Original article

Effects of Alveolar Bone Width and Density on the Rate of Orthodontic Tooth Movement

Nawaporn Ritwiroon[1], Boonsiva Suzuki[1], Eduardo Yugo Suzuki[1]

[1]Department of Orthodontics, Faculty of Dentistry Bangkokthomburi University, Bangkok, Thailand

Abstract

Accelerated orthodontic tooth movement (OTM) has been widely explored. However, the influence of individual characteristics of alveolar bone on the rate of OTM has not been fully investigated. Therefore, this study aimed to evaluate the influence of morphological features and the density of the alveolar process on the rate of OTM. The study included 24 participants (15 females, 9 males) with an average age of 20.9 years (SD± 3.4 years). Maxillary canines were retracted for three months using a standardized OTM protocol with segmental archwires and superelastic NiTi closed coil springs (50 gm) to provide light continuous force. No functional or localized occlusal interferences affected tooth movement. Pre- and post-canine retraction records were obtained with an intraoral dental scanner from which 3D dental models were created and superimposed to evaluate the amount and rate of OTM. Pre-treatment cone-beam computed tomography images of patients were used to measure alveolar bone width and density on the distal aspect of each canine. The correlation between the rate of OTM and the measured variables was investigated. The results show the mean rate OTM was 0.91 mm/month (range 0.80 - 1.03 mm/month). The rate of OTM was weakly positively correlated with the alveolar bone width to root ratio (r = 0.334, $P < 0.05$) and negatively correlated with cortical bone density (r = -0.297, $P < 0.05$). A wide range of OTM variation (range 0.04 - 0.86 mm/month) within the same individual, between right and left sides was observed in 75 % of cases indicating an asymmetric OTM pattern. The rate of OTM is influenced by alveolar bone width to root ratio and bone density which vary within the same individual. Teeth with higher bone width to root ratio and lower density tend to move faster than those with a lower ratio and higher density.

Keyword: Bone density, Bone width, Cone-beam computed tomography, Orthodontic tooth movement

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Correspondence to:
Eduardo Yugo Suzuki, Department of Orthodontics, Faculty of Dentistry, BangkokthonburiUniversity, 16/10 Leabklongtaweewatana Rd., Taweewatana District, Bangkok 10170 Thailand, Tel: +66-53-274420, Email: eduardo.suz@bkkthon.ac.th

Introduction

The possibility of accelerated orthodontic tooth movement (OTM) has been widely investigated in orthodontics. Several approaches for increasing the rate of OTM including surgical and non-surgical approaches have been proposed.[1-3] The split-mouth design is frequently used to compare the efficacy of each approach to the rate of OTM.[4] In the split-mouth study design, each of the two treatments is randomly assigned to either the right or left halves of the dentition.[5] The advantage of this design is the possibility to remove any inter-individual variability from the estimates of the treatment effect.[4-6] However, a potential problem with the split-mouth design for the assessment of the rate of tooth movement is the possible presence of the intra-individual variability.[4]

However, several factors are responsible for the rate of OTM such as archwire properties, bracket design, force delivery systems, the magnitude of the force, age of the patients, and individual biological responses. [7-10] In animal studies, Bridges *et al.*[11] and Machibya *et al.*[12] had demonstrated that although the force system andmagnitude of force have been controlled, the tooth still moves differently. They indicated that one important factor would be the density of the alveolar bone.[11,12] Moreover, not only the density but also the morphological features of the alveolar bone might be related to OTM. According to the study of Garib *et al.*[13] and Handelman[14], alveolar bone morphology is the biological limits of tooth movement.

Since cone-beam computed tomography (CBCT) images have been widely used in dental and orthodontic treatment planning, several studies use this approach to assess alveolar bone width and density.[15-21] Also, the effect of alveolar bone width and density on the rate of OTM has never been evaluated. Therefore, the purposes of this study were to evaluate the influence of the alveolar bone width and density on the rate of OTM and compare the characteristics of the alveolar bone and the rate of OTM between each side using CBCT images.

Material and Methods

The clinical protocol in this study was approved by the institutional review board of Bangkokthonburi University (approval number: 09/2561). The participants consisted of 24 patients (9 males and 15 females; mean age 20.9 ± 3.4 years) who underwent orthodontic treatment at the Graduate Clinic, Department of Orthodontics, Faculty of Dentistry, Bangkokthonburi University and had an orthodontic treatment plan involves the extraction of premolars for correction of anterior crowding with the use of miniscrew implants as a skeletal anchorage. Other inclusion criteria were as follows: no previous orthodontic treatment, no systemic health problems, and good periodontal status. The exclusion criteria included the presence of a dilacerated root of canines.

All CBCT images, made to assess the availability of bone for miniscrew placement, were obtained from the Sirona Galileos CBCT (Sirona Dental Systems, Bensheim, Germany) with 85 kVp, 7mA, 14 seconds exposure time, voxel size of 0.16 x 0.16 mm, and FOV 15 x 15 x 15 cm^3. Sidexis XG software (Sidexis Next Generation 2.4, Sirona Dental Systems, Bensheim, Germany) was used to reorientate the CBCT images. After setting the reference plane along the canine long axis, the root length was measured from the alveolar crest to the apex of the root (Fig. 1).

Then the roots were equally divided into the cervical, middle, and apical parts (Fig. 2). Axial slices (0.1 mm) were obtained from the half of each part as cervical, middle, and apical levels (Fig. 2, 3). The image of each slice was exported in a DICOM (Digital Imaging and Communications in Medicine) file and imported to be analyzed in the ImageJ software (National Institutes of Health, Bethesda, Md) on a personal computer.

The region of interest (ROI) of the alveolar bone evaluated in this study was the distal aspect of maxillary canines (Fig. 3).

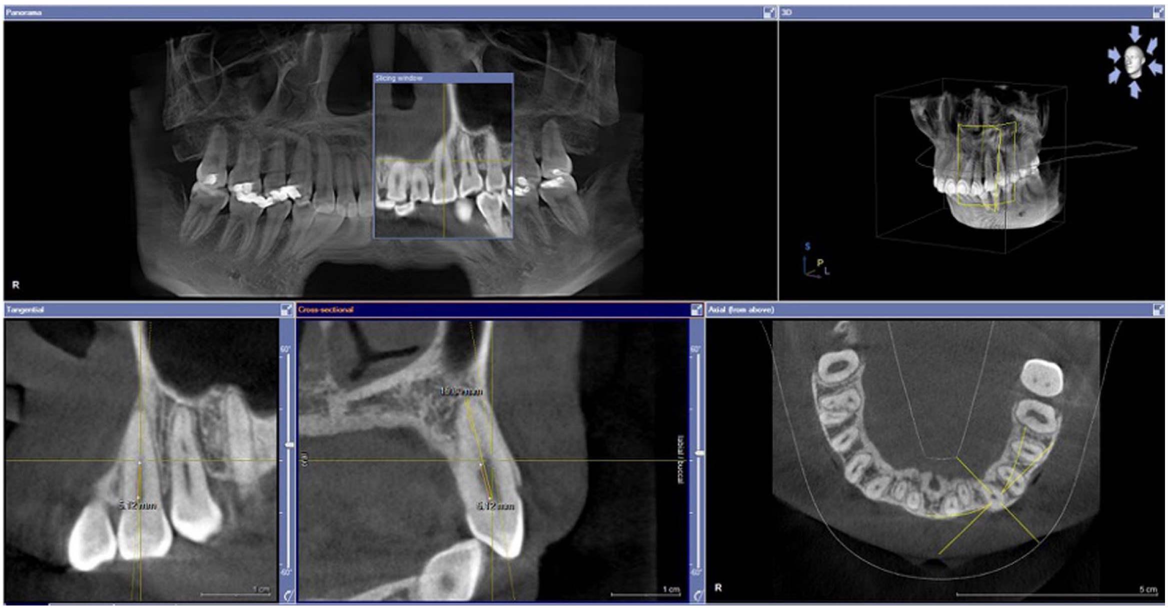

Figure 1 *Plane setting along the long axis of the maxillary canine and root length measurement*

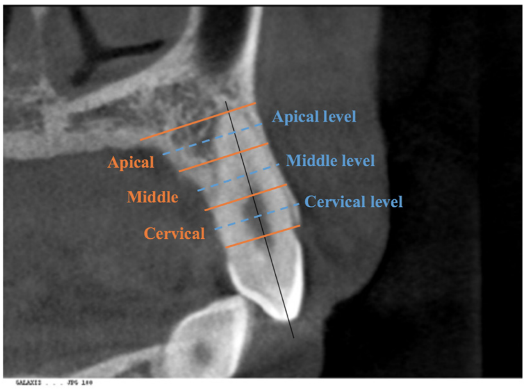

Figure 2 *The root equally divided into three parts (orange lines) and axial slices were obtained from the middle of each part as cervical, middle and apical levels (blue lines)*

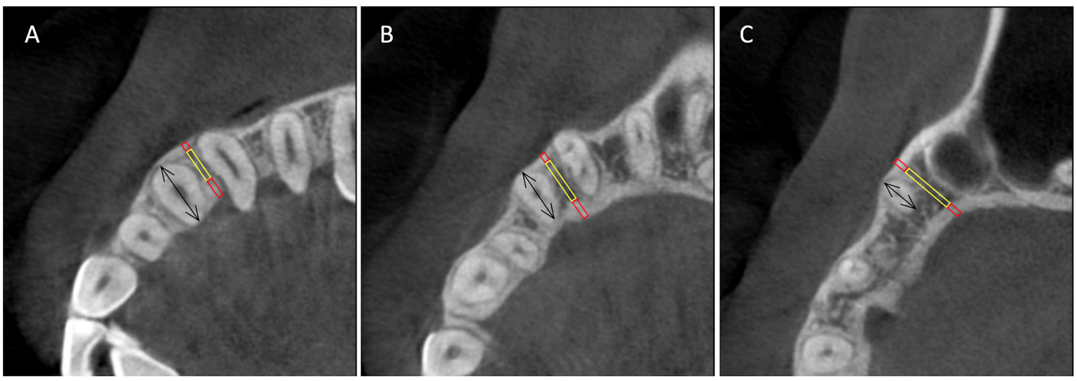

Figure 3 *Measurement of alveolar bone width and bone density in ROI (width = 1 pixel, length depends on alveolar bone width on each slice) and root width in the axial slices at cervical, middle and apical levels (A, B and C respectively); Red rectan gular lines indicate cortical bone; yellow rectangular lines indicate cancellous bone; the combination of red and yellow rectangular lines indicate total alveolar bone; black arrows indicate root width in buccolingual dimension*

In the buccolingual dimension, the total alveolar bone and cancellous bone width were measured in millimeter (mm) and the densities of cancellous, buccal cortical, lingual cortical, and total alveolar bone were measured in gray values (GVs). The root width in the buccolingual dimension was also measured at each level and the relation to bone width was calculated as the total alveolar bone width to the root width ratio and the cancellous bone width to the root width ratio. The cancellous, buccal cortical, lingual cortical, and total alveolar bone density were averaged from the densities of each level.

To perform the standardization of the method and allow comparison of GVs between different CBCT images that were made at different periods, a relative value analysis was used.[18] Maximum GVs, as observed in the cortical bone, were considered as the reference values, while all remaining values were re-calculated relatively to this value. Therefore, a 0 to 100 % scale was performed and used for the analysis of density.

After leveling and aligning for three months, an indirect palatal miniscrew for skeletal anchorage (iPanda) was used for anchorage reinforcement.[22] First premolars were extracted, and the canines were immediately retracted using segmental archwire mechanics. A segmental archwire technique using a 0.016x0.022-in improved superelastic nickel-titanium alloy wire (L&H Titan, Tomy, Tokyo, Japan) was used to provide light and continuous force during the canine distalization. This rectangular wire allows for three-dimensional control over the canine movement. A crimpable hook was connected to the segmental archwire to allow the use of the 50-gram superelastic NiTi closed coil springs (Sentalloy®, Tomy Orthodontics; Tokyo, Japan) to deliver light and continuous distalization forces. A gable bend inserted in the wire allows distal root torque control, thus providing bodily movement of the canine during retraction (Fig. 4). This technique is commonly used at TMDU. (Tokyo Medical and Dental University, Japan).[23]

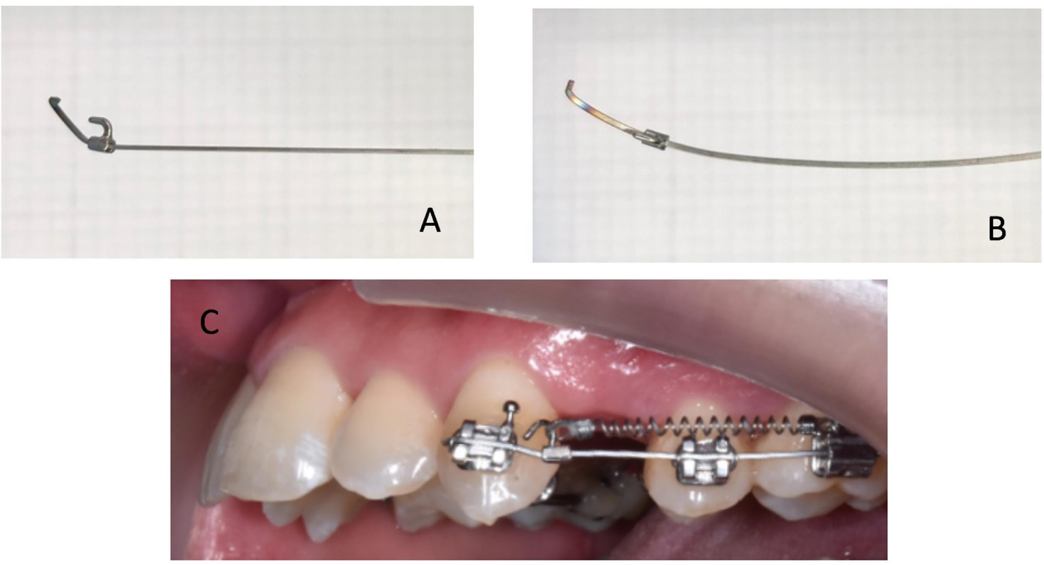

Figure 4 *Segmental archwire (A: Lateral view, B: Occlusal view) and clinical canine retraction (C)*

During canine retraction, no functional or localized occlusal interferences were affecting tooth movement. The canine retraction was observed during monthly follow-ups. The intraoral scans were performed before and after three months of maxillary canine retraction using the Trios® (3Shape Dental Systems, Copenhagen, Denmark). Then the digital 3D models were created and superimposed using both the pair of palatal miniscrews and palatal rugae as reference. The amount and rate of OTM were measured from the 3D model superimposition (Fig. 5).

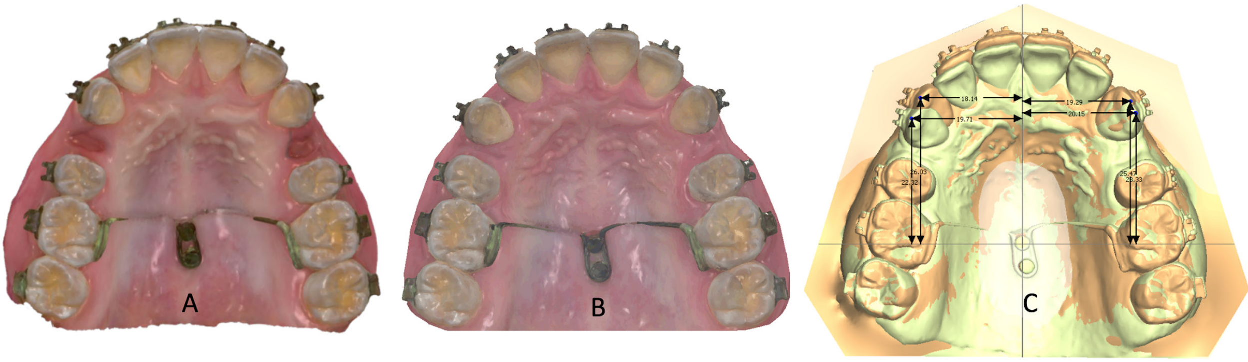

Figure 5 *The intraoral scans before (A) and after (B) canine retraction and the digital 3D model superimposition and measurement (C)*

Statistical analysis

The reliability of the measurements was tested by a re-evaluation of five randomly chosen participants two weeks after the initial measurement. The rate of OTM and alveolar bone width measurements showed good reliability (intraclass correlation coefficient; ICC = 0.90 to 0.95). Bone density measurements showed acceptable reliability (ICC = 0.86-0.91).

SPSS software (version 23.0; IBM, Armonk, NY) was used for all statistical analyses. Pearson correlation was used to carry out the correlation between the rate of OTM and the characteristics of the alveolar bone. Additionally, to support the correlation analysis, the values of the canines with the rate of OTM more than the upper bound of 95%CI and those with the lower rate were divided and compared by an independent *t*-test. Moreover, to compare the measurement values between the right and left side, the values were categorized into two subgroups regarding the rate of OTM as canine with a low rate of OTM and the contralateral with a high rate of OTM subgroups and analyzed by a paired *t*-test. Significance at $p < 0.05$ was established.

Results

A total of 24 patients following the inclusion and exclusion criteria were included in this study. The average patient ages were 20.9 ± 3.4 years (9 males and 15 females). The mean rate OTM was 0.91 ± 0.35 mm/month mm/month (95%CI; 0.80 - 1.03 mm/month).

According to Pearson correlation analysis, the rate of OTM was weakly positively correlated with the alveolar bone width to root width ratio (r = 0.334, $P < 0.05$) as shown in Table 2 and negatively correlated with buccal cortical bone density (r = -0.297, $P < 0.05$) as shown in Table 1.

Table 1 *Pearson correlation coefficients between the rate of OTM and the absolute bone width and densities*

Variables		Correlation with the rate of OTM	
		r-value	*p*-value
Bone width			
Total alveolar bone width	Cervical	0.249	NS
	Middle	0.110	NS
	Apical	0.257	NS
Cancellous bone width	Cervical	0.174	NS
	Middle	0.187	NS
	Apical	0.224	NS

Table 1 *Pearson correlation coefficients between the rate of OTM and the absolute bone width and densities (cont.)*

Variables	Correlation with the rate of OTM	
	r-value	*p*-value
Average Bone density		
Cancellous bone	- 0.111	NS
Buccal cortex	- 0.297	*
Lingual cortex	- 0.155	NS
Total alveolar bone	- 0.192	NS

** Correlation is significant at the 0.05 level (2tailed), NS = not significant.*

Also, the percentage of cancellous, buccal cortical, and total alveolar bone density were negatively correlated with the percentage of the rate of OTM (r = - 0.348, - 0.329 and - 0.336, respectively; $p < 0.05$) as shown in Table 2.

Table 2 *Pearson correlation coefficients between the rate of OTM and bone width to root width ratio and relative bone densities*

Variables		Correlation with the rate of OTM	
		r-value	*p*-value
Bone width/ root width ratio			
Total alveolar bone width/ root width ratio	Cervical	0.334	*
	Middle	0.137	NS
	Apical	0.212	NS
Cancellous bone width/ root width ratio	Cervical	0.274	NS
	Middle	0.234	NS
	Apical	0.227	NS
Percentage of Bone density			
Cancellous bone		- 0.348	*
Buccal cortex		- 0.329	*
Lingual cortex		- 0.166	NS
Total alveolar bone		- 0.336	*

** Correlation is significant at the 0.05 level (2tailed), NS= not significant.*

By subdividing the rate of OTM into high versus low groups, the following was observed: the canines with high rates of OTM (≥ 1 mm/month) had a significantly higher cancellous bone width to root width ratio than those with a low rate of OTM (< 1 mm/month) as shown in Table 3.

Table 3 *Comparison of the alveolar bone width to root ratio width and bone densities between the canines with the rate of OTM <1 and ≥ 1 mm/month*

Variable		Rate of orthodontic tooth movement				p-value
		< 1 mm/month (n=13)		≥ 1 mm/month (n=35)		
		Mean	SD	Mean	SD	
Total alveolar bone width/root width ratio	Cervical	1.10	0.15	1.24	0.19	**
	Middle	1.46	0.26	1.54	0.27	NS
	Apical	2.58	0.61	2.99	1.24	NS
Cancellous bone width/ root width ratio	Cervical	0.77	0.16	0.88	0.11	*
	Middle	0.91	0.17	1.02	0.23	NS
	Apical	1.76	0.42	2.12	1.09	NS
Bone density (GVs)	Cancellous bone	370.26	170.70	265.82	185.29	NS
	Buccal cortex	1199.93	222.23	1104.85	252.48	NS
	Lingual cortex	964.33	191.73	900.99	211.83	NS
	Total alveolar bone	619.82	162.37	516.11	189.29	NS

*** P < 0.01; * P <0 .05; NS = not significant.*

When comparing between each side, the rate of OTM and buccal cortical bone density were significantly different between the individual canines with a low and high rate of OTM ($p < 0.05$), whereas bone width to root width ratio and other densities were not (Table 4).

Table 4 *Comparison of the alveolar bone width to root width ratio and bone densities between canines with a low rate of OTM and contralateral with a high rate of OTM*

Variable		Low rate of OTM		High rate of OTM		p-value
		Mean	SD	Mean	SD	
Rate of OTM (mm/month)		**0.75**	**0.27**	**1.06**	**0.35**	**
Total alveolar bone width/root ratio	Cervical	1.13	0.16	1.14	0.18	NS
	Middle	1.46	0.23	1.48	0.28	NS
	Apical	2.61	0.56	2.77	1.05	NS
Cancellous bone width/ root ratio	Cervical	0.78	0.13	0.82	0.17	NS
	Middle	0.94	0.18	0.94	0.20	NS
	Apical	1.78	0.50	1.93	0.82	NS
Bone density (GVs)	Cancellous bone	356.51	177.54	327.44	183.08	NS
	Buccal cortex	1214.09	237.97	1134.26	223.78	*
	Lingual cortex	964.69	201.91	929.67	194.93	NS
	Total alveolar bone	612.85	172.73	570.62	177.01	NS

*** P < 0.01; * P <0 .05; NS = not significant.*

A wide range of OTM variation (range 0.04 - 0.86 mm/month) within the same individual, between right and left sides was observed in 75 % of cases indicating an asymmetric OTM pattern.

Discussion

The possibility of performing accelerated OTM has been largely investigated since it can reduce the total treatment duration for adult patients. However, the potential influence of individual characteristics, such as the morphology of alveolar bone on the rate of OTM has not been fully investigated. In this study, the effects of alveolar bone width and density on the rate of OTM was evaluated. Our results showed that the alveolar bone features such as the relative alveolar bone to root width and density have a significant correlation with the rate of OTM. Moreover, an asymmetric canine movement and the difference of alveolar bone features between the right and left sides were observed which should be considered when planning orthodontic treatment.

The significantly positive correlation observed between the bone width to root width ratio and the rate of OTM at the cervical level indicates that a wider alveolar bone than the root width may facilitate the OTM. Since the OTM is highly dependent on active bone remodeling (resorption and formation), an inadequate bone envelope might both limit and delay the rate of OTM.[13,14] Several studies have been performed to evaluate the dimensional alveolar bone changes following orthodontic treatment.[19-21] These studies have shown that alveolar bone width and height decrease following the OTM. However, to the best of our knowledge, the present study is the first study that investigated the effects of the initial alveolar bone width relation to root width and the rate of OTM. Therefore, the careful analysis of the bone width to root width ratio before the retraction of the canine into the extraction site should be considered to remove any inter-individual variability from the estimates of the treatment effect, as observed in the split-mouth design.[4]

Deficient alveolar bone to root width might increase the risks of bone defects of the alveolar bone and the risks of root resorption.[13,14,19] Handelman[14], and Garib *et al.*[13] demonstrated that a narrow alveolus limit orthodontic tooth movement as an orthodontic wall, and increases the incidence of bone loss and root resorption especially in the anterior region of hyperdivergent patients. Moreover, Ramos AL *et al.*[19] have shown that OTM into an atrophic alveolar bone increases the risk of bone dehiscence especially on the buccal plate.[19]

In the present study, although the alveolar bone to root width was correlated to the OTM, no correlation between the absolute alveolar bone width values and rate of OTM was found. The main explanation for this is the high variation in the dentoalveolar process and root sizes among the participants, while the ratio of OTM was standardized to the tooth displacement (mm) per month. On the other hand, the use of alveolar bone width to root width ratio allowed for a homogeny of the dentoalveolar process and root size. Moreover, since the OTM occurs after bone resorption in the direction of applying force, a wider alveolar bone relative to the root width might facilitate the bone remodeling process. Therefore, the ratio formula used, “alveolar bone width to root width”, might represent the most appropriate approach to investigate alveolar bone and root size and its intrinsic relationship.

In this study, it was observed that the density of the buccal cortical bone was weakly negatively related to the rate of OTM. This characteristic is particularly important for maxillary canines since their roots are often positioned close to the buccal bone cortex due to the normal morphological features of the canine eminence[13] (Fig. 1 and 2). The cortical bone, in contrast to the cancellous bone, less of cellular and vascular components, therefore bone remodeling might take longer than those within the cancellous bone.[24] Moreover, OTM through the cortical bone might require the use of higher forces that result in an increased risk of hyalinization and root resorption.[25]

For the optimum rate of OTM, the tooth should move through the cancellous bone, which is highly cellular and vascularized, thus allowing the optimum rate of bone remodeling.

The present study also found a correlation between the relative density values of cancellous, buccal cortical, and alveolar bone and the rate of OTM (Table 1 and 2). The standardization of the absolute gray values of the bone density into the relative percentage allows for a more precise correlation between bone density and the rate of OTM.

This allowed us to state that both the alveolar bone to root width and the density of the buccal cortical bone influence the rate of OTM. On the other hand, the rate of OTM through the alveolar bone with high density tends to be slower.

The findings of this study might be used for the elaboration of proper treatment planning when a high density of buccal cortical bone surrounding the maxillary canines is observed. The use of special treatment approaches for promoting accelerated OTM such as micro-osteoperforations (MOPs)[26,27], and interseptal bone reduction[28] which increase the activity of inflammatory cytokines and osteoclast to initiate RAP (Regional Acceleratory Phenomenon) and reduce bone density can be selected.

By subdividing the samples into the canines with the rate of OTM ≥ 1 mm/month versus the canines with the rate of OTM < 1 mm/month, it was observed that those with a rate of OTM ≥ 1 mm/month had a significantly higher cancellous bone width to root width ratio at the cervical level than those with a rate of OTM < 1 mm/month. Although there were no statistically significant differences, the values of the densities of the canines with the rate of OTM < 1 mm/month were higher than those of the canines with the rate of OTM ≥ 1 mm/month (Table 4). These results demonstrated that a tooth whose root is located and moved within the cancellous bone seems to move faster than one whose root is located and moved within the buccal cortex, since the buccal cortex is denser than the cancellous bone.

The findings of the present study is in agreement with previous studies. In 1988, Bridges *et al.* indicated that a greater amount and rate of tooth movement in younger animals with significantly lower mineral density before orthodontic treatment.[11] In 2018, Machibya *et al.* evaluated the effects of bone regeneration materials and orthodontic tooth movement timing on tooth movement in beagle dogs and found slower movement in the higher bone density group. They believed that high bone density may be one of the contributing factors for the slow rate of tooth movement.[12] From the previously mentioned cellular components, the bone mineral component also has a significant impact on orthodontic treatment by influencing the rate of remodeling. Many other studies have shown faster tooth movement in cases with low bone mineral density.[29,30]

According to the wide range of the rate of OTM, the results show that the canines move at different rates even if the same mechanics and magnitude of force were used. Moreover, the different rate of OTM was found not only between persons but also found within the same individual. Clinically, an asymmetric pattern of canine movement was observed in 75 % of cases which may be influenced by the difference of morphology and density of the alveolar bone between the right and left sides. These results suggest that the intra-individual variability of characteristics of the alveolar bone between sides is a problem of the split-mouth design study.[4] When performing the study of OTM, these factors should be concerned. Moreover, since bite force and occlusion influences the alveolar bone density and morphology[31,32], the unilateral chewing or parafunctional habits might relate to the asymmetric pattern of canine movement due to the asymmetric pattern of muscle tone and activations[33,34], a well-designed study should be performed.

In the present study, the use of light continuous force (50 g) provided by closed NiTi springs was used for canine retraction in all cases. This level of force has been sufficient to provide a controlled retraction of the maxillary canines while avoiding the undesirable anchorage loss.

According to Yee *et al.*[7], the use of light continuous force (50 g) reduces risks of clinical side effects such as anchorage loss and canine rotation and also the risk of root resorption.[7] On the other hand, the use of heavy forces (300 g) produces uncontrolled canine movements.

Despite the controversy about the use of CBCT imaging for bone density analysis, researchers have been motivated to evaluate its potential use in evaluating bone density.[18,35-37] A high correlation between voxel values and grey level of CBCT images and bone mineral density of multi-slice CT (MSCT) and micro-CT was reported in many studies.[35,38] Moreover, the CBCT images can provide accurate and reliable measurements of alveolar bone thickness.[39] Additionally, CBCT has a much lower radiation dose, a much lower cost, and less distortion compared with other computed tomography[18], therefore, an evaluation of the initial bone morphology and density on the CBCT image may be useful for comprehensive orthodontic treatment planning. Clinicians can consider using the different mechanics for moving each tooth with different alveolar bone width and density. Moreover, for the researcher, the difference of alveolar bone width to root width ratio and bone densities of each tooth might affect the rate of OTM, therefore, these factors should be considered especially in the split-mouth design study.

Conclusion

The results suggest that the rate of tooth movement is influenced by the alveolar bone width to root width ratio and alveolar bone density. Teeth with a higher alveolar bone width to root width ratio and lower density tend to move faster than those with a lower ratio and higher density. Moreover, an asymmetric canine movement due to the difference of alveolar bone features between the right and left sides was observed. This should be considered when planning orthodontic treatment.

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