Acceleration of orthodontic tooth movement by alveolar corticotomy in the dog

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Introduction: Tooth movement and alveolar bone reaction after corticotomies have not been thoroughly examined. In this study, the effects of corticotomies on orthodontic tooth movement and alveolar bone reaction were investigated in dogs. Methods: Corticotomies were performed on the cortical bone of the mandibular left third premolar region in 12 male adult beagles. The third premolars on the left experimental side and on the right sham side were moved mesially with a continuous force of 0.5 N. Results: Tooth movement velocities from 0 to 1 week and from 1 to 2 weeks after the corticotomies were significantly faster on the experimental side than on the sham side. Hyalinization of the periodontal ligament appeared only at 1 week after the corticotomies on the experimental sides, whereas it was observed from 1 to 4 weeks after the corticotomies on the sham sides. Tartrate-resistant-acid-phosphatase positive cells of the experimental side tended to work vigorously at an early time on the alveolar wall and in the bone marrow cavities. Conclusions: Orthodontic tooth movement increased for at least 2 weeks after the corticotomies. This might be brought about by rapid alveolar bone reaction in the bone marrow cavities, which leads to less hyalinization of the periodontal ligament on the alveolar wall. (Am J Orthod Dentofacial Orthop 2007;131:448.e1-448.e8)

A corticotomy on the alveolar bone makes orthodontic tooth movement faster than in conventional orthodontic treatment; this leads to shorter orthodontic treatment times. According to Hajji, the active orthodontic treatment periods in patients with corticotomies were 3 to 4 times more rapid compared with patients without corticotomies. It was believed that a corticotomy makes tooth movement faster because the bone block moves with the tooth. However, tooth movement after a corticotomy should be considered a combination of classical orthodontic tooth movement and the movement of bone blocks containing a tooth, because the force applied to a tooth is transmitted into the osteotomy gap through the periodontal ligament (PDL).

Bone turnover is well known to be accelerated after bone fracture, osteotomy, or bone grafting. This could be explained by a regional acceleratory phenomenon (RAP); ie, osteoclasts and osteoblasts increase by local multicellular mediator mechanisms containing precur- sors, supporting cells, blood capillaries, and lymph. RAP also occurs in the mandible. Similarly, bone turnover is increased by RAP after a corticotomy.

The velocity of orthodontic tooth movement is influenced by bone turnover, bone density, and hyalinization of the PDL. Wilcko et al mentioned, in cases of rapid orthodontics with corticotomies, that corticotomies could increase tooth movement by increasing bone turnover and decreasing bone density. However, the increase of tooth movement after a corticotomy was not always examined histologically. In our study, we intended to elucidate the mechanism of rapid tooth movement associated with corticotomies by investigating the amount of tooth movement and the alveolar bone reaction on the periodontal tissue of the compression side after corticotomies in beagle dogs.

MATERIAL AND METHODS

The experimental animals were 12 male adult beagles. They were caged individually with regulated light and temperature, and fed soft dog food...
and water to prevent any damage to the experimental orthodontic appliance. All experimental procedures were performed under intravenous anesthesia with sodium pentobarbital (25-30 mg per kilogram of body weight). The experimental conditions and procedures were approved by the Animal Ethics Committee of Miyazaki University.

The mandibular left and right third premolars (P3) were the experimental and sham sides, respectively. The mandibular second premolars were extracted on both sides to prepare the space for mesial movement of the P3.

Healing, by the formation and mineralization of callus, usually requires 4 to 16 weeks after bone injury. Therefore, at 16 weeks after extraction, the alveolar bone on the experimental side was corticotomized as follows: the gingival mucoperiosteal flaps were raised to expose cortical bone on both the buccal and lingual sides of the P3. The horizontal cut line of the corticotomy was made under the apices of the P3 on the lingual side and at the level of mental foramen on the buccal side (Fig 1). The vertical cut lines were made from the alveolar crests of the P3 to the horizontal cut lines on the buccal and lingual sides. The corticotomy process was performed with a #009 fissure bur under saline-solution irrigation. The width of bone cuts was approximately 1 mm, and the depth was carefully adjusted to reach the bone marrow by confirming bleeding through the cut lines. The mucoperiosteal flaps were sutured with absorbable surgical sutures.

Orthodontic appliances were constructed on both sides on the dental casts before the corticotomies (Figs 2 and 3). Orthodontic bands were cemented to the mandibular canines and P3 teeth. Metal tubes (diameter, 1.14 mm; length, 4.6 mm; Tomy International, Tokyo, Japan) were soldered to the orthodontic bands of the P3. Orthodontic wires (diameter, 1.0 mm; Dentsply-Sankin, Tokyo, Japan) were soldered to the mandibular canine bands and inserted through the metal tubes on the bands of the P3. The bands were cemented to the teeth with glass ionomer cement.

Immediately after the corticotomies, the P3 teeth of the experimental and sham sides were moved mesially along the orthodontic wire with a continuous force of 0.5 N by using nickel-titanium closed coil springs (Tomy International). One end of the spring was fixed to the bent loop of the orthodontic wire on the canine site with a ligature wire, and the other side was fixed to the metal tube with a ligature wire. The length of each spring, which corresponded to a contractile force of 0.5 N, was measured with a caliper and strain gauge, and the activation of the spring was set at that length. The appliance, teeth, and gingiva were checked once a day and cleaned with a toothbrush and gauze with 0.02% chlorhexidine in water, and the force delivery was measured once a week.

Standardized dental radiographs were taken at a constant distance and angle by setting the film holder with an attachment on the mandibular fourth premolar (Fig 4) before the corticotomy (T0) and at 1 (T1), 2 (T2), 4 (T4), and 8 (T8) weeks after the corticotomy. Tracing and superimposition on the mandibular fourth premolar were carried out. The distance of tooth movement was measured between the tip of protocone of the P3 at the various time points with a caliper on the tracing. The error of the method was calculated for the distance of tooth movement based on double measurements on 10 randomly selected distances of tooth.

Fig 1. Photograph of corticotomy on alveolar buccal surface on experimental side. Same incision was made on lingual side. White arrowhead, horizontal cut line was made beyond apices; black arrowhead, vertical cut line was made from alveolar crest to horizontal cut line.

Fig 2. Schematic drawing of orthodontic appliance. One side of wire (external diameter 1.0 mm) was soldered to orthodontic band of mandibular canine, and other side ran freely through the 1.14 mm metal tube (internal diameter) on mandibular third premolar. Mandibular third premolars on both sides were moved mesially with nickel-titanium coil springs. C, Canine; P3, third premolar; P4, fourth premolar.
movement measurements and was estimated as $S = \sqrt{\sum (d)^2}/2n$, where $n$ = number of paired measurements and $d$ = deviations between the 2 measurements. The error of the method for measurement of tooth movement was 0.02 mm. The tooth movement velocities (millimeters per week) from T0 to T1 (T0-1), T1 to T2 (T1-2), and T2 to T4 (T2-4) were calculated. The mean values of the distance and velocity of the tooth movement were estimated with the Mann-Whitney U test. Three dogs were killed at T1, T2, T4, and T8 for histologic examinations. Therefore, the numbers of dogs were 12, 9, 6, and 3 at T1, T2, T4, and T8, respectively.

The animals were perfused through the carotid artery with 1% paraformaldehyde and 1% glutaraldehyde in 0.1 mol phosphate buffer (pH 7.4) under deep anesthesia. The blocks of mandibular bone were dissected and refixed in the same solution at 4°C for 24 hours. The blocks were trimmed and decalcified in 10% ethylenediaminetetraacetic acid (EDTA-2Na; pH 7.4) at 4°C for 30 days. Subsequently, according to a conventional technique, serial mesiodistal paraffin sections of 8 μm thickness were made and stained with haematoxylin and eosin or tartrate-resistant-acid-phosphatase (TRAP) with methylene blue as counterstaining for detection of the osteoclasts. Although osteoclasts and osteoblasts are generally observed to assess bone turnover, we observed only osteoclasts to study the tendency of bone turnover on the periodontal tissue and simplify our experiment.

Fig 3. Photographs of orthodontic appliances used for tooth movement: A, open-mouth view; B, closed-mouth view.

Fig 4. Standardized dental radiograph taken by setting film holder with attachment on mandibular fourth premolar.

Fig 5. Comparison of distance of tooth movement between experimental and sham sides with Mann-Whitney U test. T1, 1 week; T2, 2 weeks; T4, 4 weeks after corticotomy. *P < .05; **P < .01; ***P < .001.

Fig 6. Comparison of tooth movement velocity between experimental and sham groups with Mann-Whitney U test. T0-1, Period from 0 to 1 week; T1-2, period from 1 to 2 weeks; T2-4, period from 2 to 4 weeks after corticotomy. *P < .05; **P < .01; ***P < .001.
Light microscopic observation was carried out on the compression side of the P3 mesial root in the experimental and sham sides at T1, T2, T4, and T8. All P3 teeth of the experimental and sham sides were moved mesially with slight tipping, so histological observations were performed from the alveolar crest to halfway apically at the compression side. The numbers of TRAP positive (TRAP+/H11001) cells were counted on the mesial surface of the mesial root (alveolar wall) and in the bone marrow cavities immediately adjacent to the alveolar wall according to the method of Noxon et al.\textsuperscript{15} Their numbers were counted from 3 midsagittal sections per case in the experimental and sham sides at T1, T2, and T4. The timing of TRAP+ cell increase (increasing bone turnover) and decrease (decreasing bone turnover) was observed on the alveolar wall and in the bone marrow cavities.

**RESULTS**

The distances of the tooth movement on the experimental side were significantly greater than those on the sham sides at T1, T2, T4, and T8. All P3 teeth of the experimental and sham sides were moved mesially with slight tipping, so histological observations were performed from the alveolar crest to halfway apically at the compression side. The numbers of TRAP positive (TRAP+) cells were counted on the mesial surface of the mesial root (alveolar wall) and in the bone marrow cavities immediately adjacent to the alveolar wall according to the method of Noxon et al.\textsuperscript{15} Their numbers were counted from 3 midsagittal sections per case in the experimental and sham sides at T1, T2, and T4. The timing of TRAP+ cell increase (increasing bone turnover) and decrease (decreasing bone turnover) was observed on the alveolar wall and in the bone marrow cavities.

The movement velocity on the experimental side was also faster than that on the sham side throughout the experiment (Fig 6). There was a significant difference between the experimental and sham sides at T0-1 and T1-2; movement was 2 and 5 times faster on the experimental side, respectively. There was no significant difference in movement velocity between T1-2 and T2-4 on the experimental side. On the sham side, the velocity at T1-2 was significantly slower than that at T0-1 and T2-4.

On the experimental side, undermining resorption with hyalinization of the PDL was observed on the alveolar wall only at T1 (Figs 7 and 8). Undermining resorption disappeared, and direct resorption progressed at T2, T4, and T8. In the bone marrow cavities, undermining resorption was significant at T1. No root resorption was observed at any time point after corticotomy.

On the sham side, undermining resorption with hyalinization of the PDL also occurred on the alveolar wall at T1 (Figs 7 and 8). Undermining resorption disappeared, and direct resorption progressed at T2, T4, and T8. Remarkably, in the bone marrow cavities, undermining resorption was found at T2. Root resorption was observed around the area of hyalinization at T4, and it was more striking at T8 (arrows in Fig 8).

On the alveolar wall, the numbers of TRAP+ cells increased from T1 on the experimental side (Fig 10);
the numbers increased gradually during the experiment on the sham side. Thus, TRAP+ cells seemed to work vigorously at an early time on the experimental side (Figs 10 and 11).

In the bone marrow cavities, the numbers of TRAP+ cells decreased at T2 on the experimental side (Fig 9); the numbers increased at T2 and decreased at T4 on the sham side. Timing of increase and decrease of TRAP+ cells seemed to be hastened on the experimental side.

**DISCUSSION**

The average distance of tooth movement by an orthodontic force of 0.5 N on the sham side in this study was 1 mm in 4 weeks, and this value is similar to that in a previous dog study. The distance was approximately double on the experimental side at T1, T2, and T4 compared with the sham side. Moreover, tooth movement velocity on the experimental side was significantly faster than on the sham side at T0-1 and T1-2: 2 and 5 times faster on the experimental side, respectively. Therefore, it is suggested that orthodontic tooth movement increased especially in the early stage after the corticotomies.

Time-displacement curves of orthodontic tooth movement are divided and sequenced into 4 phases: initial, lag, acceleration, and constant linear phases. The initial phase (rate of tooth movement: about the distance of PDL thickness) lasts 3 to 4 days or less, and its duration is never longer than 7 days, and the lag...
Fig 10. Timing of increase and decrease of numbers of TRAP+ cells on alveolar wall and in bone marrow cavities. Abbreviations are shown in Fig 5. ●, Number of TRAP+ cells in each tooth; ×, mean value of number of TRAP+ cells at each time point.

Fig 11. Microphotographs of periodontal tissue on experimental (Exp.) and sham sides with TRAP stain at 1 week after corticotomy. There are many TRAP+ cells (arrowheads) in experimental side. Photographs are at same scale. Abbreviations are shown in Fig 7.
Bone healing is accelerated by RAP after more responsive than those in adults in early tooth phase, because mediator levels in juveniles were faster than that in adults at an average of about 7 days. On the sham side, tooth movement velocity was still faster than that at T1-2 and T2-4. Several authors proposed that the lag phase is associated with hyalinization in the PDL, and that the efficiency of tooth movement might be improved by preventing hyalinization. Hyalinization of the PDL precedes the root resorption process during orthodontic tooth movement and can often be observed adjacent to this process. In our study, hyalinization of the PDL was eliminated at an early stage on the experimental side. Furthermore, root resorption was not observed on the experimental side, but it was observed on the sham side at T4 and T8. These results suggested that tooth movement after corticotomy increased without root resorption, and this might be due to the disappearance of the lag phase as evident by less hyalinization of the PDL in the early stage. However, tooth movement velocity at T0-1 was still faster than that at T1-2 and T2-4 on the experimental side. The initial phase was interpreted as the initial movement of a tooth in its socket, because the thickness of the PDL is reduced on the compression side by the orthodontic force. The increase of tooth movement velocity at T0-1 on the experimental side would be due to compression of the PDL and bare spongiose bone and, on the compression side, by the orthodontic force. The alveolar corticotomy procedure increases orthodontic tooth movement for at least 2 weeks after the corticotomy.1,2,6,7 However, our results suggest that conventional orthodontic force would increase the velocity of orthodontic tooth movement, possibly by acceleration of the bone turnover mechanism at an early stage after a corticotomy.

Alveolar bone turnover of the mandible is accelerated by the raising of the gingival mucoperiosteal flap per se.10 Therefore, the side without a corticotomy in this study might not be really a sham for the corticotomy in a strict sense. However, we considered that orthodontic tooth movement after the corticotomy increased by an acceleration of bone turnover accompanied by the surgery of the corticotomy and raising of the gingival mucoperiosteal flaps. Wilcko et al mentioned that bleeding of the corticotomy site is more important than creating blocks of bone for rapid tooth movement. Therefore, a more simple surgery such as gingival mucoperiosteal incision or bone perforation might be used instead of a corticotomy. Furthermore, a problem that could arise from the surgical procedure might be dysfunction accompanied by pain or swelling immediately after the corticotomy. Perhaps the effects of simple surgeries on orthodontic tooth movement and dysfunction after corticotomy should be studied.

In our study, TRAP+ cells of the experimental side seemed to work vigorously at an early time on the alveolar wall and in the bone marrow cavities. Almost no TRAP+ cells were found on the alveolar bone of sections from dogs examined in our other previous study (data not shown). When hyalinization of the PDL occurs, osteoclasts appear in the adjacent bone marrow cavities and begin attacking the underside of the bone adjacent to the area of hyalinization. Tooth movement in juveniles was faster than that in adults at an early phase, because mediator levels in juveniles were more responsive than those in adults in early tooth movement. Bone healing is accelerated by RAP after surgery. New bone formed in the trabecular bone adjacent to the incision site was caused by increasing bone turnover in rabbits. Also, after the corticotomies in our study, the alveolar bone reaction increased simultaneously with orthodontic tooth movement near the corticotomy by RAP at an early stage.

Clinically, it is generally believed that a heavier orthodontic force is needed for the en-masse movement of the bone block with the tooth after a corticotomy. However, our results suggest that conventional orthodontic force would increase the velocity of orthodontic tooth movement, possibly by acceleration of the bone turnover mechanism at an early stage after a corticotomy.

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CONCLUSIONS

The alveolar corticotomy procedure increases orthodontic tooth movement for at least 2 weeks after the corticotomy and decreases the risk of root resorption. This process might be brought about by the rapid alveolar bone reaction in the bone marrow cavities, leading to less hyalinization of the PDL on the alveolar wall.

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REFERENCES