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REVIEW

Does vitamin D levels influence the incidence of peri-implantitis? A systematic review of current evidence

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Abstract

To evaluate how vitamin D levels affect specifically the incidence of peri-implantitis rather than early implant failure. The comprehensive review of the literature resulted in 5 studies being included in qualitative synthesis. The Joanna Briggs Institute (JBI) checklist was applied to assess study quality, revealing that most studies had moderate to high methodological quality. Significant heterogeneity across all included studies precluded the performance of a meta-analysis. The findings indicate that both hypovitaminosis and hypervitaminosis D influence peri-implant health. Elevated 25(OH)D levels have been linked with greater marginal bone loss (MBL) and reduced implant survival, whereas low levels of vitamin D have been linked to an increased risk of peri-implant disease. Retrospective studies further indicate that reduced vitamin D status is associated with greater MBL compared with normal levels, and that vitamin D supplementation may enhance implant success. While existing evidence designates that vitamin D status may influence implant survival and peri-implant health, methodological inconsistencies limit definitive conclusions. Further research with standardized vitamin D assessment protocols, larger sample sizes, and longitudinal study designs is needed to elucidate its role in peri-implant disease prevention and implant success.

Keywords Peri-implantitis · Vitamin D · Osseointegration · Implant survival · Marginal bone loss (MBL) · Peri-implant health

Abbreviation

25(OH)D	25-Hydroxyvitamin D
MBL	Marginal bone loss
VDR	Vitamin D receptor
SNP	Single nucleotide polymorphism
PD	Probing depth
Wkm	Width of keratinized mucosa
mPI	Modified plaque index
mBI	Modified sulcus bleeding index
PI	Plaque index
GI	Gingival index
BOP	Bleeding on probing
CI	Calculus index
(N/A)	Not applicable
1,25(OH)2D3	25-Dihydroxyvitamin D3
ELISA	Enzyme-Linked Immunosorbent Assay
PCR	Polymerase Chain Reaction

1 Introduction

Peri-implantitis is a biofilm-driven inflammatory condition of the peri-implant mucosa that, when untreated, progresses to loss of supporting bone around the fixture. The consensus report of workgroup 4 of the 2017 World Workshop for the Classification of Periodontal and Peri-Implant Diseases and Conditions distinguishes it from peri-implant mucositis by the presence of progressive bone loss, while emphasizing its multifactorial etiology (Berglundh et al. 2018; Schwarz et al. 2018).

Evidence summarized in the Clinical Practice Guidelines of the European Federation of Periodontology (EFP) S3-level demonstrates that primordial prevention of peri-implantitis has not been well-established due to the absence of studies; however, regarding primary prevention, several meta-analyses have been conducted to examine the

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associated risk factors with the development of this pathological condition (Carra et al. 2023; Galarraga-Vinueza et al. 2025; Giok et al. 2024; Herrera et al. 2023). History of periodontal disease, insufficient or inadequate plaque control, and absence of regular maintenance therapy are recognized as established risk factors, while the absence or lack of keratinized mucosa, smoking, systemic conditions such as poor glycemic control, genetic polymorphisms and iatrogenic factors may also have an impact (Herrera et al. 2023; Giok et al. 2024).

The reported prevalence of peri-implantitis varies widely, primarily because of inconsistent disease definitions among published studies, highlighting the absence of a unified research standard. The updated analyses reported a prevalence of 19.53% at the patient level and 12.53% at the implant level correspondigly (Diaz et al. 2022). Notably, a cross-sectional analysis demonstrated that application of the new diagnostic criteria substantially reduces the reported prevalence of peri-implantitis (Shimchuk et al. 2021).

Vitamin D as a precursor hormone is a critical element that is involved throughout numerous biochemical processes (Sassi et al. 2018). It is a lipid-soluble vitamin, obtained through diet and cutaneous synthesis, circulates predominantly as 25-hydroxyvitamin D [25(OH)D] after hepatic conversion and it is activated in the kidney to 1,25-dihydroxyvitamin D3. Circulating 25(OH)D is the most reliable index of vitamin D status and links endocrine regulation of calcium with skeletal remodeling and immune function (Liang et al. 2023). Although vitamin D's importance is well established, definitions of adequate serum concentrations vary considerably. The US Institute of Medicine defines as deficient serum levels below 12 ng/mL, as insufficient 12–20 ng/mL, and levels above 20 ng/mL as sufficient (Ross et al. 2011; Duarte et al. 2020). In contrast, the European Calcified Tissue Society together with International Osteoporosis Foundation, the Endocrine Society, and American Geriatrics Society, sets the deficiency threshold at $\leq$ 20 ng/mL and classifies levels $\leq$ 10 ng/mL as severe deficient (Holick et al. 2011; Bouillon 2017; Lips et al. 2019). Furthermore, according to the Endocrine Society, concentrations between 21–29 ng/mL are considered insufficient, with only levels $\geq$ 30 ng/mL regarded as adequate (Holick et al. 2011).

Vitamin D exerts immunomodulatory, anti-inflammatory, and anti-proliferative effects, while mechanistically, it regulates calcium absorption and promotes bone mineralization. These particular bone-regulating properties have intrigued the dental field's interest, assuming that vitamin D may influence bone density and total mineral content (Molli 2020). Recent systematic reviews and meta-analyses have stated that patients with chronic periodontitis have significantly lower serum 25(OH)D levels compared with healthy controls (Liang et al. 2023; Machado et al. 2020; Hussein et al. 2024). This evidence has prompted both animal and human studies investigating the link between vitamin D status and implant treatment outcomes. Findings suggest that deficiency of vitamin D may impair the osseointegration process (Buzatu et al. 2024; Werny et al. 2022) and is considered a risk factor for marginal bone loss (MBL) (Garg et al. 2020; Bazal-Bonelli et al. 2022; Singh et al. 2023; Tabrizi et al. 2022; Tallon et al. 2024) as well as early implant failure (Alsulaimani et al. 2022; Tallon et al. 2024). Consequently, vitamin D supplementation has been proposed as a preventive strategy when serum levels fall below the normal range (Garg et al. 2020; Makke 2022).

With prevalence rates reaching 24%, 37%, and 40% in the United States, Canada, and Europe respectively (Amrein et al. 2020), vitamin D insufficiency constitutes a significant global health concern. Given the increasing number of dental implant procedures and the known influence of systemic factors on peri-implant tissue health, it is crucial to explore whether vitamin D status may contribute to peri-implant disease. This growing body of epidemiological evidence, combined with the biological plausibility of vitamin D involvement in bone metabolism and immune regulation, forms the basis for the present systematic review. Accordingly, the aim of this review is to investigate the association between vitamin D levels and the risk of peri-implantitis in patients with osseointegrated dental implants.

2 Methods

2.1 Protocol and study registration

The present systematic review was designed and reported in line with PRISMA 2020 guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (Page et al. 2021). The review followed a pre-established protocol registered in the PROSPERO database. If there were any deviations from the submitted protocol during the review process, they will be documented and discussed in the final report.

2.2 Eligibility criteria

This review aims to explore the association between Vitamin D levels and the risk of peri-implantitis. The eligibility criteria for including studies were defined using PICO-ST framework as follows:

P (Population/participants): Adults with osseointegrated dental implants who have low levels of vitamin D
I (Intervention/exposure): Serum vitamin D status
C (Comparators): Individuals with osseointegrated dental implants with normal levels of vitamin D
(Outcome): Peri-implantitis risk, peri-implant clinical indices, and marginal bone level.

S (Study design): Systematic review including cross-sectional, cohort, case–control studies, clinical studies and randomized controlled trials (RCTs)
T (Time frame): Studies published until December 2024

3 Inclusion criteria:

1 Human studies evaluating the association between vitamin D status (e.g., serum levels, deficiency, or supplementation) and peri-implant diseases (e.g., peri-implantitis or peri-implant mucositis)
2 Clinical studies with a follow-up and outcome assessment period of ≥ 6 months after implant loading
3 Both observational (cohort, case–control, cross-sectional) and interventional (randomized controlled) study designs
4 Studies published in English or Greek
5 Full-text articles available and peer-reviewed

4 Exclusion criteria:

1 Studies without abstracts
2 Animal and in vitro studies
3 Systematic and literature reviews
4 Grey literature sources, including unpublished or non-peer-reviewed studies
5 Studies with a follow-up period and outcome measurement duration of less than 6 months after implant loading
6 Studies investigating only the early failure of dental implants in correlation to Vitamin D levels

5 Search strategy:

A comprehensive electronic search was performed in PubMed and Scopus from 1964 to December 2024 using both keywords and MeSH terms, combined with Boolean operators for peri-implant conditions combined with terms for vitamin D, its metabolites, receptors, and supplementation. Reference lists of eligible articles were also screened. The following algorithms were applied in the advanced search:

(((((((peri implantitis[Title/Abstract]) OR (peri-implant*[Title/Abstract])) OR (Peri-implant disease[Title/Abstract])) OR (Dental implant inflammation[Title/Abstract])) OR (Peri-implant bone loss[Title/Abstract])) OR (Peri-implant infection[Title/Abstract])) OR (Peri-implant complications[Title/Abstract])) AND (((Vitamin D[Title/Abstract]) OR (Vitamin D deficiency[Title/Abstract])) OR (Vitamin D supplementation[Title/Abstract]) OR (25-hydroxyvitamin D[Title/Abstract]) OR (1,25-dihydroxyvitamin D[Title/Abstract]) OR (Vitamin D metabolism[Title/Abstract]) OR (Vitamin D receptor[Title/Abstract]))).

(TITLE-ABS-KEY (peri implantitis) OR TITLE-ABS-KEY (peri-implant*) OR TITLE-ABS-KEY ("Peri-implant disease") OR TITLE-ABS-KEY ("Dental implant inflammation") OR TITLE-ABS-KEY ("Peri-implant bone loss") OR TITLE-ABS-KEY ("Peri-implant infection") OR TITLE-ABS-KEY ("Peri-implant complications")) AND (TITLE-ABS-KEY ("Vitamin D") OR TITLE-ABS-KEY ("Vitamin D deficiency") OR TITLE-ABS-KEY ("Vitamin D supplementation") OR TITLE-ABS-KEY ("25-hydroxyvitamin D") OR TITLE-ABS-KEY ("1,25-dihydroxyvitamin D") OR TITLE-ABS-KEY ("Vitamin D metabolism") OR TITLE-ABS-KEY ("Vitamin D receptor")).

6 Study selection

The PRISMA flow diagram (Fig. 1) depicts the process of study selection. Two reviewers independently screened titles/abstracts, piloting the process on a sample set to calibrate decisions. Reference lists of the included studies were also manually screened to capture any relevant articles not identified electronically. To ensure consistency, a pilot screening of 10 studies was conducted. Two reviewers independently screened titles and abstracts. Inter-rater reliability was evaluated using the Kappa statistic showing substantial agreement ($\kappa = 0.82$), which indicates a high level of consistency in the selection process (McHugh 2012). Full texts deemed potentially eligible were assessed in duplicate against prespecified criteria, with disagreements resolved by discussion or a third reviewer.

The total of 180 records initially retrieved included both the results from the electronic PubMed and Scopus database search and additional articles identified through manual screening of the reference lists of included studies. To ensure accuracy, all identified records were imported into excel spreadsheet and a manual review was performed to further eliminate any remaining duplicates. After the removal of duplicates, 142 records remained for screening. Titles and abstracts of these records were screened, leaving 70 full-text articles for further assessment. Upon full-text review, 65 articles were excluded based on the following criteria: 37 studies were excluded due to unsuitable study design, and 28 studies were animal-based. This resulted in 5 studies being included in the qualitative synthesis.

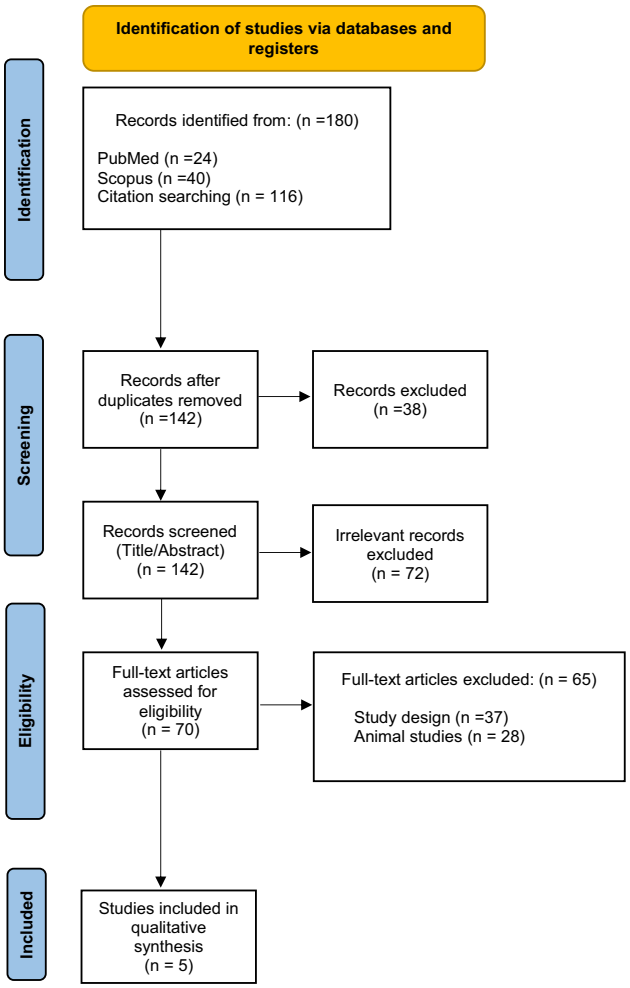

Fig. 1 Flow of records through identification, screening, eligibility, and inclusion (PRISMA 2020). Source: Page MJ, et al. BMJ 2021;372:n71. https://doi.org/10.1136/bmj.n71. This work is licensed under CC BY 4.0. To view a copy of this license, visit https://creativecommons.org/licenses/by/4.0/

7 Data collection process

Data extraction from the selected studies was conducted using standardized forms created in Excel. These forms were designed to collect information from each study, such as the country, year of publication, authors, study design, sampling method, as well as confounding factors that may influence the outcomes. It also captured inclusion and exclusion criteria for participants, along with any limitations and conflicts of interest reported in each study.

8 Risk of bias assessment

Methodological quality was appraised with the appropriate Joanna Briggs Institute (JBI) tool for cross-sectional and case–control studies (Moola et al. 2020). Items were graded as 'yes', 'no', or 'unclear' and summarized as percentage scores to categorize studies as high, moderate, or low quality.

9 Data synthesis

Given substantial heterogeneity in designs, exposure definitions, and outcome measures, we conducted a narrative synthesis of the findings rather than a meta-analysis, highlighting inconsistencies, limitations, and plausible sources of variation.

10 Handling missing data

Information that was unavailable in the included studies was reported as missing in the data synthesis, without applying any imputation techniques.

11 Publication bias assessment

Due to the limited number of included studies (five in total), an assessment of publication bias, such as Egger's test or the creation of funnel plots were not feasible. The small sample size reduces the reliability of these methods, consequently, the publication bias could not be evaluated.

12 Results

12.1 Characteristics of the included studies

12.1.1 Study location

The geographic distribution of the studies includes three countries, with most originating from Brazil (2/5) 40% (Piccolotto et al. 2019; Alvim-Pereira et al. 2008), Turkey accounts for (2/5) 40% of the studies (Acipinar et al.

2019; Ustaoğlu and Erdal 2020), while the USA contributes one study (1/5) 20% (Cheng et al. 2024). The varied demographic profiles of participants in the five reviewed studies reflect a worldwide research focus on this topic, emphasizing the important role of vitamin D in dental implantology.

12.1.2 Study designs

The included studies represent diverse methodological approaches. In total, 40% were retrospective case–control studies (Alvim-Pereira et al. 2008; Cheng et al. 2024), while 60% employed a cross-sectional design. All studies were single-centered (Acipinar et al. 2019; Piccolotto et al. 2019; Ustaoğlu and Erdal 2020).

12.1.3 Participants' characteristics

The participants' age across the included studies ranged from 25 to 80 years, with a mean of 51.7 ± 11.3 years. In contrast to the findings by Acipinar et al. (2019), where a significantly higher mean age was reported in the group of peri-implantitis compared to the healthy group ($P = 0.010$), the studies included in the present review did not consistently show such age-related differences between disease and control groups. Similarly, Acipinar et al. reported no statistically significant age differences between the peri-implant mucositis group and the other two groups ($P = 0.699$ and $P = 0.188$, respectively), consistent with the overall trend observed in the present review. All of the included studies reported a similar gender distribution across groups, except from the study of Ustaoğlu and Erdal (2020) indicating a higher proportion of female participants without providing a statistical significance value.

12.1.4 Implant system

Among the five included studies, Bicon LLC implants were used in one study (20%) (Cheng et al. 2024), the Neodent implant system (Titamax EX CM) was used in one study (20%) (Alvim-Pereira et al. 2008), and the Morse-taper connection implants (Kopp System) were used in one study (20%) (Piccolotto et al. 2019). In two of the five studies (40%), the implant system used was not specified (Acipinar et al. 2019; Ustaoğlu and Erdal 2020).

12.1.5 Time of outcome measurement and follow up

In the five included studies of this review, the evaluation of the outcome period varies. In two studies (40%), the final outcome was evaluated 36 months after implant loading and delivery of the final implant restoration (Cheng et al. 2024; Ustaoğlu and Erdal 2020). In two other studies (40%), the last evaluation was performed 12 months post-delivery (Acipinar et al. 2019; Piccolotto et al. 2019), and in one study (20%) at least 6 months post-delivery (Alvim-Pereira et al. 2008).

12.1.6 Funding and conflict of interest

Among the five included studies, two studies (40%) reported funding from institutes (Cheng et al. 2024; Alvim-Pereira et al. 2008), one study (20%) claimed financial interest in the implant system used (Alvim-Pereira et al. 2008), and one study (20%) provided vitamin D supplementation through a drugstore declaring no conflict of interest (Piccolotto et al. 2019). Two studies (40%) did not report any information regarding funding or conflict of interest (Acipinar et al. 2019; Ustaoğlu and Erdal 2020).

12.1.7 Outcome measurement methods

Various methods were employed in the included studies to assess outcomes. Among these, periapical radiographs were the most frequently used method, featured in two out of five studies (40%) in order to measure MBL monitoring the stability of the implant's surrounding bone structure (Acipinar et al. 2019; Cheng et al. 2024). In contrast, panoramic radiograph was used in only one study (20%)(Acipinar et al. 2019). The most commonly selected peri-implant indices were probing depth (PD) (4/5, 80%)(Acipinar et al. 2019; Alvim-Pereira et al. 2008; Piccolotto et al. 2019; Ustaoğlu and Erdal 2020), clinical attachment loss (CAL) (3/5, 60%) (Acipinar et al. 2019; Alvim-Pereira et al. 2008; Piccolotto et al. 2019), modified plaque index (mPI) (2/5, 40%)(Acipinar et al. 2019; Piccolotto et al. 2019), plaque index (PI) (2/5, 40%) (Alvim-Pereira et al. 2008; Ustaoğlu and Erdal 2020), gingival index (GI) (4/5, 80%) (Acipinar et al. 2019; Alvim-Pereira et al. 2008; Piccolotto et al. 2019; Ustaoğlu and Erdal 2020), modified sulcus bleeding index (mSBI) (1/5, 20%) (Acipinar et al. 2019), keratinized mucosa width (KMW) (3/5, 60%)(Acipinar et al. 2019; Piccolotto et al. 2019; Ustaoğlu and Erdal 2020), bleeding on probing (BOP) (1/5, 20%)(Ustaoğlu and Erdal 2020), calculus index (CI) (1/5, 20%)(Alvim-Pereira et al. 2008), and mobility assessment (1/5, 20%) (Alvim-Pereira et al. 2008).

12.1.8 Exposure measurement methods

In the five studies included, each used one of the following techniques to measure vitamin D levels and related parameters. The Chemiluminescence method was used in one study (Piccolotto et al. 2019), the PCR for genotype analysis of the TaqI polymorphism of the vitamin D receptor (VDR) in another (Alvim-Pereira et al. 2008), the Enzyme-Linked

Immunosorbent Assay (ELISA) for measuring FGF-23 and 25(OH)D3 in a third (Acipinar et al. 2019), the Rapid Chromatographic Immunoassay Quantitative Blood Test for measuring 25(OH)D levels in a fourth (Cheng et al. 2024), and one study does not specify which technique was used for measuring vitamin D levels from blood samples collected after a 12-h fasting period (Ustaoğlu and Erdal 2020).

12.1.9 Critical appraisal

The methodological quality of the included studies was assessed using the JBI critical appraisal tools for cross-sectional and case–control designs. The JBI critical appraisal tool was selected because it offers detailed checklists specifically designed for observational and interventional studies included in this review, allowing for a thorough and appropriate evaluation of methodological quality. The studies were scored based on these criteria:

A score of 1 point was assigned for criteria met (Yes)
A score of 0 points was given for unmet criteria (No)
A score of 0.5 points was assigned for insufficient information or unclear reporting (Unclear)

Criteria deemed not applicable (N/A) were excluded from the scoring calculation. The total score for each study was calculated as a percentage of the maximum possible points and the quality of the studies was categorized into three levels: High quality (score > 75%), moderate quality (score 50%—75%) and low quality (score < 50%).

The appraisal shows that most studies demonstrated moderate to high methodological quality. Common gaps identified included inadequate reporting of strategies to address confounding factors and not sufficient clinical follow-up periods to measure the outcome. A summary of the risk of bias assessment is presented in Table 1.

13 Synthesis of the effects

13.1 Peri-implantitis-vitamin D levels

The study by Cheng et al. (2024) investigated the effect of vitamin D levels (hypovitaminosis and hypervitaminosis D) on implant survival rate and peri-implant MBL. This retrospective case–control study analyzed 291 implants placed in 73 participants with different levels of vitamin D. The findings showed that implants in patients with hypervitaminosis D had significantly higher mean MBL 1.7mm per year ($P < 0.001$) and a reduced survival probability of 73.7% (95% CI: 56.5–84.5%) at 19 years after placement compared with those with optimum vitamin D levels. Implants placed in patients with hypovitaminosis D showed also poorer prognosis, with survival probability of 73.6% (95% CI: 32.2–92.0%) over the same period. Fisher's test did not indicate a significant correlation between low vitamin D levels and peri-implant disease ($OR = 3.9$, $P = 0.11$), however, indicated a significant correlation between elevated 25(OH)D levels and peri-implant disease ($OR = 21.1$, $P = 0.001$). The findings differed between the mandible and maxilla; implants in the maxilla had a poorer prognosis at high vitamin D levels as their average MBL rates were faster (2.5 mm/year) than those in the mandible (0.2 mm/year). The rate of MBL in the mandible was 6.0 mm/year for patients with hypovitaminosis D, while the mean bone gain in the maxilla was 0.2 mm/year ($p = 0.004$). Despite the variances, the study found that there was no significant difference in the average MBL across implant survival time, irrespective of jaw placement ($P = 0.13$).

The study by Ustaoğlu and Erdal (2020) further supported the association between vitamin D levels and peri-implant health. After adjusting for age, the lowest vitamin D levels were observed in the group of peri-implantitis ($p = 0.043$), with levels in the peri-implant mucositis group also lower than those in the healthy implant group. These findings emphasize the potential role of vitamin D in peri-implant health and disease prevention. Moreover, vitamin D levels demonstrated a negative correlation with GI values ($r = -0.191$, $p = 0.020$).

Acipinar et al. (2019) reported elevated fibroblast growth factor-23 (FGF-23) levels and reduced levels of $25(OH)D_3$ in the peri-implant fluid of patients with peri-implant disease. Specifically, the mean total amount of FGF-23 was significantly increased in the peri-implantitis group compared with the healthy implant group ($p = 0.018$), whereas vitamin D levels were significantly lower in the peri-implantitis group ($p < 0.001$).

13.2 Implant failure-polymorphism of vitamin D receptor (VDR)

The study by Alvim-Pereira et al. (2008) investigated how genetic and clinical factors influence the dental implant success and failure. The study did not find a significant association between implant failure and the TaqI polymorphism in the VDR gene ($p = 0.834$ for alleles, $p = 0.482$ for genotypes). Nonetheless, they determined that clinical parameters as primary stability ($p < 0.001$), implant placement surgical technique ($p = 0.016$), bone quantity ($p = 0.049$), and implant location appeared to be significant variables in implant survival. High rate of implant failure was observed in the posterior mandible, while longer implant lengths were associated with greater success ($p = 0.001$).

Table 1 This table provides a critical appraisal of the study design and methodology using the Joanna Briggs Institute's criteria, highlighting areas such as the comparability of groups, exposure measurement, confounding factors, outcome assessment, and statistical analysis

Study design	Author	1. Were the criteria for inclusion in the sample clearly defined?	2. Were the study subjects and the setting described in detail?	3. Was the exposure measured in a valid and reliable way?	4. Were objective, standard criteria used for measurement of the condition?	5. Were confounding factors identified?	6. Were strategies to deal with confounding factors stated?	7. Were the outcomes measured in a valid and reliable way?	8. Was appropriate statistical analysis used?	Overall appraisal score	Quality rating High: Above 75% Moderate: 50–75% Low: Below 50%		
Cross sectional	Acipinar S. et al. 2019	No	Unclear	Yes	Yes	No	No	Yes	Yes	4,5/8	Moderate		
Cross sectional	Piccolotto et al. 2019	Yes	Unclear	Yes	Yes	No	No	Yes	Yes	5,5/8	Moderate		
Cross sectional	Ustaoğlu and Erdal 2020	Yes	Unclear	Yes	Yes	Yes	Yes	Yes	Yes	7.5/8	Moderate		
Study design	Author	1. Were the groups comparable other than the presence of disease in cases or the absence of disease in controls?	2. Were cases and controls matched appropriately?	3. Were the same criteria used for identification of cases and controls?	4. Was exposure measured in a standard, valid and reliable way?	5. Was exposure measured in the same way for cases and controls?	6. Were confounding factors identified?	7. Were strategies to deal with confounding factors stated?	8. Were outcomes assessed in a standard, valid and reliable way for cases and controls?	9. Was the exposure period of interest long enough to be meaningful?	10. Was appropriate statistical analysis used?	Overall appraisal score	Quality rating High: Above 75% Moderate: 50–75% Low: Below 50%
retrospective case–control	Cheng et al. 2024	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	Yes	8,5/10	High
retrospective case–control	Alvim-Pereira et al. 2008	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	Yes	9,5/10	High

13.3 Marginal bone loss- vitamin D levels in combination with vitamin D supplements

The effects of vitamin D deficiency and supplementation on outcomes in patients with osseointegrated implants were examined in the study by Piccolotto et al. (2019). Following supplementation, the study found no significant differences in MBL, PD, mSBI, or wKM between the vitamin D-deficient and sufficient groups. Although findings of long-term effects on bone remodeling were limited due to the short study duration (8 weeks), supplementation did improve the mPI in the deficient group.

14 Discussion

Peri-implantitis is the main biological complication of dental implants, having a detrimental effect on both survival and the osseointegration process. Its development is associated with a number of tooth-related, patient-related, and iatrogenic factors that contribute to the establishment of a dysbiotic environment between the implant and the surrounding hard and soft tissues (Darby 2022). Vitamin D is one of those studied factors, as it appears to affect both implant stability via the osseointegration process and the health of peri-implant tissues. To our knowledge, this is the first review aiming to investigate the role of vitamin D in solely the incidence of peri-implantitis rather than in early implant failure. Furthermore, the review provides an analysis of the effects of vitamin D on MBL and implant survival. A notable strength of this study is the inclusion of outcome measurements across different follow-up periods, enabling insight into both short- and long-term impacts of vitamin D status. In addition, the review incorporates data on VDR polymorphisms, offering a genetic perspective, and evaluates the role of vitamin D supplementation, thereby enhancing the clinical relevance of the findings.

According to the results of the present review, the study by Cheng et al. (2024) highlighted that both hypovitaminosis and hypervitaminosis D have an impact on peri-implant MBL and implant survival. More specifically, the findings showed increased MBL in patients with hypervitaminosis D (1.7 mm/year, $P < 0.001$) and a lower probability of implant survival (73.7% over 19 years). Furthermore, patients with higher 25(OH)D levels had a 21.1-fold increase in the risk of peri-implant disease ($P = 0.001$). Individuals with low 25(OH)D levels had a 3.9 times higher likelihood of peri-implant disease ($P = 0.11$), although no statistically significant relationship was found. The failure to detect an association may be interpreted by the fact that the study groups were not equally distributed. Specifically, the hypervitaminosis D group included 31 participants, whereas the vitamin D deficiency group had only 9. Due to this small sample size, it is likely that type I statistical error could not be sufficiently minimized.

This study also examined the relationship between vitamin D levels and bone loss rate around implants. Patients with low, intermediate, and high 25(OH)D levels exhibited average annual bone loss of 1.4, 0.4, and 1.7 mm, respectively. The hypervitaminosis D group experienced a significantly higher rate of bone loss compared to the intermediate-level group ($P < 0.001$). The study included patients who had implants placed within the last three years. However, due to the retrospective nature of the study, MBL data were collected at the time of the 25(OH) D test, making it impossible to determine whether the rapid bone loss around the implants was due to a sudden increase in vitamin D levels or a result of chronic hypervitaminosis D in combination with other risk factors. Since vitamin D levels were not continuously monitored, the results can only be interpreted as short-term effects of 25(OH)D levels. As a result, without continuous measurements and evaluation of vitamin D levels, it is difficult to accurately determine the timeline of MBL. With regard to this, the average bone loss without considering the time factor might be a more reliable measure. The researchers of this study estimated that the mean MBL around implants in patients with intermediate 25(OH)D levels was 0.1 mm from the top of the implant, while the mean MBL was significantly greater (0.7 mm below the top of the implant) in patients with hypovitaminosis D ($P = 0.004$). Consistent with these findings, Singh et al. (2023) and Tabrizi et al. (2022) reported that reduced vitamin D levels were associated with greater MBL compared with normal vitamin D levels, at six and twelve months after implant loading, respectively ($P = 0.035$; $P < 0.001$). However, Tabrizi et al. (2022) found no significant difference in PD 12 months post-loading, regardless of participants' vitamin D status ($P = 0.91$).

Studies examining the relationship between vitamin D status and early implant failure indicate that insufficient vitamin D levels are associated with increased failure rates and greater MBL (Bazal-Bonelli et al. 2022). Severe vitamin D deficiency (< 10 ng/mL) has been significantly linked to a higher incidence of early implant failure compared with adequate levels (Mohsen et al. 2024). Supporting the positive role of vitamin D in implant success, several studies have reported an association between adequate vitamin D levels and improved implant stability, particularly at six months post-placement (Bhandage et al. 2022). Similarly, Al-Quisi et al. (2024) found a statistically significant positive correlation between vitamin D3 levels and successful osseointegration ($p = 0.045$), with patients exhibiting severe deficiency (< 20 ng/mL) facing an elevated risk of early implant failure.

Additionally, Markopoulos et al. (2021) indicated that while a clinical trial did not reveal a statistically significant effect of vitamin D on new bone formation in sinus augmentation procedures, retrospective studies suggest that vitamin D deficiency may increase the likelihood of early implant failure. Likewise, Pourshahidi and Yousefain (2021) and Mangano et al. (2018) reported a tendency towards higher early implant failure rates in patients with low vitamin D3 levels, although the correlation failed to establish a statistical significance. On the other hand, the systematic review by Alsulaimani et al. (2022) revealed inconsistent results between vitamin D deficiency and early implant failures highlighting a notable heterogeneity in study designs. Such variability underscores the difficulty of confirming an association in human studies, compared with the more uniform and consistent results observed in animal research (Table 2).

In addition to the effects of vitamin D levels on MBL, genetic variations related to vitamin D have been explored for their potential influence on implant outcomes. Acipinar et al. (2019) reported significantly higher total mean FGF-23 levels ($P = 0.018$) and lower $25(OH)D_3$ concentrations in the peri-implant mucosa of patients with peri-implant disease, reinforcing the association between low vitamin D and structural changes in peri-implant bone. However, no dose–response relationship was observed between the severity of periodontal disease and vitamin D levels ($P > 0.05$). Alvim-Pereira et al. (2008) examined the association between VDR polymorphisms and implant failure. The study found no significant relationship between the TaqI polymorphism and implant failure but emphasized the importance of primary stability and surgical technique. In contrast, Munhoz Pereira et al. (2019) found that specific SNPs (rs3782905, rs7136534, rs886441) were associated with an increased risk of implant failure ($OR \geq 4$), with 75% of failures occurring within the first six weeks after implant placement.

The effect of vitamin D on implant survival was also studied in relation to its supplementation. Piccolotto et al. (2019) found no significant differences in MBL or other parameters (e.g., PD) between groups with and without vitamin D supplementation. However, they stated an improvement in the mPI after eight weeks of vitamin D supplementation. In addition, vitamin D supplementation has been demonstrated to enhance new bone formation around implants and mitigate bone loss, with statistically significant findings in controlled clinical trials (Kwiatek et al. 2021). The majority of studies indicate that sufficient vitamin D levels or its supplementation can improve new bone formation, bone-to-implant contact (BIC), and overall osseointegration success (Werny et al. 2022; Javed et al. 2016). This effect appears particularly relevant in patients with systemic conditions such as osteoporosis, diabetes, and chronic kidney disease, where vitamin D supplementation may enhance the healing process and counteract the detrimental effect of these diseases on bone regeneration (Sundar et al. 2023). Notably, the combined administration of vitamin D and insulin in diabetic rats has shown synergistic benefits (Wu et al. 2013). However, certain studies did not identify statistically significant differences, potentially due to variations in study design or the localized application of vitamin D, which did not appear to deliberate the same benefits as systemic administration (Salomó-Coll et al. 2016). The available evidence suggests that evaluating and, if necessary, supplementing vitamin D may contribute to improved implant success by reducing the risk of early failure and bone loss. Although some studies have not identified statistically significant differences, the prevailing consensus indicates that vitamin D deficiency may negatively impact osseointegration and implant survival (Tallon et al. 2024; Javed et al. 2016). This underscores the need for continued research to further elucidate the exact nature of this relationship.

This review presents several limitations that may affect the generalizability of the findings. First, the sample size of the included studies is limited, which reduces the power of the conclusions. Furthermore, the studies reviewed are mostly cross-sectional, as the evaluation of periodontal and peri-implant health and the measurement of vitamin D levels were performed in the same period, causing concerns about reverse causality. It is unclear whether periodontal and peri-implant health affects vitamin D levels or vice versa. Regarding the retrospective studies, these may be subject to recall bias, as participants may not accurately remember or report their data. Additionally, the studies do not follow a longitudinal approach, as there are no multiple measurements of vitamin D levels, which is critical because vitamin D levels may be influenced by seasonal fluctuations, diet, and sun exposure. All studies used different methods to measure vitamin D without providing information on the sensitivity and specificity of these methods, making it difficult to compare their results. It is also worth noting that some studies did not control for confounding factors, which may influence the outcomes. Another limitation is that the implant placement protocol (e.g., tissue or bone level, implant surface) is not specified, which could affect the interpretation of the findings. Finally, the studies included did not use commonly accepted cutoffs for defining vitamin D levels, which creates an issue in accurately classifying the levels as deficiency, insufficiency, or sufficiency, leading to difficulties in interpreting the results.

Advancing research in this field requires addressing the methodological limitations identified in the reviewed studies. Future investigations should employ larger sample sizes and extended follow-up periods to enhance statistical power and reliability, thereby providing more robust evidence and a clearer understanding of the long-term effects of vitamin D on periodontal and peri-implant health. Additionally,

Table 2 Descriptive Results of the Systematic Review. This table summarizes the key findings from the systematic review, including the characteristics of the included studies, exposures, and outcomes measured. The results highlight the variations in study design, sample sizes, and the measurement of the interventions across different clinical studies

First Author	Country, Institution	Year	Journal	Study Design	Study Period	Single/multicenter	Sampling Method
Cheng YC	USA, Implant Dentistry Center, Boston	2024	Journal of Dentistry	Retrospective case–control	2021–2022	Single center	Random selection from database
Acipinar S	Turkey, Kirikkale University, Faculty of Dentistry	2019	Clinical Implant Dentistry and Related Research	Cross-sectional study	January 2018—July 2018	Single center	Convenience sampling
Alvim-Pereira F	Brazil, Instituto Latino Americano de Pesquisa e Ensino Odontológico (ILAPEO), Curitiba, Paraná	2008	Clinical Oral Implants Research	Retrospective case–control	1996–2006	Single center	Convenience sampling
Piccolotto A	Brazil, Dental Clinics of State University of West Parana—Unioeste, Cascavel	2019	Journal of Health Science	Cross-sectional study	2011–2013	Single center	Convenience sampling
Ustaoğlu G	Bolu, Turkey, Department of Periodontology at the Bolu Abant İzzet Baysal University	2020	Int J Implant Dent	Cross-sectional study	No reporting	Single center	Convenience sampling
Objective	Study Groups	Exposure measurement	Implant Type	Implant Surface	Implant Level	Outcome measurement	Key Findings
To investigate the correlation between hypervitaminosis D dental and implant survival	3 groups: hypervitaminosis D (> 70 ng/mL), intermediate vitamin D (> 30, ≤ 70 ng/mL), hypovitaminosis D (≤ 30 ng/mL)	25(OH)D levels measured with rapid chromatographic immunoassay quantitative blood test	Bicon LLC implants	Smooth surface	Bone level	MBL with periapical radiographs taken near the time of the 25(OH)D blood test	Patients with implant disease had 3.9 times higher hypovitaminosis D (P = .11) and 21.1 times higher hypervitaminosis D (P < .001)

Table 2 (continued)

To compare FGF-23 and 25(OH)D_3 levels in peri-implant sulcus fluid in peri-implant health and diseases	53 participants with 90 dental implant sites categorized into Peri-implant mucositis (30 sites), peri-implantitis (30 sites), peri-implant health (30 sites)	Perimplant health Clinical and Radiographic Parameters PD, CAL, S, mPI, GI, mSBI, KMW were recorded. PD, CAL, mPI, GI, and mSBI were measured at four sites per implant	No reporting	No reporting	No reporting	FGF-23 and 25(OH)D_3 Analysis PISF samples were collected from mesial and distal implant sites using paper strips inserted 1–2 mm for 30 s. Volumes were measured with a Periotron 8000 and stored at − 80 °C. FGF-23 and 25(OH)D_3 levels were determined by ELISA (CloudClone Corp., USA; Diasource ImmunoAssays SA, Belgium) with sensitivities of 6.1 pg/mL and 2.6 ng/mL, respectively	Vitamin D levels: Significantly lower in peri-implantitis vs. peri-implant mucositis and healthy groups ($P<.001$ and $P=.001$, respectively); no difference between mucositis and healthy. PISF volume: Highest in peri-implantitis, intermediate in peri-implant mucositis, lowest in healthy (all comparisons significant). FGF-23 concentration: No significant differences among groups ($F=0.904$; $P=.409$) Total FGF-23 amount: Higher in peri-implantitis vs. healthy (significant). Total vitamin D amount: Lower in peri-implantitis vs. healthy (significant)
To investigate the association between a vitamin D receptor (VDR) polymorphism (rs731236, TaqI) and dental implant loss	Study group (S) 126 patients presented at least one implant loss. Control group (C) 80 patients with at least one osseointegrated implant in function for over 6 months without any implant loss	Periodontal health analysing measurements of PPD and CAL were recorded at four points around each tooth. The following parameters were recorded: GI, PI, CI and mobility (absent or present)	Titamax EX CM, NEODENT	SLA	Bone level	VDR TaqI polymorphism with mobility DNA from buccal cells extracted with ammonium acetate and EDTA, PCR amplification	No significant association with VDR TaqI polymorphism (genotype: $P=0.482$, allele: $P=0.834$). Significant difference in PPD ($P=0.011$). More edentulous patients in C (19%) compared to S (6%) ($P=0.009$)

Table 2 (continued)

To investigate the effect of vitamin D deficiency on peri-implant clinical and radiographic findings and whether vitamin D supplementation improves prognosis	Study group (S) patients with vitamin D deficiency (< 30 ng/mL) supplemented with vitamin D and control group (C) patients with vitamin D sufficient (> = 30 ng/mL)	Vitamin D blood levels were measured by collecting samples to assess 25(OH)D using chemiluminescence in a clinical analysis laboratory. The study also evaluated the effect of Vitamin D supplements 12 months after the delivery of the implant restoration	Morse-taper connection implants, Kopp System, Curitiba	No reporting	Bone level	Periodontal health and implant success through clinical evaluations by two calibrated examiners and radiographic evaluations, analyzing the indices of PD, mBI, wKM, and mPI	Distance from bone crest to implant cervical area: Significant differences at baseline (up to 2.2 mm). Modified plaque index (mPI): Higher at baseline in both groups; significant decrease post-treatment in the VD group. wKM, modified sulcus bleeding index (mSBI), and mPI: No significant differences between control and VD deficiency groups at baseline or post-treatment (ANOVA and Tukey test; $p > 0.05$)
To investigate the serum biochemical parameters which are cardiovascular disease risk markers in individuals who have received dental implant treatment and to reveal risk factors for peri-implant diseases	58 subjects with peri-implantitis, 49 subjects with peri-implant mucositis, and 49 healthy subjects	Perimplant health assessing PD at 6 sites per teeth and implant (the distance between the mucosal margin and the probeable sulcus/pocket), GI, PI, either the presence (1) or absence (0) of BOP at six sites for each implant, and KMW	No reporting	No reporting	No reporting	Blood samples were collected from the participants after a 12-h fasting period to measure vitamin D levels	Vitamin D levels: Lowest in peri-implantitis ($P = 0.043$, age-adjusted); also lower in peri-implant mucositis vs. healthy implants. Correlation: Vitamin D negatively correlated with GI ($r = -0.191$, $P = 0.020$)
Strategy for Confounders	Inclusion Criteria	Exclusion Criteria	Limitations	Funding/Conflict of Interest	Implant Protocol	Time of function	Reporting Age Range
Control of age, gender, smoking habits, osteoporosis status, antiresorptive drug use of study participants and season variation	Patients who received dental implants at the Implant Dentistry Center between 2021–2022	Patients with no radiographs in the past three years, or with other complicating conditions	Retrospective design, Reliance on self-reported data, only used one implant system, Vitamin D levels not followed longitudinally, active form 1,25(OH)2D not assessed	Fundação de Amparo a Pesquisa do Estado de São Paulo (FAPESP)/ No conflict	No reporting	Functionally loaded for at least 36 months	Mean 66.5 ± 10.6 years

Table 2 (continued)

No reporting	Healthy peri-implant tissue, no systemic conditions, no bruxism, non-smokers, no drug use in the past 3 months	Excluded systemic diseases, metabolic bone diseases, pregnancy, smoking, alcohol use	Cross-sectional design, no serum vitamin D evaluation	No conflict	No reporting	Functionally loaded for at least 12 months	The mean age of patients in the peri-implantitis group was significantly higher than of those in the peri-implant healthy group (P = 0.010). There was no significant difference between the peri-implant mucositis group and other two groups (P = 0.699 and P = 0.188, respectively)
matching for sex, age, and smoking habits	Only patients who agreed to participate, had no reported complications during the surgical or prosthetic procedures, and were treated with NEODENT dental implants at Instituto Latino Americano de Pesquisa e Ensino Odontológico (ILAPEO) from 1996 to 2006 were included in the study	Excluded: HIV infection, pregnancy, lactation, orthodontic appliances, necrotizing ulcerative gingivitis/periodontitis, aggressive periodontitis	Retrospective design, no power calculation, potential sampling bias	Partially supported by Instituto Latino Americano de Ensino e Pesquisa Odontológico (ILAPEO), collaboration with Instituto de Biologia Molecular do Paraná (IBMP), financial interest with Neodent	No reporting	Functionally loaded for at least 6 months	mean age 51.7 ± 11.3 (range 25–80)

Table 2 (continued)

No reporting	Patients that received treatment with osseointegrated tooth implants in 2011- 2013 were recruited in the Dental Clinics of State University of West Parana—Unioeste, in the city of Cascavel, Brazil. Age 35–60 years, both men and women, adequate oral hygiene, single or multiple implant-supported prosthesis in use for at least six months, no periodontal disease	Excluded: osteoporosis treatment, certain diseases (e.g., primary hyperparathyroidism, diabetes), corticosteroids, pregnancy, smoking, and other specific conditions	Short follow-up time (2 months), limited assessment of bone remodeling and local clinical conditions	No conflict of interest, VD supplementation provided by a drugstore	No reporting	Functionally loaded for at least 12 months	35–60 years
Adjust for age	at least one dental implant in use for 36 months	systemic administration of antibiotics (or prophylactic antibiotics) for the last 3 months, pregnancy or breast feeding, having diabetes mellitus, and a history of malignancy, radiotherapy, chemotherapy, or immunodeficiency within the last 4 years	Coronary angiography was not performed to evaluate coronary artery disease Radiographic measurement was not done to calculate the amount of crestal bone loss around dental implants Analyses of peri-implant crevicular fluid to detect proinflammatory cytokines may have revealed local destruction around dental implants Limited sample size was another limitation of this study	no/no	No reporting	Functionally loaded for at least 36 months	0,181

implementing standardized and widely accepted cutoffs for defining vitamin D status (deficiency, insufficiency, sufficiency) would facilitate more consistent and comparable findings across different studies resolving methodological issues related to the inconsistent classification of vitamin D levels.

Applying these findings has the potential to improve the predictability of implant therapy through more refined patient selection and the development of individualized treatment strategies. Comprehensive preoperative evaluations that incorporate serum vitamin D assessment, periodontal health status, and systemic risk factors could provide clinicians with a more complete profile of each patient, thereby facilitating tailored treatment planning. In particular, correcting suboptimal vitamin D levels prior to implant surgery may optimize bone metabolism, enhance osseointegration, and reduce the risk of early implant failure. Conversely, avoiding excessive supplementation is equally important, as both deficiency and excess ofvd vitamin D can disturb bone homeostasis. In addition to preoperative optimization, longitudinal monitoring of vitamin D status following implant placement may prove beneficial in maintaining long-term implant stability and preventing complications such as marginal bone loss. Establishing standardized protocols for the frequency and methodology of such monitoring could further strengthen clinical outcomes. Moreover, the integration of genetic profiling—such as identifying polymorphisms in the vitamin D receptor (VDR) gene—holds promise for identifying patients who are genetically predisposed to compromised implant success. This personalized approach may allow earlier recognition of high-risk individuals, enabling clinicians to adapt surgical techniques, loading protocols, and maintenance regimens accordingly. Future research should focus on well-designed prospective clinical trials with adequate sample sizes to validate these strategies. Large-scale, multicenter studies employing standardized methods of vitamin D assessment and genetic analysis would provide stronger evidence for their clinical utility. Ultimately, addressing these research gaps could lead to the development of evidence-based, standardized guidelines that integrate biochemical, periodontal, and genetic factors into implant planning. Such advancements would support a shift toward precision dentistry, ensuring not only higher implant survival rates but also improved patient-centered outcomes through individualized care.

This systematic review underscores the potential influence of vitamin D levels on peri-implant health, implant survival, and MBL. The evidence suggests that both vitamin D deficiency and hypervitaminosis may adversely affect implant success and longevity. Additionally, genetic factors such as polymorphisms in the VDR gene appear to play a limited but noteworthy role in implant success, with clinical parameters like implant placement technique and bone quality exerting a more significant influence. Despite these insights, limitations in methodology, including retrospective designs, short follow-up periods, and inconsistent vitamin D monitoring restrict definitive conclusions. Future longitudinal studies with standardized vitamin D assessment protocols and controlled supplementation trials are needed to clarify the precise role of vitamin D in implant success and peri-implant health.

15 Conclusion

Current evidence indicates that deficient vitamin D levels may adversely affect implant outcomes, particularly regarding bone loss and early failure. Although our findings highlight the potential benefit of preoperative vitamin D evaluation, the overall strength of evidence is limited by small sample sizes, retrospective study designs, and variability in vitamin D assessment methods. Future prospective studies using standardized protocols are essential. Evaluating and correcting vitamin D status preoperatively may improve implant success and minimize complications.

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Declarations

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