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Dynamics of alloplastic bone grafts on an early stage of corticotomy-facilitated orthodontic tooth movement in beagle dogs

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최 형 주

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- ABSTRACT -

Dynamics of alloplastic bone grafts on an early stage of corticotomy-facilitated orthodontic tooth movement in beagle dogs

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Introduction

Corticotomy is known to be the most effective means to accelerate orthodontic tooth movement, but the effect only lasts a relatively short time. The immediate periodontal response has not been fully elucidated. The purpose of this study was to investigate the immediate periodontal response to a corticotomy with alloplastic bone grafts in beagle dogs.

Method

Five adult male beagle dogs were used the experiment. Orthodontic appliances were custom-made for each study model. The circumscribing corticotomy and alloplastic bone graft was performed. A closed coil spring made of nickel-titanium shape memory wire of 200 g force was applied to the second and third premolars in a bucco-lingual direction. The

animals were euthanized after 1 day, 3 days, 1 week, 2 weeks, and 4 weeks following the surgery. The sections containing the canine to the fourth premolar were retrieved. Histological examinations were conducted using a light microscope

Result

The results demonstrated that measurable tooth movement began as early as 3 days after the intervention in beagle dogs. It was difficult to determine the hyalinization layer in the 1- and 3-day slides. Interestingly, new bone surrounding the graft materials was observed on the compression side on the 2-week slides. The present study supported the hypothesis that tooth movement with an augmented corticotomy might enhance orthodontic tooth movement, because we found new bone formation at the buccal surface.

Conclusion

The findings from this study suggest that measurable tooth movement starts as early as in 3 days after augmented corticotomy-facilitated orthodontic treatment, and that this procedure might enhance the condition of periodontal tissue and the stability of orthodontic treatment outcomes.

Key Words: Accelerated orthodontic tooth movement, corticotomy-facilitated orthodontic tooth movement, alloplastic bone graft for orthodontic tooth movement

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비글 성견에서 교정력과 피질골절단술을 함께 적용할 때 나타나는 치주조직의 초기 조직학적 반응관찰

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-CONTENTS-

Ⅰ. INTRODUCTION

Ⅱ. REVIEW OF LITERATURE

Ⅲ. MATERIALS AND METHODS

Ⅳ. RESULTS

Ⅴ. DISCUSSION

Ⅵ. CONCLUSIONS

REFERENCES

Ⅰ. INTRODUCTION

New appliances, materials and mechanics of orthodontic treatment are being developed every day, but much of the biology of orthodontic tooth movement still needs to be clarified. With increasing number of adult patients who are seeking orthodontic treatment, biological and clinical differences between tooth movement of adults and adolescence should be understood. For adult patients, there is increasing chance that hyalinization can occur during orthodontic treatment. And cell mobilization and conversion of collagen fibers in much slower in adults than in adolescence. Also, adults are more prone to periodontal complications because teeth are confined in non-flexible alveolar bone.[1] Social demands have led adult patients to require shorter orthodontic treatment period, yet their expectations for results remain high.

Many adjunctive modalities are available to accelerate orthodontic tooth movement in humans, such as corticotomy,[2-11] distraction osteogenesis,[12] mechanical vibration,[13] medication with local prostaglandins,[14] and low-level laser treatment.[15,16] Among these interventions, corticotomy is known to be the most effective means to accelerate orthodontic tooth movement.[6,17] In experiments that used a split-mouth design, with corticotomy performed on one side and the other side serving as the control, the velocity of the tooth movement was accelerated on the corticotomy side.[2,18-20] and the amount of movement doubled over the duration of the experiments.[18-21]

The initial microscopic changes and early application of orthodontic force have been emphasized in corticotomy-facilitated orthodontic tooth movement,[17] and it has been hypothesized that a corticotomy or an osteotomy can lead to intensified osteoclastic activity resulting in local osteopenia and increased bone remodeling.[3,18,22,23] To date, however, the immediate periodontal response has not been fully elucidated. Most researchers have either studied the small animals such as rats, cats or rabbits,[3,5,9,21-23] for relatively long periods of

6 - 12 weeks,[10,11] or carried out gross observational studies with no histologic measurements.[2,3,8,20,24]

The purpose of this study was to investigate the immediate periodontal response to a corticotomy-facilitated tooth movement with alloplastic bone grafts in beagle dogs.

Ⅱ. REVIEW OF LITERATURE

1. Historical review

From the 1800s, a surgery-assisted orthodontic tooth movement has been performed. Corticotomy-facilitated tooth movement was first described by L.C. Byran in 1893. Bichlmayr[25] introduced a surgical technique for rapid correction of maxillary protrusion with orthodontic appliances. Wedges of bone were removed to decrease the volume of bone through which the roots of maxillary anterior teeth could need to be retracted. But Köle[26] expanded on this technique by addressing additional movements, including space closure and crossbite correction. It was the treatment modality for rapid tooth movement. This technique included a radicular corticotomy and supra-apical osteotomy. Corticotomy on alveolar bone rendered orthodontic tooth movement more rapid than that of conventional orthodontic tooth movement. The thick cortical bone was believed to be the resistance to orthodontic tooth movement, thus by eliminating cortical bone resistance, the orthodontic tooth movement could be done in shorter time. Major movements were corrected in 6 to 12 weeks without significant root resorption. However, Köle's technique was too invasive to be performed as an ordinary practice. Some of Köle's surgical preparations showed the appearance of outlined bone blocks, so there were misunderstanding that mineralized bone was moving with the roots of the teeth.[27-29]

Wilcko et al.[30] proposed an accelerated osteogenic orthodontic model based on limited selective labial and lingual alveolar decortication. Corticotomy is believed to produce a regional acceleratory phenomenon (RAP) that intensifies or exaggerates bone remodeling and allows rapid tooth movement in the demineralized bone.[31-33]

2. Biology of corticotomy-facilitated tooth movement

Corticotomy-facilitated tooth movement is theoretically based on the bone healing pattern known as the RAP. Frost[31,32] described this process in 1983, and found that the surgical wounding of osseous tissues results in accelerated regional healing process. It can accelerate both hard and soft tissue healing 2 to 10 folds and this leads to decreased regional

bone density and accelerated bone turnover.[31,32,34] The treatment periods were reduced by 1/4~1/3 compared to conventional orthodontic treatments.[35]

According to Wilcko et al.[30] however, they replicated Suya's corticotomy-facilitated orthodontics procedure[27] to resolve dental arch crowding, and achieved similar results: markedly decreased treatment periods, no loss of tooth vitality, no apical root resorption and no periodontal pocket formation. And they compared the pretreatment and post-treatment with computed tomographic scans (CT), and concluded that it was not "bony block movement" but "demineralization and remineralization" of the alveolar bone that was named "regional acceleratory phenomenon (RAP)".[31,32,34] In addition, bone turnover is accelerated by bone fracture, osteotomy, or bone grafting procedures. Corticotomy represented same phenomenon. And they suggested the "Accelerated Osteogenic Orthodontics (AOO)" procedure, which is the combination of corticotomy-facilitated orthodontic treatment and periodontal alveolar bone augmentation.[36] They insisted that the alveolar bone augmentation could provide the patients with a more structurally intact periodontium at the completion of the orthodontic treatment. Recently, they suggested periodontal accelerated osteogenic orthodontics (PAOO) which is a clinical procedure that was composed of alveolar corticotomy, particulate bone grafting, and the application of orthodontic forces.[8] However, it is very hard to find the histological observation related to the periodontal reactions of the corticotomy-augmentation procedure. Lee et al.[5] found the evidence of regional accelerated phenomenon in the alveolar bone of the corticotomy-treated animals and distraction osteogenesis in the osteotomy-assisted tooth movement using micro-CT. This confirms the hypothesis of the difference in the healing processes involved in both procedures.

Original corticotomy-facilitated orthodontic treatment involved buccal and lingual osteotomy cuts with orthopedic forces, and the use of alveolar augmentation with demineralized bone graft was advocated to cover any fenestration and dehiscence and to increase in the bony support for both the teeth and the overlying soft tissues.[30,36] Two case reports showed the results of selective corticotomy limited to the buccal and labial surfaces to reduce the operation time and postoperative patient discomfort and avoid the risk of

violating vital lingual anatomy.[37,38] Most of the related published literature showed no adverse effects of the corticotomy on the periodontium.[38-41]

3. Bone graft

The corticotomy-augmentation combination with bone graft is a complex procedure that consider a lot of factors such as applying orthodontic force, tooth movement, bone remodeling, and biological characteristics of bone graft material. However up to date, there is few research on the bone graft material and the relationship between bone graft material and root surface, new bone, periodontal ligament and soft tissue.

Wilcko et al.[42] reported satisfactory results with a combination of demineralized freeze-dried bone allograft (DFDBA), xenograft (Osteograft® /N-300, DENTSPLY Friadent CeraMed, Lakewood, CO) or a bioabsorbable alloplastic graft (PerioGlas® , NovaBoneProducts, LLC, Jacksonville, FL) for alveolar augmentation. However, particles of the xenograft were found not incorporated on the superficial surface of augmented sites at reentry. Nowzari et al.[38] reported case to present clinical study using the corticotomy-facilitated orthodontic procedure combined with alveolar augmentation with autogenous particulate bone graft harvested from the rami and mandibular exostosis, a modified PAOO approach.

An ideal bone graft substitute should be osteoconductive, osteoinductive and osteogenic. Autogenous bone graft is the gold standard among the graft materials because it provides all of these properties.[43] Autogenous bone contains viable cells that can proliferate and contribute to the formation of new bone.[44] However, autogenous bone grafts have several limitations such as the perioperative pain and morbidity associated with harvesting the graft, uncertain quality and quantity of the graft material, and limited graft shapes and sizes. Due to limited quantity and associated morbidity with harvesting autograft bone, as well as inferior biological and/or biomechanical characteristics of synthetic calcium substrates, allograft materials have largely been preferred in reconstructive procedures. However, one

drawback to using allografts was the potential risk of disease transmission. With the aim of reducing the incidence of infection, B. Loty et al. decided to sterilize massive grafts by irradiation.[45] Clinically, mineralized bone is more adaptable than demineralized bone, so mineralized bone allografts such as irradiated cancellous allograft (ICA) obtained from human cadaver sources are used frequently.[46] Some studies have found that ICA reacts similarly to autologous bone graft and is replaced by new bone consistently and predictably at low cost with few complications.[47]

Autogenous and allogenic bone grafts have several limitations, such as donor-site infection, pain, and disease transfer. Because of these limitations, biosynthetic bone graft substitutes are being investigated. The beginnings of the application of calcium phosphate material as bone substitute or bone graft maybe traced to Albee, who reported in 1920 that a 'triple-calcium phosphate' compound used in a bony defect promoted osteogenesis or new bone formation.[48] Hydroxyapatite/tri-calcium phosphate (HA/TCP) mixture is an osteoconductive material being used as a bone graft substitute. Some studies have suggested an optimum ratio of HA/ß-TCP.[49] Nery et al.[50] have shown that a higher HA ratio causes accelerated new bone formation in osseous defects. A mixture of 60% HA and 40% ß-TCP is known to be ideal for biphasic calcium phosphate ceramics as bone substitutes.[51] MBCP (Biomatlante, Vigneux de Bretagne, France) is composed of 60% HA and 40% ß-TCP. HA provides long-term stability and TCP releases ions that form acellular apatite crystals.

4. Clinical applications

Corticotomy facilitated orthodontic tooth movement can be used to accelerate tooth movement in most of the orthodontic treatment cases. It has been shown to be particularly effective in treating moderate to severe crowding, in Class II malocclusions requiring expansion or extractions, and mild Class III malocclusions.[30]

There have been some reports regarding adverse effects to the periodontium after corticotomy. These are including interdental bone loss, periodontal defects, and loss of attached gingiva.[8,52] Subcutaneous hematomas of the face and the neck have been reported.[53,54] No adverse effect on the vitality of the pulps of the teeth in the area of corticotomy was reported.[54] It is generally accepted that some root resorption is expected with any orthodontic tooth movement. However, Ren et al. reported rapid tooth movement after corticotomy in beagles without any associated root resorption or irreversible pulp injury.[55] Moon et al.[56] reported 3.0mm maxillary molar intrusion in two months using corticotomy combined with a mini-implant without root resorption.

Kim et al.[57] presented case reports using corticotomy facilitated tooth movement and osseointegrated mini-implants for minor tooth movement in severely compromised condition. The result showed this technique could be used for a rapid and stable tooth movement without root resorption.

Ahn et al.[58] showed that the augmented corticotomy provided effective decompensation of the mandibular incisors in skeletal Class III patients while maintaining labial bone thickness and with no periodontal side effects.

5. The Duration of the regional acceleration phenomenon after corticotomy

The surgical technique for corticotomy facilitated orthodontic tooth movement consists of 5 steps, or raising of the flap, decortification, particulate grafting, closure and orthodontic force application. The application of orthodontic force are should not be postponed more than 2 weeks after surgery. A longer delay will fail to take full advantage of the limited time period that the RAP is occurring. This period is usually 4 to 6 months, after which finishing movements occur with a normal speed.[7]

It is obvious that the duration of RAP is of utmost importance to evaluate the effectiveness and efficiency of this procedure.[17] There are two studies, one in humans[2] and the other in dogs[20] concerning about the duration of the regional acceleration phenomenon after corticotomy. According to the results of 2 studies, it seems that the duration of the RAP is about 4 months. After 4 months, the velocity of tooth movement would return to normal.

That is why this study was focusing the immediate periodontal response to a corticotomy-facilitated tooth movement with alloplastic bone grafts in beagle dogs.

Ⅲ. MATERIALS AND METHODS

1. Animal subjects

Five adult male beagle dogs, weighing 10 – 13 kg, were used the experiment, and their selection, care, and preparation, together with the surgical protocol, were carried out according to the guidelines for animal experiments (IRB No. KHMC-IACUC2012-024). They were caged separately under regulated conditions, and fed a normal diet, and water *ad libitum* to secure the experimental orthodontic appliances.

For the preparation processes and surgical procedures, the animals were anesthetized with a mixture of tiletamine-zolazepam and xylazine, via intramuscular-and intravenous injections using a catheter in the vessel of the ear.

2. Study preparation

Alginate impressions of each beagle were taken to make study models, and orthodontic appliances were custom made for each model. The canine and fourth premolar teeth were banded to form anchor teeth, and a Ø 0.9-mm stainless steel wire was welded onto the buccal surface of the bands. The second and third premolars were banded with a lingual button. After 2 weeks, the animals were anesthetized to fit the orthodontic appliances to the teeth (Figure 1).

3. Surgical procedures for the corticotomy and alloplastic bone graft

Under general anesthesia, 2% lidocaine with1:100,000 epinephrine was also infiltrated to the surgical sites. An intra-sulcus incision was performed with a No. #12 blade from the canine tooth to the first molar, and a full-thickness flap was lifted. The circumscribing

corticotomy (Figure 2(A)) was performed with a round bur (Ø 1.5mm) under sterile saline irrigation.

Alloplastic bone material (MBCP+, Biomatlante, Vigneux de Bretagne, France), composed of 20% hydroxyl apatite and 80% ß-tri-calcium phosphate, was used for the graft. MBCP+ was used because it was reported that MBCP+ has 20% higher bone formation rate compared to MBCP. MBCP+ is composed of 20% HA and 80% ß-TCP. The graft bone was soaked with blood, and 1 g of the MBCP+ was grafted onto the surgical surface (Figure 2(B)). The mucoperiosteal flaps were repositioned and sutured with 5-0 nylon and primary closure was obtained (Figure 2(C)). A closed coil spring made of nickel-titanium shape memory wire of 200 g force was applied to the second and third premolars in a bucco-lingual direction (Figure 2(D)).

All of the surgical procedures were performed under sterile conditions to prevent infection. After surgery, antibiotics and anti-inflammatory analgesics were administered by intramuscular injection twice a day for 6 days. A 1% chlorohexidine-gluconate solution dressing was applied simultaneously for infection control. A soft diet was supplied for 1 or 2 weeks, then a normal diet. Mechanical plaque control was performed once a week. The animals were euthanized with an over dose of thiopental sodium after 1 day, 3 days, 1 week, 2 weeks, and 4 weeks following the surgery (Figure 3).

4. Histological processing and analysis

Following a predetermined time schedule, after the animals were killed, their maxillae and mandibles were dissected, and the sections containing the canine to the fourth premolar were retrieved. The block specimens were rinsed in sterile saline and immediately immersed in 10% neutral-buffered formalin fixatives for 14 days. The block specimens were large, and rapid decalcification was performed for 6 days using 5% nitric acid because it is sufficiently strong.[59] Had this study been designed for immunohistology, the use of ethylene-diamine-tetra-acetic acid or 10% aqueous or formic acid would have been suitable

[60], but this was not the case.[10,61] The specimens were then dehydrated through a series of ethanol solutions of increasing concentrations, and embedded in paraffin. Bucco-lingual sections were sliced with a microtome set at 5 ㎛, and stained with the Masson's trichrome solution. One slide was processed per experimental tooth.

Histological examinations were conducted using a light microscope (Olympus BX 51, Olympus, Tokyo, Japan) equipped with a DP Controller 3.2.276.2 and DP manager 3.1.1.208(Olympus, Tokyo, Japan). After microscopic examination, a photograph of each slide was taken with a digital camera (Olympus DP 71, Olympus, Tokyo, Japan). With imaging software (cellSens version 1.6, Olympus), the buccal tipping angle (°) and distance (㎛) was measured (Figure 4). The buccal tipping angle was measured from the reversal line of the lingual/palatal bone wall to the lingual/palatal root surface. The buccal tipping distance was measured from the lingual/palatal alveolar crest to the shortest lingual/palatal root surface. A total of 40 slides were fabricated and examined. After taking photographs, the amount of tooth movement was measured three times in each slide for angular changes and linear displacement.

5. Statistical Data Analysis

Statistical data analysis was performed using the R programming language.[62] The data on tooth movement did not fulfill the parametric conditions of normality and equality of variance after the D'Agostino normality test was performed. The Kruskal-Wallis rank sum test, therefore, conducted to determine whether there existed a significant between-group difference in general, and the Wilcoxon test to find a significant pair between two groups. The Bonferroni correction and the Type I error was applied to counteract the problem of multiple comparisons. The data were analyzed with a confidence level of 95%.

Ⅳ. RESULTS

1. Clinical findings

Table 1 and Figure 5 show the amount of tooth movement for each beagle dog. Due to the minimal tooth movement, the buccal tipping angle at 1 day could not be measured. No significant difference was observed between the teeth in the maxilla and those in the mandible, or in the right or left part of the dentition. When the tipping movement was measured from the angular changes, no statistically significant difference was found among the experimental groups (Figure 5(A)). However, the linear measurements demonstrated statistically significant differences between 1 day and 3 days and between 2 weeks and 4 weeks after the start of the experiment (Figure 5(B)).

2. Histological observations

After 1 day of orthodontic movement, a microphotograph of the bucco-palatal/lingual section (Figure 6) showed compression of the periodontal ligament (PDL) (Figure 6(B)), extravasations of red blood cells (RBC) (Figure 6(C)) and reduced capillaries (Figure 6(E)) on the pressure side. No significant finding was observed on the tension side.

At 3 days, the PDL was more severely compressed and fewer cells were found in the PDL space (Figure 7(C)) on the buccal pressure side. The tension side at the lingual alveolar bone crest contained more cells than the pressure side, and active osteoblasts forming new bone (Figure 7(H)).

At 1 week after the start of the experiment, most of grafted MBCP+ particles were well maintained (Figure 8). On the pressure side, the PDL space was slightly widened compared with that at 3 days (Figure 8(B)), and the tension side contained abundant PDL fibroblasts and active osteoblasts (Figure 8(D),(E),(F)).

At 2 weeks, undermining resorption and a resorption bay were observed on the buccal pressure side (Figure 9(B),(C),(Q),(L)). In contrast, on the buccal tension side, new bone formation surrounding and bridging the MBCP+ particles was seen (Figure 9(D),(J),(F)) due to abundant osteoblasts (Figure 9(E),(K)).

At 4 weeks after the start of the experiment, new bone formation along the PDL formed a new buccal bone wall on the pressure side (Figure 10(A)). Also, a new bone island was formed in the center of the bone-derived mesenchymal matrix (Figure 10(D)), and osteoblasts and osteocytes were observed (Figure 10(E)). On the buccal side , grafted MBCP+ particles were bridged with newly formed bone in the bone-derived mesenchymal matrix. Entrapped osteocytes and aggregated osteoblasts were observed (Figure 10(G)). The palatal crestal (Figure 10(J)) and apical (Figure 10(L)) tension sides showed aggregated osteoblasts and active forms of osteoblasts, and a new bone-forming buccal bone wall and crest were observed (Figure 10(O); native bone (red star) and new bone (yellow star)). New bone was formed on the outer and inner surfaces of the native bone (Figure 10(N),(Q)), and the outer portion of the bone-derived mesenchymal matrix could be seen (Figure 10(T)).

Ⅴ. DISCUSSION

The biological mechanism by which the tooth movement is facilitated after a corticotomy has been suggested to be mediated by a regional acceleratory phenomenon,[31,32] which might boost the appearance of the macrophages that eliminate the hyaline as early as 1 week after the application of orthodontic force.[18,22] For this reason, the experiment was designed to determine immediate periodontal responses, which represents the first study to observe the immediate effect of corticotomy-facilitated orthodontic tooth movement. Two studies previously reported observations made 3 days after a corticotomy in rats.[3,23] However, the results obtained in small animals may differ from those in larger animals.[17] It is believed that the current study is unique because this study observed the histological responses of periodontal tissue as early as 1 day, 3 days, 1 week, 2 weeks and 4 weeks after a corticotomy and force application for orthodontic tooth movement in larger animals.

In most experiments in dogs or rats, corticotomy-facilitated tooth movement was observed at a rate of about 1 mm per month, which was almost double that observed on the control side.[18-21] In this study, the significant tooth movement was observed within 3 days (Figure 5). Measured was the width of the PDL at the crest of the lingual/palatal sides, which does not represent the direct distance of clinical tooth movement. The significant tooth movement observed 4 weeks after the start of the experiment was to be expected, but this obviously occurred earlier in the experiment. The tooth movement measurements demonstrated a similar pattern in angular changes and linear displacement, as shown in Figure 5. It was conjectured that this might imply that the pattern of rapid tooth movement was not a bodily translation in general but mostly occurred through tipping of the tooth. Therefore, during clinical orthodontic treatment, methods to control for unwanted tipping should also be considered.

Despite the similar pattern between the angular and linear changes, the linear measurements exhibited a statistically significant difference while the angular changes did

not. Linear measurements are assessed between two points while degrees of angles are measured between three points, from which a variation in angular measurements can be produced. This may be the cause of the larger variation in angular measurements than in linear measurements.

A typical cell-free zone on the pressure side and an inflammatory reaction was seen on the 1- and 3-day slides (Figures 5 and 6). A force of 200 g may be strong for tipping movement, but it was difficult to determine the hyalinization layer in the 1- and 3-day slides. The corticotomy was probably responsible for this, but the underlying mechanism was not clear. The progenitor cells regarded as osteoblasts in the 3-day slides showed strong cellular activity.

On the 1-week slide, it was observed that the PDL space was widened at the pressure side compared with that of the 3-day slide (Figure 8(B)). This could be explained by undermining resorptions. On the tension side, active osteoblasts forming new bone were observed. This new bone formation is a common phenomenon in orthodontic tooth movement.

Interestingly, new bone surrounding the graft materials was observed on the compression side on the 2-week slides (Figure 9(D)) and at the buccal sides distant from PDL (Figure 9(S),(T),(U)). Graft particles were bridged by newly formed bone and osteoclastic and osteoblastic activities were both seen (Figure 9(U)).

From the findings of the 4-week sections, the new bone formation in the center of the MBCP+ graft material on the buccal side was very distinctive (Figure 10(H),(I)), and many entrapped osteocytes and aggregated osteoblasts were observed (Figure 10(G)). However,

the cause of this new bone formation on the buccal sides around the graft materials was not certain. Further studies could provide the answer.

The slides taken at 2 and 4 weeks did not show a distinctive loss of periodontal attachment, and the small areas of root resorption that were seen were not significant.

Orthodontic patients have complained about the length of their treatment, and it has become necessary to develop adjunctive methods to tackle this problem. [2,4,6-9,12-16] Alveolar corticotomy is effective in accelerating orthodontic tooth movement. [3,6,17] However, according to pertinent studies [2,17,20], the regional acceleratory phenomenon only persists for about 4 months, after which the tooth movement rate returns to normal. To make use of this "window" period in an effective, efficient, and efficacious way, it is imperative to understand the underlying biology of early periodontal responses to tooth movement after augmented corticotomy, and to develop appropriate clinical procedures. Also, from the clinical point of view, it is important to determine how to reduce the length of total treatment time. When should the corticotomy be performed? How often should orthodontic force be applied? What magnitude of force would be optimal? These are still widely open questions that are worthy of further investigation.

Although there is no doubt that this procedure could align teeth within a shorter period of time, [2,4,7,17,30,38,42,63,64] at the present time, this cannot suggest augmented corticotomy-facilitated orthodontic tooth movement to reduce the entire length of orthodontic treatment noticeably in adult patients. In addition, there is a paucity of information in the available research to assert that grafting enhances the stability of orthodontic treatment.[17] To prove this, well designed randomized controlled clinical trials should be performed.

The combination of corticotomy with an alveolar graft was introduced by Wilcko et al., and is referred to as accelerated osteogenic orthodontics, or periodontally accelerated osteogenic orthodontics.[7,8,42,65] They asserted that bone grafting of the labial and lingual cortical bones would increase the stability of orthodontic treatment, enhance the range of possible tooth movements, increase alveolar bone volume and provide a more structurally stable periodontium. However, no convincing scientific or histological evidence was available other than clinical reports. In some case reports, increased volume of bone around the alveolus was observed after bone grafting.[4,8,10,11] The present study supported the hypothesis that tooth movement with an augmented corticotomy might enhance the stability of orthodontic tooth movement, because it was found new bone formation at the buccal surface. However, it focused on initial responses, and further investigation is needed to clarify its findings.

Tooth movement that was thought to be difficult or impossible to produce in the past has become possible due to the development of orthodontic mechanics and new appliances and materials. Therefore, orthodontic treatment is mainly limited by the scope of the alveolar bone, and orthognathic surgery is required when this limit is exceeded. If an augmented corticotomy could increase the alveolar bone volume, this would help patients who have a limited amount of supporting alveolar bone.

Augmented corticotomy surgery is not free from some morbidity. It also requires a skilled clinician, and there may be some discomfort to patients and additional costs.

VI. CONCLUSIONS

The findings from this study suggest that measurable tooth movement starts as early as in 3 days after augmented corticotomy-facilitated orthodontic treatment, and that this procedure might enhance the condition of periodontal tissue and the stability of orthodontic treatment outcomes.

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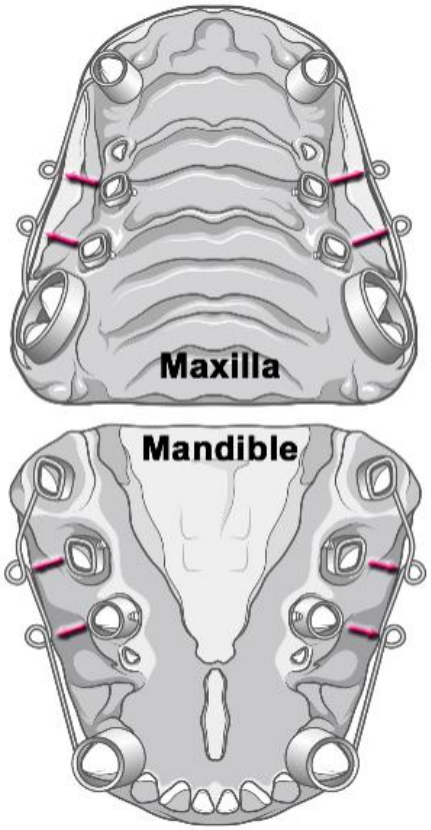
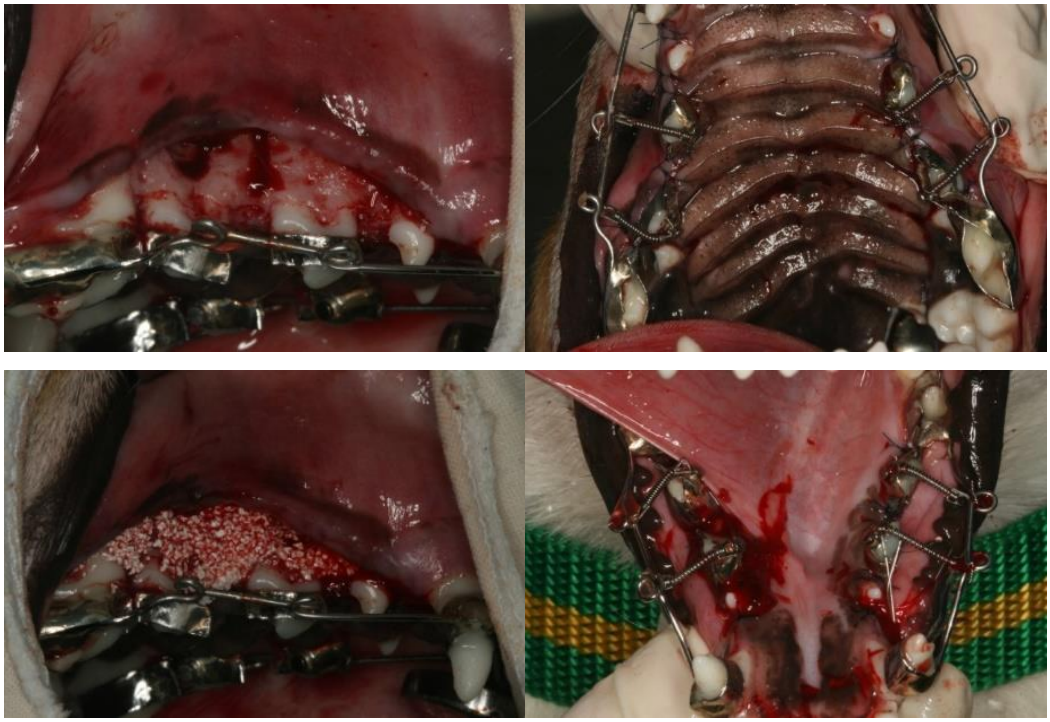


Figure 1: Orthodontic appliances were custom-made for each study model. The canine and fourth premolar teeth were banded to form an anchor tooth, and a Ø 0.9-mm stainless steel wire was welded on the buccal surface of the bands. The second and third premolars were banded with a lingual button. After 4 weeks, the animals were anesthetized to fit the orthodontic appliances to the teeth. The arrows indicate the direction of force.

A **C**



B **D**

Figure 2: Surgical procedure. (A) Corticotomy. The circumscribing corticotomy was performed with a round bur (Ø 1.5 mm) under sterile saline irrigation. (B) MBCP^{+} (Biomatlante, Vigneux de Bretagne, France), composed of 20% hydroxyl apatite and 80% β-tri-calcium phosphate, was used as the alloplastic bone graft material. The graft bone was applied soaked in blood; 1 g of the MBCP^{+} was grafted on the surgical surface. (C) A closed coil spring made of nickel-titanium shaped memory wire of 200 g force was applied to the second and third premolars in a bucco-lingual direction in the maxilla and (D) in the mandible.

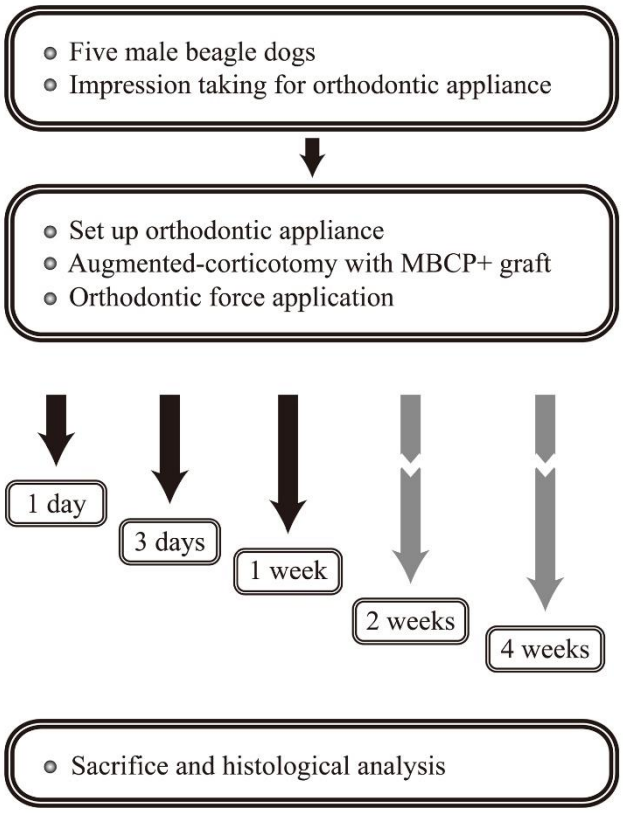


Figure 3: Schematic diagram describing the experiment design.

	Angle(°)	Distance (μm)
1 day		254.76 ± 56.09
3 days	8.17 ± 1.52	452.91 ± 57.90
1 week	6.85 ± 1.84	405.14 ± 144.52
2 weeks	6.72 ± 2.42	277.30 ± 92.31
4 weeks	12.28 ± 3.44	557.75± 236.44

Table 1: With imaging software (cellSens version 1.6, Olympus), the buccal tipping angle (°) and distance (μm) was measured. Due to the minimal tooth movement, the buccal tipping angle at 1 day could not be measured.

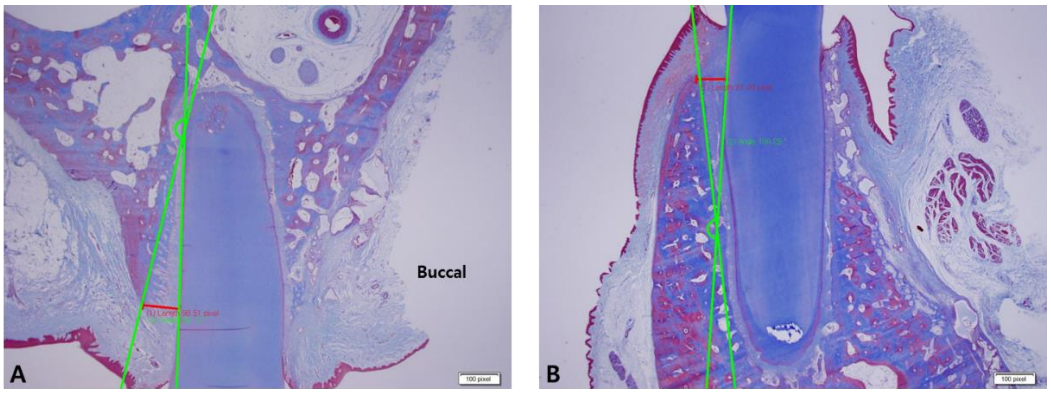


Figure 4: The buccal tipping angle (°) and distance (㎛). The buccal tipping angle was measured from the reversal line of the lingual/palatal bone wall to the lingual/palatal root surface (green line). The buccal tipping distance was measured from the lingual/palatal alveolar crest to the shortest lingual/palatal root surface (red line). (A) Maxilla. (B) Mandible.

A B

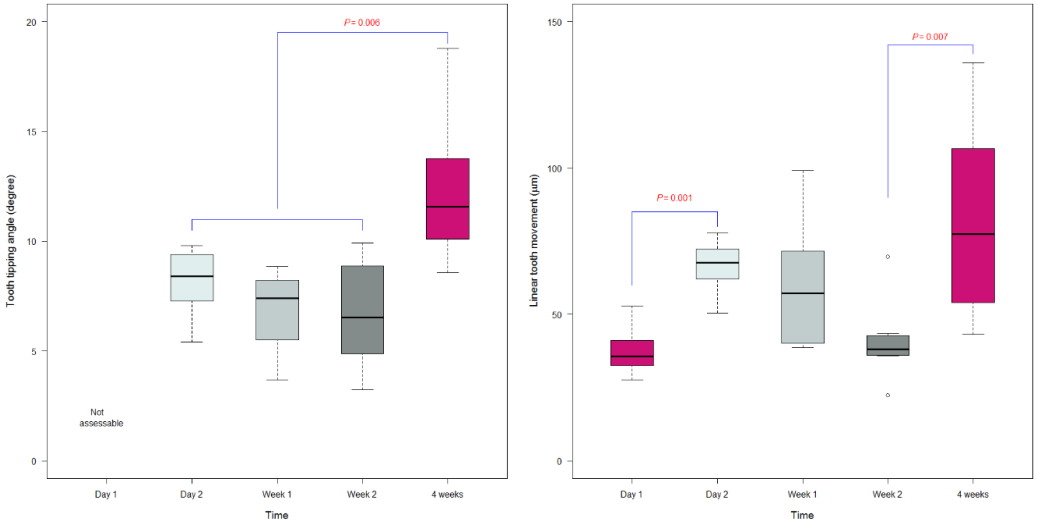


Figure 5: Box plots for the tooth movement measurements. (A) No statistically significant difference in the angular tooth movement was observed over time. (B) However, the linear measurements demonstrated statistically significant differences between 1 day and 3 days, and between 2 weeks and 4 weeks after the start of the experiment.

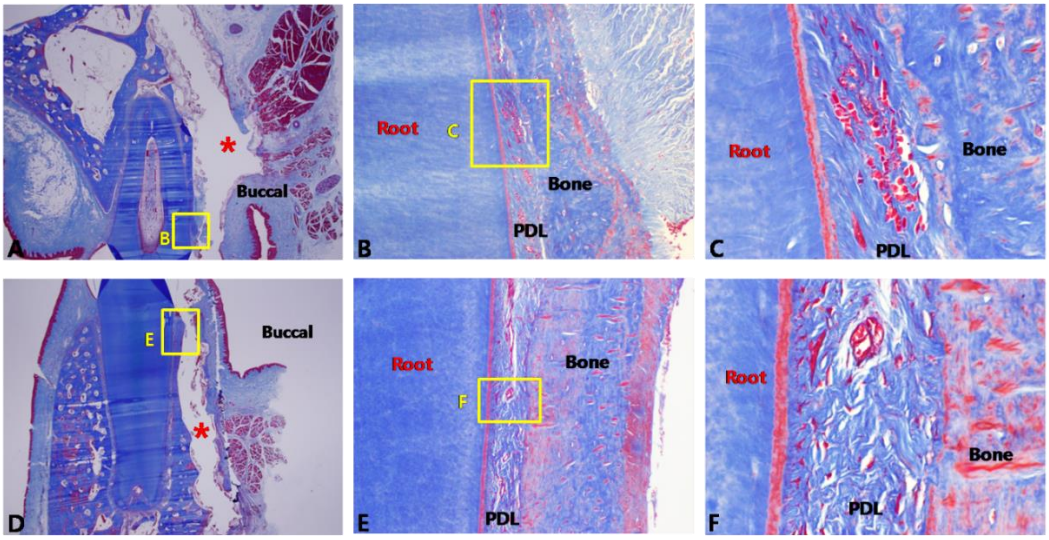


Figure 6: Microphotograph of a bucco-palatal/lingual section of the 1-day experiment. (A) Maxilla. (B) Higher magnification of (A). On the pressure side, the PDL was compressed. (C) Higher magnification of (B). Extravasation of RBC was observed. (D) Mandible. (E) Higher magnification of (D). Compression of the PDL was shown, and reduced capillaries were identified. (F) Higher magnification of (E). The number of cells was reduced, and grafted MBCP+ particles were lost in the process of making the histological section; the red * in (A) and (D) indicates empty spaces that were occupied by MBCP+ graft particles. Masson's trichrome stain. Original magnification was ×12.5 for (A) and (D); ×100 for (B) and (E); and ×400 for (C) and (F).

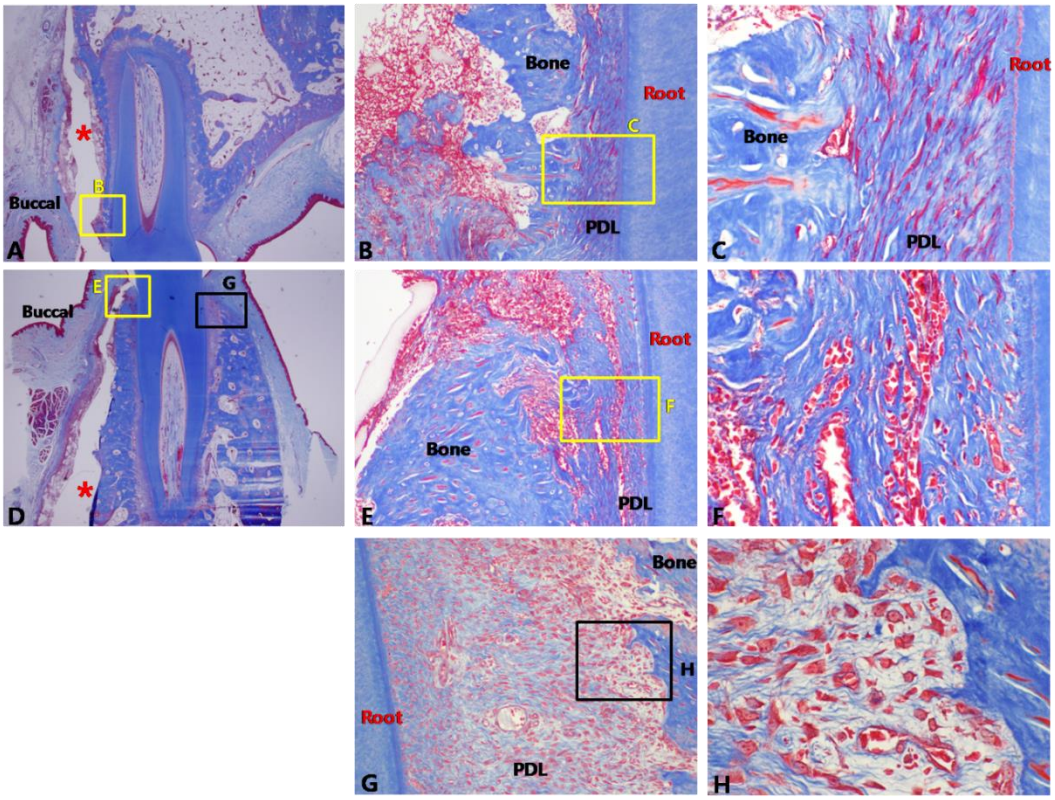


Figure 7: Microphotograph of a bucco-palatal/lingual section of the 3-day experiment. (A) Maxilla. (B) Higher magnification of (A). On the pressure side, the PDL was more severely compressed. (C) Higher magnification of (B). Few cells were observed in the PDL space. (D) Mandible. (E) Higher magnification of (D). In common with the maxilla, the PDL was severely more compressed on the pressure side. (F) Higher magnification of (D). Extravasation of RBC was observed in the PDL space. (G) Tension side at the lingual bone crest. The tension side showed abundant cells compared with the pressure side. (H) Higher magnification of (G). Active osteoblasts forming new bone were observed. Grafted MBCP+ particles were lost in the process of making the histological section; the red * in (A) and (D) indicates empty spaces which were occupied by MBCP+ graft particles. Masson's trichrome stain. Original magnification was ×12.5 for (A) and (D); ×100 for (B), (E), and (G); and ×400 for (C), (F), and (H).

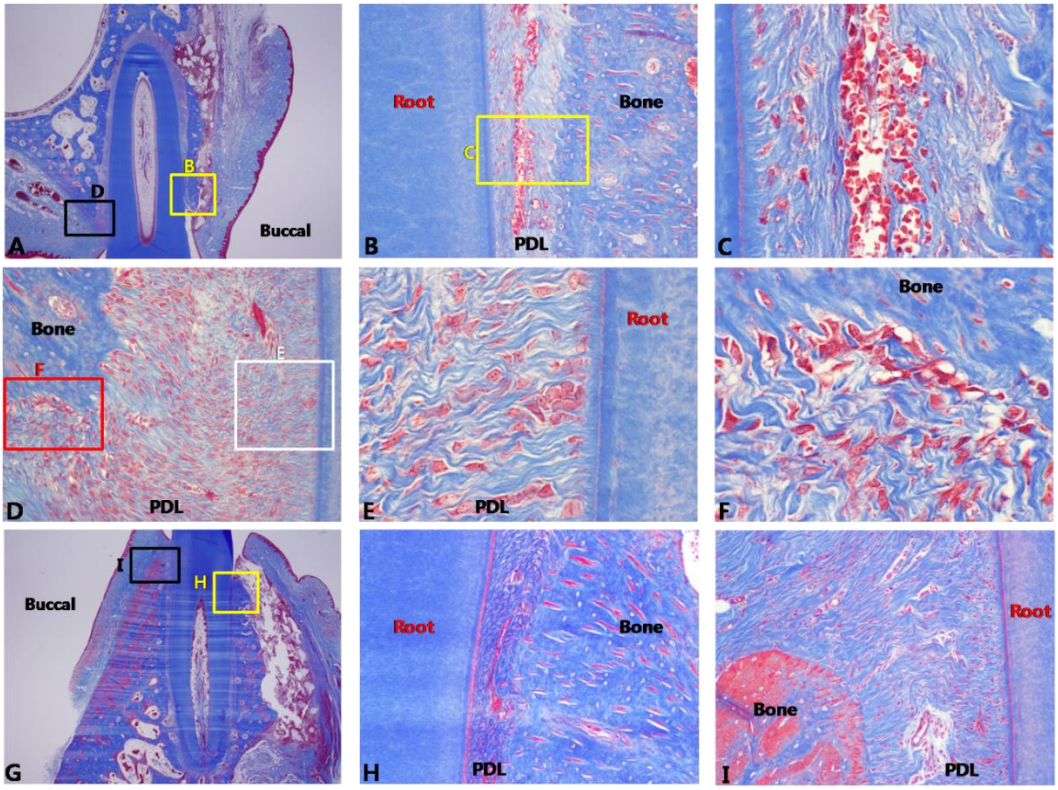
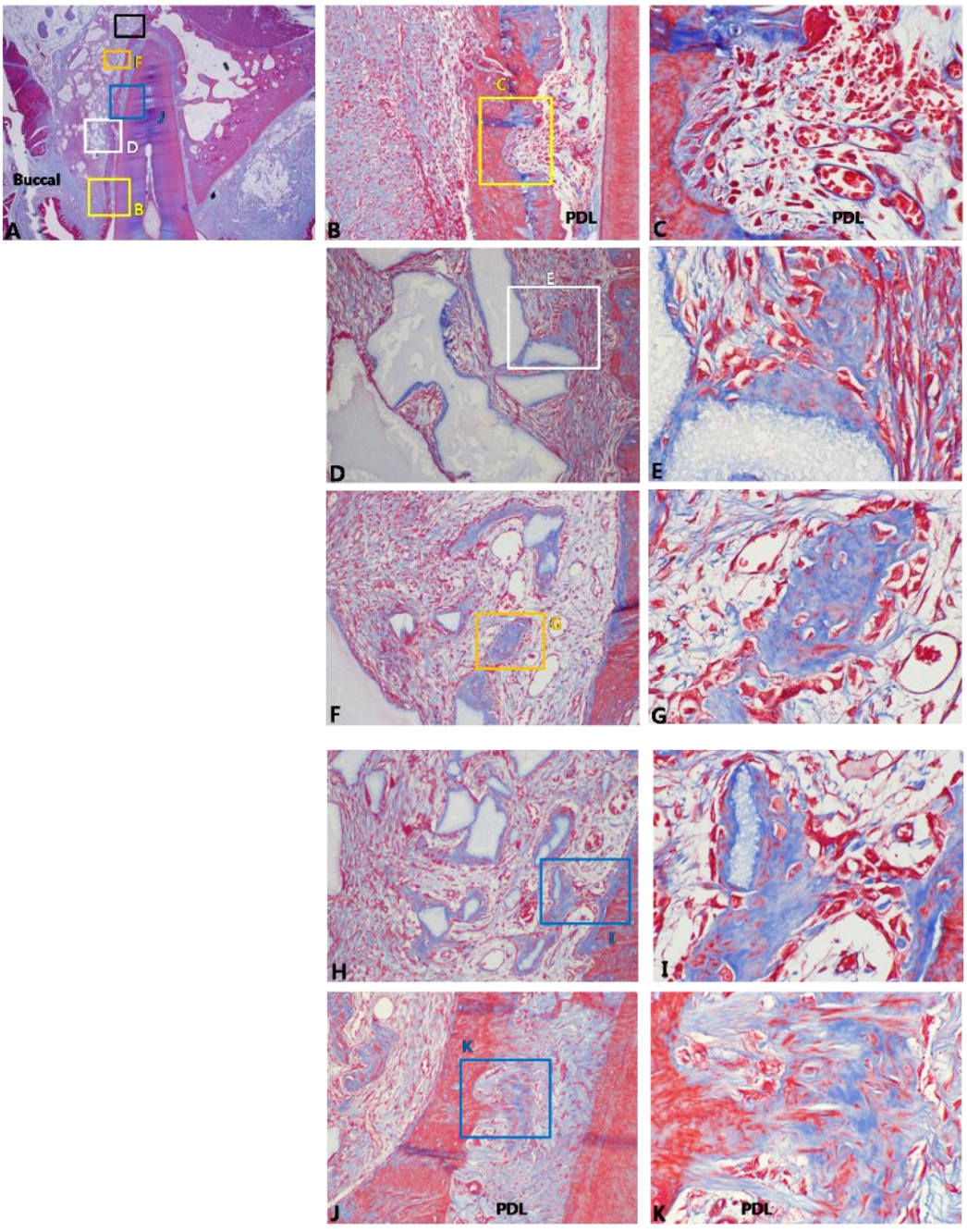


Figure 8: Microphotograph of a bucco-palatal/lingual section of the 1-week experiment. Most of the grafted MBCP+ particles were well maintained. (A) Maxilla. (B) Higher magnification of (A). On the pressure side, the PDL space was wider than at 3 days. (C) Higher magnification of (B). Extravasation of RBC was observed in the PDL space. (D) Tension side at the palatal bone crest. The tension side showed abundant cells compared with the pressure side and a widened PDL space. (E) Higher magnification of (D). Abundant PDL fibroblasts were seen. (F) Higher magnification of (D). Active osteoblasts forming new bone were observed. (G) Mandible. Most of the grafted MBCP+ particles were well maintained. (H) Higher magnification of (G). Pressure side. The PDL was compressed. (I) Higher magnification of (G). The tension side showed a widened PDL space. Masson's trichrome stain. Original magnification was ×12.5 for (A) and (G); ×100 for (B), (D), (H), and (I); and ×400 for (C) and (F).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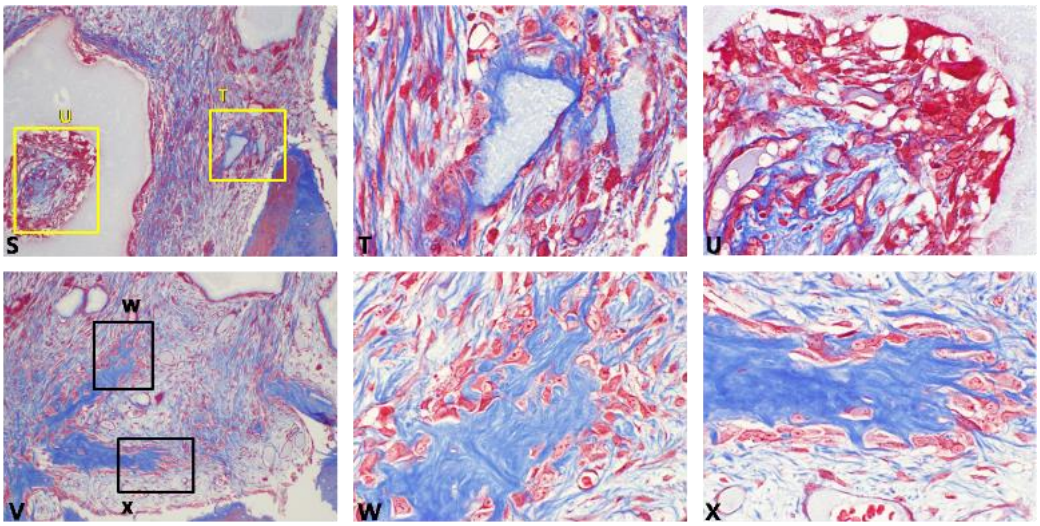
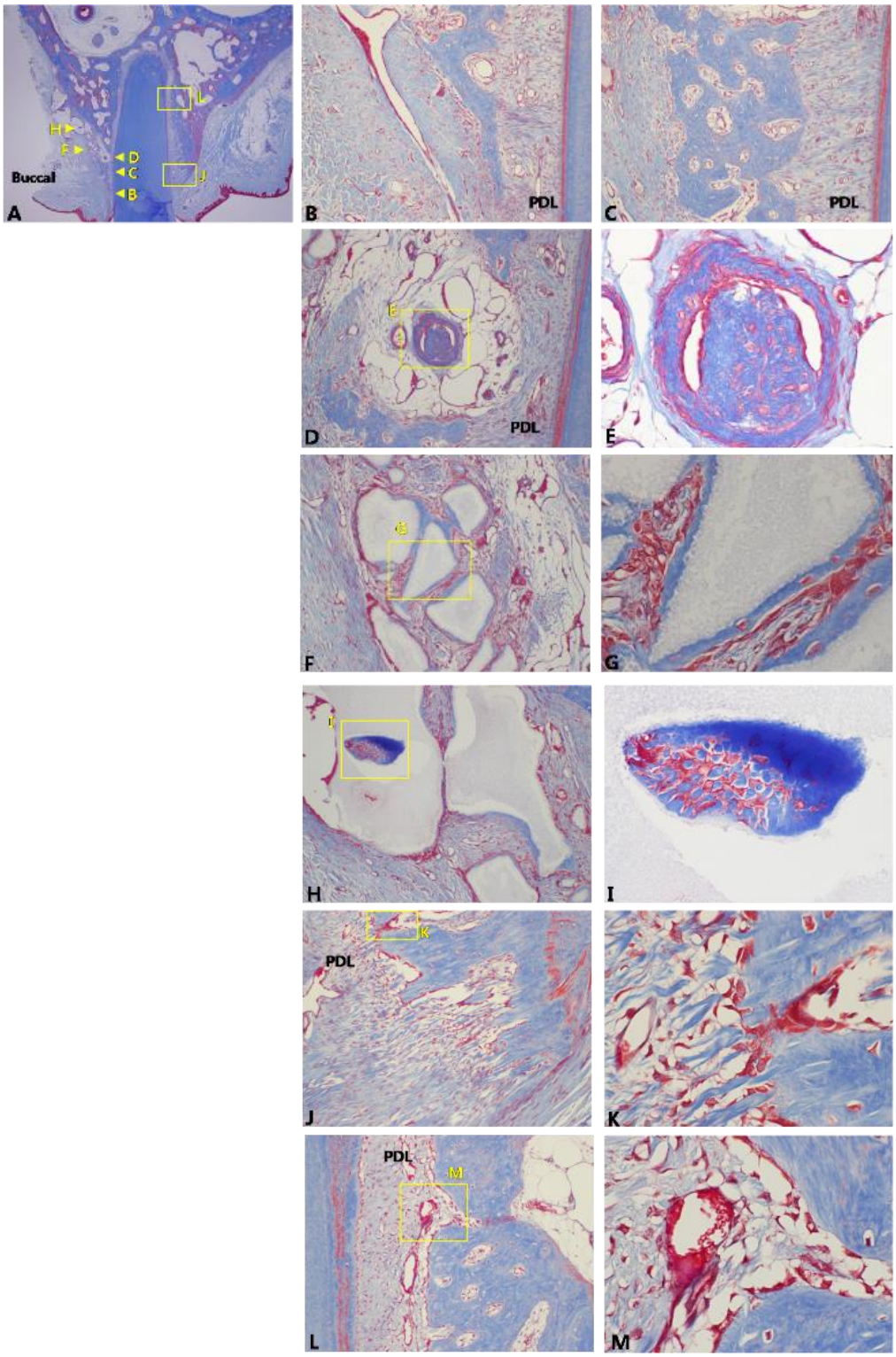


Figure 9: Microphotograph of a bucco-palatal/lingual section of the 2-week experiment. (A) Maxilla. Most of the grafted MBCP+ particles were well maintained. (B) Higher magnification of (A) at the crest area. Undermining resorption on the pressure side was observed. (C) Higher magnification of (B). Extravasation of RBC was observed in the PDL space. Resorption bays, which indicate undermining resorption on the pressure side, were also observed. (D) Higher magnification of (A) at the buccal bone surface. New bone formation surrounding the grafted MBCP+ particles was observed. Grafted MBCP+ particles were bridged by newly formed bone. (E) Higher magnification of (D). Abundant osteoblasts were forming new bone. (F) Higher magnification of (A). Osteoblasts were forming a new bone island. (H) Higher magnification of (A). Grafted particles encircled by new bone were bridged with the buccal bone surface. (J) Higher magnification of (A). New bone was formed in the PDL space at the buccal tension area. New bone was forming from the bone. (L) Mandible. Most of the grafted MBCP+ particles were well maintained. (M) Higher magnification of (L) at the crest area. Grafted particles were resorbed by osteoclasts. (N) Higher magnification of (M). (O) Higher magnification of (L). (P) Higher magnification of (L). Bone and root surface resorption by osteoclasts were observed. (Q): Higher magnification of (L). Undermining resorption at the buccal bone in the PDL area was observed. (R) Higher magnification of (Q). Many osteoblasts filled the resorption bay. (S) Higher magnification of (L). Active new bone formation was found at the buccal bone surface in the apical area. (T) Higher magnification of (S). Many

osteoblasts were forming new bone encircling the grafted MBCP+ particles. (U) Higher magnification of (S). Osteoclastic and osteoblastic activities were both observed. (V) Higher magnification of (L). New bone islands were formed. (W) Higher magnification of (V). (X) Higher magnification of (V). Abundant osteoblasts were actively forming new bone islands. Masson's trichrome stain. Original magnification was ×12.5 for (A) and (L); ×100 for (B), (D), (F), (H), (J), (M), (O), (Q), (S), and (V); and ×400 for (C), (E), (G), (I), (K), (N), (P), (R), (T), (U), (W), and (X).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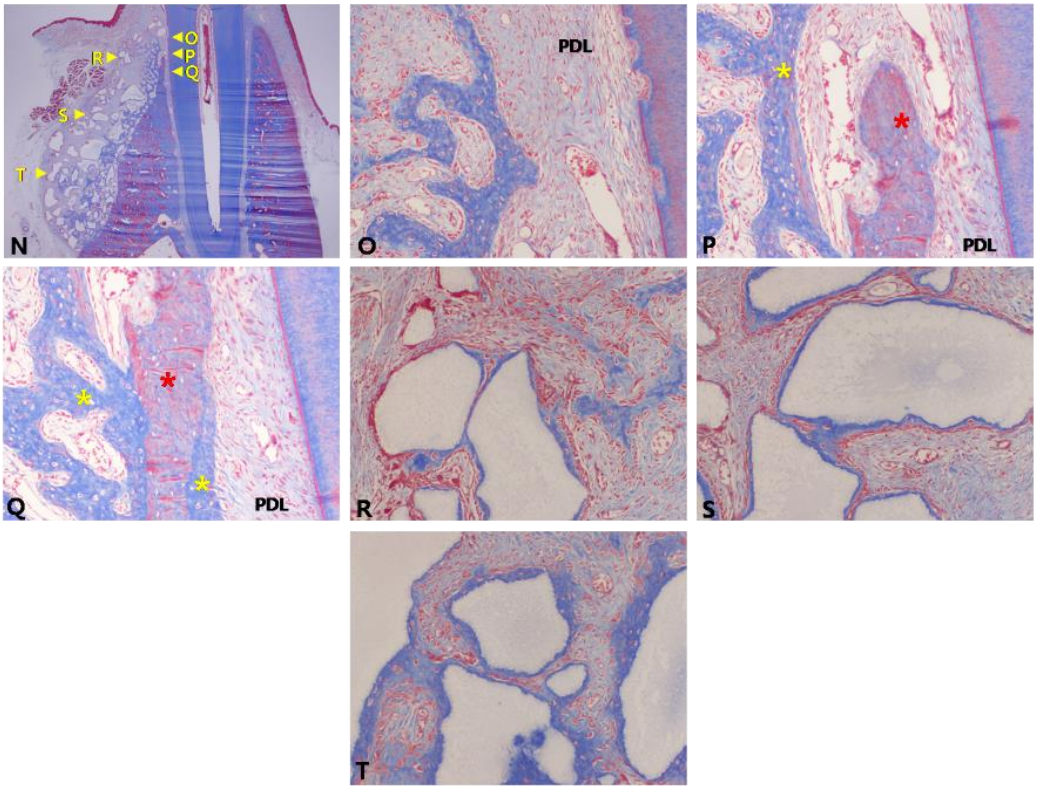

Figure 10: Microphotograph of a bucco-palatal/lingual section of the 4-week experiment. (A) Maxilla. Most of the grafted MBCP+ particles were well maintained. New bone formation along the PDL formed a new buccal bone wall. (B) and (C) Higher magnification of (A) at the crest area. (D) Higher magnification of (A). The bone-derived mesenchymal matrix bordered the PDL-derived mesenchymal matrix. A new bone island was formed in the center of the bone-derived mesenchymal matrix. (E) Higher magnification of (D). Osteoblasts and osteocytes were observed. (F) Higher magnification of (A). The grafted MBCP+ particles were bridged with newly formed bone in the bone-derived mesenchymal matrix on the buccal side. (G) Higher magnification of (F). Entrapped osteocytes and aggregated osteoblasts were observed. (H) Higher magnification of (A). (I): Higher magnification of (H). New bone was formed in the center of the grafted MBCP+ particles at the buccal side. (J) and (L) Higher magnification of (A). The palatal tension side at the crestal (J) and apical (L) areas. (K) and (M) Higher magnification of (J) and (L), respectively. Aggregated osteoblasts and

active form of osteoblasts were seen. (N) Mandible. (O) Higher magnification of (N) at the crestal area. New bone forming a buccal bone wall and crest was observed. (P) Higher magnification of (N). Native bone (red star) and new bone (yellow star). (Q) Higher magnification of (N). New bone (yellow star) was formed on the outer and inner surface of the native bone (red star). (R), (S), and (T) Higher magnification of (N). The outer portion of the bone-derived mesenchymal matrix. Grafted MBCP+ particles were bridged by the newly formed bone. Masson's trichrome stain. Original magnification was ×12.5 for (A) and (N); ×100 for (B), (C), (D), (F), (H), (J), (L), (O), (P), (Q), (R), (S) and (T); and ×400 for (E), (G), (I), (K), and (M).

국문초록

비글 성견에서 교정력과 피질골절단술 및 합성골 이식을 함께 적용할 때 나타나는 치주조직의 초기 조직학적 반응관찰

최 형 주

서울대학교 대학원 치의과학과 치과교정학 전공

(지도교수: 김 태 우)

본 연구의 목적은 비글 성견의 치아에 교정력을 가하면서 동시에 피질골 절단술과 합성골 이식을 함께 하였을 때 초기에 치아 주위조직에서 나타나는 조직학적 반응을 살펴보기 위함이다.

다섯 마리의 비글 성견을 이용하여 인상채득 후 실험을 위한 교정 장치를 제작하고 장착 후 200g 의 힘을 제 2,3 소구치에 협측으로 200g 의 힘을 가하였고, 동시에 전층판막을 형성한 후 각 치아에 피질골 절제술을 시행하고 MBCP+의 골 이식재를 약 1g 정도 이식 한 후 봉합하였다. 술 후 1 일, 3 일, 1 주, 2 주, 4 주에 희생시킨 뒤 수술부위 골을 함께 절단하여 표본을 제작하고 Masson's trichrome 염색을 시행하여 조직학적, 조직계측학적으로 평가하였다.

관찰 결과 시술 후 3 일째부터 상당한 치아이동이 관찰되었다. 또한 치아의 이동에 따른 치아 주위 조직의 손상은 관찰되지 않았다. 특히 무리한 힘이 가해졌을 때 나타나는 현상인 초자양화(hyalinization)층도 관찰되지 않았다. 2,4 주째 표본에서는 치아가 이동하는 방향인 협측에서 신생골의 합성이 관찰되기도 하였다.

이 연구로부터 피질골 절단술과 합성골 이식을 함께 이용한 교정적 치아이동 술식은 치주조직의 손상 없이 치아의 빠른 이동을 유도할 수 있으며 치주조직 재생의 가능성을 보여주었다.

주요어: 피질골절제술, 급속치아이동, 합성골이식

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