Original Article

Can posterior teeth of patients be translated buccally, and does bone form on the buccal surface in response?

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ABSTRACT

Objective: To produce buccal translation and determine whether buccal bone forms on the cortical surfaces.

Materials and Methods: Eleven patients requiring maxillary first premolar extractions participated in this prospective, randomized, split-mouth study. Pre- and posttreatment records included models, photographs, and small field of view CBCT images. One randomly chosen maxillary first premolar was moved buccally with 50 g of force applied approximately at the tooth's center of resistance. The other premolar served as the control. Forces were re-activated every 3 weeks for approximately 9 weeks, after which the teeth were held in place for 3 weeks. Pre- and posttreatment records were analyzed and superimposed to evaluate changes in the dental-alveolar complex.

Results: There was significant ($P < .05$) movement of the experimental premolar with minimal buccal tipping (2.2°). Changes in maximum bone height were bimodal, with 6 patients showing 0.42 mm and 5 patients showing 8.3 mm of vertical bone loss. Buccal bone thickness 3 mm apical to the CEJ decreased 0.63 mm. Direct measurements and CBCT superimpositions showed that buccal bone over the roots grew 0.46 mm and 0.51 mm, respectively.

Conclusions: It is possible to produce buccal bodily tooth movement with only limited amounts of tipping. Such movements are capable of producing buccal bone apposition, but there are potential limitations. (*Angle Orthod.* 2016;86:527–534.)

KEY WORDS: Tooth translation; CBCT; Patients; Bone formation

INTRODUCTION

A tooth-size-to-arch-length deficiency is one of the most common problems facing clinical orthodontists.[1] To treat such patients, clinicians must either remove tooth structure or increase arch length, usually with expansion. In recent years, the nonextraction approach has become more popular as new techniques and materials for expansion have been developed.

Despite improvements, expansion continues to present problems; one of the most notable is uncontrolled tipping.[2,3] Tipping produces compressive forces concentrated in the cervical and apical thirds of the tooth's root.[4] Strains that exceed 3000 $\mu\varepsilon$ are considered problematic, producing microcracks that accumulate and eventually lead to failure.[5] Excessive strains provide the link between dental tipping and alveolar bone loss.[3,4,6] If the same forces could be distributed over the entire buccal root surface, the adverse effects of orthodontic expansion might be minimized.

Moreover, lower translational forces could stimulate bony apposition along the buccal cortical plate. Cortical bone mass increases when microstrains fall into the range of 1500–3000 $\mu\varepsilon$.[5] New buccal cortical bone apposition with lateral tooth movements has recently been demonstrated experimentally.[3,7] However, apposition was limited to the region extending from the crest to the reversal zone, around which the teeth were tipped. If the expansion forces had been

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Table 1. Amount of Tooth Movement (mm) Measured on the Models of Patients 9 and 10, Who Were Excluded Due to the Lack of Tooth Movement

	1st Premolar Intercuspal Distance		Intermolar Distance	
ID Number	Buccal Cusps	Palatal Cusps	Central Fossae	Mesiobuccal Cusps
9	0.13	0.25	0.6	0.74
10	0.28	0.57	–0.25	0.43

spread over a larger area, new buccal bone formation might have occurred over the entire root's surface.

The aims of this clinical study were to produce buccal translation of the maxillary first premolars and to determine whether bone forms on the buccal surfaces. A force system was designed to minimize tipping and produce buccal translation with light, continuous forces.

MATERIALS AND METHODS

The project was approved by the Texas A&M University Baylor College of Dentistry IRB (BCD 2012-12) and informed consent was obtained from all patients. Orthodontic patients between 11–17 years of age were selected based on having: (1) previously accepted a treatment plan that included maxillary premolar extractions and (2) fully erupted maxillary first molars. Based on estimates of buccal tooth movement,[8] a power analysis indicated that 12 subjects were necessary to establish a 1.2-mm difference in buccal tooth movement between sides, assuming a power of 0.95, an alpha of 0.05, and a correlation of 0.5. Thirteen typical orthodontic patients were enrolled in the study; two were not included in the analyses because their premolars did not move sufficiently (Table 1).

The remaining 11 patients (5 females and 6 males) were 14.1 years of age. Pre- and posttreatment records included plaster models, limited field of view cone beam computed tomographic (CBCT) images, and digital photographic images. The CS 9000 3D (Carestream Dental, Atlanta, Ga) CBCT unit was chosen based on its small voxel size (0.076 mm, isotropic) and minimal average radiation dose (9.8 μSv). Four images (pre/post and study/control) were taken on each patient. The maxillary first premolar was centered in the field of view (3.75 $\times$ 5.00 cm) to maximize the accuracy of reconstructing the volumetric data.[9] Settings for the CBCT images were 70 kV, with 10mA, at 10.8 seconds.

The premolar on the control side was not banded and did not receive any form of treatment. The appliance was adapted from previous studies[8,10] and fabricated on the study models. It consisted of bands on the maxillary first molars and first premolars. A transpalatal arch (0.036-inch stainless steel wire) was soldered to the molar bands to maintain molar position and provide a framework for a bite plane made with Triad acrylic (Dentsply GAC, Islandia, NY) (Figure 1A). On the facial surface of the premolar band, a 0.040-inch stainless steel wire was soldered to serve as a power arm (Figure 1B). The solder joint was positioned so that the point of attachment was in the cervical third of the premolar.[11] The power arm extended to the premolar's center of resistance, which was estimated to be 40% from the apex, measured between the alveolar crest and the root apex (Figure 1C).[12] The actual power arm distance was 16.7 mm from the buccal cusp tip.

The bands, the cantilever on the premolar, and the transpalatal arch were transferred to the patient and bonded using a dual-cured, resin-modified, glass ionomer cement (Reliance Orthodontics, Itasca, Ill). Triad acrylic was added to or removed from the bite plane so that the first premolar was free of interferences during buccal movements.

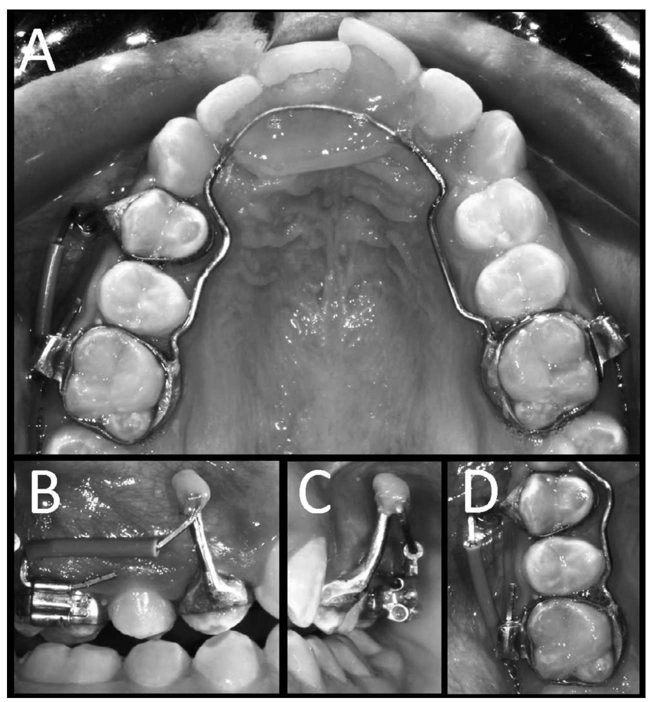

Figure 1. (A) Occlusal view of the transpalatal arch with acrylic bite plane. (B) Buccal view of cantilever arm. (C) Frontal view of the lever arm. (D) Occlusal view of active cantilever arm.

Table 2. Average Duration (Days) Between Appointments

	Delivery and 1st Reactivation	1st and 2nd Reactivation	2nd Reactivation and Maturation	Maturation and Removal
Days	21.3 ± 2.1	20.4 ± 2.0	17.7 ± 4.3	20.5 ± 2.6

A 50-g force was applied to the maxillary first premolar on the experimental side with a β-titanium alloy 0.021 × 0.025-inch sectional wire (3M Unitek, Monrovia, Calif), anchored in the auxiliary slot on the first molar band (Figure 1D). The wire was bent vertically so that its point of attachment was located at the estimated center of resistance (Figure 1B and C) and bent buccally to create a 50-g lateral force (Figure 1D), as verified with a Correx (Haag-Streit, Berne, Switzerland) gram force strain gauge. The activated wire was ligated to the premolar cantilever with a 0.001-inch stainless steel ligature tie (Figure 1B and C).

The buccal force was checked and reactivated to 50 g every 3 weeks (Table 2) for 6–9 weeks, in order to obtain adequate amounts of tooth movement. Forces were reduced for 3 additional weeks to allow the bone to adapt. A 0.021 × 0.025-inch SS wire was bent to apply 10–15 g, closely approximating buccal musculature forces.[13]

Evaluations

All measurements were taken twice by one blinded investigator and averaged. Pre- and posttreatment study models were digitally scanned using an Ortho Insight 3D model scanner (Motion View Systems, Hixson, Tenn) and evaluated using the Motion View Software (Motion View). Width measurements were taken between the buccal and palatal cusp tips of the first premolars, and between the mesiobuccal cusp tips and central fossae of the molars. Replicate analyses of seven randomly selected sets of models showed interclass correlations ranging from 0.98 to 0.94 for the interpalatal cusp and interbuccal cusp measurements, respectively.

Tipping was measured based on the angle formed between the cervical margins on the palatal sides of the control premolar, the cervical of the experimental premolar on the palatal side, and the palatal cusp of the experimental premolar. Based on replicate analysis of five randomly selected sets of digital models, the interclass correlation for the tipping was 0.88.

The CBCT images were oriented as previously described.[14] Three width measurements (Figure 2) were taken at the mesiodistal midpoint of the first premolar. Moving through the coronal slices—from mesial to distal—the operator also measured the maximum and minimum vertical distances from the crestal bone to the CEJ. Replicate analyses using six randomly selected CBCT images produced interclass correlations ranging from 0.92–0.99.

Pre- and post-CBCT images were superimposed using Invivo5 software (Anatomage, San Jose, Calif). A voxel superimposition was performed to measure changes 3 mm apical to the CEJ. Measurements were taken three times by one investigator and averaged. The interclass correlations for root movement and buccal bone thickness were 0.95 and 0.99, respectively. Change in buccal bone thickness was also calculated indirectly using the following formula:

Bone thickness was derived from the CBCT measurements, while root movement was derived from the superimpositions.

Statistical Analysis

SPSS version 22 (SPSS Inc, Chicago, Ill) was used to analyze the data. Skewness and kurtosis statistics indicated that the distributions were not normal. Central tendencies and dispersions were described with medians and interquartile ranges. Wilcoxon

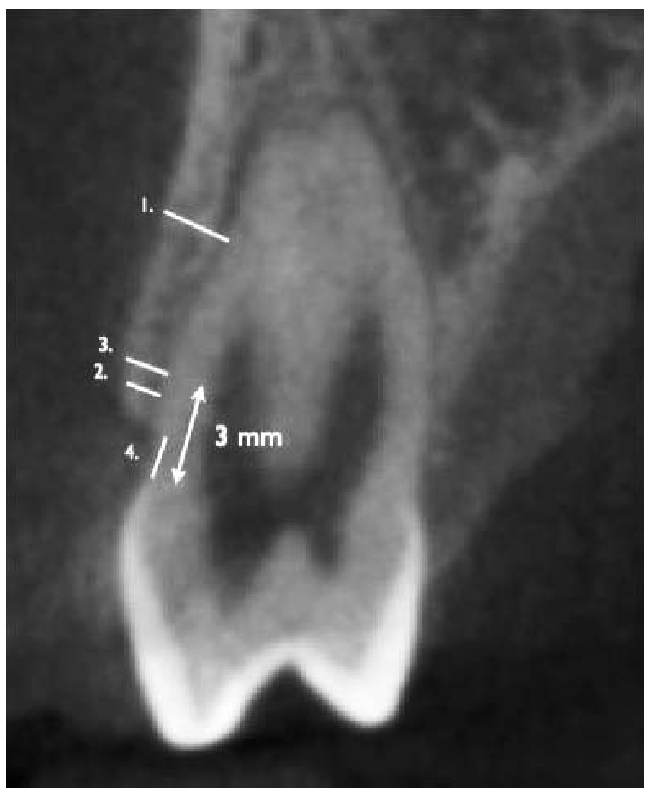

Figure 2. Buccal bone. (A) Maximum width. (B) Minimum width. (C) Width 3 mm apical to the CEJ. (D) Maximum and minimum height from CEJ to crestal bone.

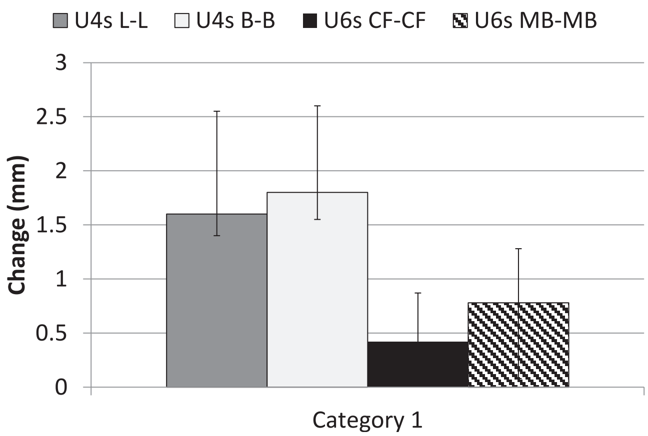

Figure 3. Medians and interquartile ranges for changes in first premolar width (taken between the lingual [U4s L-L] and buccal [U4s B-B] cusps) and first molar width (taken between the central fossae [U6s CF-CF] and the mesiobuccal cusp tips [U6s MB-MB]).

signed rank tests were used to evaluate the changes that occurred over time, compare the control and experimental sides, and compare changes in buccal bone thickness.

RESULTS

After 3 weeks, the active force had dissipated from 50 g to 40.4 ± 4.9 g. After the second and third 3-week time periods, the forces were 41.4 ± 4.6 g and 43.1 ± 4.2 g, respectively.

Model Analyses

The interpremolar distances increased significantly; the lingual and buccal cusp tips increased 1.56 mm and 1.82 mm, respectively (Figure 3). Intermolar widths increased 0.85 mm between the mesiobuccal cusp tips and 0.55 mm between the central fossae. There was slight but significant ($P = .003$) buccal crown tip of the experimental premolars. They tipped approximately 2.2°, with a range of 1.0°–5.4°.

CBCT Radiographic Analysis

Buccal bone thickness decreased significantly on the experimental, but not on the control side (Table 3). Maximum thickness decreased 0.45 mm, minimum thickness decreased 0.35 mm, and bone thickness 3 mm from the CEJ decreased 0.63 mm.

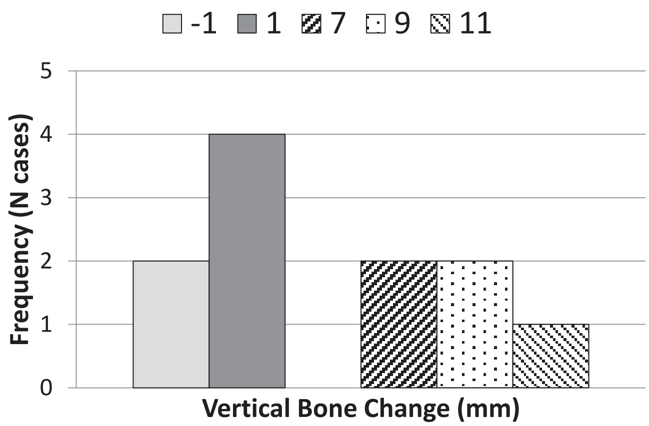

Figure 4. Changes in maximum vertical bone height on the experimental side, with six subjects concentrated around no change and five subjects with vertical height loss greater than 7 mm.

The maximum vertical distance from the CEJ to the crestal bone increased 0.60 mm on the experimental side. The control side showed no significant change. The maximum vertical changes exhibited a bimodal distribution. Six subjects had a median loss of 0.42 mm, while five subjects had a median loss of 8.54 mm (Figure 4). Changes in the minimum distances from the CEJ to the crestal bone showed no statistically significant side difference.

Analysis of 3-D Superimpositions

Movements of the experimental first premolar measured from the superimposed CBCT images were also statistically significant. The root measured 3 mm apical to the CEJ, and moved 0.96 mm on the experimental side (Table 4). Premolar movement on the control side was minimal and not statistically significant.

Direct measurement of buccal bone apposition 3 mm below the cementoenamel junction showed a median increase of 0.46 mm, which was statistically significant. All the patients added bone 3 mm below the CEJ (Figure 5). Bone measured indirectly increased 0.51 mm, which was also statistically significant. The difference between the direct and indirect measurements was not statistically significant.

Table 3. Median Changes (mm) and Interquartile Ranges of Buccal Bone Thickness and Vertical Distances From CEJ

	Experimental			Control			Group Difference
Changes in Buccal Bone	50th	25th	75th	50th	25th	75th	Prob
Thickness 3 mm apical to CEJ	−0.63	−0.79	−0.17	0.00	−0.17	0.10	.016
Maximum thickness	−0.45	−0.60	−0.20	0.05	−0.20	0.15	.011
Minimum thickness	−0.35	−0.43	−0.15	−0.08	−0.29	0.19	.041
Maximum vertical distance from CEJ	0.60	0.40	8.30	−0.05	−0.45	0.15	.003
Minimum vertical distance from CEJ	0.25	0.30	0.55	−0.05	−0.40	0.20	.262

Table 4. Experimental Root Movements (mm) 3 mm Apical to the CEJ, Bone Growth Measured From the Superimpositions 0.3 mm Apical to the CEJ, Along With Bone Growth Calculated From Differences in Bone Thickness and Root Movement

Measure	Units	50th	25th	75th	Prob*
Root movement 3 mm apical to CEJ	mm	0.96	0.29	1.3	.008
Buccal bone growth measured 3 mm apical to CEJ	mm	0.46	0.29	0.94	.005
Buccal bone growth calculated	mm	0.51	−0.40	1.00	.036

* Probability (Prob) indicates statistically significant changes.

There was a negative correlation (−0.674, $P = .033$) between the initial buccal bone thickness measured on the CBCT images and bone apposition measured from the superimpositions. There was no correlation between the initial and final bone thickness (0.202, $P = .551$).

DISCUSSION

After 9 weeks, there was 1.6 mm–1.8 mm of buccal tooth movement at the cusp tips. Another human study, using a similar appliance design with a 50-g buccal force applied at the level of the bracket for 7 weeks, produced 3.7 mm of buccal premolar movement and over 12° of uncontrolled tipping.[10] Mesiodistal tooth movements generally occur at approximately 1 mm/mo.[15] The slightly lower rate observed in the present study could have been due to the buccal cortex, which might be expected to respond differently to forces than would medullary bone.

Lateral translation can be produced with minimal (2.2°) tipping. Similar forces applied at the bracket produce substantially more (9°–14°) tipping.[2,10,16] Most importantly, lateral tooth movements caused buccal cortical bone to form. Since the bone was initially 1.4 mm thick, and the teeth were moved 0.96 mm, final thickness should have been 0.44 mm. However, the final bone thickness was 0.85 mm. This difference (0.51 mm) is consistent with the bone apposition measured on the superimpositions (0.5 mm). In fact, all teeth exhibited measurable amounts of buccal bone apposition (Figures 5 through 8). Bony apposition of cortical bone has been previously reported after lingual tooth movement.[17] Experimental studies have demonstrated osteoblastic activity and new bone formation on the buccal cortex after lateral tooth movement.[3] Cortical bone apposition is probably due to the increased strains associated with tooth movement.[7,17–19]

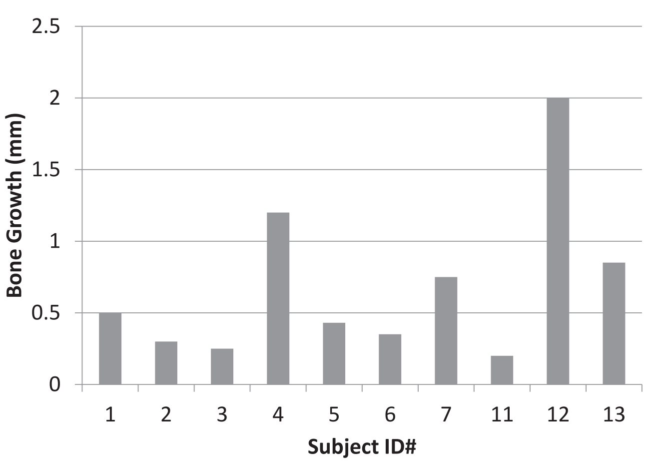

Figure 5. Buccal bone apposition of each subject measured 3 mm below the CEJ.

The roots moved through the medullary bone until they approached the cortical plate, when cortical apposition probably occurred. This explains why the patients who initially had greater amounts of buccal (trabecular and cortical) bone experienced less buccal bone apposition. This also explains why initial and final buccal bone thickness were not correlated. Tooth movements through medullary bone might be expected to have little effect on the alveolar width until the tooth approaches the cortex.[20] Finite element analyses indicate that any given buccal translational force is reduced in the periodontal ligament, and especially in the adjacent alveolar bone.[21] Reduced forces probably affect the cortex only when the tooth root is in close proximity.

While CBCT imaging is reliable for evaluating dentoalveolar changes,[9,22] there are limitations due to voxel size and the partial volume averaging effect.[22,23] When a voxel lies on two objects of different densities, the resulting voxel will reflect their average density, rather than the density of either object. This averaging effect causes bone height and thickness to be underestimated, making it falsely appear as though there is bone loss.[22–24] Accuracy in the present study was maximized by using a voxel size of 0.076 mm, which made it possible to distinguish between tooth movements and new bone formation.

Importantly, the rate of tooth movement can surpass the rate of bony apposition, at least temporarily. Reductions in buccal bone thickness indicated that the premolars had moved through the bone, as well as with the bone. The five subjects who developed significant dehiscences initially had thinner buccal bone than did the other subjects. Since there were no differences in tipping or in the amount of tooth movement, they experienced greater tooth movements through cortical bone. The location of the dehiscences (mesial to the premolar midline) further support the

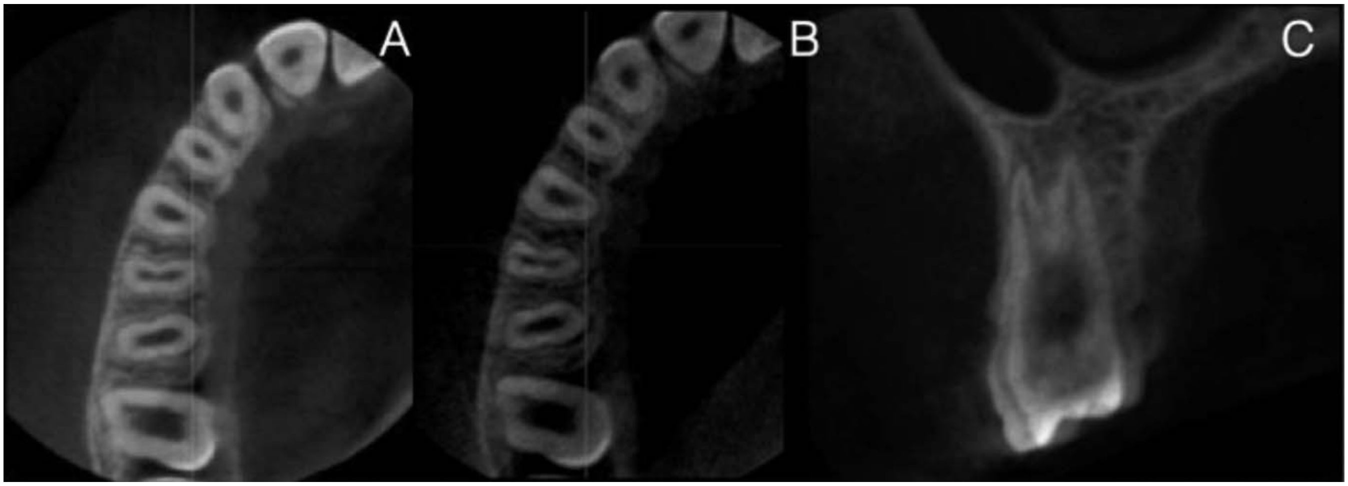

Figure 6. Patient 6, who had a minimal amount of tooth movement. (A) Coronal pretreatment view. (B) Coronal posttreatment view. (C) Frontal view of the superimposed images.

notion that the greater the movements through cortical bone, the greater the risk of dehiscences (Figure 9).

It is also possible that bone was actually present, but not evident on the CBCT images. Due to the partial volume averaging effect previously described, objects must be separated by more than two voxels in order to be discernible.[25] Since the voxel size in the present study was 0.076 mm, buccal bone would not have been evident if it was less than 0.152 mm thick. Moreover, there must be a 40%–60% difference in mineral density between objects in order to be discernable on radiographic images.[26] The new woven bone that formed in the direction of displacement[26] and the loss in mineralization associated with tooth movement[26,27] could have made it difficult to distinguish thin cortical bone.

CONCLUSIONS

- Clinically significant amounts of lateral translation of teeth can be obtained orthodontically with minimal tipping.
- Formation of buccal bone occurs during lateral tooth movements.
- The maximum distance from the CEJ to the crestal bone increases significantly with lateral translating tooth movements.

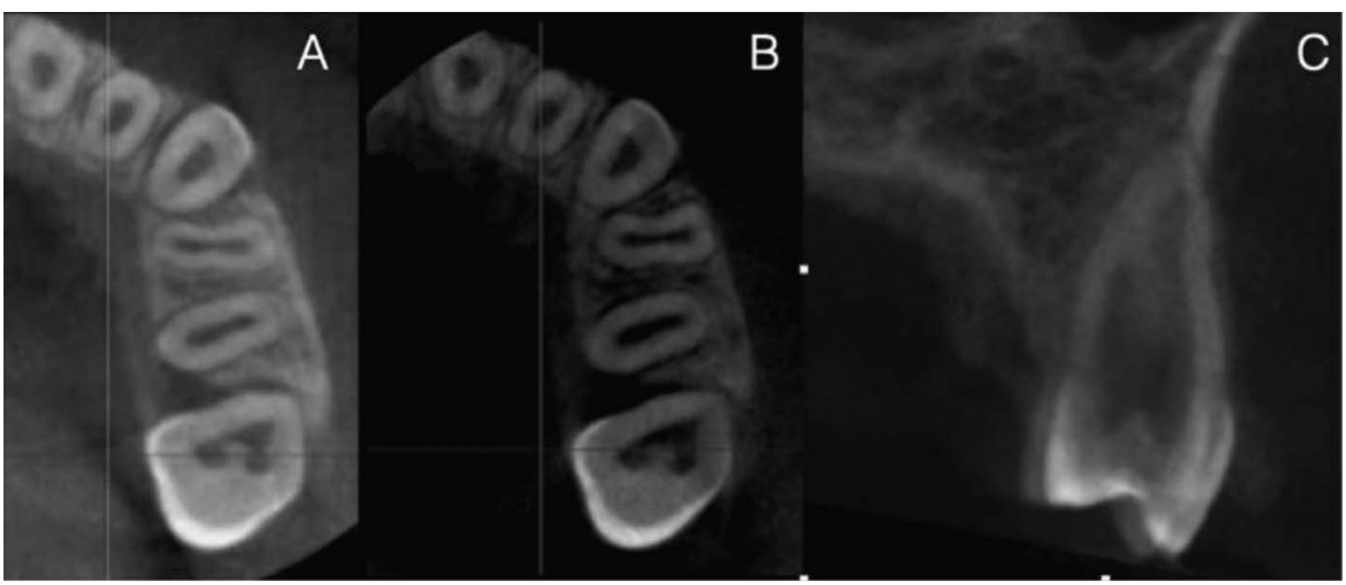

Figure 7. Patient 13, who had a average amount of tooth movement. (A) Coronal pretreatment view. (B) Coronal posttreatment view. (C) Frontal view of the superimposed images.

Figure 8. Patient 12, who had a maximal amount of tooth movement. (A) Coronal and (B) frontal view of the superimposed images.

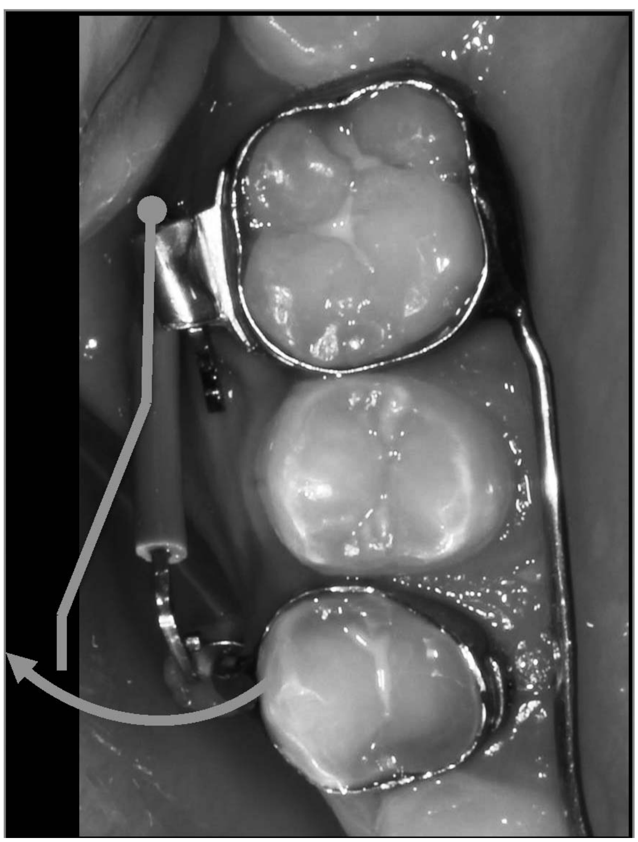

Figure 9. Occlusal photograph displaying rotational movement of the experimental premolars.

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