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ORIGINAL ARTICLE

The effect of cortical activation on orthodontic tooth movement

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OBJECTIVE: Cortical activation is one of the procedures to accelerate tooth movement by manipulating the cortical bone. In this study, the effect of cortical activation on orthodontic tooth movement was investigated clinically and histologically in the surrounding bony tissue.

MATERIALS AND METHODS: In the lower and upper jaws of two beagle dogs, cortical activation was applied to the buccal and lingual side of the alveolar bone in the right jaw where 12 holes were made on each cortical plate 4 weeks after the extraction of all the second bicuspids while under deep anesthesia. All third bicuspids on both jaws were forced to move forward by a 150-g force using NiTi coil spring with/without guiding wire. The tooth movement was measured and the animals were killed after tooth movement.

RESULTS: Rapid initial tooth movement was apparent after cortical activation. However, after 6 months of cortical activation, the cell number and cellular activity of the surrounding periodontal tissue were decreased.

CONCLUSIONS: This experiment showed that rapid initial tooth movement was apparent following the application of orthodontic force after cortical activation but the cellular activity and fibroblast structure were abnormal in the surrounding periodontal tissue.
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Keywords: cortical activation; orthodontic force; rapid tooth movement; bone change; cellular response; periodontal tissue

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Introduction

Mechanical, chemical and electrical manipulations applied to periodontal tissues have been reported to have an effect on tooth movement (Köle, 1959; Bell and Levy, 1972; Davidovich *et al*, 1980; Gantes *et al*, 1990; Suya, 1991; Anholm *et al*, 1998). Corticotomy-facilitated orthodontics, a type of mechanical manipulation, was reported to accelerate tooth movement (Köle, 1959; Bell and Levy, 1972; Gantes *et al*, 1990; Suya, 1991; Anholm *et al*, 1998). It was suggested that the increased speed of tooth movement in the case of corticotomy-facilitated orthodontics was caused by the regional acceleratory phenomena (RAP), which increase osteoclastic activity to enhance bone remodeling (Frost, 1989; Yaffe *et al*, 1994). RAP has been known to be induced not only by corticotomy-facilitated orthodontics but also by cortical activation (Wilcko and Wilcko, 1999, 2001). Cortical activation before orthodontic treatment induced the RAP to increase bone remodeling activity and tooth movement speed without any side effects (Wilcko and Wilcko, 2001). However, the effect of cortical activation on tooth movement was only clinically investigated.

In this study, the effect of cortical activation on tooth movement was identified clinically by measuring the distance from the original position to the final position with orthodontic force for 8 weeks. Histological changes were also evaluated in periodontal tissues such as alveolar bone and periodontal ligament after the application of orthodontic force for 2, 4 and 8 weeks. Furthermore, the long-term results of cortical activation on orthodontic tooth movement were investigated clinically and histologically after 6 months.

Materials and methods

All experiments were performed according to the guidelines of the Intramural Animal Use and Care Committee, College of Dentistry, Yonsei University.

Cortical activation
First, all second bicuspids were extracted from the lower and upper jaw of two beagle dogs. After 4 weeks, cortical activation was applied to the buccal and lingual side of the alveolar bone in the right quadrant of the lower and upper jaw. After retracting the mucoperiosteal flap, cortical activation was carefully performed with no. 2 round bur (diameter is 1 mm) at a 3-mm interval as to not perforate the cortical plate, as recommended in previous reports (Wilcko and Wilcko, 1999, 2001) (Figure 1a).

Application of orthodontic force
The third bicuspids on the upper jaw were forced to move forward by a simple tipping force of 150 g by using NiTi coil spring in both the experimental group and control group. On the other hand, the third bicuspids on the lower jaw were moved by 150-g force using NiTi coil spring with 0.017×0.025 S.S. guiding wire and 0.022 in. slot bracket (Figure 1c, d).

Measuring amount of tooth movement
With a digital vernier caliper, the amount of tooth movement was measured every week for 8 weeks and the difference in tooth movement between the experimental and the control group was compared (Figure 1b).

Tissue preparation for histological observation
The upper and lower jaws were isolated after perfusion and fixed with 4% paraformaldehyde solution at 2, 4 and 8 weeks and 6 months after tooth movement. The specimens were decalcified for 3 months in 10% ethylenediaminetetraacetic acid (EDTA) solution. For histological investigation under light and electron microscopes, specimens were post-fixed in 1% osmium tetroxide for 1 h, dehydrated through a graded series of ethanol, and embedded in LX-112. Sagittal semithin sections of teeth with periodontal tissue (1 μm in thickness) were stained with 0.03% methylene blue. Ultrathin sections (70 nm in thickness) were double-stained with uranyl acetate and lead citrate and examined with a Hitachi H-7100 transmission electron microscope (Hitachi High-Technologies Corp, Tokyo, Japan).

Results

Amount of tooth movement
The amount of tooth movement was evaluated by measuring the distance between the distal surface of third bicuspid and the mesial surface of the forth bicuspid (Figures 1b and 2). After 8 weeks, the right third bicuspid in the maxilla moved more mesially than

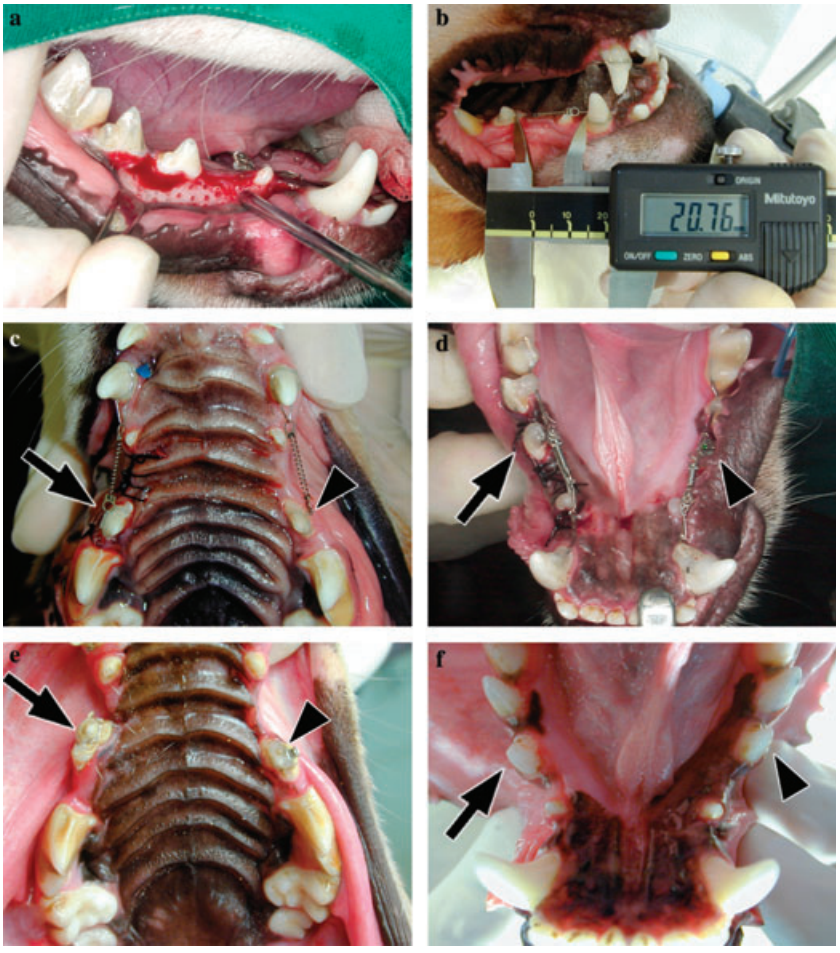

Figure 1 Cortical activation was prepared with a round bur (**a**). The amount of tooth movement is measured by a calibrator (**b**). Application of orthodontic force with NiTi coil spring (**c**, **d**). Macroscopic views of the upper and lower jaws 8 weeks after tooth movement (**e**, **f**). The cortical activation side (right) showed a significant amount of tooth movement when compared with the control side (left). Arrow: cortical activated third bicuspid; arrowhead: control third bicuspid

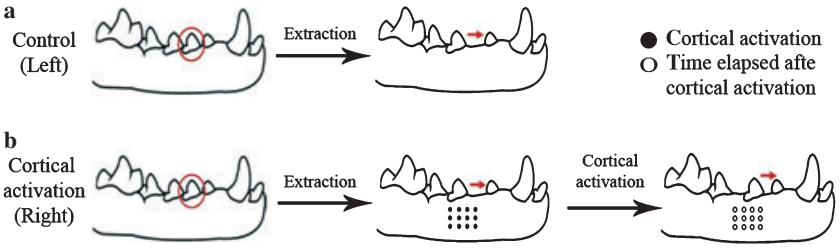

Figure 2 Diagram showing the comparative study of the amount of tooth movement in the control (**a**) and experimental (**b**) groups 4 weeks after second premolar extraction. In the experimental group (**b**), the middle and right figures show the cases that were applied with orthodontic force for 2 and 4 weeks, respectively, after cortical activation. The group that underwent 2 weeks of tooth movement after 8 weeks of experimental procedure was followed by 6 months of observation

a

tooth movement (mm) \ week		0	1	2	3	4	5	6	7	8
Upper	Right (Experimental)	0	0.6	1.2	1.4	2.5	3.6	4.5	5.3	6.4
	Left (Control)	0	0.6	0.85	0.95	0.95	0.95	1.15	1.35	1.45
Lower	Right (Experimental)	0	0.6	1.15	1.95	2.15	2.45	2.7	2.9	3.3
	Left (Control)	0	0.3	0.55	0.55	0.55	0.55	0.65	1.05	1.35

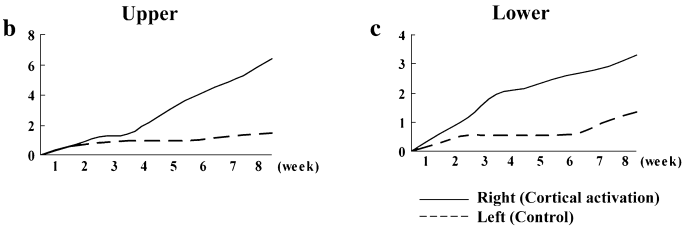

Figure 3 Amount of tooth movement for 8 weeks (**a**). Comparison between the experimental and control groups in the upper (**b**) and lower (**c**) jaw

the left third bicuspid (Figure 1e) and the third bicuspid in the right mandible moved more mesially than the left third bicuspid (Figure 1f).

Effect of cortical activation on the amount of tooth movement

Starting at 2 weeks, the right third bicuspids in both the maxilla and mandible with cortical activation showed a larger shift of movement than in the group without cortical activation (Figure 3a). After 8 weeks, the total amount of tooth movement with cortical activation was approximately four times as much as the amount of tooth movement without cortical activation in the maxilla (Figure 3a, b) and approximately two times as much in the mandible (Figure 3a, c). These results showed that cortical activation can accelerate the speed of tooth movement.

Histological effect of cortical activation during tooth movement

The histological effect of cortical activation was evaluated by analyzing the cell number, cell organelles, extracellular matrix, blood supply, and cell types in the periodontal ligament space of the third bicuspid. In the mesial periodontal ligament space of the third bicuspid without cortical activation, a few osteoclasts and lacunae were observed on the surface of the bone, which was mostly covered by the bone-lining cells (Figure 4a). Cementoblasts were situated on the surface of a clear cementoid beneath the cementum (Figure 4a′). The periodontium included the dense collagen network consisting of longitudinal fibers, vertical fibers, fibroblasts, and blood vessels (Figure 4b). Moreover, clear cytoplasm could be observed in cementoblasts and fibroblasts (Figure 4b′). These histological findings of the periodontal tissue of the third bicuspids without cortical activation were observed every week in the same manner.

In the specimens with a 2-week orthodontic force and cortical activation, the mesial periodontal ligament space of the second bicuspid contained many osteoclasts and their lacunae on the alveolar bone surface (Figure 4c), while cementoblasts were situated on the surface of the clear cementoid beneath the cementum (Figure 4c), where the Sharpey's fibers penetrated (Figure 4c′). Multinuclear osteoclasts developed their ruffled border (Figure 4d, d′). In the distal periodontal ligament space, cementoblasts were situated on the surface of the clear cementoid beneath the cementum (Figure 4e), while osteoblasts were arranged on the surface of the clear osteoid beneath the alveolar bone (Figure 4e′). Fibroblasts developed cell organelles such as rough-surfaced endoplasmic reticulum (rER) (Figure 4f). Osteoblasts showed a cuboidal shape and possessed well-developed rER (Figure 4f′).

In the specimens with a 4-week orthodontic force after cortical activation, the mesial periodontal tissue showed numerous osteoclasts with the developed ruffled border remaining on the surface of the alveolar bone (Figure 4g, g′). The distal periodontal ligament tissue showed an increasing number of cementoblasts and fibroblasts, which possessed relatively developed cell

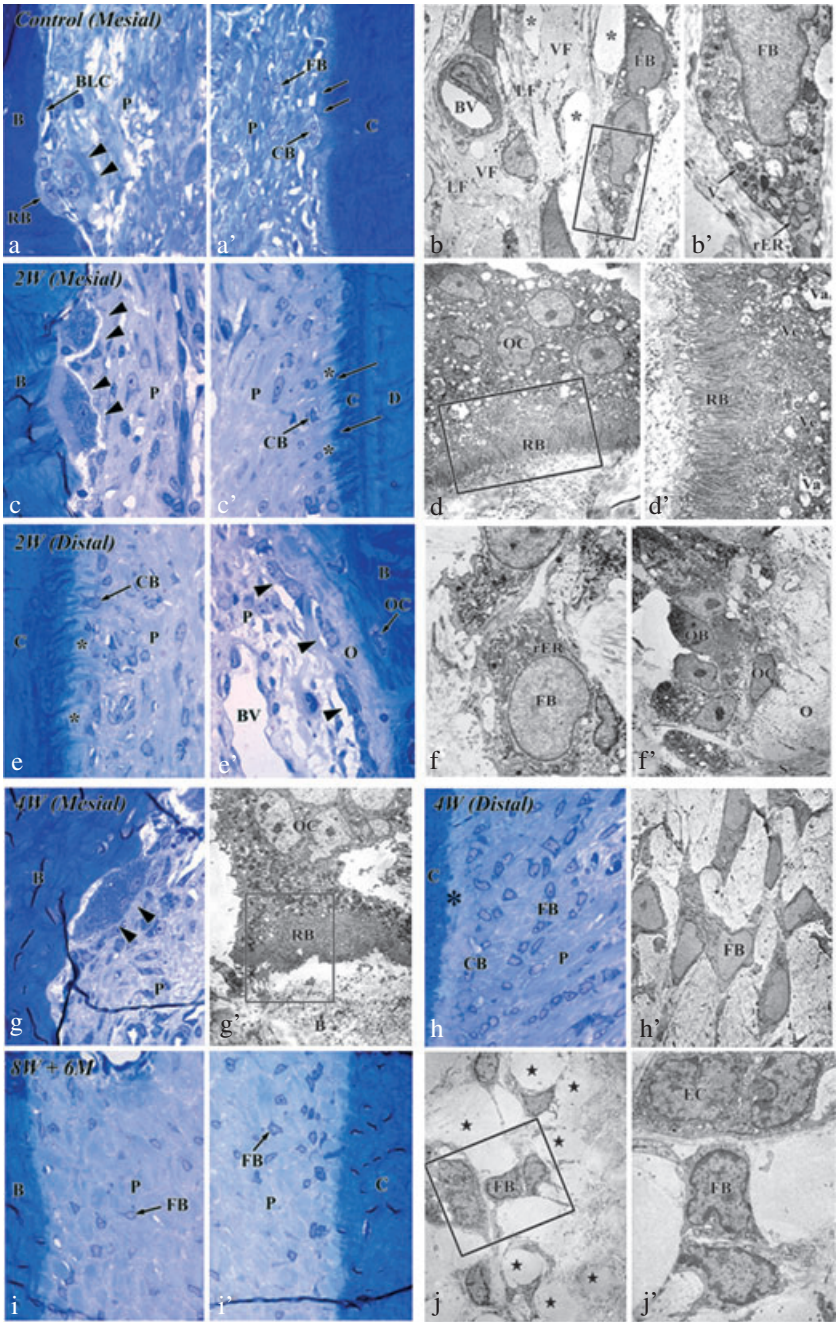

Figure 4 Light and transmission electron micrographs of the mesial and distal periodontal tissue. The mesial periodontal tissue in the control (**a**, **a′**, **b**, **b′**). In the case of tooth movement without cortical activation, an osteoclast (arrowheads) with the ruffled border is observed on the alveolar bone in the mesial periodontal tissue (**a**). This multinuclear osteoclast (arrowheads) is located between flattened bone lining cells (BLC) with dark nuclei (**a**). The cementoblasts are placed on the clear cementoid surface (arrows) (**a′**). The fibroblasts are located in the intermingled matrix of longitudinal (LF) and vertical principal fibers (VF) with artificial gaps (*) (**b**). Higher magnification of the boxed area in **b** (**b′**). The fibroblast possesses moderately developed organelles including rER and vesicles (V). The mesial periodontal tissue in the experimental group 2 weeks after tooth movement (**c**, **c′**, **d**, **d′**). The cementoblast is placed on the clear cementoid surface (*) and Sharpey's fibers reach deep into the cementum (**c′**). Numerous multinuclear osteoclasts (arrowheads) not only form a ruffled border as a control but also include many vesicles and vacuoles in the cytoplasm (**c**, **d**, **d′**). Higher magnification of the boxed area in **d** (**d′**). The distal periodontal tissue in the experimental group 2 weeks after tooth movement (**e**, **e′**, **f**, **f′**). The periodontium contains a dense collagen network of vertical fiber with fibroblasts and vessels (**e**, **e′**). The cementoblasts are located on the clear cementoid surface (*) and osteoblasts are lined the on clear osteoid surface (O) (**e**, **e′**). Fibroblasts contain cell organelles such as rER (**f**). The osteoblasts show cuboidal features and possesses well developed rER (**f′**). The mesial (**g**, **g′**) and distal periodontal (**h**, **h′**) tissue in the experimental group 4 weeks after tooth movement. Multinuclear osteoclast (arrowheads) form a ruffled border and the cytoplasm includes mitochondria, vesicle and vacuole (**g′**). Numerous fibroblasts are seen in the periodontium. Fibroblasts contain relatively developed cell organelles relatively distal after 4 weeks during tooth movement by cortical activation (**h**, **h′**). After 6 months, fibroblasts are decreased in number between the dense collagen fibers in the periodontium (**i**, **i′**). Fibroblasts include non-developed organelles in their cytoplasm (**j**, **j′**). FB, fibroblasts; P, periodontium; OC, osteoclast; RB, ruffled border; BLC, bone-lining cells; B, alveolar bone; CB, cementoblasts; C, cementum; LF, longitudinal fibers; VF, vertical fibers; BV, blood vessel; rER, rough-surfaced endoplasmic reticulum; O, osteoid; OS, osteocyte; S, Sharpey's fiber; EC, endothelial cells; FB, fibroblasts; *cementoid; , collagen fibers

organelles (Figure 4h, h′). The group with applied orthodontic force for 2 and 4 weeks after cortical activation showed higher cellular activities when compared with the group without cortical activation.

Long-term effect of cortical activation on periodontal tissues

Six months following the 8-week tooth movement with cortical activation, the specimens showed only a few osteoclasts and fibroblasts that were considerably decreased in number throughout the mesial periodontal tissue even with the 2-week orthodontic force (Figure 4i, i′). The periodontal tissues included numerous thick collagen fibers (Figure 4j, j′).

Discussion

Corticotomy-facilitated orthodontics was reported to accelerate the tooth movement (Köle, 1959; Bell and Levy, 1972; Gantes *et al*, 1990; Suya, 1991; Anholm *et al*, 1998). The acceleration of the tooth movement in the case of the corticotomy-facilitated orthodontics was reported to be attributed to RAP through wound healing (Frost, 1989; Yaffe *et al*, 1994). RAP has been known to be induced not only by corticotomy-facilitated orthodontic force but also by cortical activation (Wilcko and Wilcko, 1999, 2001). Cortical activation before orthodontic treatment induced RAP to increase bone remodeling activity and speed of tooth movement without any side effects (Wilcko and Wilcko, 2001). Thus, cortical activation before orthodontic treatment increased not only the speed of tooth movement but also remodeling of alveolar bone (Chang, 1984).

Cortical activation accelerates tooth movement

In this study, the total amount of tooth movement with cortical activation was approximately four times as great as the amount of tooth movement without cortical activation in the maxilla and approximately two times as great in the mandible. These results showed that cortical activation can accelerate the speed of tooth movement. These findings are similar to those in the previous report, where the tooth with cortical activation moved two or three times faster than that without cortical activation (Wilcko and Wilcko, 2001).

Cortical activation increases cellular activity in periodontal tissues

Compared with the bicuspids without cortical activation, the third bicuspids with cortical activation showed higher cellular activity, induced by the orthodontic force for 2 or 4 weeks. In the periodontal tissues with cortical activation, an increasing number of osteoclasts with developed organelles and ruffled border were situated on the mesial alveolar bone surface. Furthermore, fibroblasts, cementoblasts, and osteoblasts also showed higher cellular activity in the periodontal ligament and on both the tooth and bone surface, respectively. These results showed that cortical activation increased the activity of numerous cellular components including formative (fibroblasts, cementoblasts, and osteoblasts) and resorptive (osteoclasts) cells in periodontal tissues.

Cortical activation decreases cellular activity after 6 months

Six months after cortical activation, the osteoclasts, fibroblasts, cementoblasts, and osteoblasts were decreased in number and cellular activity. Especially, fibroblasts were considerably decreased in number and showed less developed organelles, while thick principal collagen fibers occupied most of the periodontal tissue. This result showed that the periodontal tissues, where the orthodontic force following cortical activation was applied, became static, expressing low cellular activities in response to the orthodontic force. This result was coincident with other evidence that the bone matrix became denser and older at an extended time after cortical activation or orthognathic surgeries such as anterior segmental osteotomy. Moreover, this result may be related to the compressed periodontal ligament cells that were eliminated by apoptosis in the early phase of tooth movement (Hatai *et al*, 2001).

In summary, initial tooth movement was apparently rapid when orthodontic force was applied after cortical activation and the cellular activity of periodontal cells such as fibroblasts, cementoblasts, osteoblasts, and osteoclasts was increased over a short time range. On the other hand, cellular activities of these cells were severely decreased after 6 months.

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