Analysis of the Relationship Between Vitamin D Levels and Dental Caries

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Submitted: 10-11-2024 Accepted 15-01-2025 Published: 22-01-2025

Abstract: Background: Vitamin D is essential for calcium regulation and bone health, with growing evidence of its role in dental health, including the prevention of dental caries. Dental caries, a widespread condition, disproportionately affects populations with low socioeconomic status (SES) and poor nutritional habits. This study investigates the association between vitamin D levels and the prevalence of dental caries, emphasizing its implications for public health.

Methods: This study was conducted using data from 12,000 participants . Serum 25(OH)D levels were categorized into sufficiency, insufficiency, moderate deficiency, and severe deficiency. Dental health was assessed using the Decayed, Missing, and Filled Teeth (DMFT) index and untreated caries prevalence. Covariates such as SES, dietary sugar intake, and BMI were included. Statistical analyses involved logistic and Poisson regression models, adjusting for demographic and behavioral factors.

Results: Severe vitamin D deficiency (<25 nmol/L) significantly increased the odds of untreated caries (adjusted OR = 1.95, 95% CI: 1.64–2.33) compared to vitamin D sufficiency (>75 nmol/L). Higher DMFT scores and untreated caries prevalence were observed in populations with lower SES, high BMI, and low parental education. The prevalence of vitamin D sufficiency was highest among individuals with higher education and income levels, highlighting disparities in nutritional and dental health.

Conclusion: This study underscores the significant association between vitamin D deficiency and dental caries, emphasizing the need for targeted public health interventions to address nutritional and socioeconomic disparities. Promoting adequate vitamin D levels through dietary interventions and education could reduce caries prevalence and improve overall oral health outcomes. Future research should explore causal relationships and evaluate the efficacy of vitamin D supplementation in diverse populations.

Keywords: Vitamin D Deficiency, Dental Caries, Socioeconomic Disparities in Oral Health.

1. Introduction

Vitamin D, a fat-soluble vitamin, is vital for maintaining overall well-being, particularly in bone health and immune system regulation. It is primarily produced in the skin upon exposure to sunlight and can also be sourced from foods and supplements [1]. A critical role of vitamin D is in maintaining calcium balance, essential for healthy skeletal function. Its significance in preventing rickets and promoting bone development has been acknowledged since the 1930s [2]. By facilitating calcium absorption in the small intestine [3], vitamin D aids in the formation of hydroxyapatite crystals, which contribute to bone strength. Therefore, adequate intake of both calcium and vitamin D is essential for proper bone mineralization [3].

Recently, the relationship between vitamin D and dental caries has drawn considerable attention due to its implications for oral health. Dental caries, commonly known as tooth decay, is a widespread chronic condition affecting individuals across various age groups [4]. It can be particularly severe in young children, impacting primary teeth during infancy and early childhood [5]. Numerous factors contribute to the risk of dental caries, including the presence of cariogenic bacteria, inadequate salivary flow, insufficient fluoride exposure, poor oral hygiene practices, suboptimal infant-feeding habits, and socioeconomic challenges [5].

Education and economic factors often influence oral health practices, with limited access to preventive dental care such as fluoride treatments, oral hygiene guidance, and nutritional advice being more common among individuals with lower educational and income levels [6, 7]. Populations facing such challenges are often reliant on diets high in processed and sugary foods, which lack essential nutrients like vitamin D [8, 9]. Processed sugars, composed largely of sucrose, are abundant in these diets [10]. Sucrose encourages the growth of Streptococcus mutans, a bacterium that ferments sugars into acids, reducing oral pH and facilitating enamel demineralization, which accelerates the development of cavities [11, 12]. Additional risk factors for dental caries include poor oral hygiene, unhealthy eating patterns (including disordered eating), and shifts in oral microbial composition [13]. Parental oral hygiene practices significantly influence children's habits, including brushing frequency, duration, and technique, as well as the areas of the mouth most often cleaned [14]. Enhancing access to dental care through affordable insurance options and the integration of oral and general healthcare services could help address these issues [15].

Emerging evidence highlights a strong association between vitamin D levels and the occurrence of dental caries [16, 17]. A systematic review of clinical trials revealed that vitamin D supplementation could lower the risk of caries by nearly half [18]. Vitamin D deficiencies have been linked to decreased activity of antimicrobial peptides such as cathelicidins and defensins, reduced saliva production, and lower calcium levels in saliva [19, 20]. Adequate levels of vitamin D may support tooth mineralization, bolster immune defenses, and regulate inflammatory processes, thereby reducing caries risk [21]. Furthermore, vitamin D plays a crucial role in calcium utilization, essential for maintaining normal salivary composition and electrolyte balance in the parotid gland [22]. Factors like low saliva flow rates and increased saliva thickness are known to elevate caries risk [23].

While research has extensively examined the role of vitamin D supplementation in preventing dental caries [18, 24], the broader determinants of caries development, including biological, environmental, and behavioral factors, are often overlooked. A more comprehensive understanding of these interactions is essential for designing effective preventive strategies [25, 26]. This study aims to delve deeper into the role of vitamin D in dental caries and identify opportunities for improving prevention and management approaches.

2. Materials and Methods

This study relied on data collected from a comprehensive health and nutrition survey. The survey used a stratified multistage probability sampling approach to obtain representative data from the general non-institutionalized population. Data collected included interviews, physical examinations, and laboratory tests, ensuring standardized assessments. The inclusion of data allowed for detailed analysis due to the availability of additional demographic variables and precise oral health assessments. included approximately 10,000 participants, with response rates of 72.6% (2011–2012), 71.0% (2013–2014), and 61.3% (2015–2016) [27].

For this study, we analyzed participants with complete data on vitamin D levels and oral health, initially including 15,000 individuals. After excluding 3,000 participants with incomplete records, the final sample size was 12,000.

Dental caries were assessed by licensed professionals trained in survey-specific protocols, using specialized tools at designated health centers. Two primary indicators were examined: the decayed, missing, and filled teeth (DMFT) index and the presence of untreated caries. Untreated caries were defined as at least one tooth surface or root tip showing a condition score of 0 to 4, indicative of untreated decay [29].

Vitamin D levels, the independent variable, were quantified by measuring serum 25(OH)D concentrations, including both 25(OH)D2 and 25(OH)D3, using advanced chromatographic techniques [30]. Vitamin D status was categorized into severe deficiency (<25 nmol/L), moderate deficiency (25–50 nmol/L), insufficiency (50–75 nmol/L), and sufficiency (>75 nmol/L) [31, 32, 33, 34].

Several potential confounding factors were accounted for, including demographic information, body mass index (BMI), dietary sugar intake, and socioeconomic status (SES). SES was assessed using the poverty income ratio (PIR), categorized into low income (PIR ≤ 1.3), middle income (PIR > 1.3–3.5), and high income (PIR > 3.5) [35, 36, 37]. Demographic data included age, gender, race/ethnicity, and the highest family educational attainment (<9th grade, 9th–11th grade, high school graduate or equivalent, some college, or college graduate and above).

Dietary sugar intake was estimated using a food composition database, which quantifies added sugar content in foods and beverages in teaspoon equivalents (1 tsp. eq. = 4.2 g sugar). Added sugars included those incorporated during food processing, preparation, or consumption [38, 39, 40].

Height and weight measurements were collected using standardized procedures by trained personnel. Height was measured with a stadiometer, while weight was recorded using calibrated digital scales. BMI categories included underweight (<18.5), normal weight (18.5–25), and overweight (>25) [34, 41].

Statistical Analyses

Comparative analyses for categorical variables were conducted using Chi-square tests, while continuous variables were analyzed using the Mann–Whitney U test for two-group comparisons and the Kruskal–Wallis test for comparisons across more than two groups. When significant differences were detected in Kruskal–Wallis tests, post-hoc analysis using Dunn's multiple comparison test was performed.

Logistic regression models were employed to evaluate the relationship between vitamin D levels and untreated caries, presenting results as odds ratios (ORs) with 95% confidence intervals. Poisson regression was utilized to assess the association between vitamin D levels and overall caries experience, with results expressed as rate ratios (RRs).

3. Results

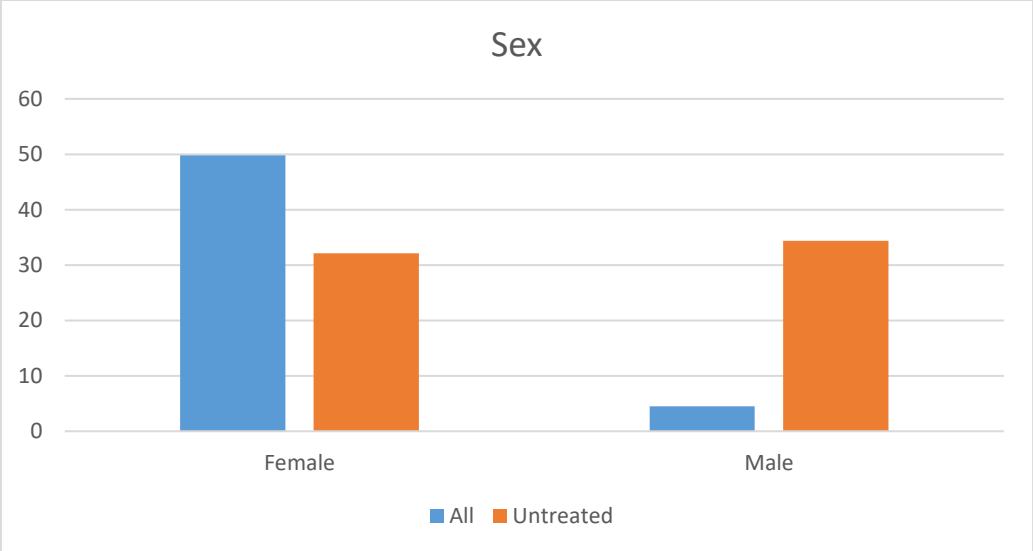
Data from 12,000 participants were analyzed. The mean DMFT score was 10.34 (SD = 8.14), with a 33.2% prevalence of untreated dental caries. The participants had a mean age of 35.33

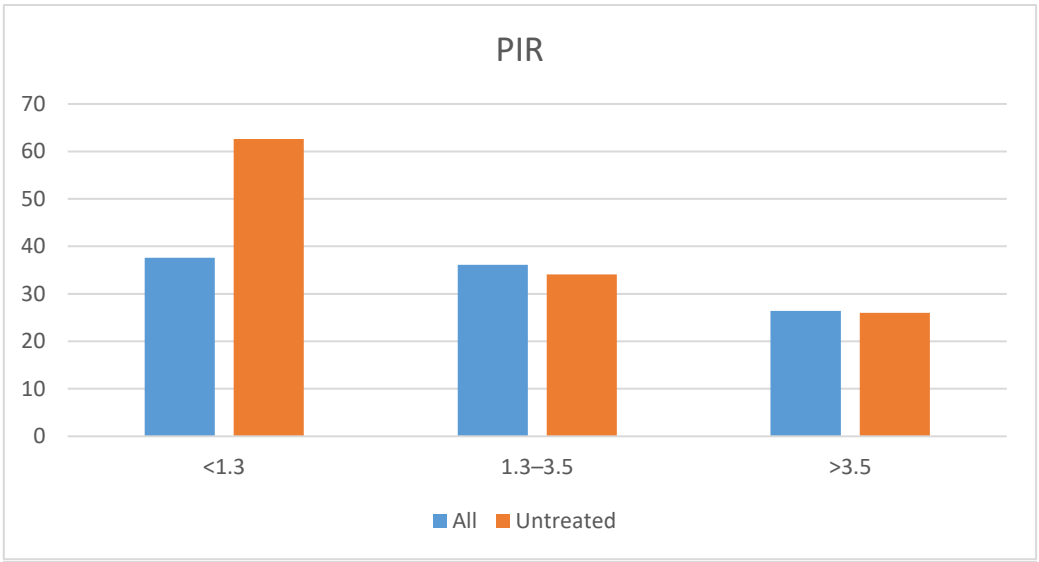
years (SD = 23.30), and females comprised 50.2% of the sample. The average intake of added sugars was 72.67 g (SD = 64.72).

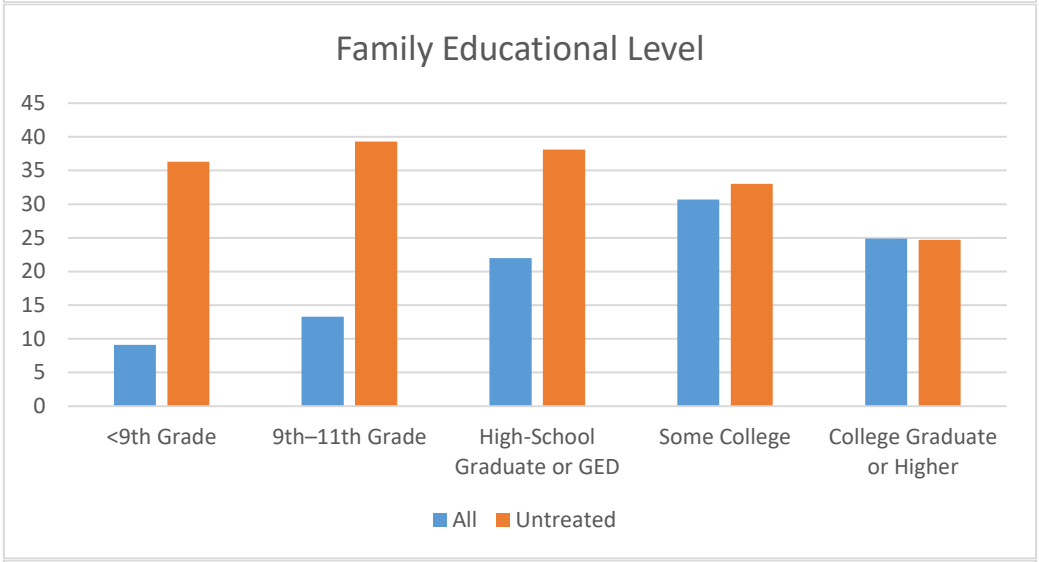
Table 1 presents the bivariable analysis of untreated dental caries, revealing significant associations with all examined demographic factors, including the PIR and BMI. The findings indicate higher occurrences of untreated dental caries in males (34.4%), in individuals from lower socioeconomic backgrounds (62.6%), in children of parents with a lower educational level (specifically those who completed 9th to 11th Grade, at 39.3%), and in participants with a higher BMI (39.8%).

Table 1. Prevalence of untreated caries and DMFT score according to sociodemographic variables

Variables	(%)	Untreated Caries (%)	p-Value	DMFT Mean (SD)	Median (Range)	p-Value
Sex						
Female	(50.20)	(32.10)	0.02 *	10.46 (7.99)	8 (27)	<0.05 a
Male	(49.80)	(34.40)		10.21 (8.29)	8 (27)	
PIR						
<1.3	(37.60)	(62.60)	<0.05 *	10.51 (8.60)	8 (27)	0.83 b
1.3–3.5	(36.10)	(34.10)		10.38 (8.26)	8 (27)	
>3.5	(26.40)	(26.00)		10.01 (7.21)	9 (27)	
Family Educational Level						
<9th Grade	(9.10)	(36.30)	<0.05 *	10.93 (9.04)	8 (27)	<0.05 b
9th–11th Grade	(13.30)	(39.30)		11.43 (8.77)	9 (27)	
High-School Graduate or GED	(22.00)	(38.10)		10.77 (8.34)	8 (27)	
Some College	(30.70)	(33.00)		10.17 (7.96)	8 (27)	
College Graduate or Higher	(24.90)	(24.70)		9.19 (7.17)	7 (27)	
Body Mass Index						
<18.5	(16.50)	(17.60)	<0.05 *	5.40 (5.30)	4 (27)	<0.05 b
18.5–25	(30.80)	(30.20)		9.46 (7.85)	7 (27)	
>25	(52.70)	(39.80)		11.52 (8.29)	10 (27)	







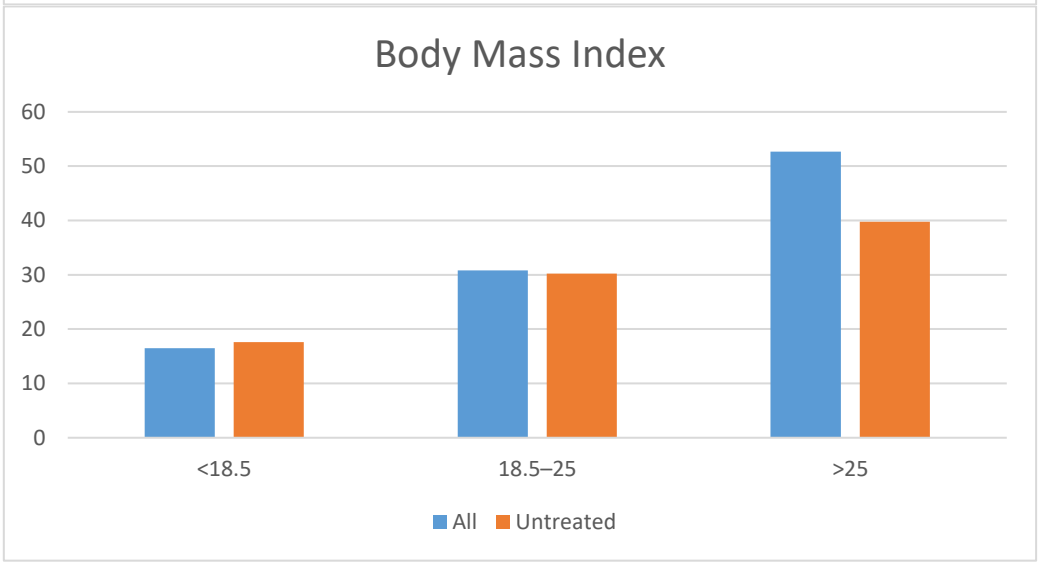


Table 1 also reports the DMFT scores, showing higher averages in females (mean = 10.46, SD = 7.99). Significant differences were observed across family educational level and BMI categories. Notably, participants with parents who had lower educational levels (9th–11th Grade: mean = 11.43, SD = 8.77) and participants with the highest BMI (mean = 11.52, SD = 8.29) recorded greater DMFT scores. Following significant findings from the omnibus test, the

post hoc test demonstrated significant differences in DMFT scores between all groups pairwise except the following:

1. <9th Grade and Some College groups ($p > 0.05$).
2. High-School Graduate or GED and <9th Grade groups ($p > 0.05$).
3. High-School Graduate or GED and Some College groups ($p > 0.05$).
4. <9th Grade and 9th–11th Grade groups ($p > 0.05$).

The total sample comprises 12,000 participants, with vitamin D sufficiency (>75 nmol/L) observed in 28.90% of participants and severe deficiency (<25 nmol/L) in 3.50%.

Among females, vitamin D sufficiency was 30.70%, compared to 27.10% in males, with no significant difference observed between sexes ($p = 0.30$). PIR levels showed a significant association with vitamin D status ($p < 0.05$), with higher PIR (>3.5) correlating with greater sufficiency (38.90%) and lower rates of severe deficiency (2.20%). Conversely, participants in the lowest PIR group (<1.3) exhibited higher rates of severe deficiency (4.30%) and lower sufficiency (22.20%).

Educational attainment revealed a strong correlation with vitamin D levels ($p < 0.05$). Those with a college degree or higher had the highest sufficiency (37.00%) and the lowest severe deficiency (2.50%), while individuals with less than a 9th-grade education had the highest severe deficiency rate (2.80%) and the lowest sufficiency (19.80%). BMI also demonstrated a significant association ($p < 0.05$), with vitamin D sufficiency decreasing as BMI increased. Individuals with a BMI >25 had the highest rates of severe deficiency (4.50%) and the lowest sufficiency (27.10%), while participants with a BMI <18.5 showed the highest sufficiency (31.00%).

Vitamin D sufficiency (>75 nmol/L) is used as the reference category.

For untreated caries, severe vitamin D deficiency (<25 nmol/L) was strongly associated with increased odds, with adjusted odds ratios (OR) of 2.22, 2.26, and 1.95 across Models 1, 2, and 3, respectively, indicating a consistent and significant relationship ($p < 0.05$). Moderate deficiency (25–50 nmol/L) also showed increased odds across all models (OR = 1.42, 1.53, and 1.36; $p < 0.05$). Mild insufficiency (50–75 nmol/L) showed a smaller, yet significant increase in risk (OR = 1.11, 1.28, and 1.21; $p < 0.05$). These findings indicate a dose-dependent relationship, with more severe deficiencies correlating with higher risk.

For caries, a similar trend was observed. Severe deficiency (<25 nmol/L) was associated with lower odds in the unadjusted model (OR = 0.73) but higher odds after adjustment for demographics and other factors in Models 2 and 3 (OR = 1.29 and 1.25, respectively; $p < 0.05$). Moderate deficiency (25–50 nmol/L) showed a comparable pattern, with lower odds in the unadjusted model (OR = 0.78) but higher odds after adjustment (OR = 1.14 and 1.11; $p < 0.05$). These findings suggest that vitamin D insufficiency and deficiency are significant predictors of both untreated caries and caries after controlling for confounders, emphasizing the importance of vitamin D in dental health.

4. Discussion

This study identified multiple factors associated with untreated dental caries, DMFT scores, and vitamin D levels, including socioeconomic indicators, BMI, and educational background. Vitamin D is essential for calcium regulation and absorption, playing a key role in maintaining dental health. Data analysis from the NHANES dataset revealed that individuals with severe vitamin D deficiency (VDD) were over twice as likely to experience dental caries compared to those with sufficient levels. The interplay between low vitamin D levels and factors such as dietary habits and demographic variables intensifies the risk of dental caries. Previous research supports these findings, showing a strong correlation between insufficient vitamin D levels and the prevalence of untreated dental caries across diverse populations [16, 26, 42].

While most studies focus on the role of vitamin D during early development and primary dentition, its importance in adult dental health requires further investigation. One study noted that severe VDD (<25 nmol/mL) significantly increased the likelihood of caries among adults compared to sufficient levels (≥75 nmol/mL) [16]. Another study on children and adolescents highlighted similar trends, with lower vitamin D levels linked to first-molar caries [26]. This study included participants across a wide age range, with an average age of 35.33 years, highlighting that vitamin D deficiencies affect individuals of all ages.

Race and ethnicity also played a role in vitamin D levels and dental caries. Consistent with prior studies, Non-Hispanic Black participants had the highest rates of severe VDD, reflecting reduced efficiency in synthesizing vitamin D due to darker skin pigmentation [41]. Non-Hispanic Black and Mexican American groups showed a higher prevalence of untreated caries compared to Non-Hispanic White participants, possibly due to barriers such as limited access to preventive education and resources [44, 45]. Conversely, Non-Hispanic White participants demonstrated higher DMFT scores, likely reflecting greater access to restorative dental care [45]. These findings emphasize the need to address disparities in dental health care access and education.

Socioeconomic status (SES) emerged as a significant determinant of both vitamin D levels and dental health outcomes. Participants from lower-income backgrounds exhibited higher rates of untreated caries and severe VDD, consistent with prior research indicating a threefold higher prevalence of untreated caries among individuals living below the poverty line [46, 47]. Limited access to dental care and insufficient vitamin D intake are common among lower-income populations [50–52], reinforcing the importance of addressing financial and logistical barriers to improve oral health outcomes.

Parental education was another key factor influencing dental health. Individuals with parents who had lower educational attainment exhibited higher DMFT scores and rates of untreated dental caries. Conversely, higher parental education levels were associated with improved vitamin D levels and lower caries prevalence, as better-educated families are more likely to prioritize dental hygiene and seek preventive care [53, 54, 56]. These findings highlight the critical need for targeted education and intervention programs aimed at families with lower SES and educational backgrounds.

A patient-centered approach is vital for addressing these disparities. Dental professionals should assess patients holistically, considering factors such as SES, education, and nutritional status. Providing tailored advice, including strategies for improving vitamin D levels through diet and supplementation, may help mitigate the risk of dental caries in at-risk populations.

5. Conclusions

This study demonstrates a significant relationship between vitamin D levels and dental caries, with lower levels contributing to higher rates of untreated caries and elevated DMFT scores. These associations persist after adjusting for sociodemographic variables, underscoring the critical role of vitamin D in dental health. Proactive measures to maintain adequate vitamin D levels, such as dietary modifications and supplementation, could serve as effective strategies for reducing caries prevalence. Addressing disparities in education and socioeconomic status is essential for achieving equitable oral health outcomes. Future research should expand on these findings by exploring additional risk factors and evaluating interventions aimed at improving dental health.

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