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The Correlation between the Bone Morphotype and Density and Root Apical Resorption of the Anterior Teeth Due to Orthodontic Forces

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Abstract

The potential side effects of modern orthodontic treatment and its unfavorable impact on dentition and hard tissues have been extensively discussed in professional literature for decades. The presence of uncontrolled forces can result in pulp necrosis, radicular reabsorption, and/or loss of alveolar bone. Dehiscence and fenestration are more commonly found in anterior than posterior teeth, where only the periodontal ligament and the mucosa protect the dental root.

Most studies investigating the effect of periodontal phenotype over gingival recession in orthodontic patients have primarily focused on examining the soft tissues. However, due to the vulnerability of thin alveolar bone, the previous evaluation of orthodontic candidate patients may also include the analysis of hard tissues. Bone density plays an important role in facilitating orthodontic tooth movement, such that reductions in bone density can significantly

increase movement velocity. These types of localized density changes can affect the rate of orthodontic tooth movement and may also influence the risk of unwanted outcomes, such as the occurrence of dental external apical root resorption.
According to the literature, the links of root resorption with the bone morphotype and the density are relevant in clinical dentistry but have not been studied in detail. However, the existing data is not yet conclusive.

Keywords: External tooth root resorption (EAAR), bone mineral density (BMD), orthodontic tooth movement (OTM), the bone morphotype, cone beam computed tomography (CBCT)

Introduction

The potential side effects of modern orthodontic treatment and its unfavorable impact on dentition and hard tissues have been extensively discussed in professional literature for decades. However, the existing data are not yet conclusive (Katarzyna et al., 2021).

One of the axioms in orthodontics holds that the bone follows the tooth during its movement through the alveolus. This is possible thanks to bone remodeling — a coupled process of bone resorption and apposition elicited by the mechanical force applied to the tooth by an orthodontic appliance (Krishnan V, et al., 2009), (Nouri M, et al., 2014).

The ratio between remodeling of the alveolar process and tooth movement is claimed to be 1:1. If this ratio is preserved, the root of the tooth is always supported by the alveolar bone, and no bone loss occurs during orthodontic treatment (Baloul S, et al., 2016).

External apical root resorption (EARR), a permanent loss of hard tissue on the root apex of a tooth, is one of the most undesirable side effects during orthodontic treatment. The prevalence of ARR varies from 20 to 100% among orthodontic patients (Baumrind S, et al., 1996).

Literature review

Severe External Apical Root Resorption (EARR) is rare, with an incidence between 1 and 5%, but the resorption can be more than 5 mm or one-fourth of the root length. EARR can cause an imbalanced ratio of crown and root in the affected teeth, and even tooth loss, affecting patients' quality of life and orthodontic treatment results (Brezniak N, et al., 2002).

Orthodontic tooth movements are possible due to both bone resorption and apposition resulting from the application of forces on the dental crown. A primordial factor for this movement is the presence of enough alveolar bone thickness surrounding the root of the tooth (Iwasaki LR, et al., 2000). Orthodontists use force to move teeth in a controlled fashion to facilitate the proper positioning of the teeth and achieve a uniform distribution of forces during occlusion. Tooth movement through the alveolar bone envelope, triggered by orthodontic strain, is a phenomenon that depends directly on the coordinated activity of osteoblasts, osteocytes, and osteoclasts. External apical root resorption (EARR) is root resorption that can be seen on standard diagnostic radiographs caused by the undesirable activity of osteoclastic cells on the root surface (Weltman B, et al., 2010).

The presence of uncontrolled forces can result in pulp necrosis, radicular reabsorption, and/or loss of alveolar bone. Alveolar bone loss that results in a defect without a bony lining is called dehiscence. However, if some bone remains in the most coronary part, the defect is defined as fenestration. Dehiscence and fenestration are more commonly found in anterior than posterior teeth, where only the periodontal ligament and the mucosa protect the dental root (Lindhe J, et al., 2015). Although it can occur in the absence of orthodontic treatment, its incidence increases when concurrent with orthodontic treatment.

Regardless of whether or not EARR is facilitated by orthodontic mechanical factors, the process leading to EARR implicates specific molecular pathways that orchestrate non-physiological cellular activation for root demineralization and the creation of dental root resorption pits. Differing alveolar bone densities and bone modeling/remodeling processes affect the strain on the dental root, thus influencing the orthodontic tooth movement (OTM) process and the increased occurrence of EARR as a deleterious secondary effect (Hartsfield JK, et al., 2009).

However, EARR concurrent with orthodontic force is a complex trait, with multiple factors involving the reaction of the dental root, periodontal ligament, and alveolar bone to the force-induced strain on the root. It is clear that how all of these factors affect alveolar bone density has an effect on the degree and duration of strain on the dental root, leading to a cascade of resorption of the dental root. The combination of factors that may result in this complex trait appears to vary from sample to sample and likely varies from individual to individual, making a precise prediction of the occurrence of EARR unlikely. Although with sufficient study, a relatively qualitative high, medium, or low risk may someday be possible to determine, these would not be absolutes (Alejandro I-L, et al., 2016), (Januário AL, et al., 2008).

Bone density plays an important role in facilitating orthodontic tooth movement, such that reductions in bone density can significantly increase movement velocity. These types of localized density changes can affect the rate of OTM and may also influence the risk of unwanted outcomes, i.e., the occurrence of dental external apical root resorption (Alejandro I-L, et al., 2016).

Bone mass is a function of bone size and volumetric bone mineral density (BMD) and is a key determinant of bone strength. It is a measure of the combined amount of bone matrix and mineral content within a segment of bone. Bone Mineral Density (BMD) is a clinical proxy for estimating bone mass that takes into account the concentration of calcium and other minerals and estimates bone strength (Alejandro I-L, et al., 2016).

Bone modeling changes the shape of bone resulting in changes in bone morphology. The ability to change bone morphology is due to bone resorption and formation occurring in an uncoupled manner and on separate surfaces. In contrast, bone remodeling is the mechanism based on the coupled and balanced activities of bone resorption and formation along specific sites on the same bone surface that ensures turnover while maintaining bone mass and gross morphology. This allows for adaptation to both mechanical loading and the requirements of calcium and phosphate metabolism (Baron R, et al., 2013), (Roberts WE, et al., 2006). While modeling along the periosteal surface is key for maintaining alveolar bone support during tooth movement, both bone modeling and remodeling are involved in the orthodontic response (Roberts WE, et al., 2006).

Alveolar bone density on root resorption is assessed controversially. A part of the studies has established that the denser the alveolar bone, the more root resorption occurs during orthodontic treatment. According to Reitan, a strong continuous force affecting alveolar bone of less density causes the same root resorption as a mild continuous force affecting alveolar bone of higher density (Brezniak N, et al., 1993). It is more difficult to resorb with orthodontic pressure than bundle bone. Wainwright has stated that bone density determines tooth movement rate but has no relation to the extent of root resorption (Brezniak N, et al., 1993). In 1985, Lekholm and Zarb listed four bone qualities found in the anterior regions of the jawbone (Fig.1) (Lekholm U, et al., 1985).

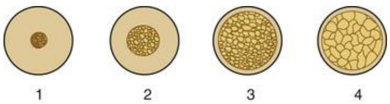
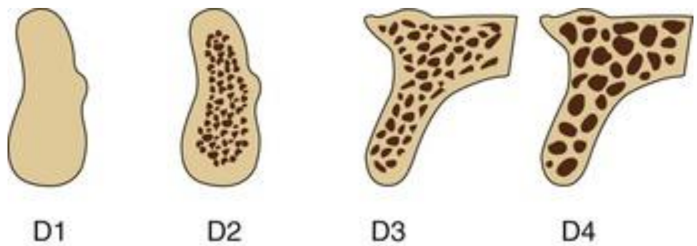


Figure 1. Lekholm & Zarb classification:
Type I: The entire bone is composed of very thick cortical bone.
Type II: A thick layer of cortical bone surrounds a core of dense trabecular bone.
Type III: A thin layer of cortical bone surrounds a core of trabecular bone of good strength.
Type IV: A very thin layer of cortical bone with low-density trabecular bone of poor strength

In combination, these four macroscopic densities constitute the four bone categories described by Misch (D1, D2, D3, and D4). D1 bone is primarily dense cortical bone, D2 bone has dense to thick porous cortical bone on the crest and coarse trabecular bone underneath, D3 bone has a thinner porous cortical crest and fine trabecular bone within, and D4 bone has almost no crestal cortical bone. The fine trabecular bone composes almost all of the total volume of bone (Misch CE, Bidez MW, et al., 2005) (Fig. 2).

Figure 2. Misch Bone Density Classification

Bone Density	Description	Tactile Analog	Typical Anatomical Location
D1	Dense cortical	Oak or maple wood	Anterior mandible
D2	Porous cortical and coarse trabecular	White pine or spruce wood	Anterior mandible Posteriormandible Anterior maxilla
D3	Porous cortical (thin) and fine trabecular	Balsa wood	Anterior maxilla Posteriormaxilla Posterior mandible
D4	Fine trabecular	Styrofoam	Posterior maxilla



Cementum is harder than alveolar bone and more mineralized; more fibers of periodontal ligaments are inserted into cementum than in alveolar bone. Thus, osteoclasts have less possibility to injure the cementum layer and induce root resorption (Roberts-Harry D, et al; 2004).

Non-invasive Techniques for Bone Mass Measurement

The gingival phenotype, characterized by gingival thickness and keratinized tissue width, and bone morphotype, characterized by bone thickness and its morphology, are the main parameters used to categorize periodontal phenotype. Most studies investigating the effect of periodontal phenotype on gingival recession (GR) in orthodontic patients have primarily focused on soft tissues. However, due to the vulnerability of thin alveolar bone, the previous evaluation of orthodontic candidate patients may also include the analysis of hard tissues (Jaime A. et al; 2021).

Nowadays, the gold standard for the 3D study of bone morphotype is cone-beam computed tomography (CBCT).

The literature on the anatomy of the alveolar bone of the anterior teeth, utilizing high-resolution cone-beam computed tomography (HR-CBCT), is still lacking despite the significance of 3D evaluation of bone morphotypes. Our objectives were to identify apical root resorption in orthodontic patients and to evaluate alveolar bone thickness and bone density.

Materials and methods

The search for patient archives from the previous study at the Grigol Robakidze University Dental Center "Gruniverse" was conducted systematically. The required information was gathered by a team of trained professionals using the center's database and record-keeping system. The search was performed based on specific criteria, including the study timeframe from June 2022.

According to the data from our previous research related to the Impact of Orthodontic Forces on the Occurrence of Iatrogenic Tooth Root Resorption, the most commonly affected age group was 18-35, treated with non-removable orthodontic appliances (brace system). External apical root resorption (EARR) of tooth roots was mostly observed in women. The frequency of the abovementioned complication of orthodontic treatment was observed primarily in cases of the upper and lower incisors. Complications due to orthodontic forces occurred in only 12 patients in total.

The objectives of the recent research are as follows:

Assess the relationship between bone morphotype and density and tooth root resorption caused by orthodontic treatment.

Establish exclusion criteria: Patients with systemic diseases or the use of any prescription drugs that might have an impact on bone metabolism processes and patients with odontogenic acute or chronic apical periodontitis. This study comprised 56 patients, including 28 patients with non-removable orthodontic appliances of different age groups: 14 patients from Group A (12- to 17) and 14 patients from Group B (18- to 35), and 28 patients with removable orthodontic appliances of different age groups: 14 patients from Group A1 (12- to 17) and 14 patients from Group B1 (18- to 35). Regarding gender distribution, there were 14 males and 14 females in Groups A, and A1 (50%/50%), and the same pattern was observed in Groups B and B1.

To achieve the study goal, patients from both the research and control groups underwent cone-beam computed tomography (CBCT) studies, and statistical processing and comparative analysis of the obtained results were carried out. The HR-CBCT images were taken using a KAVO, Dental Excellence, OP 3D device (Finland).

The bone morphotype resulted in a mean buccal bone thickness of 0.343 (0.135) mm for the thin biotype and 0.754 (0.128) mm for the thick/average biotype. Bone morphotypes have been radiographically measured with cone-beam computed tomography (CBCT) (Pierpaolo Cortellini, et al., 2016).

The evaluation included 336 anterior teeth (canines (C), lateral incisors (LI), and central incisors (CI)) of the 56 patients from the 1st and 3rd quadrants. Each image was positioned along the main axis of the tooth, passing the sagittal plane over the root's longest buccal-lingual diameter. The thickness of the alveolar bone was measured in both the maxilla and mandible at three levels on the buccal surfaces: (1) Cervical level (CeL), at the level of a line perpendicular to the tooth's main axis, traced at 1 mm from the CEJ, (2) Apical level (ApL), at the level of a line perpendicular to the tooth's main axis, passing through the root apex, and (3) Middle level (MiL), at the level of an equal line between the previous two (Fig. 1, Fig. 2)).

The purpose of this study was to quantitatively evaluate the density of the alveolar bone at the incisors and canines of both the upper and lower jaw. Fifty-six sets of computed tomographic (CT) images were selected, and bone density was measured.

Figure. 1. The measurement of the bone morphotype by CBCT scan (teeth 1.2, 3.1 with EARR)

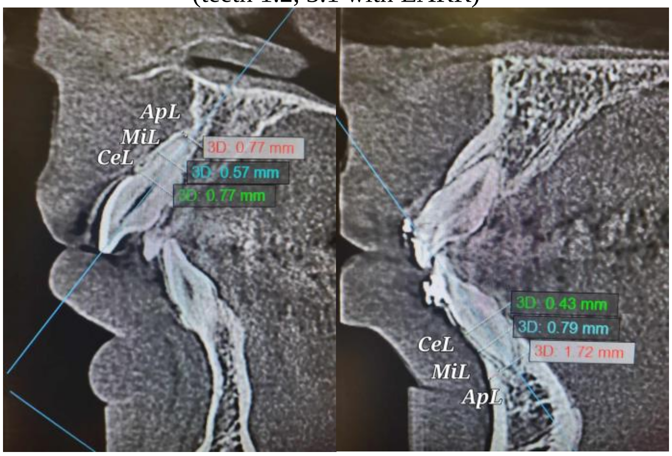
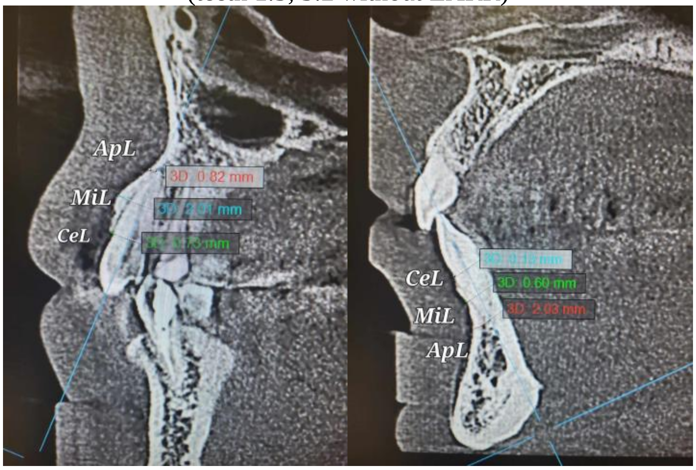


Figure. 2. The measurement of the bone morphotype by CBCT scan (teeth 1.3, 3.2 without EARR)



Statistical Analysis

The study results were processed statistically. First of all, was analyzed how much tooth resorption in the study groups is statistically significantly higher. was calculated relative risk (RR)

$$RR = \frac{a/(a+b)}{c/(c+d)}$$

$$\mathrm{SE}\{\ln(RR)\} = \sqrt{\frac{1}{a} + \frac{1}{c} - \frac{1}{a+b} - \frac{1}{c+d}}$$

$$95\%\ \mathrm{CI} = \exp\left(\ln(RR) - 1.96 \times \mathrm{SE}\{\ln(RR)\}\right) \quad \text{to} \quad \exp\left(\ln(RR) + 1.96 \times \mathrm{SE}\{\ln(RR)\}\right)$$

The relative risk (RR), its standard error, and 95% confidence interval were calculated according to Altman, 1991 (Altman DG, 1991). As a result, a statistically significant difference was observed between the study and control groups regarding the risk of tooth root resorption as a complication of exposure.

Bone morphotype and bone density were observed in all four groups of patients to establish statistical evidence of the correlation between morphotype and bone density with tooth root resorption. Predictors and standard deviation were determined for this segment. The relationship with the development of tooth root resorption in patients with different tooth morphotypes was determined by the t-test. Mean values of the morphotype data and standard deviation were calculated in the groups with and without resorption before conducting the t-test (Tab. 1)

Table 1:

Root Resorption	The bone morphotype Mean ± SD
Root Resorption-YES (n=11)	1.14 ± 0.58
Root Resorption-NO (n=45)	1.30 ± 0.28

t-test = 1.312, p=0.195 (Non-Significant)

Results

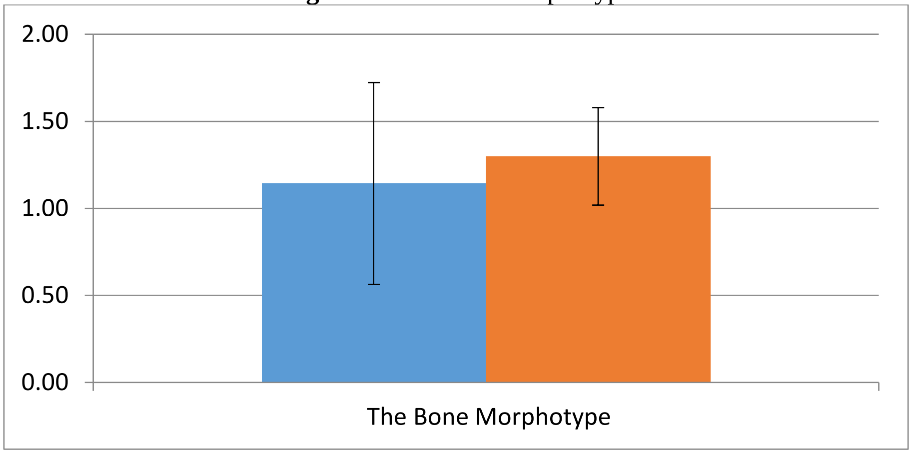
According to the research comparing the following three points (ApL, MiL, CeL) on the upper and lower jaw, the results are as follows: the point (CeL) is less than 1 mm in 98% in both jaws, the point (ApL) is more than 1 mm in 100% in both the maxilla and mandible, and the point (MiL) is less than 1 mm in 56% and more than 1 mm in 44% in the upper jaw, and less than 1 mm in 38% and more than 1 mm in 62% in the lower jaw.

The mean CBT for the maxillary canines and lateral and central incisors was 1.7 mm (range: 1.1 – 1.23 mm), 1.29 mm (range: 0.74 – 1.1 mm), and 0.88 mm (range: 0.56 – 1.21 mm), respectively. For the corresponding mandibular anterior teeth, it was 1.43 mm (range: 0.88 – 1.99 mm), 1.02 mm (range: 0.74 – 1.31 mm), and 1.22 mm (range: 0.82 – 1.63 mm), respectively.

From the studied 56 patients, the thick bone morphotype was observed in 39 patients, and 17 patients had the thin morphotype. As mentioned above, tooth root resorption due to orthodontic forces occurred only in 12 patients in total. Regarding age and sex, the bone morphotype was apportioned as follows: from the study group A, three patients had the thin morphotype, and one of them had the thick morphotype. From the study group A1, the thin morphotype was revealed in one patient and the thick morphotype in one patient as well. From the control group B, four patients with a thin morphotype and two of them with a thick one were observed. The average bone thickness was greater in the upper maxilla at the point (ApL). Similarly, the bone was significantly thicker at the same point in the mandible.

In patients with apical root resorption, the tendency toward thinning of the cortical bone is observed at the site of resorbed teeth; however, there is no susceptibility to thinning at the site of healthy teeth.

Figure. 3. The bone morphotype



t-test = 1.312, p=0.195 (Non-Significant)

The statistically significant difference in tooth root resorption was observed among patients with different tooth morphotypes (Fig. 3, Fig. 5). The bone density of the maxilla ranged approximately between 899 and 1266 Hounsfield units (HU) at the alveolar bone. The bone density of the mandible ranged between 988 and 1548 HU at the alveolar bone. The highest bone density was observed in the lower canines. The density of the cortical bone was greater in the mandible than in the maxilla and showed a progressive increase from the incisor to the canines. In the maxilla, a lesser degree of regularity was observed.

The results of our study did not show any significant correlation between the bone morphotype and density and the rate of root resorption associated with orthodontic treatment. Despite the same bone morphotype and density, apical tooth root resorption is mostly revealed in females. No significant age difference was found (Table 2, 3, 4).

Figure 4. Measurement of the bone density by CBCT scan.

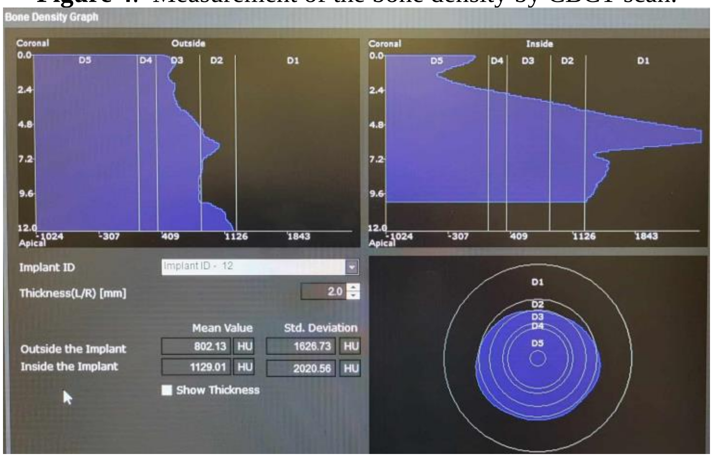


Figure 5. The average rate of bone density in the different tooth sites

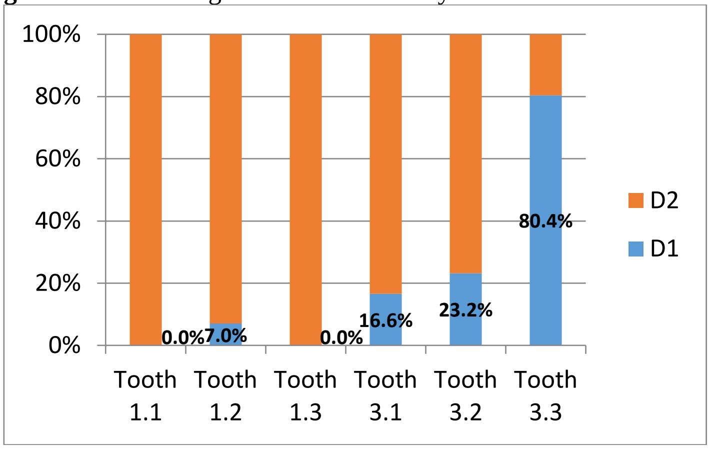


Table 2. The bone morphotype and density of the patients from study group A with EARR

Tooth number	Number of cases	The bone morphotype	The bone density	Fem.	Mal.
1.1	1	0.97	D2	1	0
1.2	1	1.2	D2	1	0
1.3	1	1.45	D2	1	0
3.1	4	1.12-1,2	D2	3	1
3.2	3	1,46-1.84	D2	2	1

Table 3. The bone morphotype and density of the patients from study group A1 with EARR

Tooth number	Number of cases	The bone morphotype	The bone density	Fem.	Mal.
1.1	1	0.11	D2	1	0
1.2	1	1.18	D2	1	0
3.1	1	1.76	D1	1	0

Table 4. The bone morphotype and density of the patients from study group B with EARR

Tooth number	Number of cases	The bone morphotype	The bone density	Fem.	Mal.
1.1	1	1,5	D2	1	0
1.2	3	0,93-1,02	D2	3	0
3.1	3	1.12-1,34	D2	1	2
3.2	3	1.1,46-1,57	D2	1	2
3.3	1	1,98	D2	0	1

Conclusion

Despite having the same bone morphotype and density, apical tooth root resorption of anterior teeth was mostly observed in females, with no significant age difference found. Out of the 56 studied patients, 39 had a thick bone morphotype, while 17 had a thin morphotype. The average bone thickness was greater in the upper maxilla at the point (ApL), and a similar pattern was observed in the mandible. In patients with apical root resorption, a tendency toward thinning of the cortical bone was observed at the site of resorbed teeth, with no susceptibility to thinning at the site of healthy teeth.

The highest bone density was observed in the lower canines. The density of the cortical bone in the anterior segment was greater in the mandible than in the maxilla and showed a progressive increase from the incisor to the canines. In the maxilla, a lesser degree of regularity was observed.

According to the results of the recent study, there was no significant correlation found between the occurrence of tooth root apical resorption of the anterior teeth due to orthodontic treatment and the bone morphotype and density of the patients.

Given the relevance of the problem, further research is required to determine the relationship between root hard tissue resorption caused by orthodontic forces and the shape of the apex, and the length of the root. Taking into account the patient's individual characteristics and choosing an orthodontic appliance to prevent complications caused by orthodontics, we believe that detailed studies will significantly simplify treatment planning. In addition to making treatment outcomes more predictable, they will also contribute to its stability and safety.

Conflict of Interest: The authors reported no conflict of interest.

Data Availability: All of the data are included in the content of the paper.

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