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Review Article

Effect of Vitamin D Deficiency on Orthodontic Tooth Movement

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Abstract: Vitamin D plays a crucial role in calcium homeostasis and bone metabolism, both of which are essential for efficient orthodontic tooth movement (OTM). This study aims to explore the effects of Vitamin D deficiency on the rate and biological mechanisms of OTM. Evidence from animal models and clinical observations suggests that insufficient Vitamin D levels can impair bone remodeling by reducing osteoblastic activity and altering osteoclastic function. As a result, tooth movement may become slower and less predictable in Vitamin D-deficient individuals. Additionally, such deficiency may increase the risk of root resorption and prolonged treatment duration. Understanding the influence of Vitamin D status on OTM could aid in optimizing orthodontic treatment plans and outcomes. Further clinical studies are needed to establish clear guidelines regarding Vitamin D assessment and supplementation in orthodontic patients.

Keywords: Vitamin D deficiency, Orthodontic tooth movement, Bone remodeling, Orthodontics, Calcium metabolism, Tooth movement rate.

INTRODUCTION

Orthodontic tooth movement (OTM) involves applying mechanical forces that induce bone remodeling and bone resorption at the pressure sites and bone formation at the tension sites (Kapoor P, 2014). Osteoblasts secrete osteoprotegerin (OPG), whose main function is blocking the activity of the osteoclast cells, and consequently the bone resorption (Yamaguchi M, *et al.*, 2009). Vitamin D3 was shown to decrease the receptor activator nuclear factor-kappa B (RANKL/OPG) ratio, reducing the osteoclastic bone resorption via Vitamin D Receptor (VDR) in mature osteoblasts. On the other hand, increased levels of vitamin D were shown to increase the RANKL/OPG ratio, inducing osteoclastic bone resorption via VDR in less-mature osteoblasts (Yu X, *et al.*, 2019). They showed that RANKL was overexpressed, leading to an increased RANKL/OPG ratio during the pressure. This finding confirms that vitamin D might have an impact on the balance between bone formation and resorption, which is considered crucial for the orthodontic tooth movement (Küchler EC, *et al.*, 2021). The scientific interest in vitamin D has been increasing in the last decade. In dentistry, vitamin D supplementation has been proposed to promote oral health. (Ferrillo M, *et al.*, 2022). The scientific literature has been focused on accelerating the rate of tooth movement and on inducing bone turnover in combination with mechanical forces. (Ferrillo M, *et al.*, 2022). Moreover, the potential relationship between calcitriol and orthodontic tooth movement has been recently investigated, although the role of vitamin D on bone remodeling remains a subject of debate and its influence on molecular processes remains widely un-known (Al-Attar A, *et al.*, 2021).

Therefore, this review of literature aimed to evaluate the current evidence on the role of vitamin D on orthodontic tooth movement, EARR, bone biomarkers expression, and bone remodeling.

1.1 Remodeling of Orthodontic Tooth Movement and Vitamin D Relation

Orthodontic tooth movement in the presence of a mechanical stimulus depends on the remodeling of the alveolar bone and periodontal ligament. In bone remodeling, bone resorption occurs at places of stress and formation at places of tension. The magnitude often applied force and the biological response of the periodontal ligament can control orthodontic tooth movement. Bone remodeling that occurs after the application of orthodontic force, includes the resorptive phase and bone formation in the alveolar process (Huang *et al*., 2014). Accelerate tooth movement in orthodontic treatment can provide benefits such as shorter treatment duration, reduced side effects (oral hygiene problems, root resorption, and open gingival embrasure spaces), and increased post-treatment stability. Biological approaches using various pharmacological agents have been used for a long time to accelerate orthodontic tooth movement and have achieved successful results. Vitamin D and 1,25 dihydroxycholecalciferol (1,25 DHC), which is an active metabolite of vitamin D along with parathyroid hormone (PTH) and calcitonin, control total calcium and phosphorus levels. Intraligamentary injection of vitamin D metabolites causes an increase in the number of osteoclasts (Collins and Sinclair, 1988), and consequently in the rate of bone resorption which leads to an increase in the rate of tooth movement during canine retraction (Huang *et al*., 2014; Raja *et al*., 2016; Al-Attar *et al*., 2021). Orthodontic tooth movement (OTM) is influenced by individual variations so the generalizability of the study and results is limited. Factors such as patient age, tooth brushing technique, dietary habits, and quality of tooth extraction can be considered as some potential sources of bias that may influence the rate of canine distalization. Mandal *et al*., suggested that a 12-week reduction in treatment time from the median time was clinically significant in terms of efficiency. There were no significant differences between groups regarding root resorption, therefore vitamin D levels were not among the clinical variables that are a potential contributor to OIRR (orthodontically induced root resorption) (Al-Attar *et al*., 2022).

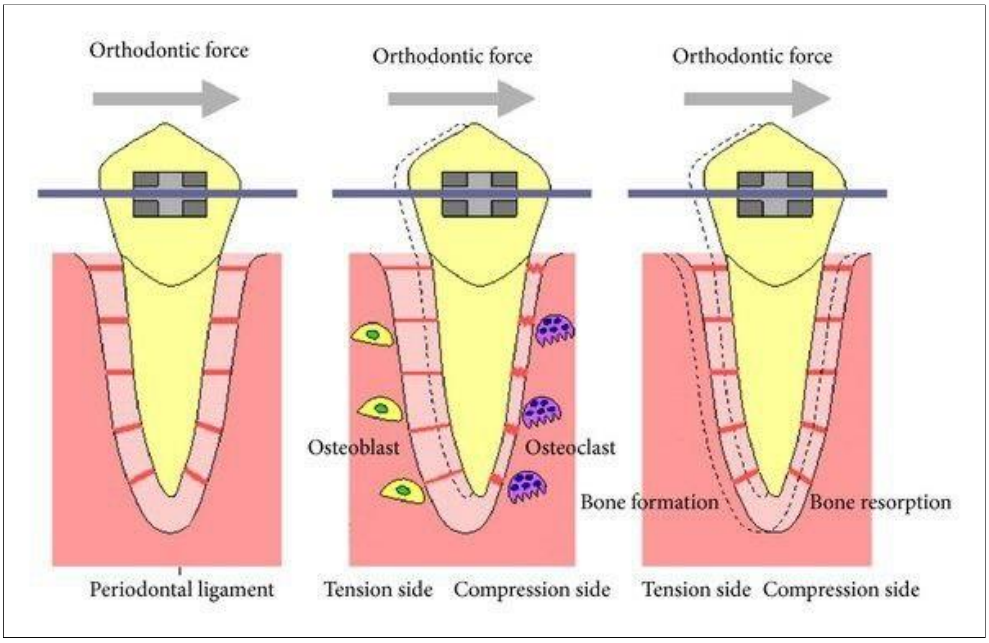

Figure 1: Schematic diagram of tooth movement. Applying orthodontic force to the tooth causes compression of the periodontal ligament. The compressed side of periodontal ligament is called the compression side and the side where the periodontal ligament is pulled is called the tension side. Osteoclasts appear on the compression side and osteoblasts on the tension side. The tooth moves as osteoclasts resorb bone while osteoblasts form bone (Hideki, *et al*, 2014)

1.2 Metabolism and Biological Activity of Vitamin D for Calcium Metabolism

Once vitamin D3 is made in the skin or vitamin D2 and vitamin D3 are ingested from the diet, the vitamin D (vitamin D without a subscript represents either vitamin D2 or D3) is transported to the liver where it is metabolized to its major circulating form, 25-hydroxyvitaminD (25-hydroxycholecalciferol and 25-hydroxyergocalciferol; 25 OH-D) (Holick, *et al.*, 1995). 25-OH-D is biologically inert on calcium metabolism at physiological concentrations and requires a further hydroxylation in the kidney to form its biologically active metabolite,1,25-dihydroxyvitaminD [1,25 dihydroxycholecalciferol and 1,25-dihydroxyergocalciferol; 1,25(OH)2D]. The major biological function of vitamin D is to maintain the serum calcium in the normal physiological range to preserve neuromuscular and cellular functions. 1,25(OH)2D maintains the blood calcium in the normal range by enhancing the efficiency of intestinal calcium absorption and by increasing the mobilization of stem cells to become osteoclasts that, in turn, mobilize calcium stores from bone (Darwish, *et al.*, 1995) (Fig. 1).

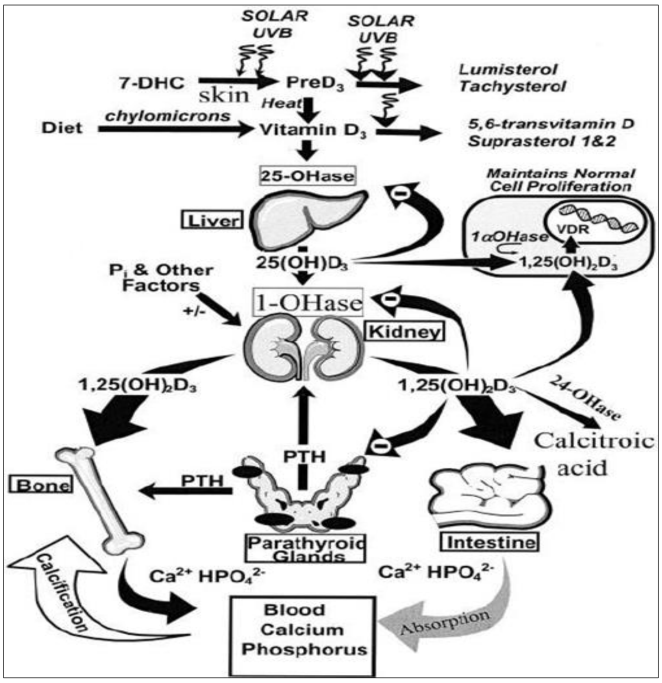

Figure 2: During exposure to solar UVE photons, 7-dehydrocholesterol (7-DHC) is converted in the skin to previtamin D3 (preD3). Once formed, preD3 undergoes a thermally induced isomerization to vitamin D3. Vitamin D (vitamin D2 or vitamin D3) from the skin or diet is metabolized sequentially to 25-hydroxyvitamin D(25-OH-D) and 1,25-dihydroxyvitamin D3 1,25(OH)2D) which, in turn, stimulates intestinal calcium absorption and bone calcium mobilization. Parathyroid hormone (PTH) is one of the major regulators of 1,25 (OH)2D production and stimulates calcium mobilization from the bone. The net effect of 1,25 (OH)2D is to maintain a normal serum calcium and phosphorus to promote bone mineralization

1.3 Biological Function of Vitamin D in Bone

1.3.1 Regulation of Calcium and Phosphate Metabolism:

Vitamin D enhances calcium and phosphate absorption in the intestines, which are crucial for bone mineralization and strength (DeLuca, H. F., 2004).

1.3.2 Promotion of Osteoclastogenesis:

Vitamin D increases RANKL (Receptor Activator of Nuclear Factor Kappa-B Ligand) expression and suppresses OPG (Osteoprotegerin), promoting osteoclast activity essential for bone remodeling (Suda, *et al.*, 2003).

1.3.3 Maintenance of Bone Mineral Density (BMD): Adequate vitamin D levels are associated with higher BMD, reducing risks of osteoporosis and fractures (Holick, M. F., 2007).

1.3.4 Facilitation of Bone Remodeling: Vitamin D is crucial for bone resorption and formation processes, maintaining structural integrity (Bikle, D. D., 2012).

1.3.5 Influence on Muscle Function: Vitamin D supports muscle strength and coordination, indirectly reducing fall risks and associated fractures (Bischoff-Ferrari, *et al.*, 2004).

1.4 Vitamin D

1.4.1 Relation of Vitamin D and Orthodontic Tooth Movement

Orthodontic tooth movement (OTM) is the process of moving teeth to correct misalignment and improve dental occlusion (Castroflorio *et al.*, 2023). During OTM, mechanical forces are exerted on the teeth, remodeling the surrounding alveolar bone. This mechanism entails the formation of new bone on the tooth's tension aspect and the bone's resorption on the compression side (Yang *et al.*, 2023). Orthodontists perform this procedure using braces or other orthodontic appliances (Ganesh & Pandian, 2017). However, OTM is not just a mechanical process; it also involves an inflammatory response and can cause tooth pain, also known as orthodontic pain (Zainal Ariffin *et al.*, 2011). Additionally, OTM can result in changes in dental occlusion, which is the way the upper and lower teeth come together when biting or chewing (Wang *et al*., 2023). Individual responses to OTM differ markedly, with some patients acclimating smoothly to the process, whereas others might endure considerable discomfort or struggle with the adjustments in bite occlusion (Cioffi, 2023).

1.5 Type of Tooth Movement Affected by Vitamin D Deficiency during Orthodontic Treatment

The type of tooth movement affected by vitamin D deficiency during orthodontic treatment includes bodily movement, tipping, intrusion, extrusion, and retention/relapse. Below are the relevant details supported by scientific studies:

1.5.1 Bodily Movement (Translation):

The entire tooth moves uniformly in one direction without rotation or tilting. Effect of Vitamin D Deficiency: Slower bodily movement due to impaired bone resorption and formation caused by reduced osteoclast and osteoblast activity (Khamees and Al-Groosh, 2023).

1.5.2 Tipping Movement:

The crown moves in one direction while the root moves in the opposite direction. Effect of Vitamin D Deficiency: Reduced bone remodeling efficiency at the tension and pressure sides results in slower tipping.

(Khalaf and Almudhi, 2022).

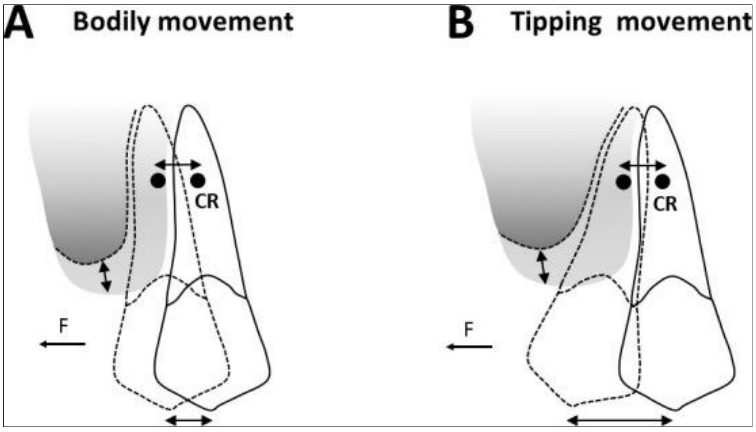

Figure 3: CR is defined as the point crossed by a force vector at which bodily tooth movement is achieved. CR is considered to be located at approximately one-third of the tooth root in height, and, therefore, applying orthodontic force to a crown generally causes a tipping tooth movement. If the position of CR is clearly determined during orthodontic treatment, tooth movement will be accurately predicted without difficulty. In addition, it was reported that the CR is advocated to be most suitable as a reference point for measuring tooth movement (Smith RJ, *et al*., 2014)

1.5.3 Intrusion and Extrusion:

Intrusion Definition: Movement of a tooth deeper into the alveolar bone. Extrusion Definition: Movement of a tooth out of the alveolar bone. Effect of Vitamin D Deficiency: Impaired due to reduced alveolar bone density and slower bone turnover rates (Khamees and Al-Groosh, 2023).

1.5.4 Retention and Relapse:

Retention is the phase of maintaining teeth in their new position, while relapse refers to their return to original positions. Effect of Vitamin D Deficiency: Higher relapse rates due to delayed periodontal ligament and bone remodeling (Khamees and Al-Groosh, 2023).

1.6 Vitamin D Deficiency and Bone Health

Vitamin D deficiency continues to be a significant concern for bone health, as it impairs the body's ability to absorb calcium and phosphorus, both essential for strong bones. Recent research highlights the link between low vitamin D levels and conditions like osteomalacia and osteoporosis (Dr. Michael F. Holick, 2020).

1.6.1 Impact on Bone Mineral Density and Structural Integrity

Impact on Bone Mineral Density and Structural Integrity on Orthodontic Tooth Movement:

1. Bone Mineral Density (BMD) is a key factor influencing the rate and efficiency of OTM, as it determines the strength of the bone and its ability to respond to mechanical. Individuals with lower BMD may experience slower tooth movement due to impaired bone remodeling (Takahashi and Suzuki, 2019).
2. Structural integrity of the alveolar bone is essential for proper tooth movement, as compromised bone structure can lead to increased tooth mobility and treatment

complications. Weakened bone structure, such as in cases of osteoporosis, can hinder efficient tooth movement during orthodontic treatment (Lee and Park, 2017).

3. Bone remodeling, which is crucial for OTM, is influenced by the balance between bone resorption and formation. Vitamin D plays a significant role in bone resorption and formation, and deficiency in vitamin D can impair these processes, slowing tooth movement (Nagaoka and Yamaguchi, 2020).
4. Osteopenia or low bone mineral density (BMD) can impair orthodontic tooth movement, Patients with lower BMD showed a slower rate of tooth movement and a higher risk of bone-related complications during orthodontic treatment (Tepedino and Ricketts, 2015).
5. Alveolar bone structure impacts the forces required for tooth movement, with poor bone integrity causing a higher risk of bone resorption during orthodontic treatment. The bone architecture plays a critical role in the efficiency of OTM, as more resilient bone structure supports faster and more stable tooth movement (Feng and Li, 2018).

As the review above, for successful orthodontic treatment, assessing a patient's vitamin D levels during the initial evaluation is essential. Addressing deficiencies through dietary supplements, increased sunlight exposure, or medical intervention can help achieve adequate vitamin D levels.

1.7 Phases of Tooth Movement

Orthodontic tooth movement progresses through three stages:

Initial Phase: Occurs immediately after the application of force onto the tooth. This results in rapid tooth movement over a short distance and then stops. This movement displaces the tooth within the periodontal membrane and bends the alveolar bone to a certain extent. The initial phase results in about 0.4 to 0.9 mm of tooth movement and usually occurs within a week after applying initial force (Maltha, *et al*., 2021).

Lag Phase: It sees little to no tooth movement and witnesses the formation of hyalinized tissue in the periodontal ligament. This hyalinized tissue must undergo resorption before further tooth movement can occur. The duration of the lag phase depends on the amount of force applied. Supposedly a clinician applies lighter force, the amount of hyalinized tissue will be less; hence resorption of the same will occur faster. In contrast, a more prolonged lag phase is seen when heavier forces are applied orthodontically. The duration of the lag phase also depends on factors such as the patient's age and the density of the alveolar bone (Li, *et al.,* 2021).

Post Lag Phase: After the resorption of the hyalinized tissue or the lag phase, tooth movement progresses rapidly. This occurs in the post-lag phase, where bone undergoes resorption via the help of osteoclasts, resulting in direct resorption of the bone that faces the periodontal ligament (Maltha, *et al*, 2021).

1.7.1 Vitamin D Role in Accelerating Tooth Movement

Vitamin D is a potent stimulator of osteoclastic activity by promoting the recruitment of osteoclast precursors in bone remodeling. In addition, the prevalence of Vitamin D deficiency is high, so it is important to investigate the clinical application of these findings, including the potential use of Vitamin D metabolites to enhance the rate of tooth movement during orthodontic treatment. Vitamin D inadequacy is a problem, especially among elderly patients and osteoporosis patients. Factors that contribute to low Vitamin D are lack of exposure to sufficient sunlight and inadequate dietary intake and supplementation; other factors contributing are obesity, age, use of medication, sunscreen, exposure to sunlight, and skin color. Fortunately, we find Vitamin D supplements to be widely available and relatively inexpensive. (Holick MF, 2006) Vitamin D plays a crucial role in mediating calcium absorption and regulating musculoskeletal health. It is a steroid hormone that has specific receptors in many target organs and tissues. The action is by activating DNA and RNA within the target cell, producing proteins and enzymes which can be used for the bone resorption process (Norman AW, 1979).

1.7.2 Tooth Movement Accelerating Methods

Tooth movement is divided into three phases: the initial phase, rapid movement after the application of force; then the lag period, with little or no movement, followed by last phase, where there is gradual or sudden increase of movement. In the acute phase of tooth movement, there are acute inflammatory responses, which are characterized by leucocytes migrating out of blood capillaries, producing cytokines, which stimulate the excretion of prostaglandins and growth factors. And the chronic phase involves the proliferation of fibroblast, endothelial cells, osteoblasts, and alveolar bone marrow cells remodeling process. Experiments have been done using these molecules exogenously to enhance tooth movement both in animal experiments and humans. Examples of these are Vitamin D, prostaglandin E (PGE), cytokines that including lymphocytes and monocytes-derived factors, receptor activator of nuclear factor kappa B ligand (RANKL), and macrophage colony-stimulating factor (MCSF). (Boyce RW, Weisbrode SE, 1985).

Accelerating tooth movement in orthodontics typically requires promoting optimal bone health and remodeling (Yamaguchi, *et al*., 2005). While vitamin D plays a crucial role in calcium and phosphorus metabolism, which are vital for bone mineralization, there is no direct evidence to suggest that vitamin D deficiency would accelerate tooth movement (Holick, M. F. (2007). In fact, vitamin D deficiency can impair bone remodeling and compromise the speed of tooth movement. Instead, ensuring adequate vitamin D levels is critical for maintaining healthy bone density and structure, which supports effective tooth movement. Sufficient vitamin D promotes better bone remodeling, reducing the risk of complications like root resorption and slowing the overall orthodontic treatment (Yamaguchi, *et al*., 2005).

In summary, addressing vitamin D deficiency is important for optimizing and protecting the process of tooth movement, not for accelerating it. If you want to promote healthy tooth movement, focusing on adequate vitamin D intake (through sunlight exposure, diet, or supplementation) is beneficial, but deficiencies should be avoided rather than used as a tool for acceleration.

1.7.3 Factors Affecting Orthodontic Tooth Movement

1. Hormones: Hormones such as estrogen, androgens, and thyroid can influence the rate of orthodontic tooth movement. A clinician should pay special attention to a patient's medical conditions that might cause fluctuations in their hormone levels (Asiry, M.A., 2018).
2. Vitamin D: Influences the absorption of essential hormones such as calcitonin that influence the cells responsible for bone remodeling. Monitoring vitamin D levels under the supervision of a specialist can ensure an optimal rate of orthodontic tooth movement (Almoammar, K., 2018).
3. Drugs: Non-steroidal anti-inflammatory drugs or NSAIDs are clinically used as anti-inflammatory medications. NSAIDs inhibit prostaglandin synthesis; hence, patients undergoing long-term acetylsalicylic acid therapy may show slow orthodontic tooth movement (Yezdani, A.2019). Bisphosphonates are potent inhibitors of bone resorption and are prescribed therapeutically during conditions such as osteoporosis and osteopenia. Bisphosphonates can inhibit tooth movement and impair bone healing (HenKrishnan, S., 2015). it is essential for patients to inform their doctors about any medications they might take. This will allow clinicians to optimize their orthodontic treatment plan accordingly (Krishnan, S., 2015).
4. Patient age: Younger patients may experience faster orthodontic tooth movement during the first phase of the treatment than older age groups (Schubert, A., *et al*., 2020).

However, it is still possible to have successful treatment outcomes as adults. The evolution of modern treatment modalities like aligners has led to hundreds of adults seeking out successful orthodontic treatments year after year.

1.8 Effect of Vitamin D Deficiency on Post-Orthodontic Relapse

Relapse cases that occur in patients after active orthodontic treatment have different possibilities for each patient, these relapse cases can occur partially, completely, and can even cause new malocclusions in the patient. Several studies report that administration of vitamin D can increase tooth movement during orthodontic treatment and reduce inclination relapse after orthodontic tooth movement. Vitamin D deficiency can increase bone and root cementum resorption and decrease deposition after orthodontic retention, which may play an important role in the occurrence of relapse (Khamees *et al*., 2023). Relapse in orthodontics is considered one of the undesirable side effects of orthodontic treatment (Littlewood *et al*., 2016). Many studies found that the prevalence of relapse after orthodontic treatment ranged from 30% to 50% of the satisfactory alignment of orthodontic patients after 10 years, and only 10% of the treated cases retained an acceptable alignment after 20 years (Yu *et al*., 2013). Numerous factors might contribute to orthodontic relapses, such as periodontal, muscular, anatomical, sex, occlusal, and orthodontic treatment mechanics-related factors (Ben Mohimd *et al*., 2018), in addition to other factors, including habits, neuromuscular imbalance, and continuous craniofacial growth (Littlewood *et al*., 2016). Results showed no significant difference in the number of osteoclast cells. This result could be due to the force-related activity, where the number of osteoclasts on the compression sides appeared higher after 7 days of force application (Li *et al*., 2016); however, during force-induced reversal action, that is, from bone resorption to bone formation, the number of osteoclast cells was reduced due to apoptosis (Kobayashi *et al*., 2000).

CONCLUSION

Vitamin D deficiency impairs bone remodeling, delays orthodontic tooth movement, increases the risk of root resorption, and impacts treatment outcomes. Regular monitoring of vitamin D status. Along with appropriate supplementation or dietary adjustments, is vital to enhance treatment efficiency, minimize complications, and ensure the best possible results for OTM. It is a common desire for individuals to maintain their teeth in optimal condition and to observe favorable outcomes following orthodontic treatment. However, it is observed that some patients may experience a relapse, with their teeth reverting to their original positions post-treatment, necessitating further intervention. Vitamin D plays a key role in bone metabolism by regulating the function of osteoblasts, which are responsible for forming new bone, and osteoclasts, which break down old bone. This coordination is essential for the process of bone remodeling, which is continuously required for successful OTM. When vitamin D levels are insufficient, the availability of calcium and phosphate—crucial minerals for bone mineralization—is reduced. As a result, bone mineralization becomes impaired, compromising the structural strength of the bone. This leads to a slower rate of bone resorption and formation, processes critical for the adaptation of the alveolar bone during OTM. Such disruptions may cause delays in tooth movement, prolong orthodontic treatment times, and increase the likelihood of complications related to inadequate bone remodeling or suboptimal treatment outcomes.

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