Original Article

Alveolar bone defects influence rate of tooth movement

Nawaporn Ritwiroon[a]; Boonsiva Suzuki[b]; Eduardo Yugo Suzuki[a]

ABSTRACT

Objectives: To examine how defects in alveolar bone affect movement of teeth during orthodontic treatment.

Materials and Methods: Pretreatment cone-beam computed tomography images from 26 patients: 15 females and 11 males, with a mean age of 21.5 years (SD $\pm$ 3.7 years), were used to evaluate the buccal alveolar bone on the maxillary canine. Maxillary canines (n = 52) were subsequently categorized into three groups: control or no bone defects (n = 17), fenestration (n = 20), and quasidefect (n = 15). Each canine was displaced distally for 16 weeks using nickel-titanium closed coil springs (50 g) and segmental archwire mechanics. The rate and amount of tooth movement were evaluated using superimposition of lateral cephalograms and three-dimensional digital dental models between before and after canine retraction. Rate of tooth movement was evaluated among different bone defect groups.

Results: Rate of movement was significantly decreased in the fenestration (0.87 $\pm$ 0.23 mm/mo) and quasidefect groups (0.62 $\pm$ 0.14 mm/mo) compared to the control group (1.17 $\pm$ 0.40 mm/mo). Also, 85% of all subjects exhibited an evident asymmetric pattern of tooth movement, and 77% of these subjects presented with unilateral bone defects.

Conclusions: The type and existence of alveolar bone defects have a substantial effect on rate of tooth movement. Therefore, when conducting orthodontic tooth movement investigations and planning orthodontic treatment, it is important to consider the existence of alveolar bone defects. (*Angle Orthod*. 0000;00:000–000.)

KEY WORDS: Bone defects; Orthodontic tooth movement; Canine retraction; Cone-beam computed tomography

INTRODUCTION

The presence of alveolar bone surrounding the dental roots primarily determines the boundaries of orthodontic tooth movement and facilitates the biological events of bone remodeling in the alveolar process.[1–3] Any localized alveolar bone defect, such as a dehiscence or fenestration, can reduce the thickness of the bone surrounding the roots. Therefore, the presence of any bone defect might impact the biological and biomechanical mechanisms of tooth movement and could impair the normal rate of movement.

Dehiscence has been defined as the lack of cortical plate at the cervical area, whereas fenestration refers to the exposure of the root surface with bone remaining in the cervical region.[2,4] Numerous studies have used cone-beam computed tomography (CBCT) imaging to examine the morphology of alveolar bone prior to and during orthodontic treatment.[1,2,4–11] The bone defects are considered common anatomic findings in the dental arches with relatively high prevalence.[4–6] Several factors, such as the direction, magnitude, and duration of orthodontic forces, the initial condition of periodontal tissues, and the amount of alveolar bone thickness around the roots, can exacerbate bone defects.[1,2,4–8] Therefore, any defective alveolar bone morphology could affect treatment planning, leading to limitations in choosing the most suitable orthodontic treatment.

When analyzing CBCT images in cross-sectional view, a prior study found an association between rate of tooth movement and the width and density of alveolar bone.[3] According to the available literature, no

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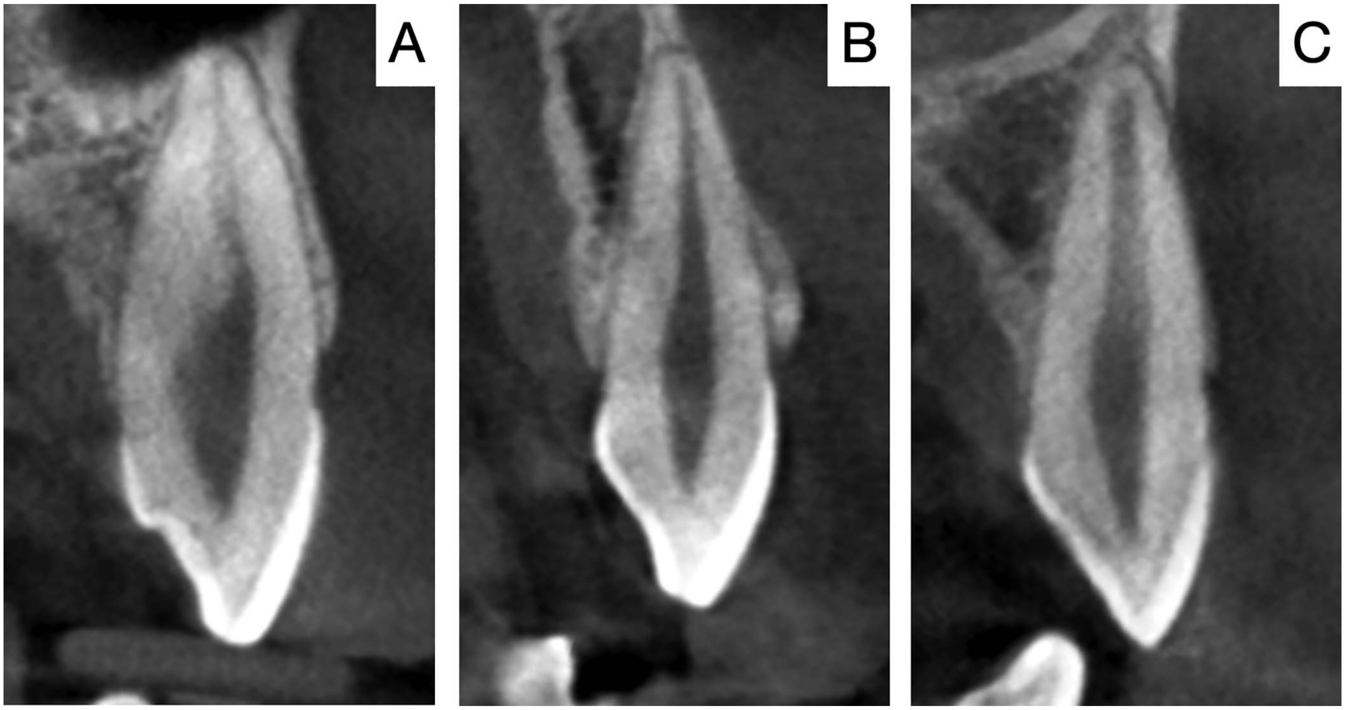

Figure 1. Cross-sections of maxillary canines on CBCT images show alveolar bone defects. (A) No bone defect (control); (B) fenestration; (C) quasidefect. CBCT indicates cone-beam computed tomography.

studies have clinically assessed how initial alveolar bone defects affect the rate of tooth movement. Therefore, the purpose of this study was to investigate how defects of alveolar bone affect the movement of teeth. The hypothesis was that a defect in the buccal cortical plate would influence the periodontal supporting tissues and, consequently, the orthodontic biomechanics and rate of tooth movement.

MATERIALS AND METHODS

Subjects

Adult orthodontic patients aged 18–30 from the Postgraduate Orthodontic Clinic, Bangkokthonburi University, were chosen based on having Class I or Class II malocclusions requiring first premolar extraction and canine retraction for relief of crowding. Patients exhibiting signs of periodontitis and systemic problems, or taking medication that could potentially affect bone condition, were excluded from the study. The study enrolled 26 patients and investigated 52 maxillary canines based on these criteria. These subjects were included in the sample of a previous study[3] and were continuously enrolled. The study received ethical approval from the Bangkokthonburi University institutional review board, with the reference number 09/2561. All participants provided written informed consent prior to beginning the study.

CBCT Analysis and Identification of Bone Defects

CBCT images were acquired using a Sirona Galileo CBCT system (Sirona Dental Systems, Bensheim, Germany). The voxel size was 0.125 mm, and field of view was 15 $\times$ 15 cm. The exposure parameter was set at 85 kVp, 7 mA, and a 14-s exposure time. After image recording in a Digital Imaging and Communications in Medicine (DICOM) file, bone defects were identified using Sidexis XG software (Sirona Dental Systems).

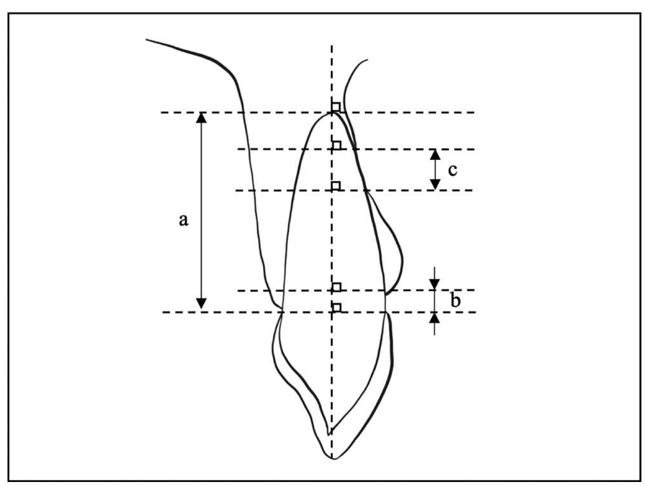

Figure 2. Percentage of bone coverage measurement. (A) CEJ to root apex; (B) CEJ to alveolar crest; (C) root exposed beneath the alveolar crest. Bone coverage (%) = a − (b + c)/a * 100. CEJ indicates cementoenamel junction.

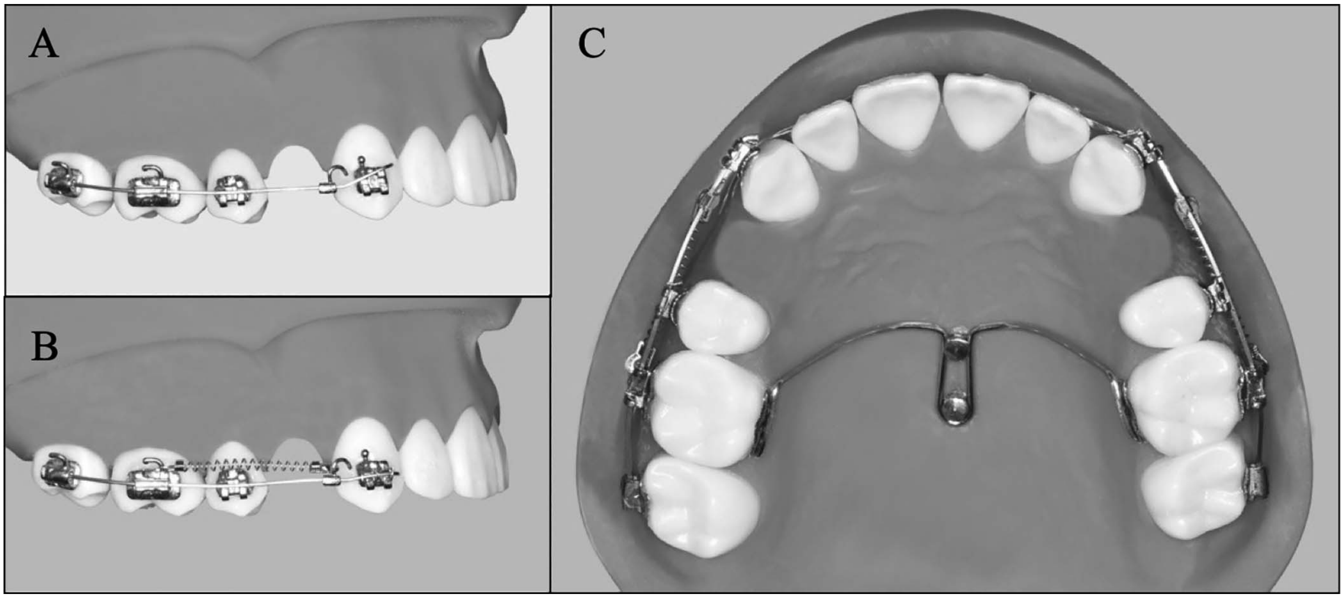

Figure 3. Mechanics of canine retraction. (A) Engagement of segmental archwire; (B) Canine retraction using a 50 g closed NiTi coil spring; (C) Indirect palatal miniscrews for anchorage. NiTi indicates nickel titanium.

Determination of the bone defects was made by two calibrated examiners (EYS and NR) with blinding of patient information and the results of each other. After reorientation of the CBCT images, the maxillary canines were positioned so that their long axes were perpendicular to the horizontal plane, allowing for an assessment of root length in both cross-sectional and axial views. Images that showed discontinuity of the cortical bone on the buccal side of the root in at least three consecutive views were identified as an alveolar bone defect.

Defects were classified as fenestrations when the buccal bone plates were discontinuous, resulting in partial root exposure without affecting the alveolar crest. The criteria proposed by Evangelista et al.[5] were used to define a "quasidefect" when the buccal cortical plate thickness was less than 0.5 mm. In their study, the "quasidefect" represented an extremely thin alveolar bone thickness and, therefore, should be considered a defect. Images that showed alveolar bone with no defects were defined as the control group (Figure 1). Cases that had fenestration or quasidefect on both sides were counted as bilateral defects, and cases that had alveolar bone defects on only one side were counted as unilateral defects. The percentage of bone coverage (buccal cortical thickness greater than 0.5 mm) was measured and calculated using the calculation formula shown in Figure 2.

Clinical Procedures

After leveling and aligning, an indirect palatal miniscrew[12] (Dual Top Anchor system, Jeil Medical Co, Seoul, Korea) was used to reinforce skeletal anchorage (Figure 3C). For canine retraction, a segmental archwire, 0.016 × 0.022 nickel-titanium (NiTi) Neo Sentalloy (Sentalloy, GAC International, Bohemia, NY, USA), with a V bend and antirotation bend and crimpable hook for applying force, was engaged in the bracket slots of the second premolar, first molar, and second molar. After extraction of the first premolars, a NiTi closed coil spring (Sentalloy, Tomy Orthodontics; Japan) providing 50 grams of force was placed from

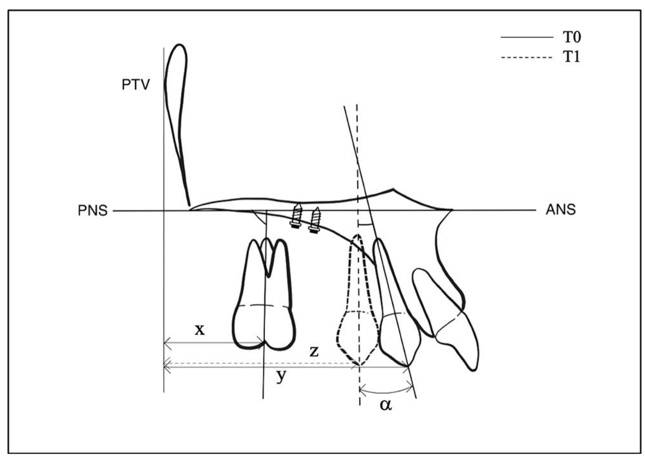

Figure 4. Angular and linear measurements in the superimposition of lateral cephalograms before (T0) and 16 weeks after (T1) canine retraction. The angle between the palatal plane (ANS-PNS) and the long axis of the canines and molars was measured. Lines and dashed lines represent the measurement at T0 and T1, respectively. The alteration of canine angulation (α) was the difference between T0 and T1. The distance between the molars and PTV (x) was measured to investigate anchorage loss. The distance between the cusp tip of the canines and PTV at T0 (y) and T1 (z) was measured and calculated as the total displacement.

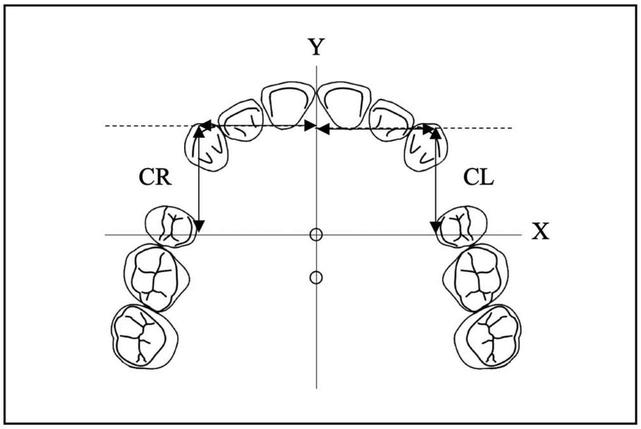

Figure 5. Diagram of model analysis. The centers of the miniscrews were used as a reference for the y-axis, and the center of the anterior miniscrew was used as a reference for the x-axis in the construction of the coordinate system (x, y), as described by Suzuki and Suzuki.[12] The distance between the cusp tip of the right (CR) and left (CL) canines and the x-axis was measured.

the hook of the first molar tube to a crimpable hook of the segmental archwire (Figure 3). Canine retraction was observed monthly during visits to ensure that there was no occlusal interference. Prior to (T0) and 16 weeks after canine retraction (T1), lateral cephalograms and intraoral scans were obtained.

Cephalometric Analysis

Lateral cephalograms were superimposed between T0 and T1 using the palatal plane (ANS-PNS) as a reference to examine alteration of canine angulation. The palatal miniscrew was used as a reference to ensure correct superimposition. Alteration of canine angulation was represented by the angular difference between the tooth long axis and the palatal plane at T0 and T1. Additionally, alteration in position of the canine and molar was observed to confirm movement of the canine (distalization) and molar (anchorage situation). The distance between the molar and canine cusp tips to the Pterygoid vertical line (PTV) at T0 and T1 was measured (Figure 4).

Since linear measurements in the horizontal plane might be inaccurate due to head rotation and magnification of lateral cephalograms,[13,14] linear measurements on the digital 3D models, which were more accurate, was used for statistical analysis.

Digital 3D Model Analysis

Digital models at T0 and T1 created from intraoral scans (3Shape Trios Dental Systems, Copenhagen, Denmark) were superimposed. The palatal miniscrews[12] were used as a reference to construct a coordinate system (x, y). The x-axis passed through the center of the anterior miniscrew, and the y-axis passed through the centers of the miniscrews, as described by Ritwiroon et al.[3] The distance between the canine cusp tip and the x-axis was measured as shown in Figure 5. The total displacement of the canine was the difference in distance between T0 and T1. The rate of canine retraction was calculated from the displacement per month (mm/mo).

Statistical Analysis

A reevaluation of 10 subjects 2 weeks after the initial measurement was carried out to verify reliability of the measurements. Interobserver and intraobserver agreement were evaluated using the interclass correlation coefficient (ICC) and Kappa statistic.

All statistics were done using SPSS software (version 23.0; IBM, Armonk, NY, USA) with a significance level of 0.05. One-way analysis of variance was employed to compare values in the fenestration, quasidefect, and control groups. Descriptive statistics were used to analyze the distribution of bone defects and patterns of tooth movement.

RESULTS

Twenty-six patients with a mean age of 21.5 ± 3.7 years, consisting of 15 females and 11 males, were included in this study. Bone defect determination showed perfect reliability (Kappa value = 1.0). Model

Table 1. Comparison of Mean Values Among Bone Defect Groups (One-Way ANOVA)[a]

Variables	Control (n = 17)		Fenestration (n = 20)		Quasidefect (n = 15)		*P* Value
	Mean	SD	Mean	SD	Mean	SD	
Root length (mm)	15.29	1.33	15.71	1.86	15.39	2.12	N.S.
Bone coverage (%)	83.26	7.73	56.18	13.15	33.73	13.39	**
Tooth movement rate (mm)	1.17	0.40	0.87	0.23	0.62	0.14	**
Total displacement (mm)	4.66	1.59	3.48	0.90	2.49	0.54	**
Change in angulation (degree)	10.0	7.0	9.5	6.0	5.5	4.0	N.S.

** $P < .01$.

ANOVA indicates analysis of variance; N.S., not significant.

Table 2. Multiple Comparison of the Mean Values Among Bone Defect Groups

Multiple Comparison	Bone Coverage (%) Mean Difference	Bone Coverage (%) *P* Value	Tooth Movement Rate (mm/mo) Mean Difference	Tooth Movement Rate (mm/mo) *P* Value	Total Cisplacement (mm) Mean Difference	Total Cisplacement (mm) *P* Value
Control vs fenestration	27.08	**	0.30	**	1.18	**
Control vs quasidefect	49.53	**	0.54	**	2.17	**
Fenestration vs quasidefect	22.44	**	0.25	**	0.99	**

** $P < .01$.

analysis demonstrated canine displacement measures had high reliability with an ICC of 0.95. Reliability of cephalometric angular and linear measurement was high, with an ICC of 0.85–0.90. According to the alveolar bone defect determination, 52 maxillary canines were divided into fenestration ($n = 20$), quasidefect ($n = 15$), and control ($n = 17$) groups. Only three patients had no bone defects at the canine. Four patients had bilateral bone defects, and 19 patients had unilateral bone defects.

After dividing the canines into three groups, no significant difference in the root length was found (Table 1). The control group had a significantly greater bone coverage percentage (83.3%) in comparison to the fenestration (56.2%) and quasidefect (33.7%) groups, as shown in Table 2 and Figure 6.

Cephalometric analysis showed that, after canine retraction using segmental archwire mechanics with the miniscrews as anchorage, only canine movement was observed, and molar movement was not.

The rate of tooth movement was significantly lower in the fenestration (0.87 ± 0.23 mm/month) and quasidefect (0.62 ± 0.14 mm/mo) groups compared to the control (1.17 ± 0.40 mm/mo), as shown in Figure 7. However, alterations of canine angulation were not significantly different (Table 1). In addition, most of all subjects (85%) exhibited an evident asymmetric pattern in the rate of tooth movement, and 77% of those subjects had unilateral bone defects (Table 3 and Figure 8).

DISCUSSION

The boundaries of tooth movement are highly dependent on the presence of alveolar bone surrounding the dental roots to undergo the biological events of bone remodeling of the alveolar process. Therefore, alveolar bone characteristics may be crucial in determining the rate of tooth movement.[2,15,16] Based on the available literature,[1,2,4–11] there are a lack of studies investigating how alveolar bone defects affect the rate of tooth movement. Consequently, it was examined in this study.

The quasidefect group had the lowest rate of tooth movement and total displacement. The control group, which had no defects, had the highest rate of movement and total displacement (Table 1). This finding indicated that alveolar bone defects could impair the rate of tooth movement. The explanation is that there is insufficient bone thickness surrounding the roots. The groups had significant differences in the percentage of bone coverage. The control group had the highest percentage (83.26%), whereas the quasidefect group had the lowest (33.73%). Displacement of teeth with bone defects indicated that part of the root passed through

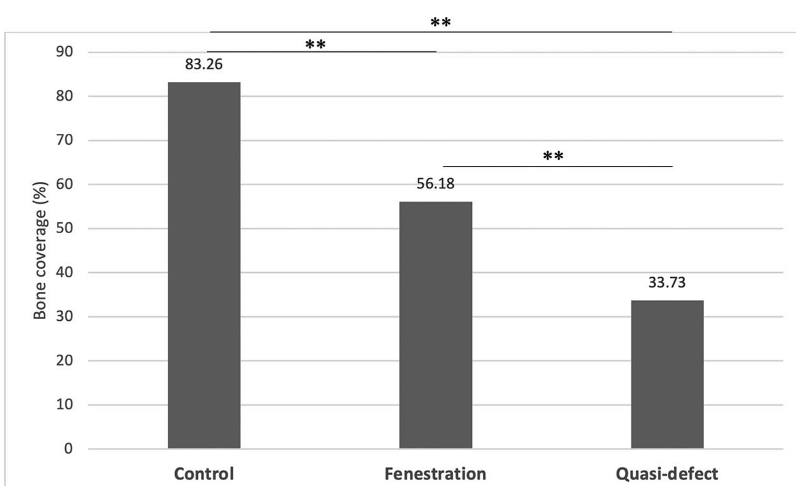

Figure 6. Comparison of bone coverage (%) among bone defect groups.

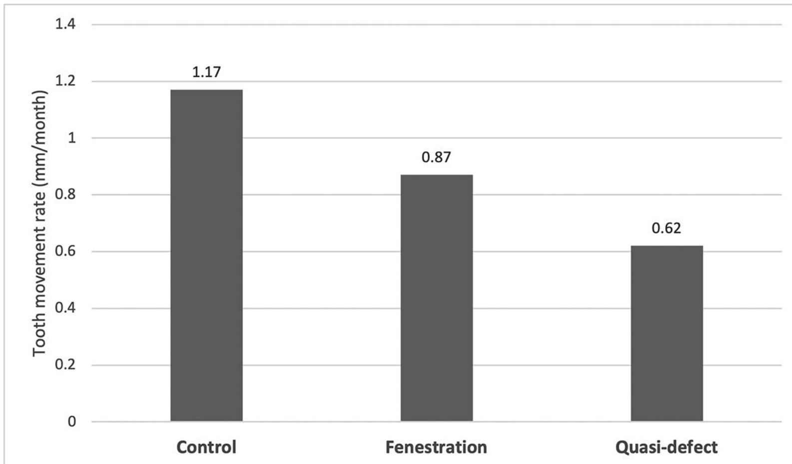

Figure 7. Comparison of rate of tooth movement (mm/month) among bone defect groups.

dense cortical bone, which lacks adequate cellular and vascular components. Consequently, the duration of bone remodeling may be extended. Conversely, in the displacement of teeth without bone defects, the roots moved through the surrounding bone, mostly cancellous bone, characterized by low density, a lot of cellular and vascular components, and significant capacity for bone remodeling.[17] The results were in agreement with previous findings that the quantity of bone surrounding moving teeth influences orthodontic tooth movement.[3]

Although it was greatest in the control group, the change in canine angulation did not significantly differ among the groups. The explanation could have been that there was high variation of the initial angulation of the canines. However, the final angulation of all canines was clinically acceptable. Since segmental arch wire mechanics had a V-bend (for antitipping), and light continuous force was used, tooth movement could be controlled, and there were no effects on the anterior teeth.

Another finding in this study was that unilateral bone defects were found in 19 patients (73% of all patients), which clinically resulted in an asymmetric pattern of tooth movement. Only a few patients had bilateral defects or no alveolar defects in the canine area. The asymmetric movement pattern of the canines was found in 77% of all patients and 89.5% of the patients with unilateral bone defects. It may be speculated that unilateral bone defects might be related to an asymmetric pattern of tooth movement. The split-mouth study design for evaluating tooth movement may, therefore, have inherent issues due to the intra-individual diversity in alveolar bone morphology between sides, as indicated by these data. Therefore, when a study of orthodontic tooth movement is performed, alveolar bone defects should be considered. However, the relationship between unilateral bone defects and asymmetric tooth movement patterns should be confirmed in a larger study designed for that purpose; in the current study the number of patients with bilateral bone defects and symmetric movement patterns was too small.

Table 3. Distribution of Symmetric and Asymmetric Movement Pattern in Bilateral and Unilateral Bone Defects

	Canine Movement Pattern			
Bone Defects	Symmetric		Asymmetric	
Unilateral	2	50.0%	17	77.3%
Bilateral	2	50.0%	5	22.7%
Total	4	100.0%	22	100.0%

According to the results, the clinical implication for the orthodontist is in the treatment planning stage and informing patients if their alveolar bone characteristics indicate some factors that might reduce orthodontic tooth movement and increase adverse effects such as bone defects and root resorption. According to Ramos et al.[1], moving a tooth into atrophic alveolar bone may increase bone defects such as dehiscence and fenestration. Thus, an alternative treatment plan option may be "Periodontally Acceleratory Osteogenic Orthodontics" (PAOO), since it not only increases alveolar bone thickness, but also accelerates tooth movement by inducing the Regional Acceleratory Phenomenon (RAP).[8,18] For example, Sun et al.[8] demonstrated improvement in dehiscences and fenestrations after corticotomy-assisted orthodontic treatment. Considering the direction of orthodontic movement, since the maxillary canines had a high prevalence of bone defects,[5] especially buccal movement of the canines should be planned carefully.

However, not only buccal movement, but also mesiodistal movement could increase bone defects and slow down the rate of movement because the canines have a larger root volume and a thinner buccal plate than other teeth in the dental arch.[2] Before initiating canine

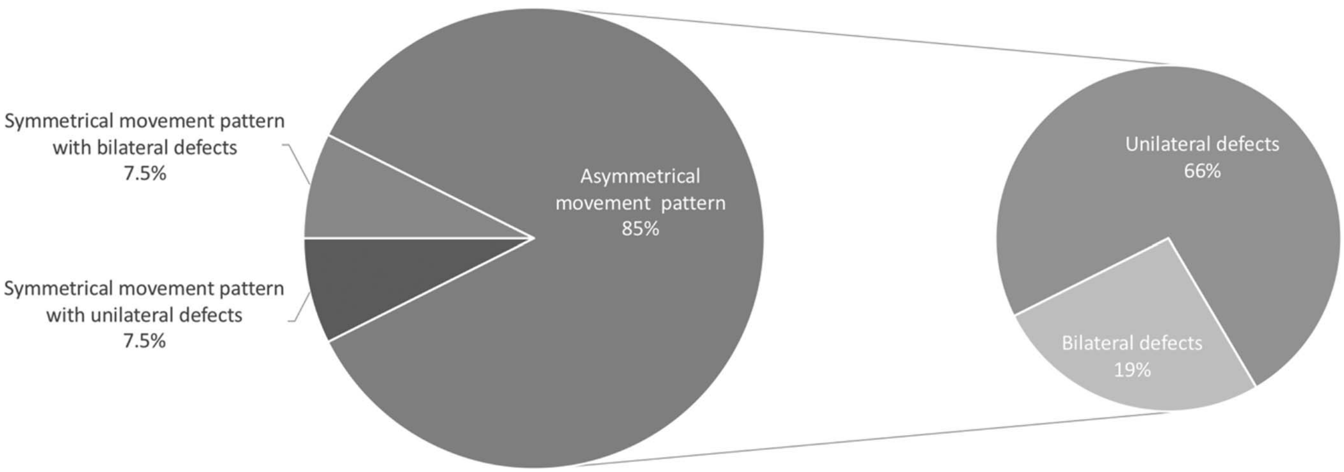

Figure 8. Distribution of symmetric and asymmetric movement patterns in bilateral and unilateral bone defects.

retraction, clinicians should ensure that the tooth has been moved into the bone by palatal root torque. This should occur at least 1 month after the placement of a rectangular wire. In this study, a superelastic NiTi closed coil spring was used to create a light continuous force with an expectation for improved bone remodeling by balancing bone resorption and bone formation, preventing hyalinization of the periodontal ligament, undermining resorption, and root resorption.[19] Unfortunately, it was not possible in this study to conduct a post-treatment CBCT evaluation due to ethical considerations. Obtaining a CBCT at a 4-month interval after canine distalization would have been inappropriate. Nonetheless, CBCT evaluation of these patients should be performed after the completion of treatment in the further effort to observe alterations of the bone. In addition, assessment of alveolar bone morphology using CBCT while planning orthodontic treatment is recommended.

CONCLUSIONS

- The presence of initial alveolar bone defects has a substantial effect on the rate of tooth movement. Particularly, a tooth with the quasidefect exhibits the lowest rate of tooth movement.
- Most cases show a unilateral bone defect, which can lead to an asymmetric pattern of tooth movement.
- Alveolar bone defects should be investigated and considered when the assessment of tooth movement and orthodontic treatment planning are performed.

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