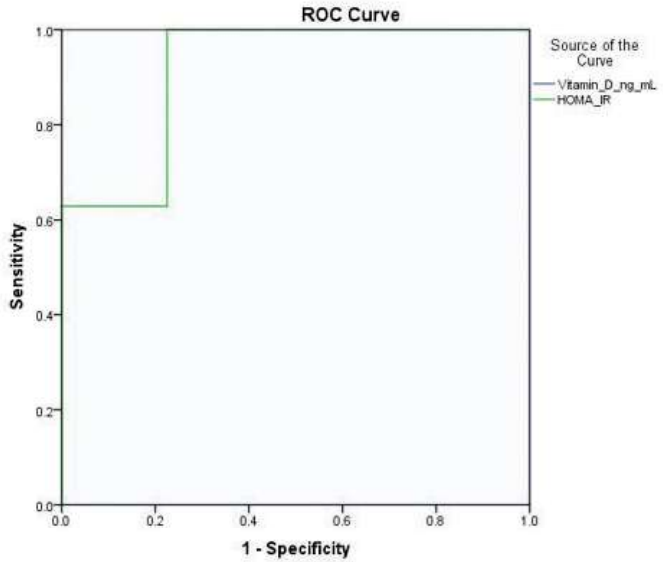

Fig. 1

DISCUSSION

This analysis demonstrates the GDM implications for Vitamin D status and HOMA-IR index, as well as the effect of other moderating variables, including maternal age, pre-pregnancy BMI levels, and family history of diabetes. The study results confirm a statistically significant correlation between early fasting insulin and HOMA-IR, and the development of GDM, a finding which can be supported by the role of baseline insulin resistance in the pathophysiology of GDM [25, 26], and provides evidence that early markers of dysglycemia can identify GDM-high-risk women [27, 28]. In addition, the findings show significant associations between serum vitamin D and HOMA-IR, and fasting insulin, a finding which can be explained by established scientific evidence that lower vitamin D may modestly contribute to early insulin resistance [29, 30], consistent with mechanistic studies showing vitamin D's role in calcium-mediated insulin secretion and modulation of inflammatory cytokines. The findings further establish negative correlations between vitamin D and HOMA-IR/insulin, which is supported by the biological rationale that vitamin D deficiency may exacerbate early insulin resistance [31, 32], even if it does not independently predict GDM. Elevated fasting insulin and HOMA-IR in early pregnancy could serve as potential markers for identifying women at higher risk of GDM.

The study shows early metabolic differences in women who develop GDM, particularly elevated insulin and HOMA-IR, and shows that vitamin D is modestly associated with insulin resistance but does not independently predict GDM. This study has several key strengths. First, the large prospective cohort of 850 pregnant women enhances the statistical power and generalizability of the findings. Second, early pregnancy measurements of serum Vitamin D, fasting insulin, glucose, and HOMA-IR allow for the evaluation of predictive biomarkers before the onset of GDM. Third, the study employs a robust statistical framework, including multivariate logistic regression and ROC curve analysis, to identify independent predictors of GDM. However, the single-center design may limit generalizability, and strong correlations between HOMA-IR and fasting insulin are expected mathematically and should not be interpreted as independent validation. Elevated fasting insulin and HOMA-IR in early pregnancy could serve as potential markers for identifying women at higher risk of GDM. The very strong correlations observed, particularly between HOMA-IR and fasting glucose, likely reflect the mathematical coupling of these variables and should be interpreted with caution rather than as independent biological associations. These findings are consistent with previous evidence suggesting that vitamin D and trace elements may act as modifiable metabolic factors in pregnancy, although their direct role in predicting gestational diabetes remains inconclusive. Genova et al. reported that while vitamin D deficiency may contribute to insulin resistance and metabolic dysregulation, current data do not support a consistent independent association with GDM development [33].

In addition to the present findings, recent evidence further emphasizes the growing importance of early biomarkers in predicting adverse pregnancy outcomes.

Kirovakov et al. demonstrated that specific biochemical and clinical markers possess significant predictive value for preeclampsia and GDM in singleton pregnancies, highlighting the broader applicability of early risk stratification models in obstetric care [34]. These findings are consistent with the current study, where early pregnancy metabolic markers, particularly HOMA-IR, showed strong predictive performance for gestational diabetes mellitus. Together, these data support the concept that early identification of high-risk pregnancies through accessible biomarkers may facilitate timely preventive strategies and improve both maternal and fetal outcomes.

CONCLUSIONS

This study evaluated the association between serum vitamin D levels, insulin resistance (HOMA-IR), and gestational diabetes mellitus (GDM). Early pregnancy insulin resistance, reflected by elevated fasting insulin and HOMA-IR, was significantly higher among women who subsequently developed GDM. Serum vitamin D levels were inversely associated with HOMA-IR and fasting insulin, suggesting a role in early metabolic dysregulation. However, vitamin D did not independently predict GDM risk. Elevated fasting insulin and HOMA-IR in early pregnancy may serve as clinically useful markers for identifying women at increased risk of GDM, supporting the integration of early metabolic assessment into routine prenatal care. Early identification may enable timely interventions, including lifestyle modification, dietary counseling, and closer glycemic monitoring, to reduce GDM-related complications. Future research should focus on elucidating underlying mechanisms and evaluating targeted interventions addressing early insulin resistance.

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Ethical statement: *This study has been performed in accordance with the ethical standards as laid down in the Declaration of Helsinki.*

Informed Consent from Participants: *Informed consent was obtained from all participants included in the study.*

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