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ORIGINAL ARTICLE

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Effects of increased surgical trauma on rates of tooth movement and apical root resorption in foxhound dogs

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Structured Abstract

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Purpose – To experimentally determine the effects of increased surgical trauma on the rates of tooth movement and apical root resorption. Two surgical techniques for rapid protraction of multi-rooted teeth in foxhound dogs immediately following premolar extraction were compared.

Methods – Split-mouth design to randomly assign two surgical techniques [periodontal ligament distraction (RAP side) and a modified form of dentoalveolar distraction (RAP+ side)] to the maxillary quadrants. First premolars were extracted, and second premolars were protracted 0.5 mm per day for 15 days using a custom made jack-screw distractor. Serial caliper and radiographic measurements were performed to quantify tooth movements and apical root resorption.

Results – Both techniques demonstrated significant movement of the crown and apex. The second premolar crowns were protracted significantly more on the RAP+ side (2.9 mm) than on the RAP (1.8 mm) side. The premolars on both sides demonstrated significant tipping (4.3 and 3.9 degrees for the RAP+ and RAP sides, respectively). The distal root apex showed almost twice as much apical root resorption than the mesial root apex, but resorption was limited (<0.16 mm) and not statistically different between sides.

Conclusions – Increased surgical trauma increased the rate and, ultimately, the amount of tooth movement. The heavy forces used to protract the teeth produced statistically, but not clinically, significant apical root resorption on the mesial and distal roots of the maxillary second premolars.

Key words: regional acceleratory phenomenon; root resorption; surgical trauma

Introduction

The American Association of Orthodontics estimates that most comprehensive orthodontic treatments take between 18 and 30 months to complete, depending on case complexity and treatment decisions. Although case complexity is out of the control of the orthodontist, treatment decisions involving extractions can significantly prolong orthodontic treatment. Orthodontists' top cited reasons for extraction of premolars include crowding, incisor protrusion, profile improvement, AP discrepancy, and stability (1–3). Extraction of premolars is relatively common, including approximately 30% of treated cases (3–6). Orthodontic

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treatment time could be reduced with techniques that accelerate space closure.

Conventional tooth movement is a biologically rate-limited process that involves the application of a force, which is secondarily transmitted to the surrounding periodontal ligament, and eventually causes the surrounding alveolar bone to either resorb or proliferate depending on how the bone is stimulated. The literature consistently reports extraction space closure rates of approximately 1 mm/month using conventional mechanics (7–28). Based on a 7 -mm premolar extraction site, this could add significant time to orthodontic therapy.

A phenomenon termed regional acceleratory phenomenon, or RAP, has been shown to occur in bone following the application of noxious stimuli. Frost described it as a regional reaction of both hard and soft tissues to noxious stimuli, characterized by an acceleration of most normal processes (29–32). An increase in osteoclastic activity and a hastening of alveolar ridge resorption have been observed in the maxilla and mandible following the application of a bony insult. RAP was used by the Wilcko brothers to accelerate tooth movement through cortical damage (33). They reported markedly decreased treatment times, no loss of tooth vitality, no significant apical root resorption, and no periodontal pocketing. Experimental and clinical work has confirmed the ability of RAP to increase the rate of orthodontic tooth movement (34–44).

In an attempt to accelerate space closure beyond that possible with corticotomies only, several surgical techniques have been developed to rapidly retract canines into extraction sites. Liou and Huang introduced a procedure called dental distraction, which used heavy forces to bypass the normal resorptive response of the bone; the applied forces distracted the periodontal ligament and distalized the canines bodily about 6.5 mm in 3 weeks, with almost no anchorage loss and minimal root resorption (45). In 2002, Kisnisci and Iseri introduced dentoalveolar distraction osteogenesis, which accelerated canine distalization by creating a transport segment that included the tooth and surrounding alveolar bone (46). The canines were distalized about 7 mm in 8 to 12 days, with no anchorage loss, root resorption, or ankylosis.

While RAP has been shown to accelerate tooth movement, there are currently no guidelines pertaining to tooth movements associated with variable amounts of RAP derived from larger noxious stimuli (42, 47, 48). Melsen has shown that applying orthodontic forces can initiate the RAP (49) Sanjideh et al. recently demonstrated the same relationship indirectly by showing that extractions with corticotomies produce greater tooth movements than extractions alone (48). To determine whether increased surgical trauma increases the rate of tooth movement or if there is a level at which increased trauma begins to slow the process, studies need to systematically evaluate the associations between noxious insults, RAP, and tooth movement. While several clinical studies show rapid tooth retraction with such procedures, (45, 46, 50–58) there is no experimental evidence supporting the effectiveness when applied to multi-rooted teeth. A procedure to aid orthodontists in protracting multi-rooted teeth would be extremely valuable clinically.

This split-mouth designed study in foxhound dogs compared the rate and effectiveness of varying amounts of RAP, through modifications of previously reported canine retraction techniques, for the rapid protraction of multi-rooted teeth. The null hypotheses of this study were as follows:

1) There is no difference in the rate of tooth movement between the RAP and RAP + surgical procedures.
2) There will be no difference in apical root resorption between the RAP and RAP + surgical procedures.

Materials and methods

Experimental model

Ten skeletally mature male foxhound dogs with fully erupted dentitions between 1 and 2 years of age and weighing 25 to 30 kg were utilized. The housing, care, and experimental protocol were approved by the Institutional Animal Care and Use Committee at Baylor College of Dentistry, Dallas, Tex. The foxhound was selected because it is a well-established model for investigating tooth movement (59–66). Foxhounds were used because their periodontal ligaments and alveolar bone are similar to those in humans, and the size of the foxhound mouth and dentition is more similar to humans than the commonly used beagle dogs. Following 10 days of quarantine, ultrasonic prophylaxis and initial records, including maxillary and mandibular alginate impressions, photographs, and radiographs, were taken. The impressions were formed on a dried foxhound skull using custom trays fabricated from Triad material (Dentsply, York, PA, USA).

Appliances

Alginate impressions were poured in die-stone, and the distraction devices were fabricated from the models. The distraction appliances included two custom pinched bands on the maxillary canines and second premolars and a Hyrax expansion screw (Dentaurum, Ispringen, Germany) (Fig. 1C, D). The bands were made using orthodontic band material (3M Unitek, Monrovia, CA, USA), which was adapted to the teeth and welded. The expansion screw was opened to allow protraction of the maxillary second premolar upon activation, before it was adapted and soldered to the custom bands. One activating turn of the screw closed the screw 0.25 mm. After soldering, the inside of the bands were roughened, and small holes were drilled to increase retention following cementation. Finally, all rough edges were smoothed, and the appliances were polished to improve their comfort.

Radiographic stents were also fabricated from the maxillary models. Triad custom tray material was adapted to the crown of the maxillary first molar and extended mesially to hold an intraoral posterior bite block film holder.

Surgery

On the day of surgery, the animals were sedated with ketamine (2.2 mg per kilogram, intramuscularly) and xylazine (0.22 mg per kilogram, intramuscularly), given a brief dental examination, and had their teeth scaled with ultrasonic instrumentation. Tantulum bone markers, 1.5 mm long and 0.5 mm in diameter, were placed in the distal crest of the canine alveolar ridge and between the roots of the second premolar using a driver and a mallet. The markers served as stable reference points. Using digital film (Air Techniques, Melville, NY, USA) and a Nomad handheld x-ray unit (Aribex, Orem, UT, USA), pre-operative periapical radiographs of both maxillary quadrants were taken. The animals were intubated and placed under general anesthesia with 1% isofluorane with oxygen at 1 l per min. Local anesthesia (2% lidocaine with 1:100 000 epinephrine) was administered (approximately 1 carpule per quadrant) via regional infiltration. Vital signs, including heart rate, respiratory rate, and blood oxygen saturation, were monitored throughout all procedures and maintained within normal physiological limits (70 BPM, 15 RPM, 95%). The maxillary first premolars were elevated and extracted bilaterally. After extraction of the first premolars, the extraction sites were extended distally to within 1 mm of the second premolar using a Stryker surgical handpiece

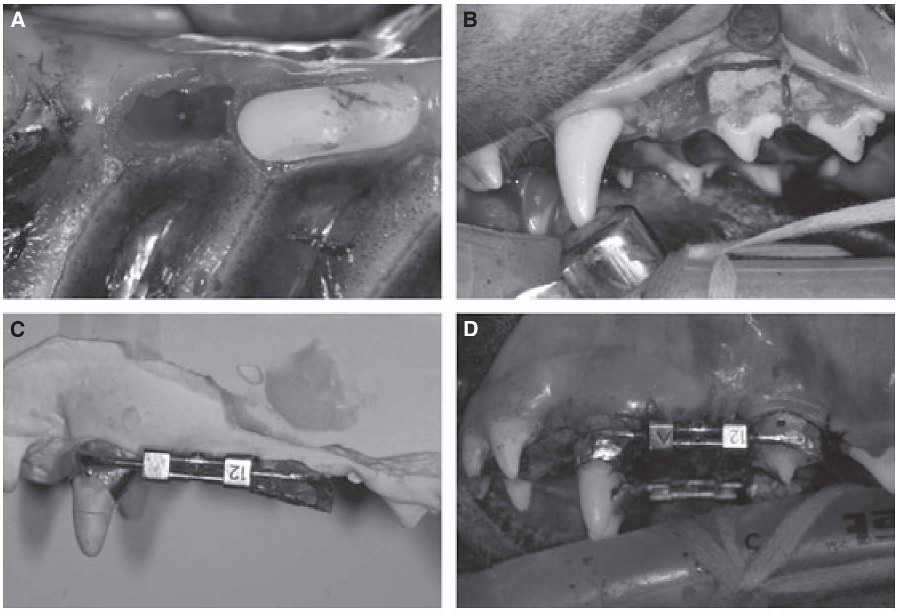

Fig. 1. (A) Post-op RAP (B) Post-op RAP + (C) Fabricated distraction device (D) Cemented distraction device.

(Stryker, Kalamazoo, MI, USA) and a Brasseler (Brasseler USA, Savannah, GA, USA) 701 tapered fissure bur under copious saline irrigation, to simulate human interseptal bone. This was necessary because of the anatomy of the foxhound dogs, including no interproximal tooth contact and wide interseptal bone. Based on random assignment, one maxillary quadrant was selected for a surgical procedure similar to that described by Liou and Huang (45) (RAP); the other side was assigned a modified surgical procedure described by Kisnisci et al. (46) (RAP+). On the RAP side, the interseptal bone mesial to the second premolars was undermined with the same bur used for the interseptal reduction by grooving vertically inside the extraction socket along the buccal and lingual sides; the grooves were extended obliquely toward the base of the interseptal bone without cutting through to the second premolar, to weaken its resistance and stimulate the RAP (Fig. 1A).

On the RAP + side, a horizontal incision was made from the canine to the third premolar, and a full thickness gingival flap was raised with a periosteal elevator. Using a 701 tapered fissure bur and copious irrigation, the buccal plate between the second premolar and canine was then removed, along with any interferences to translation of the tooth and bony segment. A vertical osteotomy extending to, but not through, the lingual cortex was then performed 1 mm distal to the second premolar. The vertical osteotomy and extraction site were then connected by a horizontal corticotomy 1–2 mm deep and 3–5 mm apical to the second premolar (Fig. 1B). This procedure differed from that introduced by Kisnisci and Iseri's in that the segment was not mobilized. Doing so would have resulted in a large communication with the maxillary sinus. All osteotomies were flushed and irrigated well with sterile saline before the flap was sutured with 3–0 silk sutures (Patterson, St. Paul, MN, USA). Sutures were removed during distraction to prevent impeding mesial movement of the second premolar. After surgery was completed, the distraction devices were cemented in place, the dogs were extubated, and post-operative radiographs and photographs were taken. Post-surgical pain management included 0.3 mg of Buprenorphrine (q 12 h for first 3 days) and 200 mg Ibuprofen (200 mg for 3 days). Penicillin G Benzathine (300 000 units/10 lbs of body weight) was administered for the prevention of post-surgical infection.

Bonding procedure

The distraction devices were cemented following surgical intervention. All appliances were tried in place to confirm a proper fit. Hemostasis was achieved using cotton rolls, firm pressure, and Viscostat (Ultradent, South Jordan, UT, USA) if needed. Maxillary canines and second premolars were etched using 37% phosphoric acid gel for 30 s. After irrigation and drying, the teeth appeared frosty white and were coated with equal parts A and B primer from the All-Bond 2 dental adhesive kit (Bisco, BC, Canada). The primer was cured for 10 s using an Ortholux LED curing light (3M Unitek, Monrovia, CA, USA), followed by application of the associated adhesive resin, which was also cured for 10 s. While the teeth were being prepared, the bands of the distraction device were loaded with Filtek supreme restorative composite (3M ESPE, St. Paul, MN, USA), which was chosen because of its durability and chemical and mechanical retention. The distraction device was then seated on the canine and second premolar, any gross excess cement was removed, and the cement was cured for 40 s. Any voids between the band and the tooth were filled with composite and cured as described. Any excess or rough surfaces were reduced with a high speed handpiece and 330 carbide bur (Brasseler USA) for improved comfort. Notches were cut into the mesial aspect of the canine, above the cemented band, and the distal aspect of the second premolar cusp, above the cemented band, to allow accurate and consistent intraoral measurements. Occlusion was checked while the animal was intubated and equilibration was performed on both the canines and canine bands. The occlusion was again checked after extubation to assure no interferences. Finally, post-operative periapical radiographs were taken.

Premolar protraction

Protraction of the maxillary second premolars was initiated immediately after surgery. Based on the amounts of tooth movement reported by Liou and Huang (45), and Kisnisci and Iseri (46), the premolars were protracted at a rate of 0.5 mm per day (2 closing turns of the hyrax screw) for 15 days (Fig. 2). The animals were physically restrained each day as the appliances were activated and checked for stability. Every third day, the animals were sedated with ketamine and

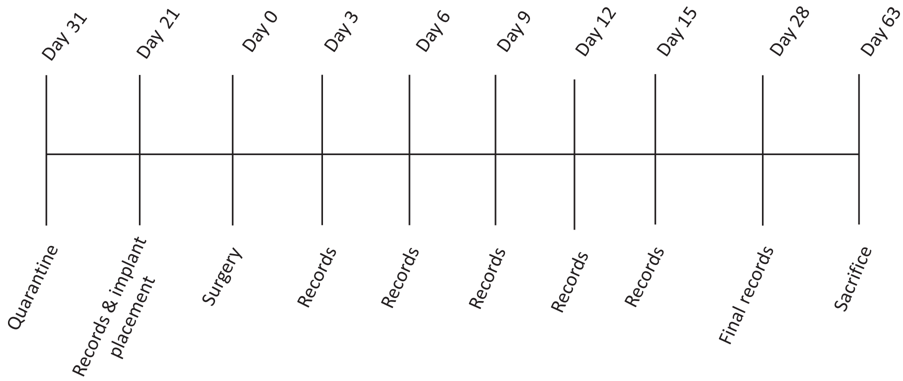

Fig. 2. Timeline of events.

xylazine (1 ml/10 lbs) to take periapical radiographs and duplicate intraoral measurements, using a digital caliper. The distracted teeth were given a 6 -week consolidation period during which the second premolars were retained by the distraction appliance, after which the experimental animals were sacrificed. The duration of the consolidation period was based on previous experimental work showing that the RAP effect peaks 1–3 weeks post-surgery and lasts approximately 6 weeks (28, 33, 34).

Data analysis

Digital periapical radiographs were digitized using a custom protocol in Viewbox 3.1 (DHAL Software, Kifissia, Greece). Ten radiographic points were digitized for each of the six time points including the cusp tip and apex of the canine, mesial and distal premolar crown and apex, mesial and distal bone markers, and crest of the alveolar ridge distal to the canine and mesial to the third premolar (Fig. 3A). From these ten points, seven measurements were calculated, including four horizontal distances from a perpendicular line running through the mesial bone marker to the mesial and distal apices and the mesial and distal of the premolar crown, the angle of the premolar crown in relation to a reference line constructed by connecting the canine and third premolar alveolar crests, and finally the length of the mesial and distal second premolar roots (Fig. 3B).

Statistical analysis

The initial pre-treatment values were subtracted from the subsequent measures to standardize the starting values. SPSS (SPSS, Chicago, IL, USA) statistical software was used to calculate the average tooth movement and variation in tooth movements over time. Multilevel statistical models were used to statistically determine treatment differences in the amount of tooth movement and root resorption. The models were developed using the MLwiN (Center for Multilevel

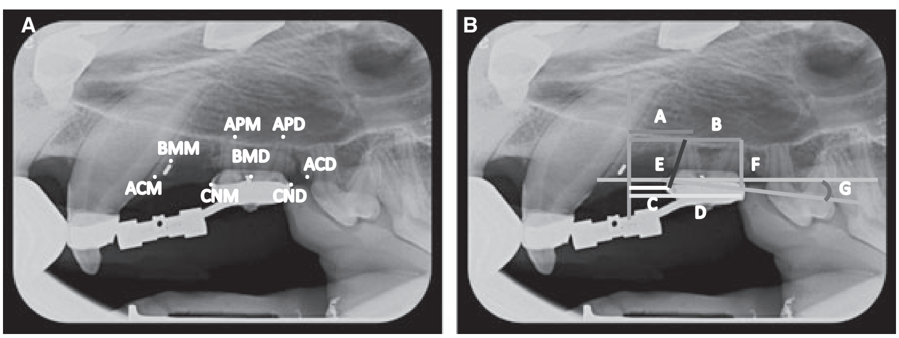

Fig. 3. (A) Periapical radiograph with digitized points; ACM: mesial alveolar crest, ACD: distal alveolar crest, BMM: mesial bone marker, BMD: distal bone marker, CNM: mesial crown, CND: distal crown, APM: mesial apex, APD: distal apex (B) Periapical radiograph with measurements; A: horizontal distance to APM, B: horizontal distance to APD, C: horizontal distance to CNM, D: horizontal distance to CND, E: mesial root length, F: distal root length, G: premolar crown angle.

Modeling, Institute of Education, London, UK) software and iterative generalized least squares estimating procedures.

The fixed portion of each model determined the polynomial that best fit the repeated measurements of tooth movement and root resorption as a function of time. The terms were tested statistically based on the standard errors; higher order terms were rejected sequentially until a lower order term attained significance ($p < 0.05$). The constant term described the tooth movement or resorption at day 15, the linear term described the rate of change (velocity), and the quadratic term described the change in rate (acceleration).

Results

All of the dogs tolerated treatment, but showed some signs of swelling and inflammation during the experimentation phase, which resolved during retention. Although oral hygiene was maintained with brushing and chlorhexidine lavage, some inflammation of the gingiva was observed during the active tooth movement period. All of the appliances were stable and remained bonded throughout the procedure.

Based on intraoral caliper measurements, the second premolar was protracted 1.8 and 2.9 mm for the RAP and RAP+ sides, respectively (Tables 1 and 2, Fig. 4A). Tooth movements followed a quadratic curve, with rates decelerating over time. Multilevel analysis showed statistically significant ($p < 0.05$) differences between the RAP and RAP+ sides in the amount of movement that occurred (1.8 vs 2.9 mm) and the rates at which tooth movements occurred (0.07 vs. 0.10 mm/day). Group differences in the changes in rate (0.005 vs. 007 mm/day^2) were not statistically significant. The premolar crowns tipped forward 3.9 degrees in the RAP side and 4.4 degrees in the RAP+ side (Table 1, Fig. 4B). Changes in the premolar angle showed no statistically significant group differences.

The radiographic measures of the second premolar crown and apices all showed statistically significant rate and positional changes over time. All showed decreasing distances over time. The mesial and distal crown points in the RAP group were protracted 2.32 mm over the 15 days, while the mesial and distal apices moved only 0.55 and 0.87 mm, respectively (Table 1, Fig. 5). For the RAP+ side, the mesial and distal crown points moved 2.73 and 3.08 mm, while the mesial and distal apices moved 0.94 and 1.44 mm, respectively. Statistically significant group differences were found for all four measures, with the RAP+ side demonstrating greater amounts of movement and greater rates of movement.

The multilevel models also showed statistically significant amounts of resorption of both root apices, with almost twice as much resorption found on the distal than on the mesial root apex. Both techniques showed about 0.09 mm of mesial apical root resorption over the 15 days, with 0.16 and 0.14 mm of distal apical root resorption for the RAP and RAP+ sides, respectively (Table 1, Fig. 6). No statistically significant differences were found between groups in the amounts or rates of apical root resorption that occurred.

Discussion

Increased surgical trauma, and therefore, an increased regional acceleratory phenomenon, increased the rate and, ultimately, the amount of tooth movement. The RAP side of the maxilla, which was subjected to a less invasive procedure, consistently demonstrated less tooth movement than the RAP+ side, based on both caliper and radiographic measurements. A RAP-associated increase in velocity of tooth movement in dogs following decortications has been previously demonstrated (42, 47, 48).

Over 2 weeks, Cho et al. and Iino et al. reported 0.85 and 0.5 mm of protraction for beagle maxillary third premolars on the control side using 150 and 50 grams, respectively; over the same time period and with the same amounts of force, there were 1.2 and 1.25 mm of protraction on the corticotomy side (42, 47). Sanjideh et al. also reported approximately twice as much protraction on the corticotomy side than on the non-corticotomy side of foxhounds, but the total amount of movement after 2 weeks of protraction with 200 grams was only 0.5mm (48). Although the experimental conditions were not identical, these results suggest that protraction of maxillary third premolars is slower in foxhounds than in beagles. Nevertheless, these reported values are all less than the 1.8 and 2.9 mm of crown movement reported in this study for the RAP and RAP + groups, respectively. Because of the significant tipping that occurred, the actual amount of tooth

Table 1. **Multilevel results describing differences between the RAP and RAP+ sides in tooth movements and premolar angulation changes after 28 days, as well as daily rates of tooth movements (measured with calipers and radiographically as the horizontal distances from the mesial bone marker to the mesial (M) and distal (D) premolar apices and crowns)**

	RAP						RAP +						Difference			
Measurement	Day 28	SE	Rate	SE	Δ in Rate	SE	Day 28	SE	Rate	SE	Δ in Rate	SE	Day 28	SE	Rate	SE
Caliper (mm)	−1.77E+00	2.09E−01	7.03E−02	2.16E−02	4.58E−03	7.42E−04	−2.93E+00	2.30E−01	1.01E−01	2.82E−02	7.31E−03	9.69E−04	−1.45E+00	2.43E−01	−4.49E−02	1.24E−02
Premolar Angle (deg)	4.37E+00	7.67E−01	−3.05E−02	8.38E−02	−7.03E−03	2.88E−03	4.58E+00	8.03E−01	−8.46E−02	7.93E−02	−9.79E−03	2.72E−03	NS	NS	NS	NS
M Premolar Apex (mm)	−5.08E−01	6.79E−02	1.64E−02	5.43E−03	1.20E−03	1.87E−04	−1.02E+00	1.29E−01	1.12E−02	1.29E−02	1.73E−03	4.42E−04	−5.66E−01	1.10E−01	−1.98E−02	5.64E−03
M Premolar Crown (mm)	−2.25E+00	1.58E−01	5.85E−02	1.43E−02	5.12E−03	4.92E−04	−2.76E+00	2.01E−01	5.41E−02	2.31E−02	5.73E−03	7.93E−04	−5.70E−01	1.96E−01	−2.12E−02	1.00E−02
D Premolar Apex (mm)	−8.54E−01	9.51E−02	2.06E−02	7.79E−03	1.83E−03	2.68E−04	−1.53E+00	1.59E−01	1.96E−02	1.70E−02	2.78E−03	5.85E−04	−7.72E−01	1.38E−01	−2.72E−02	7.08E−03
D Premolar Crown (mm)	−2.32E+00	2.17E−01	5.09E−02	1.95E−02	4.93E−03	6.69E−04	−3.10E+00	1.90E−01	6.38E−02	2.33E−02	6.56E−03	7.99E−04	−9.51E−01	2.13E−01	−3.22E−02	1.09E−02
M Premolar Root Resorption (mm)	−9.81E−02	1.06E−02	1.01E−03	1.08E−03	1.61E−04	3.72E−05	−9.82E−02	1.02E−02	6.15E−04	8.91E−04	1.47E−04	3.06E−05	NS	NS	NS	NS
D Premolar Root Resorption (mm)	−1.70E−01	1.32E−02	2.03E−03	1.31E−03	2.88E−04	4.49E−05	−1.62E−01	1.16E−02	4.46E−04	1.41E−03	2.22E−04	4.85E−05	NS	NS	NS	NS

NS=not statistically significant.

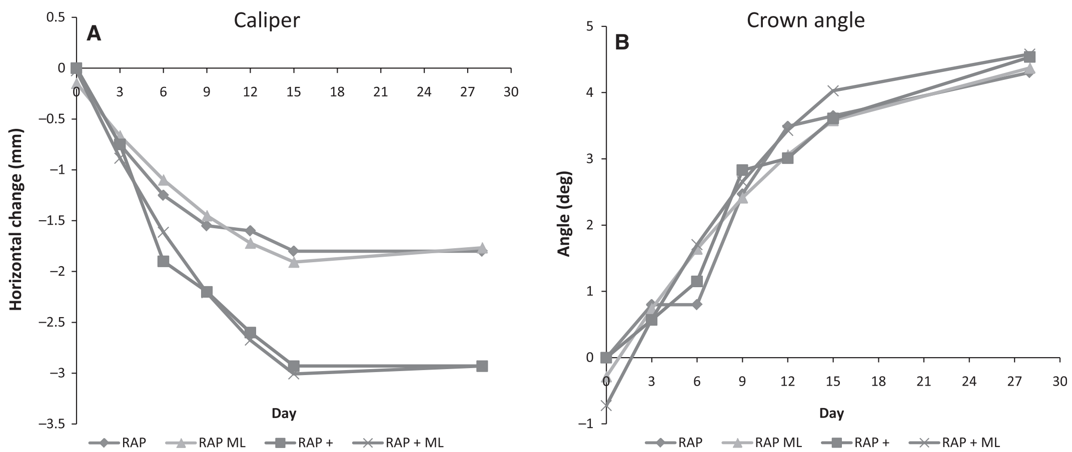

Fig. 4. (A) Intraoral caliper measurements of maxillary second premolar (B) Radiographically measured maxillary second premolar crown angle. (ML = multilevel estimates)

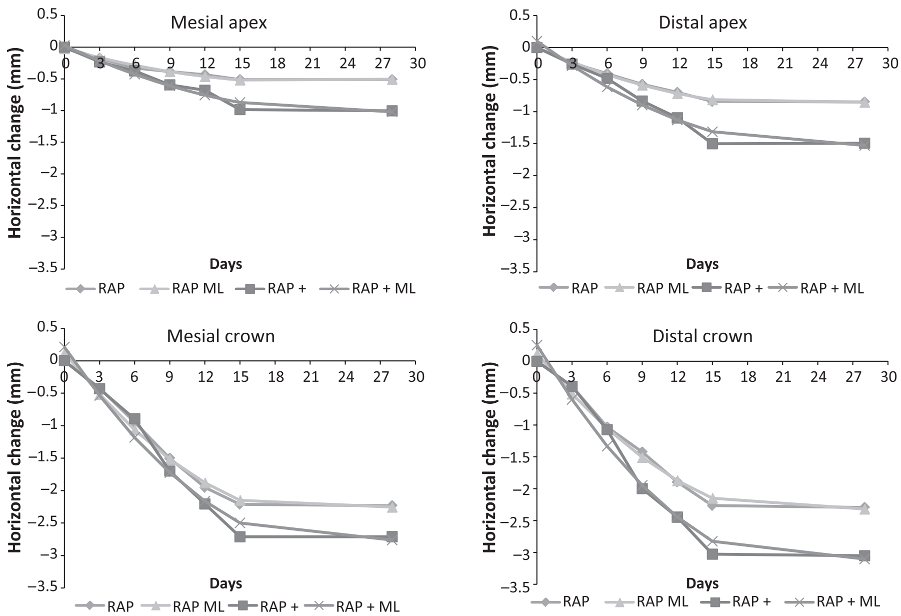

Fig. 5. Radiographic movement of maxillary second premolar crown and apex. (ML = multilevel estimates)

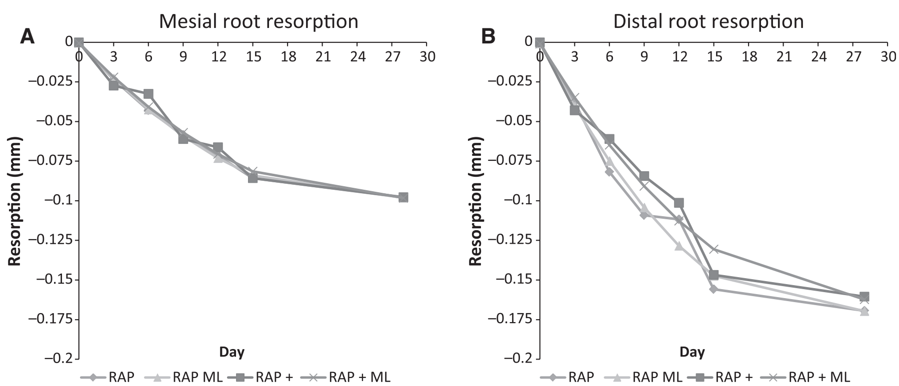

Fig. 6. (A) Radiographically measured maxillary second premolar mesial apical root resorption (B) Radiographically measured maxillary second premolar distal apical root resorption. (ML = multilevel estimates)

Table 2. **Variation between dogs and over time in tooth movements (measured with calipers and radiographically as the horizontal distances from the mesial bone marker to the mesial (M) and distal (D) premolar apices and crowns) and angulation changes**

	Between Dogs				Over Time			
	RAP		RAP +		RAP		RAP +	
Measurement	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Caliper	2.03E−01	1.06E−01	1.28E−01	8.42E−02	2.40E−01	4.37E−02	4.08E−01	7.46E−02
Premolar Angle	2.34E+00	1.28E+00	3.28E+00	1.67E+00	3.61E+00	6.59E−01	3.23E+00	5.89E+00
M Premolar Apex	3.13E−02	1.50E−02	8.29E−02	4.26E−02	1.51E−02	2.77E−03	8.50E−02	1.55E−02
M Premolar Crown	1.47E−01	7.24E−02	1.35E−01	7.84E−03	1.05E−01	1.92E−02	2.73E−01	4.99E−02
D Premolar Apex	5.98E−02	2.87E−02	1.07E−01	2.78E−02	3.11E−02	5.69E−03	1.49E−01	2.71E−02
D Premolar Crown	2.78E−01	1.37E−01	8.65E−02	5.69E−02	1.95E−01	3.55E−02	2.78E−01	5.08E−02
M Premolar Root Resorption	5.39E−04	2.80E−04	6.43E−04	3.14E−04	6.00E−04	1.10E−04	4.08E−04	7.45E−05

translation is best approximated at the mesial apex, which was protracted approximately 0.5 and 0.85 mm for the RAP and RAP + groups, respectively. The rates of tooth movement observed in the present study were considerably higher than those reported for conventional space closure mechanics in dogs, which range from 0.9 to 1.3 mm/month in beagles (62, 63, 67).

While the tooth movements were substantial, the rates for the foxhound maxillary premolars were much lower than the rate previously reported for canine retraction in humans. Based on caliper measurements, the premolars were protracted 1.8–2.9 mm at rates ranging between 3.6 and 5.9 mm/month, which is considerably slower than the 8.7 mm/month rate of space closure described by Liou and Huang (45). The rate differences reported for foxhound dogs and humans could be because of the thicker cortical bone found in the foxhounds, which resists and slows tooth movements. Also, significant resistance was provided by the lingual cortex, which was not freed from the bony segment and could have obstructed the path of protraction of the second premolar (Fig. 1A). Second, the surgical techniques utilized in this study did not exactly mimic those previously described for humans. Dogs have very thick interseptal bone, which had to be reduced to mimic the human mouth. Liou and Huang suggest their rapid canine retraction as due to stretching of the periodontal ligament, but the extraction and surgical insult also stimulate the RAP, which facilitates the acceleration of tooth movement. The RAP + group's surgical technique was loosely based on the Kisnisci and Iseri technique, but the bone and tooth segments were not mobilized.

The main difference between the present study and previous studies reporting more rapid tooth movements was the use of a multi-rooted rather than single-rooted tooth. Liou and Huang's technique is based on the ability of the PDL mesial to the distalized canine to become stretched during tooth movement, much like the midpalatal suture during maxillary expansion. This same phenomenon, however, is apparently not possible with the multi-rooted premolar because the interradicular bone impeded the movement of the distal root. Apparently, the interradicular bone mesial to the distal root could not resorb as quickly as the PDL could stretch. This probably slowed the entire process and caused increased tipping as the distal root rode up the interradicular bone. The interradicular bone lowered the center of resistance and therefore increased the moment placed on the tooth as the distance from the applied force to the center of resistance increased. The crown in both techniques tipped forward about 4 degrees as the premolar was protracted. The tipping was significant, but less than the amounts of tipping reported in human rapid canine retraction studies, which ranged between 11.5° and 16.5° (54, 55). It is interesting that tipping was possible even with a semi-rigid appliance. This is similar to the buccal crown tipping seen during rapid maxillary expansion with a jack-screw type appliance.

The teeth were not protracted as much as the jack-screw was closed. This suggests that the appliance might have been bent slightly by the heavy distraction forces used. In addition, the devices were not fabricated perfectly. Although they were fabricated to deliver a force parallel the alveolar ridge, some of the closure force could have been vertical, rather than purely horizontal, which would explain some of the differences observed.

Statistically significant apical root resorption was seen on the mesial and distal roots of the maxillary second premolars for both techniques. There was, however, no significant difference found between the two groups. Although statistically significant, both measurements were clinically insignificant (i.e. <1 mm). The mesial roots showed 0.09 mm and the distal roots showed 0.16 mm of apical root resorption. Carrillo et al. found little to no root resorption after intrusion with 50 and 200 gram springs (68). Owman-Moll et al. classified a small depth of root resorption in humans as less than 0.27 mm, and a large depth of apical root resorption as greater than 0.27 mm (69). The experimental length and treatment mechanics were very different in this study, but it shows that the observed absolute amount of resorption was small, even after applying very high forces. In beagles, after applying distalizing forces, Maltha et al. found between 0.25 and 0.35 mm of root resorption (70). Segal et al. showed that the two factors most highly correlated to apical root resorption were the length of treatment, which was small in the present study, and total apical displacement (71). Sameshima et al. also found horizontal root displacement to be one of the most important predictors of apical root resorption; the mechanics, including slot size or use of elastics, and the force applied, were not correlated with apical root resorption (72). There was more resorption observed on the distal apex, which was in constant contact with the interradicular bone and which had to move a greater distance, as it was forced up the interradicular bone. Given the major role played by genetics (73), it is also possible that dogs are less predisposed to external root resorption than human.

Conclusions

Increased surgical trauma increased the rate as well as the total amount of tooth movement when heavy forces were applied to the second maxillary premolars of foxhound dogs. The RAP+ side consistently showed significantly greater tooth movements than the RAP side. The crowns were protracted significantly more than the root apices, with similar amounts of tipping on both sides. Statistically significant apical root resorption was seen on the roots of the premolars, with significantly greater resorption of the distal than mesial roots. Although statistically significant, the actual amount of resorption that occurred was clinically insignificant, despite the application of heavy constant forces.

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