The Role of Vitamin D in Preventing Root Resorption - Implications for Different Orthodontic Appliances

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Abstract

AIM: This literature review evaluates the influence of vitamin D on external apical root resorption (EARR), orthodontic tooth movement rate, and associated complications, with consideration of orthodontic appliance design.

METHODS: A structured search was conducted using PubMed databases for clinical studies published before February 2025. Nineteen studies were included, involving various orthodontic appliances and vitamin D administration routes.

RESULTS: Vitamin D, especially when locally injected, was associated with accelerated tooth movement and a potential reduction in EARR. However, results were not consistently statistically significant. Appliance design influenced outcomes: self-ligating systems and clear aligners showed lower EARR incidence compared to conventional brackets, likely due to reduced force magnitude and improved control.

CONCLUSION: Vitamin D may positively regulate orthodontic tooth movement and root resorption, though effects vary by biological and mechanical context. Appliance selection and force application strategies remain critical in minimising adverse effects and optimising outcomes.

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Archive of Orofacial Data Science

Accepted: Tuesday 2nd December, 2025. **Data availability statement:** All relevant data are within the article or supplement files unless otherwise declared by the author(s).

1 Introduction

Malocclusion, a common dental condition characterised by improper alignment of the teeth or jaw, can lead to various oral health problems such as tooth wear, temporomandibular joint (TMJ) pain, and difficulty in chewing. Additionally, it may affect facial aesthetics and self-confidence. The causes of malocclusion range from disordered tooth arrangement and missing teeth to abnormal jawbone development. In many cases, orthodontic treatment is required to address these issues, often utilising appliances such as traditional fixed braces or clear, removable aligners (Lombardo et al., 2020).

Orthodontic appliances apply mechanical forces to the teeth, triggering biological responses in the surrounding tissues and initiating a process of bone remodelling that involves both bone resorption and formation. During tooth movement, the periodontal ligament senses these forces, leading to the recruitment of osteoclasts in the pressure zones and osteoblasts in the tension zones (Kapoor et al., 2014). This remodelling process is mediated by biochemical signals originating from the extracellular matrix, which regulate the differentiation, activation, and apoptosis of bone cells (Kobayashi et al., 2000; Meikle, 2006).

Vitamin D plays a critical role in bone metabolism by regulating calcium absorption and maintaining skeletal health. It exerts its effects through the modulation of key molecular pathways, including receptor activator of nuclear factor kappa-B ligand (RANKL), osteoprotegerin (OPG), and tumour necrosis factor (TNF) (Xiong et al., 2015). The balance of these molecules influences osteoclastogenesis, and an elevated RANKL/OPG ratio can result in excessive bone resorption. This dysregulation has been implicated in external apical root resorption (EARR), a common iatrogenic effect in orthodontic treatment (Masella et al., 2006; Uematsu et al., 1996). By restoring molecular balance, vitamin D has the potential to mitigate root resorption and enhance bone formation, contributing to more predictable orthodontic outcomes (Küchler et al., 2021).

The prevalence of vitamin D deficiency in the general population varies widely and is influenced by factors such as geography, age, skin pigmentation, and sun exposure. A U.S.-based study reported a deficiency rate of approximately 15% in children aged 1 to 11 years (Mansbach et al., 2009). Orthodontic patients, who undergo constant bone remodelling during treatment, may have increased physiological demands for vitamin D. Consequently, vitamin D insufficiency in these individuals could compromise bone turnover and negatively affect treatment efficacy.

Various orthodontic systems are available to facilitate tooth movement, including conventional fixed appliances, self-ligating systems such as the Damon System, and clear aligners. These appliances differ in their mechanical design, frictional characteristics, and patient compliance requirements. Fixed appliances may generate greater friction and require frequent adjustments, whilst self-ligating brackets reduce friction and potentially improve efficiency (Paduano et al., 2008). Clear aligners are known for their aesthetic appeal and comfort but rely heavily on patient adherence. The interaction between vitamin D levels and these appliance systems is still under investigation. Preliminary evidence suggests that adequate vitamin D levels may support more effective orthodontic tooth movement and reduce side effects such as EARR, regardless of appliance type (Nabhan et al., 2016).

This review examines vitamin D's effects on bone resorption, tooth movement, and appliance performance in orthodontics, aiming to improve treatment efficiency and reduce adverse outcomes like root resorption.

2 Methods

The requisite literature search was performed utilising the PubMed database. The search employed specific keywords, with inclusion criteria restricted to clinical studies published during the preceding 20 years (2005–2025).

The search strategy was structured according to the PICO framework. The population (P) comprised patients undergoing orthodontic treatment with various types of orthodontic appliances, including traditional fixed braces, self-ligating systems, and clear aligners. The intervention/condition (I) examined was vitamin D supplementation, whilst the comparator (C) consisted of the absence of vitamin D supplementation. The outcomes (O) evaluated included the extent of root resorption, the degree of tooth movement during orthodontic treatment, and the rates of pain or complications.

The search terms employed and their corresponding results are presented in **Table 1**. The initial search yielded varying numbers of results, which were subsequently refined by applying the temporal limitation (2005–2025) and the specific inclusion and exclusion criteria.

Table 1. Search terms and corresponding results from the PubMed database. Filter1: hits 2005-2025. Filter2: hits according to in- and exclusion criteria. RR = root resorption; TM = tooth movement; CLA = clear aligner; VIT = vitamin.

Search terms	**hits**	**filter1**	**filter2**
(fixed appliance) AND (RR)	324	250	56
(self-ligating) AND (RR)	34	34	8
((removable appliance) OR (CLA)) AND (RR)	87	71	11
(fixed appliance) AND (TM)	1781	1252	331
(self-ligating) AND (TM)	184	170	83
((removable appliance) OR (CLA)) AND (TM)	1139	670	63
(fixed appliance) AND (RR) AND (VIT D)	3	2	2
(self-ligating) AND (RR) AND (VIT D)	0	0	0
((removable appliance) OR (CLA)) AND (RR) AND (VIT D)	0	0	0
(fixed appliance) AND (TM) AND (VIT D)	4	2	1
(self-ligating) AND (TM) AND (VIT D)	0	0	0
((removable appliance) OR (CLA)) AND (TM) AND (VIT D)	0	0	0

The inclusion criteria for this review encompassed studies published in English within the past twenty years that employed specific methodological approaches to investigate root length changes. Eligible studies included randomized controlled trials, retrospective cohort studies, prospective cohort studies, and clinical studies that utilized cone beam computed tomography (CBCT) as the primary measurement tool for assessing alterations in root length.

Studies were excluded from this review if they focused on dental trauma or involved the use of mini-implants or mini-screws as part of the intervention or treatment protocol. Additionally, publications that were not available in the English language were excluded from consideration to ensure consistent interpretation and analysis of the findings.

An initial search using the keyword “root resorption” in PubMed yielded 7,657 papers. A second search using the keywords “tooth movement” yielded 15,060 papers. When the keywords “root resorption” were combined with “fixed appliance”, the number of results dropped to 324. When the keyword “root resorption” was combined with “fixed appliance”, filtered from 2005 to 2025, and limited to clinical trials and randomized controlled trials,

there were 65 papers. For "removable appliance" combined with "root resorption", filtered from 2005 to 2025 and limited to clinical trials and randomized controlled trials, there were 11 papers.

After a thorough full-text review of the retrieved articles, duplicate publications and studies unrelated to the research objective were excluded. As a result, a total of 19 eligible studies were ultimately included for integrative analysis, with particular attention given to the content presented in the Results sections (**Figure 1**).

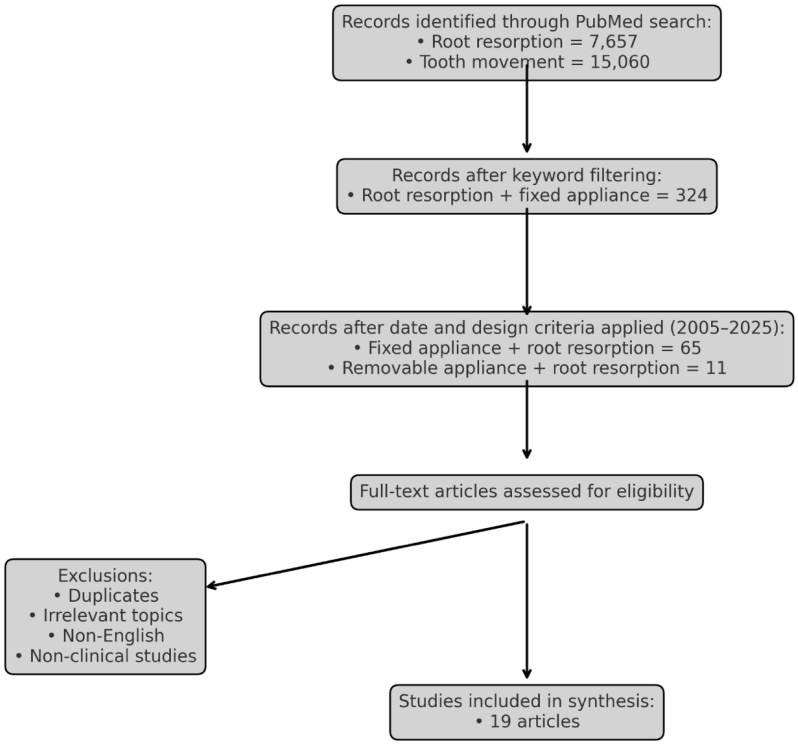

Figure 1. Article selection process.

Key information from each eligible study was manually retrieved and organised into structured tables. The extracted content encompassed publication details (author and year), research methodology, participant numbers, demographic characteristics (such as age and gender), type of orthodontic appliance, form of vitamin D use, clinical outcomes related to root resorption (measured in millimetres or percentage) and tooth movement (in millimetres), treatment duration, as well as the primary observations. All data were compiled using Microsoft Excel for consistency.

Subsequently, a qualitative review was conducted. The studies were categorised according to the presence or absence of vitamin D application and the orthodontic appliance employed. Outcome measures were reported as numerical ranges and average values when available. Owing to considerable variation in methodologies, dosage forms, and outcome assessments, statistical pooling was not undertaken.

2.1 Statistics

Descriptive statistics, frequency analysis, and content analysis were employed as part of the qualitative methodology to systematically analyze the textual content of the included studies. It is important to note that, given the narrative nature of this study, regression analysis and meta-analysis techniques were not deemed suitable for the analytical framework.

3 Results

This review incorporated 19 clinical studies investigating the relationship between vitamin D and external apical root resorption. Based on the study design, the collection includes six randomised controlled trials (RCTs), five retrospective cohort studies, three prospective cohort studies, and five clinical studies. Seven studies administered oral or local vitamin D supplements or measured plasma vitamin D concentrations (Azizi et al., 2022), or vitamin D receptor gene polymorphism (de Almeida et al., 2018) to analyse the effects of vitamin D on root resorption and tooth movement during orthodontic treatment.

Fontana et al. (2012) included the largest study population, 377 individuals distributed across three subgroups. Conversely, Jacobs et al. (2014) had the second-largest sample size, including 213 people. Iosub Ciur et al. (2016) had the lowest sample size, with four individuals. Gender distribution was specifically documented in 14 articles. The age range of participants mainly was between 11 and 34 years.

Concerning the dental attributes of participants, anterior crowding was the most often documented issue, noted in around 10 studies. Tooth extraction treatment plans were reported in around five investigations, while instances of deep overbite or anterior open bite (AOB) were noted in 3 studies. Regarding appliance types, standard fixed appliances were used in 10 publications, self-ligating brackets in seven studies, and clear aligner systems (e.g., Invisalign) in five studies.

For the anatomical site of appliance implantation, 14 research studies focused on maxillary arch therapy, whereas six addressed mandibular application. Seventeen studies focused on front teeth, while about five studies evaluated the posterior area, including premolars and molars.

The maximum treatment duration recorded by Tehranchi et al. (2017) was around four years. The briefest treatment period was noted in the research article conducted by Al-Hasani et al. (2011), which spanned about three weeks. Detailed information is shown in supplementary **Table S1**.

3.1 Root resorption measurement

When measuring orthodontic-induced external apical root resorption (EARR), absolute root length changes in millimetres (mm) and relative root resorption as a percentage (%) are routinely utilised in quantitative approaches. Ten studies measured crown-root length (CRL) from the incisal border or from the apical tip to the apex. The former approach primarily used imaging techniques to assess the CRL, with the amount of resorption expressed as

$$\text{EARR (mm)} = CRL_{\text{pre}} - CRL_{\text{post}}.$$

Commonly used imaging tools include cone-beam computed tomography (CBCT) and periapical or panoramic radiographs, whereas CBCT has the highest resolution and can provide more accurate measurements of root length changes.

Conversely, seven studies used percentages (%) to express the relative root resorption (rRR), calculated as

$$\text{rRR } (\%) = \left[\frac{CRL_{\text{pre}} - CRL_{\text{post}}}{CRL_{\text{pre}}}\right] \times 100.$$

This method is more commonly applied in studies using two-dimensional images (such as panoramic radiographs) and is suitable for situations in which magnification cannot be precisely corrected. However, incorrect image magnification may cause inaccuracies.

In general, when CBCT is used as an assessment tool, millimetres are the preferred unit of measurement. If radiographic images are used and no image scale correction is available, percentages are a more reliable way to express relative changes. Some of the literature included in this study reported both data sets to enhance the consistency and transparency of comparisons of results.

3.2 Vitamin D related studies on root resorption

In this review, five clinical studies of vitamin D were included. The study designs comprised oral supplementation, local injection, serum concentration assessment and genetic polymorphism analysis, all addressing the association between vitamin D and external apical root resorption (EARR). All five studies used fixed orthodontic treatment (FOT) for outcome evaluation (**Table 2**). Regarding appliance location, three studies focused on the maxillary region, one investigated the mandibular anterior teeth, and one included both the maxillary and mandibular (Mx/Md) canine regions.

Table 2. Comparative summary of clinical studies evaluating the association between vitamin D status or interventions and external apical root resorption during orthodontic treatment.

AUTHOR (YEAR)	VIT D RELATED	A-TYPE	A-POS	EARR (MM OR %)	P-VALUE
Al-Attar (2022)	Yes (oral supplement Vit D)	FOT	Mandibular anterior	nomal Vit D level: 0.77 mm, control group: 0.89 mm	> 0.05
Azizi (2022)	Yes (serum Vit D detected)	FOT	Maxillary anterior	75% of individuals have maxillary incisor EARR. Vitamin D serum levels did not correlate with EARR Low Vit D group: significantly higher resorption	0.423
Fontana (2012)	Yes (Vit D receptor gene polymorphism)	FOT	Maxillary central incisor	Treat: 0.81 mm; Untreat: 2.24 mm	< 0.01
Iosub Ciur (2016)	Yes (local injected Vit D in periodontal ligament)	FOT	Single canine (Mx/Md)	No EARR observed (CBCT monitored)	
Tehranchi (2017)	Yes (serum Vit D detected)	FOT	Maxillary anterior	18.84 ± 9.78%; lateral higher than central; Vit D no significant correlation with EARR	0.38

EARR: external apical root resorption, FOT: fixed orthodontic treatment

Maxillary EARR was measured in millimetres (mm) and ranged from 0.81 mm to 2.24 mm; when expressed as a percentage, the mean resorption was $18.84 \pm 9.78\%$. Azizi et al. (2022) reported that 75% of participants exhibited EARR in the maxillary anterior teeth, but found no significant correlation between serum vitamin D levels and EARR ($p = 0.423$); nevertheless, resorption was more pronounced in the low-concentration subgroup (Azizi et al., 2022). Fontana et al. (2012) analysed vitamin D receptor (VDR) gene polymorphisms and reported that individuals with specific genotypes treated with fixed orthodontic appliances

had an average resorption of 0.81 mm, whereas those without orthodontic treatment had an average resorption of 2.24 mm, a difference that reached statistical significance ($p < 0.01$) (Fontana et al., 2012).

In the mandible, only Al-Attar and Abid (2022) provided quantifiable root-resorption data. The oral vitamin D supplementation group had a mean root resorption of 0.77 mm, which was lower than that of the non-vitamin D control group (0.89 mm). This difference was not statistically significant ($p > 0.05$) (Al-Attar and Abid, 2022).

Iosub Ciur et al. (2016) conducted a trial of local vitamin D injection into the periodontal ligament, monitored by CBCT, and observed no root resorption. Tehranchi et al. (2017) examined the relationship between serum vitamin D concentration and maxillary anterior EARR and reported a mean resorption of $18.84 \pm 9.78\%$; resorption was greater in lateral incisors than in central incisors, but no significant correlation was found between vitamin D concentration and EARR ($p = 0.38$) (Tehranchi et al., 2017).

Although the current findings do not consistently reach statistical significance, the reviewed evidence suggests that vitamin D may reduce the extent of root resorption during orthodontic treatment. All available clinical studies, however, were conducted using conventional fixed orthodontic systems; no clinical data are currently available concerning the application of vitamin D in cases treated with clear aligners or self-ligating brackets. This paucity of comparative research limits conclusions regarding whether vitamin D produces similar effects when combined with alternative appliance designs.

3.3 Non vitamin D related studies on root resorption

The effects of various orthodontic appliances on external apical root resorption (EARR) were separately investigated in twelve clinical studies that did not include vitamin D administration (**Table S2**). The appliance types comprised four main systems: conventional fixed appliances (FOT-Conv) in seven studies, fixed self-ligating appliances (FOT-SL/Damon) in six studies, continuous-arch fixed appliances (CIA/continuous arch) in one study, and clear aligner therapy (CAT) in five studies. Several studies compared two or more systems simultaneously. Regarding appliance placement, five studies focused exclusively on the maxillary arch, two on the mandibular arch, and five examined both arches concurrently.

According to the reported data, maxillary EARR, measured in millimetres (mm), ranged from 0.04 mm to 3.06 mm; when expressed as a percentage, it ranged from 1.28% to 10.02%. Mandibular EARR, measured in millimetres (mm), ranged from 0.04 mm to 2.08 mm; when expressed as a percentage, it ranged from 3.0% to 6.97%.

Across appliance systems, CAT generally exhibited lower root resorption values, particularly in the posterior region. For example, Withayanukonkij et al. (2023) reported posterior-tooth EARR in the clear-aligner group of 0.04–0.09 mm, which was significantly lower than in the fixed-appliance group (0.38–0.47 mm; $p < 0.05$). Yi et al. (2018) found that the CAT group had a lower percentage of resorption (5.13% vs. 6.97%; $p < 0.001$) compared with the FOT group. Han et al. (2005) compared root resorption of maxillary first premolars under intrusion and expansion treatment and reported a resorption rate of 5.75% in the intrusion group, significantly higher than the 1.28% observed in the expansion group ($p < 0.01$), indicating that the direction of force application markedly affects EARR.

Overall, both self-ligating and conventional fixed orthodontic appliances may be associated with significant root resorption, whereas clear aligners were reported to carry a lower risk of EARR in some studies, particularly in the posterior region.

3.4 Tooth movement

A total of seven studies reported data related to tooth movement in this review. Four of these studies involved vitamin D intervention, including three that used local injection methods (Al-Hasani et al., 2011; Iosub Ciur et al., 2016; Varughese et al., 2019) and one that employed oral supplementation (Al-Attar & Abid, 2022). The remaining three studies did not involve any vitamin D-related interventions and simply assessed tooth movement with different orthodontic appliances (de Almeida et al., 2018; Scott et al., 2008; Withayanukonkij et al., 2023). Six studies used fixed orthodontic appliances (FOT); only Withayanukonkij et al. (2023) used both fixed appliances and clear aligners. Treatment durations ranged from a minimum of 3 weeks (Al-Hasani et al., 2011) to a maximum of 9 months (Scott et al., 2008). Regarding the location of orthodontic appliance placement, four studies were conducted in the maxillary region, while two studies focused on the mandibular anterior teeth (Al-Attar & Abid, 2022; Scott et al., 2008), and one study was conducted on a single canine without distinguishing between the maxillary and mandibular regions (Iosub Ciur et al., 2016). Detailed information is shown in **Table 3**.

Table 3. Comparative summary of clinical studies examining vitamin D related orthodontically induced root resorption associated with different appliance modalities and tooth positions.

AUTHOR (YEAR)	VIT D RELATED	A-TYPE	A-POS	MOVEMENT (MM)	P-VALUE
Al-Attar (2022)	Yes Oral supplement	FOT	Mandibular anterior	Improvement percentages ND3G: 91.94%; CG: 76.86%	< 0.001
Al-Hasani (2011)	Yes local injection	FOT	Upper canine	15pg calcitriol (E side: 1.42 mm, C side: 1.29 mm) 25pg calcitriol (E side: 1.57 mm, C side: 1.04 mm) 40pg calcitriol (E side: 1.15 mm, C side: 1.04 mm) 25pg: 51% in E side faster canine tooth movement than C side	> 0.05
Iosub Ciur (2016)	Yes local injection	FOT	Single canine (Mx/Md)	42 pg calcitriol (E side: 1.70 mm, C side: 1.0 mm) E side 70% compared to C side	0.031
Varughese (2019)	Yes local injection	FOT	Upper canine	Vit D: 1.57; 1.71; 1.20 mm Control: 1.02、1.08、0.94 mm	< 0.05
de Almeida (2018)	No	FOT	Maxillary anterior	CIA: Average inward retraction of 2.23 mm; Continuous: Slight outward expansion of 0.3 mm	< 0.05
Scott (2008)	No	FOT	Mandibular anterior	FOT (SL) = 0.125 mm/day, FOT (CO) = 0.128 mm/day	> 0.05
Withayanukonki (2023)	No	FOT/ CAT	Maxillary first molars	FOT: 1.49 mm; CAT: 0.68 mm	< 0.05

CAT: clear aligner therapy, CG: control group, CIA: Connecticut intrusion arch, FOT(CO): fixed orthodontic treatment conventional, FOT(SL): fixed orthodontic treatment self-ligating, FOT: fixed orthodontic treatment, ND: normal dose

3.5 Vitamin D related studies on tooth movement

In the four studies related to vitamin D included in this review, fixed orthodontic appliances (FOT) were used for treatment, and tooth movement was observed at different sites. The tooth movement distance in the vitamin D intervention group ranged from 1.15 mm to 1.71 mm, which was higher than that in the group that did not receive supplementation

(0.94 mm to 1.29 mm). Three studies reported statistically significant differences in tooth movement with vitamin D supplementation.

Al-Attar & Abid (2022) reported that, over 16 weeks, the tooth movement improvement rate was 91.94% in the vitamin D supplementation group, which was significantly faster than in the control group (CG: 76.86%) ($p < 0.001$). Al-Hasani et al. (2011) designed an experiment with three different doses of local vitamin D_3 (calcitriol) injections, dividing the canine tooth region into an experimental side (E side) and a control side (C side), and observed tooth movement over three weeks. In the 15 pg group, the E side was 1.42 mm and the C side 1.29 mm; in the 25 pg group, the E side was 1.57 mm and the C side 1.04 mm; and in the 40 pg group, the values were 1.15 mm and 1.04 mm, respectively. Although the E side showed a 51% faster movement rate than the C side in the 25 pg group, the overall comparison did not reach statistical significance ($p > 0.05$).

Iosub Ciur et al. (2016) administered 42 pg of calcitriol via local injection into a single canine tooth (upper or lower jaw) and observed tooth movement over three months. The experimental side (E) showed an average tooth movement of 1.70 mm, significantly higher than the control side (C), which was 1.0 mm, with a movement efficiency improvement of approximately 70% ($p = 0.031$). This indicates that local vitamin D injections at specific doses can effectively accelerate tooth movement.

Varughese et al. (2019) also conducted a controlled trial using local vitamin D injection, observing the distal movement of maxillary canine teeth over three months. The movement distances at three measurement points in the vitamin D group were 1.57 mm, 1.71 mm, and 1.20 mm, while those in the control group were 1.02 mm, 1.08 mm, and 0.94 mm. Statistical analysis revealed significant differences ($p < 0.05$). Based on these findings, vitamin D has potential benefits in promoting tooth movement, regardless of whether it is administered orally or via local injection.

3.6 Non vitamin D related studies on tooth movement

In three studies that did not involve vitamin D supplementation, fixed orthodontic appliances (FOT) or combinations thereof were used to observe tooth movement. The study designs primarily focused on the effects of appliance type and design differences on the efficiency of tooth movement.

In the maxillary anterior region, patients using the CIA appliance achieved an average tooth intrusion of 2.23 mm within 6 months, whereas those using the continuous archwire system exhibited only a slight extrusion of 0.3 mm, with the difference being statistically significant ($p < 0.05$). In the mandibular anterior region, the Damon self-ligating orthodontic appliance (FOT-SL) and traditional fixed orthodontic appliance (FOT-CO) demonstrated similar average daily tooth movement rates of 0.125 mm/day and 0.128 mm/day, respectively, with no statistically significant difference between the two ($p > 0.05$).

In the maxillary posterior region, comparing fixed appliances with clear aligner therapy (CAT) over six months, fixed appliances achieved 1.49 mm of distal movement, while CAT achieved only 0.68 mm, indicating that fixed appliances are more effective than clear aligners for posterior tooth movement, with the difference being statistically significant ($p < 0.05$).

Combining the results of these three studies, it can be concluded that even without vitamin D supplementation, tooth movement efficiency varies depending on appliance design, force application methods, and treatment area

3.7 Pain control and vitamin D

In seven studies related to vitamin D, only Al-Attar & Abid (2022) reported on the relationship between vitamin D supplementation and pain control during orthodontic treatment, using the Visual Analogue Scale (VAS) to assess pain intensity.

As shown in **Table 4**, during the 7-day observation period, the VAS scores of participants who supplemented with vitamin D in the first three days ranged from 10.93 to 11.73, which was significantly lower than those of participants who did not supplement with vitamin D (range 19.27 to 20.07, $p < 0.05$).

Following the fourth day, the VAS scores of the two groups gradually converged, with no statistically significant difference between the groups. By the seventh day, the scores of both groups were 15.50 ($p = 1.000$).

Table 4. Effect of vitamin D supplementation on VAS-assessed pain intensity during orthodontic treatment (Al-Attar & Abid, 2022).

DAY	VIT D	NON VIT D	P-VALUE
Day 1	11.43	19.57	0.01
Day 2	11.73	19.27	0.019
Day 3	10.93	20.07	0.004
Day 4	13.50	17.50	0.217
Day 5	15.00	16.00	0.775
Day 6	14.50	16.50	0.539
Day 7	15.50	15.50	1.000

3.8 Additional observations

Of the 19 studies included in this review, four presented additional findings relevant to treatment characteristics or biological responses. In Varughese et al.'s (2019) study, the experimental group received localized administration of 1,25-dihydroxycholecalciferol at a concentration of 50 pg/0.2 mL on the designated side, while the control side was treated with a placebo gel. Despite the intervention, anchorage loss showed no statistically significant difference between groups ($p = 0.769$). Aras et al. (2018) evaluated root resorption patterns under different bracket systems and reported that conventional fixed appliances were associated with a higher prevalence of slanted root resorption (FOT-CO: 21.87%) compared to self-ligating systems (FOT-SL: 6.25%). In de Almeida et al. (2018), the use of CIA was characterised by low-force application and was considered biomechanically safe and predictable for managing anterior intrusion. Furthermore, Withayanukonkij et al. (2023) observed that maximum bite force (MBF) increased post-treatment, with the clear aligner group (CA) reporting greater values than the fixed appliance group (FM). A positive correlation was also noted between MBF enhancement and the degree of achieved intrusion. The other 15 studies included in the review did not report any notable complications during the treatment or follow-up periods.

4 Discussion

This literature review addressed four core questions: (1) the effect of vitamin D on root resorption in relation to different orthodontic appliances, (2) its influence on the efficiency of tooth movement, (3) the factors contributing to an elevated risk of EARR, and (4) strategies to reduce EARR in clinical practice. The findings suggest that vitamin D could play a role in moderating root resorption and accelerating tooth movement, particularly when delivered locally. However, current evidence is limited to studies involving conventional fixed appliances. No investigations were identified that examined the use of vitamin D alongside self-ligating brackets or clear aligner systems, leaving the first and fourth research questions only partially addressed. The diversity in study methodologies, delivery routes, and outcome evaluations further complicates the ability to draw generalized conclusions. These results underscore the complex interaction between systemic biological conditions and applied mechanical forces in shaping orthodontic outcomes.

The aetiology of EARR is multifactorial. One well-accepted mechanism involves localised ischaemia within the periodontal ligament induced by orthodontic force, which causes hyalinised zones and initiates an inflammatory cascade leading to root resorption (Brezniak & Wasserstein, 1993). Among biological factors, studies such as Azizi et al. (2022) and Fontana et al. (2012) have emphasised the roles of serum vitamin D levels and VDR gene polymorphisms in modulating individual susceptibility to EARR.

Mechanical factors also play a pivotal role. Han et al. (2005) demonstrated that intrusive forces result in substantially greater resorptive activity than extrusive forces, emphasising the importance of vector direction in orthodontic biomechanics. Anatomical site-specific susceptibility was also noted, with Tehranchi et al. (2017) observing that lateral incisors are more vulnerable than central incisors, and Leite et al. (2012) indicating a greater prevalence of resorption in the maxilla compared to the mandible. These biomechanical and anatomical interactions align with the pathophysiological model of EARR, in which excessive or improperly directed forces exacerbate localised inflammatory responses around the root apex.

Importantly, the design and configuration of orthodontic appliances appear to influence the incidence and severity of EARR. Aras et al. (2018) reported that traditional conventional brackets (FOT-CO) were associated with a significantly higher frequency of slanted root resorption compared to self-ligating systems (FOT-SL), suggesting that bracket mechanics and force expression contribute to differential tissue responses. Similarly, Scott et al. (2008) and Liu et al. (2012) found that although the magnitude of tooth movement was similar between different bracket types, variations in force delivery may still underlie differences in biological outcomes such as EARR. Moreover, de Almeida et al. (2018) linked the use of cortically anchored intrusion appliances (CIA) to more pronounced root movement patterns, raising concerns about potential root stress concentration. These comparisons between self-ligating and conventional systems reveal that reduced friction and lower continuous forces in SL brackets may attenuate EARR severity, supporting the adoption of more biologically compatible appliance mechanics.

Parallel to fixed appliances, aligner-based systems (CAT) have emerged as a biomechanically distinct modality, offering intermittent and lighter force applications. In the studies by Yi et al. (2018) and Withayanukonkij et al. (2023), CAT demonstrated a lower prevalence of EARR compared to FOT, which may be attributable to the cyclical nature of aligner wear, allowing intermittent recovery periods for periodontal tissues. These findings suggest

that fixed and removable systems engage fundamentally different delivery mechanisms, each associated with unique periodontal responses.

Taken together, these findings underscore the multifactorial aetiology of EARR, where both systemic factors like vitamin D status and local biomechanical variables such as appliance selection and force vector direction interact to influence clinical risk. This highlights the necessity of a comprehensive treatment planning approach that accounts for biological variability and mechanical design to mitigate adverse tissue responses.

In evaluating tooth movement effectiveness, several studies have indicated that vitamin D supplementation, whether administered orally or through local injection, may contribute to an increased rate of orthodontic tooth displacement. However, this effect is not isolated, as it appears to be influenced by the mechanical properties and structural design of the appliances used. Although groups receiving vitamin D often exhibited greater movement distances, a comprehensive assessment must also consider appliance configuration and the directionality of applied forces. Notably, vitamin D has been linked to anti-inflammatory activity and the regulation of osteoclastic function, which may affect both the perception of discomfort and the remodelling of alveolar structures during orthodontic force application. Some studies, such as Varughese et al. (2019), observed reductions in pain scores following calcitriol injection. However, these findings were presented independently of any analysis related to EARR, and no direct correlation between pain outcomes and root resorption was established in the reviewed literature.

All included studies employed fixed orthodontic appliances, yet differences in appliance systems yielded varied biomechanical responses. Notably, none of the reviewed studies investigated the combined effect of vitamin D with either self-ligating brackets or clear aligner systems. This gap limits the interpretation of vitamin D's influence across various appliance types and leaves the first research question only partially addressed. For example, the study by de Almeida et al. (2018) found that the Cortically Anchored Appliance produced a mean retraction of 2.23 mm in maxillary incisors, while the continuous archwire group showed only minor outward expansion. This result highlights the capability of certain systems to achieve targeted tooth movement more effectively under specific force conditions.

In contrast, Scott et al. (2008) reported no significant difference in the average daily rate of anterior tooth movement between self-ligating and conventional brackets, both achieving approximately 0.125 mm per day. Despite the lack of statistical significance, the findings suggest that bracket mechanics may still influence movement quality and biological response, even when gross rates appear comparable.

Withayanukonkij et al. (2023) compared vertical molar intrusion between fixed appliances and clear aligners. Their results demonstrated that fixed systems achieved a movement of 1.49 mm, while clear aligners reached only 0.68 mm, a difference that was statistically significant. Although aligners are often preferred for their comfort and aesthetic appeal, this finding suggests limitations in their vertical force control compared to fixed systems. This discrepancy reflects fundamental differences between continuous and intermittent force delivery, where the former may be more effective for certain types of controlled tooth movement, albeit at the cost of higher biological strain.

In summary, while some studies suggest that vitamin D may improve the rate of orthodontic tooth movement, this outcome should be viewed in relation to the mechanical features of the appliances involved. The second research question was addressed with reasonable depth, particularly in studies evaluating local application of vitamin D. However, the influence of vitamin D in combination with self-ligating brackets or clear aligners remains

unexplored, and no intervention-based strategies to mitigate EARR were clearly outlined in the included studies. These gaps indicate that the first and fourth questions were only partially resolved. Further research should aim to integrate appliance configuration, biological factors, and individual variability to produce more clinically meaningful insights.

Several studies have explored the relationship between orthodontic appliance design and the occurrence of EARR and related complications. Comparisons between conventional fixed appliances, self-ligating systems, and clear aligners have revealed clinically relevant patterns. Clear aligners were associated with lower EARR incidence and reduced discomfort in some studies, possibly due to their intermittent and lighter force delivery (Yi et al., 2018; Withayanukonkij et al., 2023). Self-ligating brackets, which apply lower continuous force, have also been linked to reduced prevalence of slanted root resorption compared to conventional systems (Aras et al., 2018), although some differences were not statistically significant (Scott et al., 2008).

In certain cases, patients treated with clear aligners demonstrated more rapid recovery of occlusal function, particularly in relation to posterior tooth intrusion, suggesting a biomechanical advantage associated with cyclic force patterns (Withayanukonkij et al., 2023). These findings support the view that appliance systems with better control over force magnitude and direction may offer biological advantages in reducing stress on periodontal structures. Furthermore, vitamin D supplementation has been associated with lower pain intensity in the early phases of treatment, as reported by Al-Attar and Abid (2022), suggesting a potential role in modulating inflammatory responses. While current data do not establish a definitive link between vitamin D intake and reduced EARR, supplementation between 800 and 2000 IU per day may be considered for patients with documented deficiency, under appropriate medical supervision (Mansbach et al., 2009).

To reduce the risk of EARR in orthodontic practice, several clinical strategies may be implemented. These include the selection of appliance systems that exert controlled, biologically compatible forces, such as self-ligating brackets or clear aligners (Pandis et al., 2008; Nabhan et al., 2016); avoiding excessive intrusive mechanics, particularly in anatomically vulnerable teeth like lateral incisors (Tehranchi et al., 2017; Han et al., 2005); and conducting pre-treatment assessments of root morphology. Additionally, minimising the duration of high-force phases and adjusting force vectors according to individual anatomical characteristics may help mitigate root damage. While these approaches are supported by observational trends, further research is needed to validate their effectiveness in controlled clinical settings.

4.1 Limitations

This review is limited by the heterogeneity of the included studies in terms of intervention protocols, sample sizes, and measurement parameters. Differences in vitamin D dosage, administration route, orthodontic force systems, and treatment duration may confound direct comparisons across studies. Additionally, most included studies lack long-term follow-up data, making it difficult to assess the sustained effects of vitamin D on EARR or tooth movement. Finally, potential publication bias and language limitations may have led to the exclusion of relevant data.

Moreover, a major constraint of this review lies in the absence of studies directly examining the combined use of vitamin D supplementation with either self-ligating brackets or clear aligner systems. This data gap limits the ability to extend the findings to all or-

thodontic modalities and prevents a thorough assessment of the first and fourth research objectives. Furthermore, although pain-related outcomes associated with vitamin D were reported, they were not explicitly evaluated in connection with EARR, thereby restricting a deeper understanding of their potential relationship.

Conclusions

Vitamin D may play a supportive role in orthodontic treatment by reducing root resorption and facilitating tooth movement, particularly when delivered locally. Its effectiveness appears to depend on both systemic biological status and the mechanics of the appliance used. Integrating vitamin D screening into pre-treatment evaluation for high-risk individuals, especially those with documented deficiency, may aid in managing early-phase discomfort and minimising adverse outcomes. These findings emphasise the need for individualised treatment planning that combines biological assessment with appropriate appliance selection and force control to improve safety and therapeutic efficacy.

Acknowledgements

Not applicable.

Ethical approval

No ethical approval was required for this study as it did not involve human participants, animal subjects, or sensitive data. This study falls under the category of data collection without participant identification.

Consent for publication

Not applicable.

Authors' contributions

The author(s) declare that all the criteria for authorship designated by the International Committee of Medical Journal Editors have been met. More specifically, these are: (a) Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work; AND (b) Drafting the work or revising it critically for important intellectual content; AND (c) Final approval of the version to be published; AND (d) Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Competing interests

The author(s) declare that there are no competing interests related to this work.

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