치의학박사 학위논문

Evaluation of the Alveolar Bone and Roots of the Maxillary Anterior Teeth before and after En-Masse Retraction Using Cone-Beam Computed Tomography

CBCT 를 이용한 상악전치부 후방이동에 따른 상악전치부 치조골 및 치근의 변화 평가

2012 년 8 월

서울대학교 대학원
치의과학과 치과교정학 전공

안 효 원

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이 논문을 치의학박사 학위논문으로 제출함

2012 년 5 월

서울대학교 대학원

치의과학과 치과교정학 전공

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ABSTRACT

Evaluation of the Alveolar Bone and Roots of the Maxillary Anterior Teeth before and after En-Masse Retraction Using Cone-Beam Computed Tomography

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Objective: To evaluate the changes of alveolar bone area, vertical bone level, root length, and root area of the maxillary anterior teeth after en-masse retraction with maximum anchorage.

Materials and Methods: The samples consisted of 37 female adult patients who had Class I dentoalveolar protrusion and were treated by extraction of the first premolars and en-masse retraction with maximum anchorage. Using three-dimensional cone-beam computed tomograms (3D-CBCT) taken before treatment (T1) and after space closure (T2), the maxillary central incisors (N = 66), lateral incisors (N = 69), and canines (N = 69) were superimposed using individual reference planes according to their long axis and clinical crown. Alveolar bone area (ABA) at the cervical, middle, and apical levels, and vertical bone level (VBL), root length (RL), root area (RA), and prevalence of dehiscence (PD) were measured and statistical analyses were performed.

Results: On the palatal side, ABA significantly decreased in every level of all maxillary anterior teeth. Maxillary central and lateral incisors exhibited more decrease in the ratio of change in palatal ABA than maxillary canines. Palatal/labial ABA ratios decreased in maxillary central and lateral incisors. They showed greater amounts and ratios of changes in VBL on the palatal side than the labial side. The palatal side showed more PD than the labial side in all maxillary anterior teeth. The lowest percentage of dehiscence was observed in maxillary central incisors on the labial side and in maxillary canines on the palatal side. Root resorption occurred significantly in all maxillary anterior teeth but did not show difference among maxillary central incisors, lateral incisors, and canines.

Conclusion: During en-masse retraction with maximum anchorage in cases with Class I dentoalveolar protrusion, the ABA and VBL on the palatal side, RL and RA of the maxillary central and lateral incisors were significantly decreased.

Keywords: alveolar bone; root; maxillary anterior teeth; en-masse retraction; extraction space closure; 3D-CBCT

Student number: 2010-31199

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I. INTRODUCTION

There are two assumptions in orthodontic tooth movement in terms of alveolar bone remodeling. If the alveolar bone is remodeled with coordinated resorption and apposition, tooth movement and bone remodeling occur at a one to one ratio, and the tooth remains in the alveolar housing. This kind of tooth movement is known as the ‘with-the-bone’.[1] However, if balance between resorption and apposition of the alveolar bone is not established during tooth movement, the tooth will move out of the alveolar housing, which is referred to the ‘through-the-bone’.[2]

Bialveolar protrusion is one of the most common chief complaints in Asian orthodontic patients.[3,4] The conventional treatment modality is extraction of the first premolars and retraction of the anterior teeth with maximum anchorage.[3,4] Excessive retraction of the anterior teeth may result in iatrogenic sequelae such as root resorption, alveolar bone loss, dehiscence, fenestration, and gingival recession.[5-8] Morphometric evaluation of the alveolar bone and roots of the anterior teeth after en-masse retraction may be a good model to explain the biologic limitation of orthodontic tooth movement and to define the “with-the-bone” and “through-the-bone” assumptions.

Conventional two-dimensional (2D) lateral cephalograms have several limitations for investigating the changes in the alveolar bone and roots, especially in the anterior region, due to the midsagittal projection.[5,9-11] The advent of cone-beam computed tomography (CBCT) has made it possible to qualitatively and quantitatively evaluate the height and thickness of the alveolar bone and the length and thickness of the root.[8,12-15]

Recently, three-dimensional (3D) CBCT image fusion based on the cranial base region has begun to be used in orthodontics to compare the pre- and post-surgical data and to evaluate facial growth.[16,17] It provides more accurate and reliable evaluation on treatment outcomes by sharing the same coordinate axis between the pre- and post-treatment. However, few studies have investigated the alveolar bone and root of the individual tooth according to a customized reference plane based on the clinical crown and its long axis. The purpose of this study was to evaluate the changes of alveolar bone and roots of the maxillary anterior teeth after en-masse retraction with maximum anchorage using superimposition of individual teeth with CBCT images. The null hypothesis was that the alveolar bone area (ABA) and vertical bone level (VBL) on the palatal or labial side and root length (RL) and root area (RA) of maxillary anterior teeth before treatment were not different after space closure.

II. REVIEW OF LITERATURE

1. Basic assumption of alveolar bone modeling in orthodontic tooth movement

1-1. 'Through-the-bone' vs. 'with-the-bone' assumptions

Tissue reaction to orthodontic tooth movement is known to occur either 'through-the-bone' or 'with-the-bone'.[18] 'Through-the-bone' is characterized by indirect or undermining resorption starting at the bone marrow, at a distance from the adjacent periodontal ligament (PDL), while no formative activity on the tensional side.[19,20] Hyalinization is generated by excessive compressive force to PDL. After hyalinization is eliminated by undermining resorption, orthodontic tooth movement is possible and at this time, bone apposition on the tension side is initiated.[19] During the period of removal of hyalinization tissues, the teeth are not being displaced but forces are transferred in the direction of the tooth movement, therefore resulting in a dramatic increase in density.[1] Previous study also showed that the response to increased mechanical strain might be caused by the formation of woven bone if the strain was intense enough.[21]

'With-the-bone' is related to the direct resorption that the activity of bone resorption and apposition is synchronized as a remodeling cycle.[22] There is evidently a narrow range of pressure that on the one side stimulates the differentiation of osteoclasts and, thus, resorption of bone, while it does not damage cementoblasts or osteoblasts that continue in the function of appositional growth elsewhere in the periodontium. Corresponding to resorption on the alveolar bone in the force direction, apposition occurs at a certain distance within the alveolar process or on the external surface of the alveolus. In this way, the bone not only makes room for the moving tooth but also follows it; hence the expression, "The alveolar socket moves with the moving tooth." Direct resorption could occur as a part of the macro bony structural units (BSU) and actually be a response to the relaxation of the PDL fibers, resulting in a loading below the limit for minimum effective strain (MES) whereby remodeling starts with resorption.[23] Whether orthodontic tooth movement occurs with or through the bone depends on the stress/strain distribution in PDL and which is determined by several factors such as forced magnitude, bone area, and distribution of the force.[19, 24]

1-2. Alveolar bone modeling according to the types of orthodontic tooth movement

A basic axiom in orthodontics is that "bone traces tooth movement" which suggests that whenever orthodontic tooth movement occurs, bone around the alveolar socket will remodel to the same extent, therefore, the ratio of bone remodeling to tooth movement (B/T) of 1:1 develops.[25] However, according to the direction of orthodontic tooth movement, the B/T ratio does not remain 1:1 all the time. Remodeling capacity of the alveolar bone is concerned principally with the osteogenic potential of the periosteum covering the alveolar process. However, the alveolar periosteum is not the site of significant cellular activity. Furthermore, the remodeling capacity of the alveolar periosteum becomes progressively limited with age by the size of the cell population so that fewer cells are available to respond to the appropriate mechanical stimulus, a characteristic common to all connective tissues. [26]

In the vertical dimension, during orthodontic tooth extrusion, bone apposition of alveolar crest is usually less than the dental displacement, leading to an increase in the clinical crown. This is favorable in forced eruption procedures in which a reduced clinical crown has to be extended for prosthetic restoration[27] and unfavorable when impacted teeth are aligned.[28] Orthodontic extrusion combined with supracrestal fiberotomy resulted less migration of gingival tissue and alveolar bone than non-fiberotomy group.[27] Kajiyama et al.[29] found that bone followed tooth extrusion by nearly 80% which could justify the clinical application of the forced eruption technique. On the other hand, tooth intrusion showed more coherence in maintaining a 1:1 B/T ratio, though it exceeded bone reduction.[30]

In the transverse dimension, dehiscence and fenestration of the buccal cortical plate have been reported in rapid maxillary expansion, suggesting that root movement of the buccal dental segment surpassed lateral bone remodeling.[31] Even a single tooth movement in a buccolingual direction could produce the same effect.[6] It was doubtful whether or not a 1:1 B/T ratio is preserved when a slow expansion regimen was applied.

In the sagittal dimension, a different reaction was demonstrated between the posterior and anterior segments. In the posterior dental segment, a 1:1 B/T ratio was well maintained as long as tooth movement was restrained between the two cortical plates, i.e., affecting the intermittent cancellous bone.[25] Approximation of the buccal and lingual cortical plates by narrowing of the alveolar trough as in missing teeth, edentulous region, or cleft palate could often cause alveolar bone loss and failure of space closure.[32] When moving a tooth into edentulous areas with reduced bone height, a vertical bone gain of 1.1 mm was accomplished, although no tooth extrusion was performed.[33] However, in another study, a predominant vertical bone loss (1.3 mm) associated with space closure by means of the mesial movement of the lower second molars was shown.[34] In the anterior segment, both the palatal (or lingual) and the labial cortical plates are involved in all anteroposterior tooth movements of the anterior dental segments. Previous studies supported that a 1:1 B/T ratio did not maintained in the anterior segment.[26,35-38] Protraction of maxillary incisors produced dehiscence of the labial cortical plate that was reversible once the tooth returned to its original position.[35,36] The same restriction was observed in retraction movements affecting the palatal cortical plate.[26,37]

2. Morphometric change of alveolar bone in maxillary anterior region by anteroposterior tooth movement

In 1995, the maxilla of a deceased 19-year-old young woman who had been treated with an edgewise appliance was removed during autopsy.[38] At the time of her death she had completed 19 months of treatment, which included two phases tooth movement: an uncontrolled tipping (root movement to vestibular) had been followed by palatal root torque. Widespread dehiscences and fenestrations of the alveolar bone cortical plates, as well as extensive lateral, buccal, and palatal root resorption were observed. These destructive changes were particularly pronounced in the teeth that had been subjected to uncontrolled tipping, and less severe in the teeth moved by translation.

In this section, the capacity of the alveolar bone modeling in the maxillary anterior teeth during retraction is further described according to the image modality.

2-1. Evaluation of the alveolar bone modeling by two-dimensional lateral cephalogram studies

In recent studies, there were limitations to the amount of tooth movement that could be accomplished by alveolar remodeling. The previous studies have all shown that when extensive palatal movement of the maxillary incisors was attempted, the roots of these teeth might be brought into contact with the palatal alveolar cortex.[5,37,39] The cortex will bend and remodel to a limited extent, but once contact has been made, further movement will lead to eventual penetration of the cortical plate, accompanied by bone loss, root resorption, and subsequent relapse.

According to Edwards' study,[37] when the extent of lingual movement of the incisors was so large and/or the labiolingual width of alveolar process was relatively so narrow, the roots of the teeth moved lingually outside the existing alveolar bone. He suggested that retraction was restricted to an anteroposterior range of 1.5 to 2.5 mm since the palatal cortical plate did not tolerate the structural changes. The greatest change was observed in the marginal area of the alveolus, and progressively less alteration of the bone toward the apex of the root. The junctional area of the anterior palate where the vault was sloping from horizontal to vertical appeared to be an anatomic limitation to the distal movement of maxillary incisor teeth. The labiolingual width of the marginal and midroot alveolus remained relatively constant (within 1 mm) before and after treatment, however the root of the tooth always remained farther from the labial plate and closer to the palatal plate than before treatment.

Ten Hoeve and Mulie[5] investigated the effect of incisor retraction on the palatal cortex in 23 patients with severe Class II malocclusions under treatment with the Begg technique. They demonstrated that it was unlikely that routine cephalograms would show a perfectly clear x-ray view of the bony structures. For this reason, they studied the anterior portion of the palate using laminagraphy. They showed that a palatal cortex could not be detected immediately after retraction of the maxillary incisors. Approximately six months after treatment, the laminagrams revealed a thin layer of new cortex. Within two years, this layer seemed to have reshaped and resembled the pretreatment cortex in six of their patients. This new cortical plate was thin and irregular, and not comparable to the original cortex. Root resorption was found in many of the laminagrams in the apical region of the upper incisors.

However, Wainwright[6] investigated the tissue response to the cortical plate penetration by the premolars in Mucaque speciosa monkeys, and found that once the cortical plate was penetrated, the buccal root surface became devoid of bone. Although some osteogenesis took place during the 4-month retention period, it was not sufficient to cover the root completely. The repair of the perforation site took place only after the teeth had relapsed.

Remmelink and van der Molen[36] re-examined the same patients of Ten Hoeve and Mulie[5] seven to ten years later, using identical observation techniques. Ten of the 15 patients showed a relapse of torque and one patient revealed some progression of the root resorption. All patients revealed a well defined, dense cortical plate, equivalent to the image before treatment. The curvature of the palatal cortex had smoothed. However, this bone apposition was accompanied by some relapse of root torque. The roots of the incisors that had been torqued against the cortical plate moved away from the cortical plate after treatment.

Vardimon et al.[11] compared the alveolar bone modeling between 'retraction with uncontrolled tipping' and 'retraction with palatal root torque' group and a bone remodeling/tooth movement ratio of 1:2 and 1:2.35 was obtained, respectively. In retraction with tipping movement, the apical one third of the root tipped labially reducing the superior area of labial maxillaris by 19%. However, due to the compensating effect of the retraction movement, no apex approximation to the labial cortical plate occurred (eliminating the hazard of root resorption, dehiscence, or fenestration). In retraction with torque movement, the increase in both superior (28%) and inferior (65%) labial maxillaris areas was indicative for the hazard of root approximation to the palatal cortical bone. They recommended using the 1:2 bone remodeling / tooth movement ratio as a guideline to determine the biocompatible range of orthodontic tooth movements. In regard to the protraction of maxilla, Goldin[40] have shown the limitation of advancing point A by more than 2 mm. Since the distance apex to the labial cortical plate was less than half the distance apex to palatal cortical plate, the implication of the 1:2.35 B/T ratio was more crucial in maxillary protraction movement, where the labial cortical plate did not maintain pace with the anterior root displacement, terminating in the mentioned deleterious sequela.

2-2. Evaluation of alveolar bone modeling by three-dimensional cone-beam computed tomography (CBCT)

The maxillary anterior region is the best model to examine bone remodeling to tooth movement relationship. However, quantitative studies have been limited to changes in point A only in lateral cephalogram.[40] A full morphometric study of the various changes of anterior maxilla during maxillary incisor retraction has not been carried out nor has the bony change during diverse types of root movement been fully studied. In the 1990s, CBCT was introduced in dentistry and it has gained widespread acceptance in orthodontics due to the high spatial resolution, low radiation dose, and relative affordability of this technique.[41] The ability to provide distortion-free slice images of single roots provides the excellent possibilities to study root resorption or alveolar bone change. CT findings have proven to be statistically similar to the histologic measurements for the evaluation of the sites of dehiscence.[9]

In 2002, CT was first utilized in studying the maxillary and mandibular alveolar bone following incisor retraction by controlled tipping in patients with bimaxillary protrusion.[8] Comparing pre- and post-retraction records revealed that in both jaws, there had been significant reductions in the width of the lingual bone as a result of treatment, with some patients demonstrating dehiscences that were not visible macroscopically or cephalometrically. While in the labial side, original thickness of alveolar bone was well maintained on both arches.

By the late 2000s, several studies for evaluation of the anterior alveolar bone by CBCT were reported.[12-15,42] Most of them focused on the fenestration, dehiscence, or facial alveolar bone thickness for implant installation. Only a few studies assessed the alveolar bone changes after orthodontic treatment.[12,15] They were all focused on dental decompensation in Class III malocclusion. Lee et al.[15] reported the alveolar bone loss around lower incisors incurred during Cl. III surgical orthodontic treatment. Kim et al.[12] also demonstrated that the mandibular incisors showed reduced vertical alveolar bone levels than the maxillary incisors, especially on the lingual side during presurgical orthodontic treatment for Class III patients. The alveolar bone thickness was significantly greater on the lingual side in the maxillary incisors, whereas the mandibular incisors exhibited an opposite result.[12]

Recently, more than the evaluation of morphometric change of the alveolar bone, CBCT has been used for bone density change of the anterior alveolus.[43,44] Hsu et al.[43] showed the mean reduction in bone density around the anterior teeth was 24% after application of orthodontic forces for 7 months. The bone density reduction around the teeth was largest for the upper-right and upper-left central incisor (29% and 26%, respectively). The mean bone density reduction showed no significant differences between the cervical, portion, and apical portions of the teeth (26%, 22%, and 24%, respectively). Chang et al.[44] further reported that the direction of tooth movement is associated with the side of maximum bone density reduction.

2-3. Accuracy and reliability for CBCT measurement

For visualization of subtle anatomic structures, factors such as voxel size, scatter radiation, gray scale bit depth, and artifacts caused by metallic objects are important.[45] More specifically, the smaller the voxel size, the higher the spatial resolution, and the smaller the field of view, the less noise from scatter radiation.

Misch et al.[46] conducted a study measuring intrabony and dehiscence defects using CBCT at 0.4 mm voxel size. The systematic difference in height of both defects combined was found to be 0.41 mm. Patcas et al.[47] evaluated the accuracy of CBCT with different voxel resolutions (0.125 mm vs. 0.4 mm voxels). Bony measures obtained using CBCT were accurate and differed only slightly from the physical findings. Presence of the soft tissue as well as different voxel size affected the precision of the data. However, even the 0.125 mm voxel protocol did not depict the thin buccal alveolar bone covering reliably, and there was a risk of overestimating fenestrations and dehiscences. Leung et al.[48] reported that by using a voxel size of 0.38 mm at 2 mA, CBCT alveolar bone height could be measured to an accuracy of about 0.6 mm, and root fenestrations could be identified with greater accuracy than dehiscences.

Timock et al.[49] also evaluated the accuracy and reliability of buccal alveolar bone height and thickness measurements derived from CBCT images. For the protocol used in their study (i-CAT, 0.3 mm voxel size), CBCT measurements did not differ significantly from direct measurements, and there was no pattern of underestimation or overestimation. The mean absolute differences were 0.30 mm in buccal bone height and 0.13 mm in buccal bone thickness with 95% limits of agreement of -0.77 to 0.81 mm, and -0.32 to 0.38 mm, respectively. Buccal bone height had greater reliability and agreement with direct measurements than did the buccal bone thickness measurements.

3. The characteristics of anterior alveolar bone and changes of anterior teeth after en-masse retraction in bialveolar protrusion patients

3-1. Characteristics of the anterior alveolar bone in bialveolar protrusion patients

Nahm et al.[13] reported that incisor periodontal support was poor and alveolar bone loss was severe even prior to the start of orthodontic treatment in bialveolar patients by their 3D CBCT images. All the anterior teeth were supported by less than 1 mm of the alveolar bone thickness on the labial surfaces up until 8/10 of root length. Alveolar bone area was statistically greater on the lingual aspect than the labial aspect in the lower incisors. The alveolar bone loss was 26.98% in the lower labial region, 19.27% in the upper labial aspect, and most severe on the lower lingual plate with 31.25% compared with the labial plate. Fenestrations were 1.37 times more frequent on the lower incisors than the upper incisors.

Lee et al.[42] also reported that, in Korean adults, the thickness of maxillary anterior buccal plate was very thin within 1 mm and the thickness of palatal plate was thick, relatively. Mean thickness of the buccal plate 3 mm below CEJ was 0.68 ± 0.29 mm at the central incisor, 0.76 ± 0.59 mm at the lateral incisor, and 1.07 ± 0.80 mm at the canine. Mean thickness of the palatal plate 3 mm below CEJ was 1.53 ± 0.55 mm of the central incisor, 1.18 ± 0.66 mm of the lateral incisor, 1.42 ± 0.77 mm of the canine. The buccal bony curvature below the root apex of the maxillary central incisor was higher than that of the lateral incisor and the canine. It seemed that the buccal bony plate below the root apex of the central incisor was most curved.

3-2. Evaluation of the anterior teeth after en-masse retraction according to the anchorage

Conventional treatment plan for bialveolar protrusion patients includes extraction of the bilateral maxillary premolars, followed by retraction of the anterior teeth with maximum anchorage.[50] Maximum anchorage to prevent forward movement of the maxillary posterior teeth during retraction of the anterior teeth can be provided with different approaches. Orthodontic anchorage can be prepared by using distal tip-back of the posterior teeth, cortical anchorage via buccal root torque of the molars, intraoral holding appliances such as Nance holding arch or transpalatal arch, and extraoral headgear appliances.[51] Recently, orthodontic mini-implants (OMIs) has been widely used as absolute anchorage sources.[52]

In comparison between extraoral headgear and OMIs for maximum / absolute anchorage in dentoalveolar protrusion patients, Yao et al.[53] demonstrated that greater retraction of the maxillary incisor (8.17 mm vs. 6.73 mm) and less anchorage loss of the maxillary first molar (0.88 mm vs. 2.07 mm) in OMI group. Upadhyay et al.[54] also showed the 0.55 mm distal movement and -0.13° distal tipping of maxillary first molars in the OMIs group, and 1.95 mm mesial movement, and 3.7° mesial tipping in conventional anchorage group. However, the amount of incisor retraction was not different significantly between the OMIs group (6.23 mm) and conventional anchorage group (5.72 mm). Retraction with OMIs was primarily achieved by controlled tipping and partly by translation because the forces applied were closer to the center of resistance of the maxillary anterior teeth. Statistically significant amounts of intrusion of the maxillary central incisor were recorded in OMIs group (2.13 mm vs. 0.2 mm). The occlusogingival position of the mini-implant and the vertical height of the crimpable hook or power arm played a crucial role in directing the forces of retraction and intrusion through the anterior teeth.

Lai et al.[55] showed that three-dimensional analysis of the maxillary dental models in the buccopalatal, anteroposterior, and vertical directions showed significant differences in tooth movements between the headgear and skeletal anchorage (OMIs or miniplate) groups. Both skeletal anchorage groups had greater incisor retraction (6.9 mm for the OMIs, 7.3 mm for the miniplate) than did the headgear group (5.5 mm). Mesialization of occlusal centroid of the maxillary molar in the skeletal anchorage groups was less than that in the headgear group (1.3 mm for the OMIs, 1.4 mm for the miniplate, and 2.5 mm for the headgear group).

Cho et al.[56] also reported individual tooth movement in bialveolar protrusion patients by superimposing three-dimensional virtual models. The maxillary central and lateral incisors were significantly inclined lingually (12.3° vs. 5.8°), extruded (2.9 mm vs. 2.3 mm), and moved posteriorly (5.4 mm vs. 5.2 mm) and laterally (0.7 mm vs. 1.7 mm). The linguoversion of the central incisors was significantly greater than that of the lateral incisors. The ratio of anteroposterior movement between the maxillary anterior and posterior teeth was 5:1. There was no significant change in angulation and rotation of the canines. It inclined lingually (2.0°), extruded (1.7 mm), moved backward (5.5 mm), and displaced laterally (2.6 mm).

III. MATERIALS AND METHODS

The samples consisted of 37 female adult patients with Class I dentoalveolar protrusion (mean age = 26.62 ± 8.46 years; treatment duration = 1.81 ± 0.42 years; SNA, 81.40°; SNB, 77.83°; maxillary central incisor to SN, 127.74°; IMPA, 98.93°; Table 1), who were treated by a single orthodontist (MSC) with extraction of the four first premolars and sliding mechanics using en-masse retraction with maximum anchorage. Working wire was .019 X .025-inch stainless-steel without extra torque and .022-inch straight wire appliance with Roth set-up (Clippy-C, Tomy, Futaba, Fukushima, Japan) was used. Conventional anchorage such as TPA and/or headgear and elastic chains with a force of 200 g from the maxillary second molar to anterior hook between lateral incisor and canine were used. The amount of retraction of maxillary central incisor according to every 1 mm anchorage loss of the maxillary first molar (MX1 to MX6 ratio) was 3.67 ± 0.58 mm (Table 1).

Inclusion criteria for sampling were as follow: skeletal and dental Class I canine and molar relationships, mild anterior crowding (arch length discrepancy less than 3 mm), labioversion of the maxillary central incisor (MX1-SN more than 120°), and controlled tipping movement of the maxillary central incisors from superimposition of the lateral cephalograms before treatment (T1) and after space closure (T2). In lateral cephalometric analysis, the maxillary central incisors were retracted 5.7 mm at the incisal edge and 0.7 mm at the root apex and uprighted by 10.4° through controlled tipping movement on the average (Table 1 and Figure 1). Exclusion criteria were tooth size anomaly, root resorption, periodontal problem, and spacing or moderate to severe crowding of the maxillary anterior teeth before orthodontic treatment. Final sample was composed of maxillary central incisors (N = 66), lateral incisors (N = 69), and canines (N = 69). This retrospective study was performed under approval from the Institutional Review Board of Kyung Hee University Dental Hospital (IRB number: KHD IRB-1108-04).

To evaluate the alveolar bone change accurately, CBCT images were taken before treatment (T1), and after space closure (T2) (Implagraphy, Vatech, Seoul, Korea; 12 X 9 cm field of view, 90 kVp tube voltage, 4.0 mA tube current, 0.2 mm voxel size, and 24 seconds scan time). The obtained data were reformatted and analyzed by InVivo Dental software (Anatomage, San Jose, CA). Images were generated parallel to the tooth axis in the axial, coronal and sagittal planes. The sagittal plane of each maxillary anterior tooth through the midpoint of incisor edge to root apex was used for evaluation. To set an identical long axis on the sagittal image between the T1 and T2 stages, three-dimensional (3D) superimposition of each six anterior teeth was performed. Because the region of interest is the labial and palatal contour of alveolar bone, each anterior tooth could serve as a reference based on the longitudinal axis and clinical crown. Superimposition was performed as follows (Figure 2): First, the long axis of each anterior tooth was set on the sagittal image at the T1 stage. Next, 3D superimposition was performed by the best-fit method using two sets of homologous landmarks in each CBCT image and a manual refinement process. Then, the T2 image was reoriented on the same coordinate axis as the T1 image.

Definitions of landmarks, reference planes, and variables are enumerated in Figure 3. The amounts of alveolar bone area (ABA) were measured at the cervical, middle, and apical levels. Trisection of the root length into the cervical, middle, and apex levels was duplicated in the T2 stage to guarantee the same slice levels with those at the T1 stage. Vertical bone level (VBL), root length (RL), root area (RA), and prevalence of dehiscence (PD) were measured both on the palatal and labial sides. Dehiscence was determined when the ABA covering the cervical root 1/3 decreased to zero at the T2 stage on the sagittal reference plane. Percentage of VBL to RL, ratio of ABA change, and ratio of palatal to labial ABA were calculated.

Since there was no significant difference in the values of all variables between the right and left sides, the data were combined to progress the statistical analysis. All of the measurements were repeated by the same operator (AHW) after two weeks. The difference of CBCT analyses ranged from 0.27 mm to 0.35 mm for the linear measurements, and from 0.31 mm^2 to 0.48 mm^2 for the area measurements according to Dahlberg's formula.[57] The difference of cephalogram analyses ranged from 0.34 mm to 0.42 mm for the linear measurements, and from 0.25° to 0.47° for the angular measurements. The mean of two measurements was used for this study. Independent t-test for the comparison between palatal and labial sides and paired t-test for the comparison between the T1 and T2 stages were used. One-way analysis of variance (ANOVA) with Duncan's multiple comparison test was performed for the comparison between maxillary central incisors, lateral incisors and canines. Crosstab analysis was performed to evaluate PD.

IV. RESULTS

1. Amount and ratio of changes in the labial and palatal ABA (Table 2)

On the labial side, ABA increased in the middle level of maxillary central incisors (2.4 mm^2 vs. 3.1 mm^2, $P < .001$) and in the middle and total levels of maxillary lateral incisors (1.3 mm^2 vs. 2.1 mm^2, $P < .001$ and 4.0 mm^2 vs. 5.0 mm^2, $P < .05$). However, on the palatal side, ABA decreased in all levels of maxillary central incisors (cervical, 2.3 mm^2 vs. 0.5 mm^2; middle, 7.2 mm^2 vs. 2.9 mm^2; apical, 15.9 mm^2 vs. 9.3 mm^2; total, 25.4 mm^2 vs. 12.6 mm^2, all $P < .001$), lateral incisors (cervical, 1.8 mm^2 vs. 0.4 mm^2; middle, 6.2 mm^2 vs. 2.8 mm^2; apical, 13.1 mm^2 vs. 7.0 mm^2; total, 21.1 mm^2 vs. 10.1 mm^2, all $P < .001$), and canines (cervical, 3.3 mm^2 vs. 1.7 mm^2; apical, 31.5 mm^2 vs. 23.3 mm^2; total, 47.8 mm^2 vs. 35.7 mm^2, all $P < .001$; middle, 13.0 mm^2 vs. 10.7 mm^2, $P < .01$).

Although maxillary central and lateral incisors showed a significant decrease in the ratio of change in ABA (ΔABA-ratio) compared to maxillary canines on the palatal side (cervical, 78% and 80% vs. 48%, $P < .01$; middle, 60% and 55% vs. 18%, $P < .05$; apical, 42% and 47% vs. 26%, $P < .05$; total, 50% and 52% vs. 25%, $P < .001$), maxillary central incisors exhibited greater amount of change in ABA (ΔABA-amount) than maxillary canines only in the middle level (-4.3 mm^2 vs. -2.3 mm^2, $P < .05$).

2. Palatal to labial ABA ratio (Table 3)

Although palatal to labial ABA ratio decreased in all areas of maxillary central incisors (cervical, middle, total, $P < .001$; apical, $P < .05$) and in some areas of maxillary lateral incisors (cervical, $P < .001$; apical, $P < .05$), maxillary canines did not show differences in any of the areas between the T1 and T2 stages. Differences in Δpalatal to labial ABA ratio among maxillary central incisors, lateral incisors, and canines were not significant in any of the areas.

3. VBL of the alveolar bone (Table 4)

At the T1 stage, amount and ratio of VBL (VBL-amount, VBL-ratio, respectively) was greater on the labial side than on the palatal side in maxillary anterior teeth (maxillary central incisors and lateral incisors, P <.001; maxillary canines, P <.01). At the T2 stage, VBL-amount and VBL-ratio of maxillary anterior teeth increased both on the palatal and labial sides. Although maxillary central and lateral incisors exhibited greater ΔVBL-amount and ΔVBL-ratio on the palatal side than the labial side, maxillary canines did not exhibit differences in ΔVBL-amount between the labial and palatal sides (ΔVBL-amount; 0.2 mm vs. 3.7 mm, 0.6 mm vs. 4.4 mm; 1.4 mm vs. 2.4 mm, maxillary central and lateral incisors, P <.001; ΔVBL-ratio; 1.6% vs. 29.3%, 4.9% vs. 36.1%, 8.3% vs. 15.3%, maxillary central and lateral incisors, P <.001; maxillary canines, P <.05).

In comparison of ΔVBL on the palatal side, maxillary central and lateral incisors showed higher values than maxillary canines in terms of the amount and ratio (P <.001). However, on the labial side, maxillary canines had greater ΔVBL-amount than maxillary central incisors (P <.05).

4. Root resorption (Table 5)

Although significant root resorption occurred in maxillary central incisors, lateral incisors, and canines (RL, 12.3 mm vs. 11.3 mm; 12.3 mm vs. 11.1 mm; 15.8 mm vs. 14.9 mm, all P<.001; RA, 55.9 mm^2 vs. 52.3 mm^2; 55.1 mm^2 vs. 51.6 mm^2; 85.2 mm^2 vs. 82.5 mm^2, all P<.001), the amounts of decreases in RL and RA did not show difference among maxillary central incisors, lateral incisors, and canines.

5. PD in the cervical area (Table 6)

Root exposure (dehiscence) in the cervical area occurred more frequently on the palatal side than on the labial side (maxillary central and lateral incisors, P<.001; maxillary canines, P<.01). In addition, there was a higher percentage of dehiscence in maxillary lateral incisors and canines than maxillary central incisors on the labial side (14% and 12% vs. 2%, P<.05) and in maxillary central and lateral incisors than maxillary canines on the palatal side (67% and 68% vs. 32%, P<.001).

V. DISCUSSION

The findings that ABA increased in the middle level of maxillary central incisors ($P <.001$) and in the middle and total levels of maxillary lateral incisors ($P <.001$ and $P <.05$, respectively) on the labial side and decreased in all the levels of maxillary central incisors (all $P <.001$), lateral incisors (all $P <.001$), and canines (cervical and total, $P <.001$; middle, $P <.01$) on the palatal side (Table 2) implied that en-masse retraction of the maxillary anterior teeth might result in tooth movement like the "through-the-bone". This implication was confirmed by the fact that palatal to labial ABA ratio decreased in all areas of maxillary central incisors (cervical, middle, total, $P <.001$; apical, $P <.05$) and in some areas of maxillary lateral incisors (cervical, $P <.001$; apical, $P <.05$) from the T1 to T2 stages (Table 3). This finding of reduced alveolar bone thickness in the direction of tooth movement agreed with the results of previous studies.[5-7,11]

The increase in ΔABA-amount on the labial side was much lower than the decrease in ΔABA-amount on the palatal side (4% vs. -50% in maxillary central incisors, 24% vs. -52% in maxillary lateral incisors, Table 2), which means that bone apposition in the tension area of the inner side of the labial alveolar bone was not sufficient and/or bone resorption occurred on the outer side of the labial alveolar bone. Sarikaya et al.[8] reported that the apposition process in the inner cortical plate of the labial alveolar bone was somewhat slower than the resorption process in the outer cortical plate of the labial alveolar bone.

The decrease in ABA of maxillary central and lateral incisors was more significant in the cervical region of the palatal side (-78% and -80%, respectively; Table 2) because the maxillary anterior teeth of the samples showed a controlled tipping movement pattern, leading to a greater accumulation of pressure in the alveolar crest region on the palatal side. However, on the labial side, the middle area of maxillary central and lateral incisors showed a greater increase in ABA than the cervical area where more tension existed (27% vs. -10%, 65% vs. 4%, respectively; Table 2). The reason that the cervical area did not show an increase in ABA on the labial side seems to be an inflammatory periodontal response concentrated in the cervical area, resulting in loss of VBL in spite of the greater tensional force. Therefore, the entire alveolar housing, not merely the bone in the apical zone, should be considered when a clinician tries to define the therapeutic limits for orthodontic tooth movement.[8]

At the T1 stage, VBL-amount and VBL-ratio on the labial side were greater than those on the palatal side in all of the maxillary anterior teeth (maxillary central and lateral incisors, $P < .001$; canines, $P < .01$, Table 4). These findings are consistent with the results of Nahm et al.[13] that reported VBL-ratios of 19.3% and 15.0% for the labial and palatal aspects of the maxillary anterior teeth. Careful inspection of bony defect before orthodontic treatment is required because it can be existed at the initial stage. The findings that, at the T2 stage, maxillary central incisors and lateral incisors showed a greater VBL-amount and VBL-ratio and a higher PD on the palatal side than on the labial side compared to canines (Tables 4 and 6) might result from the discrepancy in the direction of tooth movement in relation to the labiolingual long axis of the roots between maxillary central incisors, lateral incisors, and canines (Figure 4).

Dehiscence is one of the major bony defects, which is closely related with thin alveolus and difficult to determine its presence on conventional 2D x-ray films.[58] Previous CBCT studies defined the dehiscence as no cortical bone around the root in at least three sequential views when the distance from alveolar crest to CEJ was more than two mm.[59,60] However, in this study, dehiscence was determined when the ABA covering the cervical root was zero on the sagittal reference image. In spite of this strict definition of PD, our results showed a strikingly higher PD in the cervical area on the palatal side after space closure (67% of maxillary central incisors, 68% of lateral incisors, and 32% of canines, respectively; Table 6). Since the upper part of the roots of maxillary anterior teeth are supported by thin alveolar bone,[13] these areas are vulnerable to dehiscence during retraction. If the bracket prescription with excessive root torque is used in the maxillary anterior teeth, excessive root movement can cause a significant root resorption and PD of the labial or palatal cortical plate.[7] However, potential limitation of this result was the risk of overestimating dehiscence. Leung et al.[48] reported that positive predictive value of dehiscence was only 0.51 and alveolar bone height could be measured with an accuracy of about 0.6 mm using CBCT with a voxel size of 0.38 mm at 2 mA. Patcas et al.[47] also indicated that an alveolar bone thickness of 1 mm might be missed completely, even with a high-resolution protocol (0.125 mm voxels). Moreover, due to the additional bone remodeling continued slowly after active tooth movements, our results should be interpreted conservatively when applying them to the clinical situation.

Since patients with dentoalveolar protrusion usually have thin and elongated anterior alveoli and/or bony defect before treatment,[8,11,13] pushing the tooth against thin cortical bone may cause root resorption and/or alveolar bone defect easily (Figures 5 and 6). For these patients, retraction of the anterior teeth using absolute anchorage with orthodontic mini-implants might not always be a right answer. If labioversion of the incisors is excessive and the alveolus is thin, retraction of the anterior teeth combined with corticotomy of the alveolar bone can be an effective alternative to minimize the risk by uncontrolled movements of the anterior teeth.[3,4,11]

Another important issue is whether or not the repair of alveolar bone loss is possible after space closure and during retention period. In this study, some patients who were able to take CBCT at debonding stage did not show spontaneous bone apposition on the labial and palatal sides (Figure 6). Previous studies reported that once the cortical plate had been penetrated by the root, recovery of the well-defined dense cortical plate would not occur.[6,8,36,39] Therefore, further longitudinal studies are required to investigate whether repair of the alveolar bone defect takes place after space closure and during retention period and to find the discriminative factors for good and poor capacity of the alveolar bone remodeling.

VI. CONCLUSIONS

1. The null hypothesis that the alveolar bone area and vertical bone level on palatal or labial side and root length or area of maxillary anterior teeth before treatment were not different after space closure was rejected.
2. During en-masse retraction with maximum anchorage in cases with Class I dentoalveolar protrusion, the alveolar bone area and vertical bone level on the palatal side, root length and root area of the maxillary central and lateral incisors were significantly decreased.

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FIGURE LEGENDS

Figure 1. Reference planes and variables on the lateral cephalogram. **A.** Reference planes: Horizontal reference plane (HRP), a horizontal plane angulated 7° clockwise to Sella-Nasion plane passing through Sella; Vertical reference plane (VRP), a perpendicular plane to the HRP passing through Sella; Variables: 1. Δedge-AP, the amount of change in the sagittal distance (Δsagittal-distance) from VRP to the incisal edge of the maxillary central incisor (MXCIE); 2. Δedge-V, the amount of change in the vertical distance (Δvertical-distance) from HRP to MXCIE; 3. Δroot-AP, Δsagittal-distance from VRP to the root apex of the maxillary central incisor (MXCIA); 4. Δroot-V, Δvertical-distance from HRP to MXCIA; 5. Δaxis, the angular change of the long axis (LA) of maxillary central incisor; 6. ΔMX6M-AP, Δsagittal distance from the VRP to the most mesial point of the mesial surface of the maxillary first molar. **B.** Variables: 1. SNA (°); 2. SNB (°); 3. ANB (°); 4. SN-mandibular plane angle (°); 5. Facial height ratio (%); 6. maxillary central incisor -SN (°); 7.IMPA (°); 8. Interincisal angle (°).

Figure 2. Three-dimensional (3D) superimposition of cone-beam computed tomography (CBCT) images of the right maxillary central incisor based on its LA and clinical crown between the T1 and T2 stages. **A.** Setting of a LA of the maxillary central incisor on the sagittal image at the T1 stage. **B.** After 3D-superimposition by the best-fit method between the two sets of homologous landmarks in the T1 and T2 images, a manual refinement process is performed. **C.** Reorientation of the T2 image with the same LA of the T1 image through 3D-superimposition (left: raw image, right: reoriented image at the T2 stage)

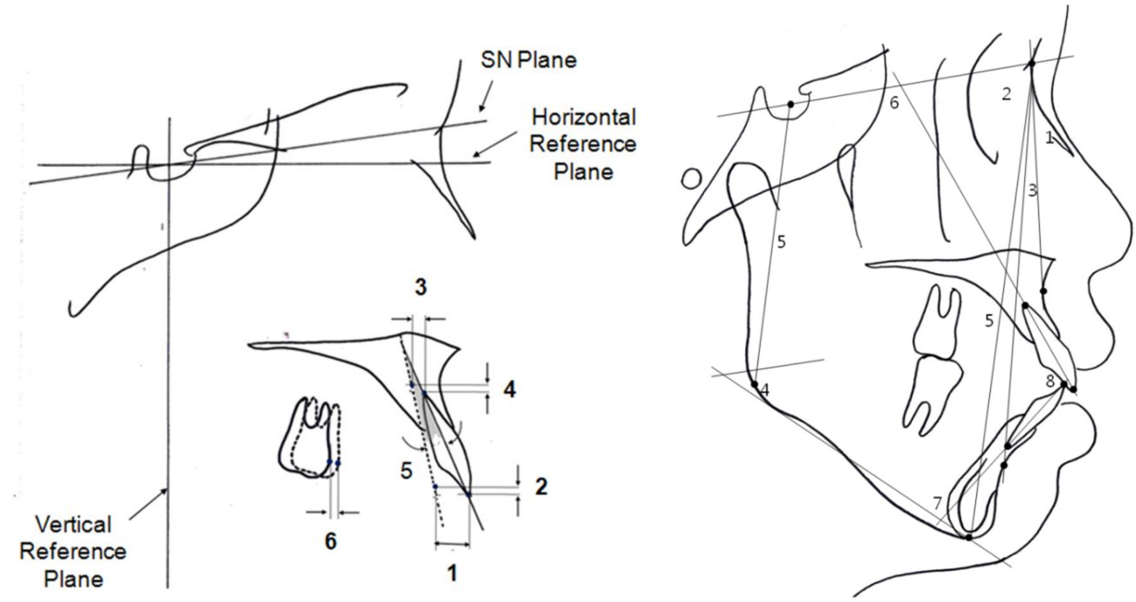
Figure 3. A. Landmarks and reference planes. 1. incisor edge or canine tip point; 2. root apex (RA) point; 3 and 4. cementoenamel junction (CEJ) points; 5 and 6. alveolar crest (AC) points; 7. CEJ-line (a line which connects points 3 and 4); 8. intersection point between long axis (LA, a line from points 1 to 2) and CEJ-line; 9. intersecting line perpendicular to LA at the upper

third of root length; 10. intersecting line perpendicular to LA at the lower third of root length; 11. intersecting line perpendicular to LA at RA; **B.** Variables. A. root length (distance from points 2 and 8); B. root area (root area below CEJ line); C and D. vertical alveolar bone level (distance from CEJ to AC parallel to LA); E and F. cervical alveolar bone area (ABA); G and H. middle ABA; I and J. apical ABA; K and L. total ABA on the labial (E+G+I) and palatal sides (F+H+J). Paired variables are the labial and palatal sides.

Figure 4. Direction of tooth movement from the T1 to T2 stages (solid arrow). The labiolingual LA of the maxillary anterior teeth at the T2 stage are used as a reference for the sagittal image (dashed line).

Figure 5. Examples of the sagittal images of the maxillary central incisor (A), lateral incisor (B), and canine (C) at the T1 (left image) and T2 stages (right image).

Figure 6. Examples of the maxillary central incisors (A), lateral incisors (B), and canines (C) at the T1 (left), T2 (middle), and debonding (right image) stages.



A **B**

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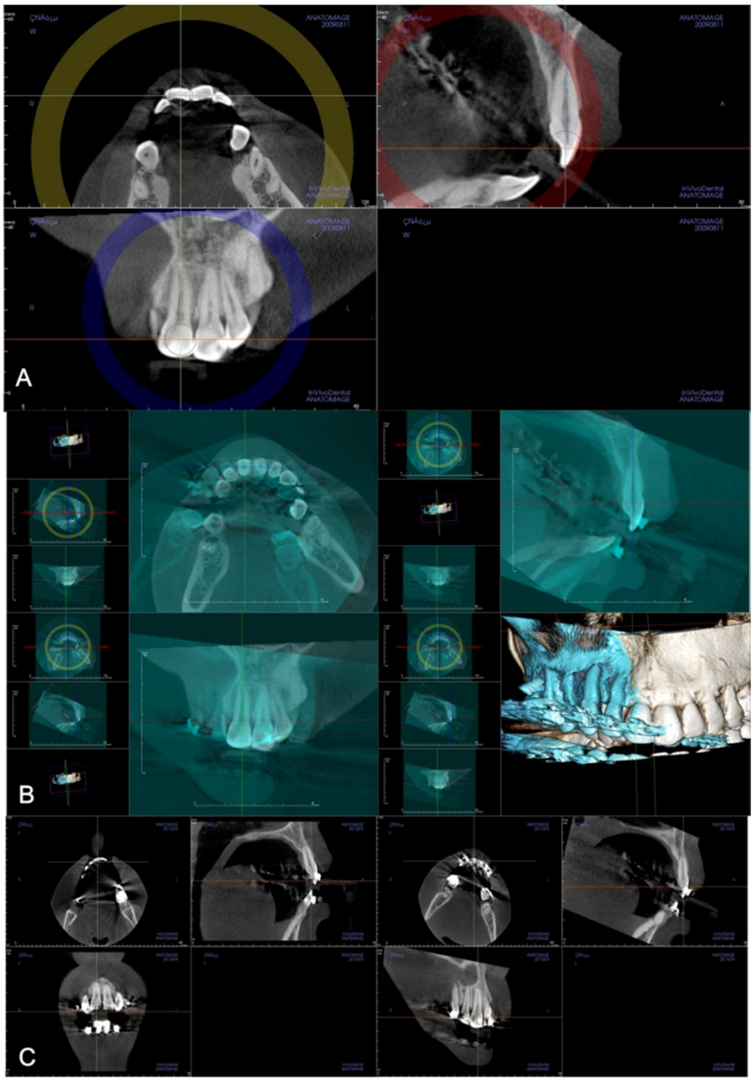
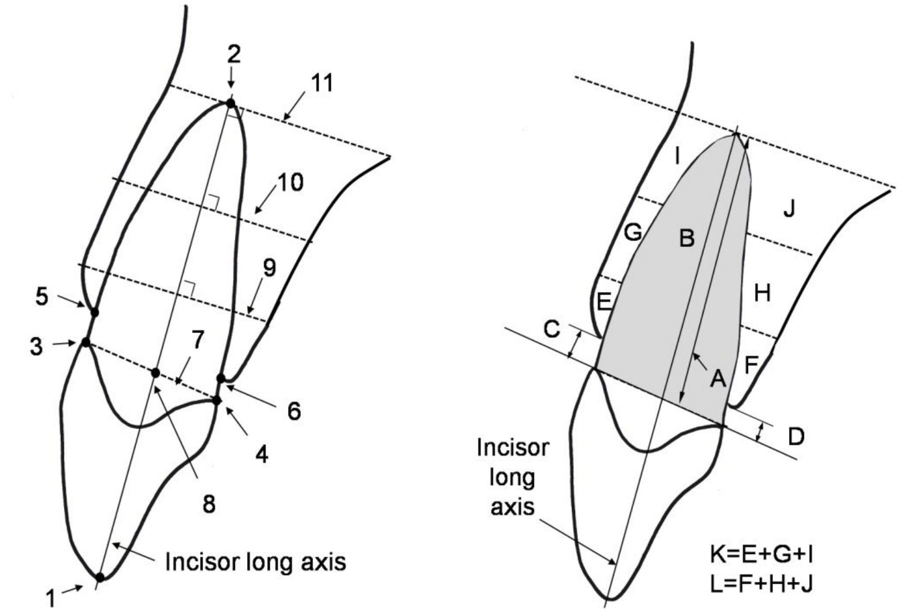


Figure 2. Three-dimensional (3D) superimposition of cone-beam computed tomography (CBCT) images of the right maxillary central incisor based on its long axis (LA) and clinical crown between the T1 and T2 stages. **A.** Setting of a LA of the maxillary central incisor on the sagittal image at the T1 stage. **B.** After 3D-superimposition by the best-fit method between the two sets of homologous landmarks in the T1 and T2 images, a manual refinement process is performed. **C.** Reorientation of the T2 image with the same LA of the T1 image through 3D-superimposition (left: raw image, right: reoriented image at the T2 stage)



A B

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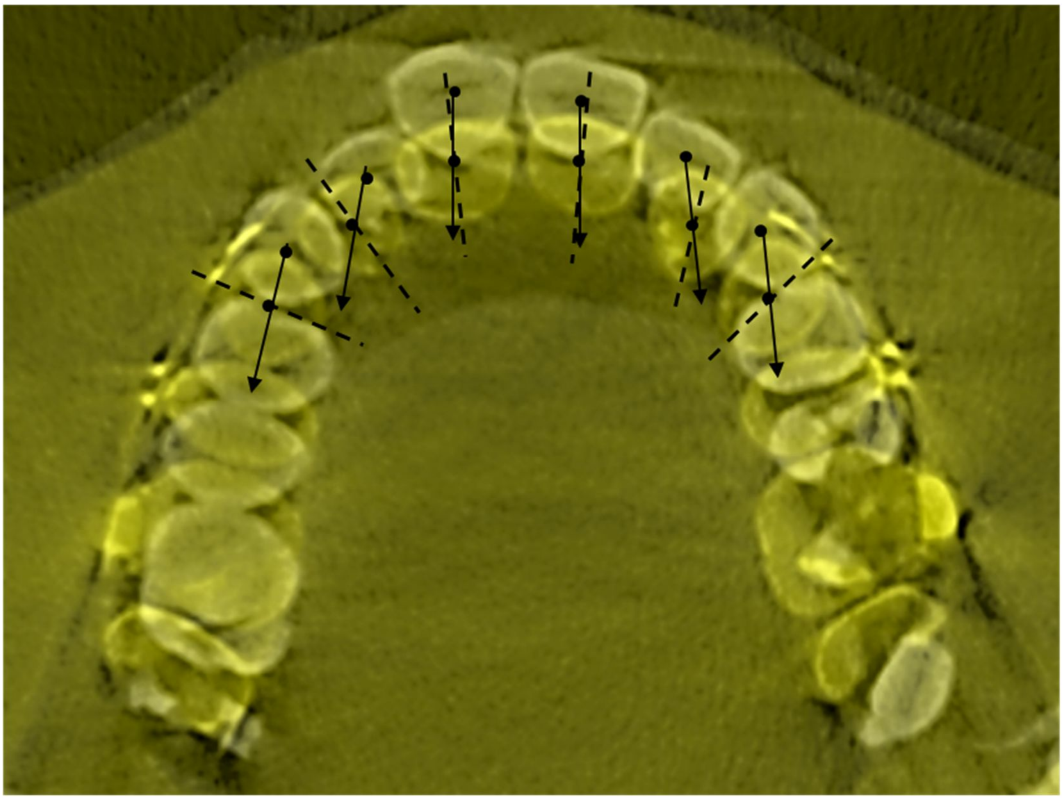

Figure 4. Direction of tooth movement from the T1 to T2 stages (solid arrow). The labiolingual LA of the maxillary anterior teeth at the T2 stage are used as a reference for the sagittal image (dashed line).

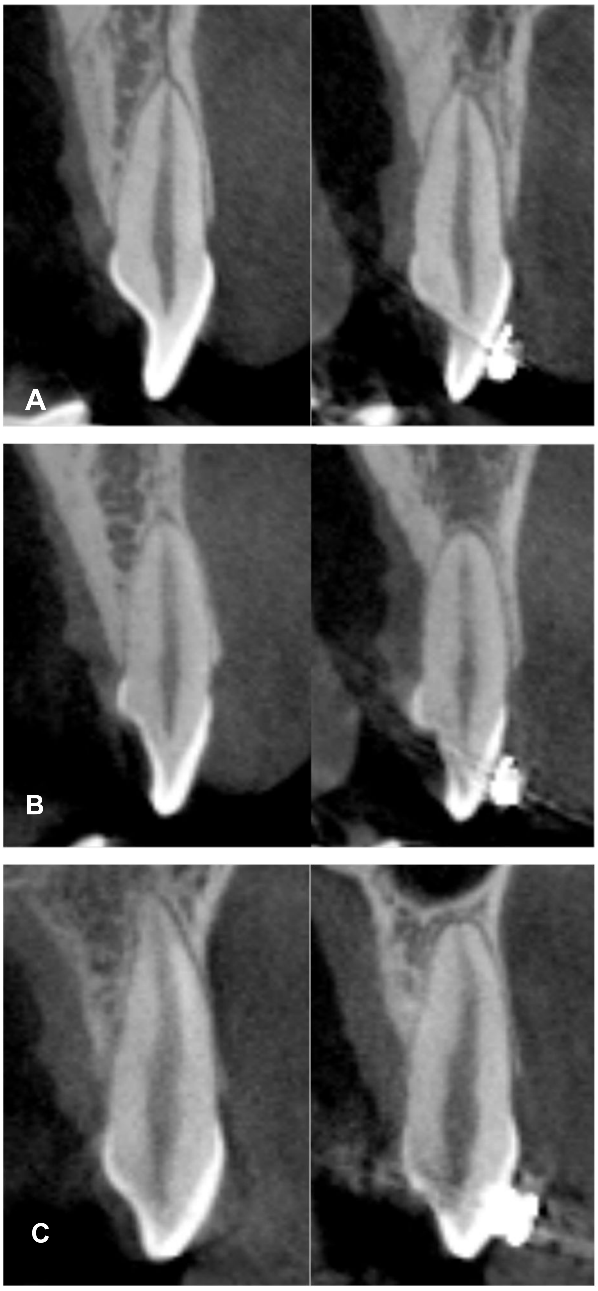

Figure 5. Examples of the sagittal images of the maxillary central incisor (A), lateral incisor (B), and canine (C) at the T1 (left image) and T2 stages (right image).

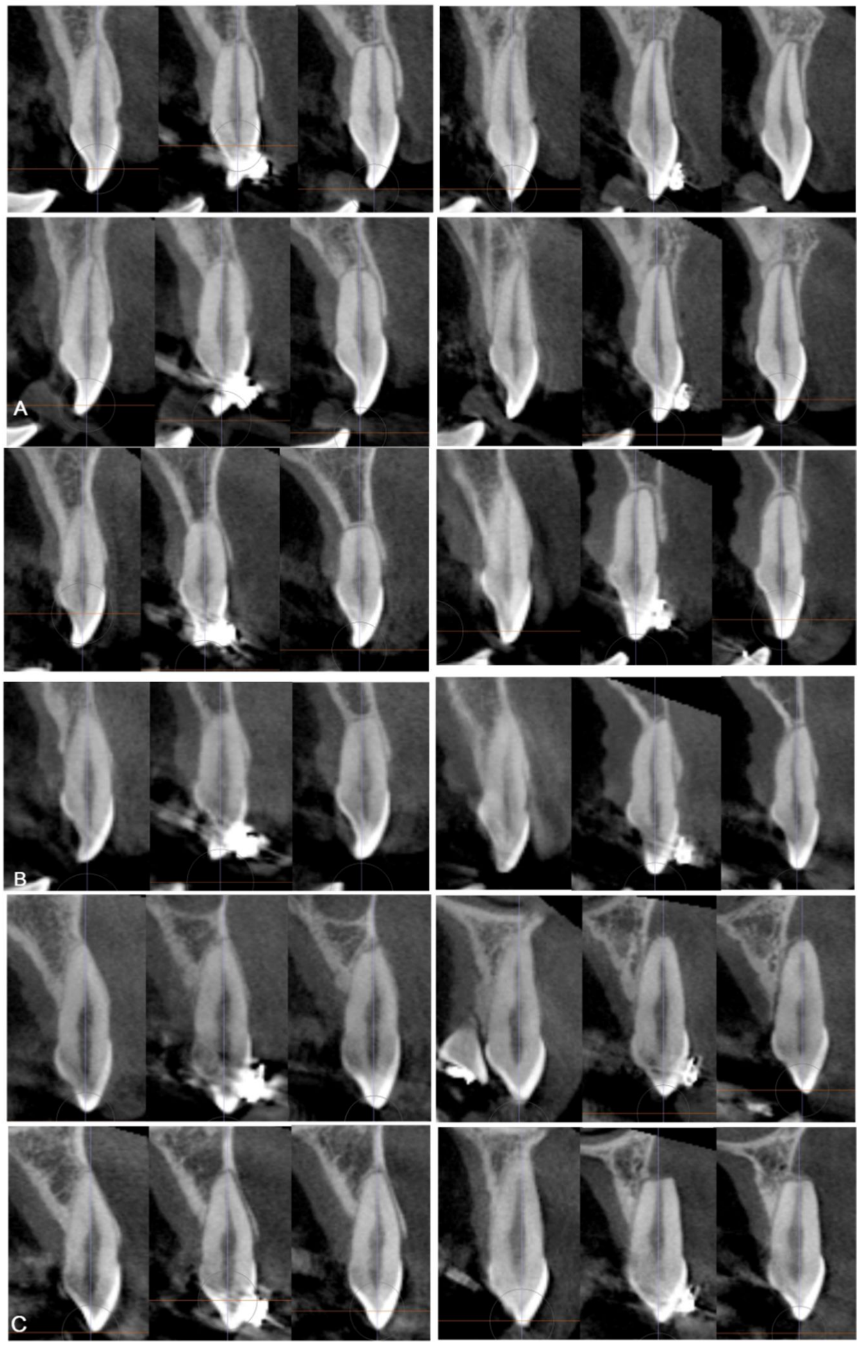

Figure 6. Examples of the maxillary central incisors (A), lateral incisors (B), and canines (C) at the T1 (left), T2 (middle), and debonding (right image) stages.

Table 1. Cephalometric characteristics of the samples (N = 37, females)

Variables		Mean	SD
Age (years)		26.62	8.46
Duration of orthodontic treatment (years)		1.81	0.42
Skeletal horizontal	SNA (°)	81.40	3.81
	SNB (°)	77.83	3.91
	ANB (°)	3.57	2.48
Skeletal vertical	Posterior/Anterior facial height ratio (%)	63.62	4.57
	SN to mandibular plane angle (°)	37.87	5.54
Dental	maxillary central incisor-SN (°)	127.74	3.49
	IMPA (°)	98.93	6.43
	Interincisal angle (°)	112.35	6.75
Changes of MXCI	ΔEdge-AP (mm)	-5.66	1.53
	ΔEdge-V (mm)	-0.69	0.89
	ΔRoot-AP (mm)	0.63	1.44
	ΔRoot-V (mm)	-0.30	1.05
	Δaxis change (°)	10.42	5.94
Anchorage value	ΔMX6M-AP (mm)	1.70	0.53
	MX1 to MX6 ratio	3.67	0.58

SD represents standard deviation; Δ, difference between pre-treatment (T1) and after space closure (T2); ΔEdge-AP, the amount of change in the sagittal distance (Δsagittal-distance) from vertical reference plane (VRP) to the incisal edge of maxillary central incisor (MXCIE); ΔEdge-V, the amount of change in the vertical distance (Δvertical-distance) from horizontal reference plane (HRP) to MXCIE; ΔRoot-AP, Δsagittal-distance from VRP to the root apex of the maxillary central incisor (MXCIA); ΔRoot-V, Δvertical-distance from HRP to MXCIA; Δaxis change, the angular change of the long axis (LA) of maxillary central incisor; ΔMX6M-AP, Δsagittal distance from the VRP to the most mesial point of the mesial surface of the maxillary first molar crown; MX1 to MX6 ratio [(ΔEdge-AP)/(ΔMX6M-AP)x(-1)], the amount of retraction of MXCIE according to every 1mm anchorage loss of the maxillary first molar.

Table 2. Comparison of the amounts of the alveolar bone area between the T1 and T2 stages in each tooth and the amounts of change during the T1 and T2 stages and ratio among the maxillary anterior teeth

Alveolar bone area		Maxillary central incisors (N = 66)						Maxillary lateral incisors (N = 69)					
		T1		△T		△T/T1 ratio	*P-value* [a]	T1		△T		△T/T1 ratio	*P-value* [a]
		Mean	SD	Mean	SD			Mean	SD	Mean	SD		
Labial side	cervical	1.56	1.98	-0.16	1.89	-0.10	0.5005	1.05	0.80	0.05	0.98	0.04	0.6922
	middle	2.41	1.13	0.65	1.47	0.27	0.0007‡	1.29	0.96	0.84	1.49	0.65	<0.0001‡
	apical	3.30	2.29	-0.19	2.42	-0.06	0.5247	1.69	1.74	0.09	1.62	0.05	0.6409
	total	7.27	4.17	0.30	3.78	0.04	0.5243	4.03	2.74	0.98	3.31	0.24	0.0168*
Palatal side	cervical	2.32	1.35	-1.82	1.18	-0.78	<0.0001‡	1.75	1.14	-1.40	0.94	-0.80	<0.0001‡
	middle	7.18	3.58	-4.32	3.09	-0.60	<0.0001‡	6.17	4.00	-3.38	3.30	-0.55	<0.0001‡
	apical	15.92	7.17	-6.66	6.62	-0.42	<0.0001‡	13.14	6.95	-6.17	6.27	-0.47	<0.0001‡
	total	25.42	11.43	-12.79	9.75	-0.50	<0.0001‡	21.06	11.76	-10.95	9.62	-0.52	<0.0001‡

[a] Paired t-test was performed to compare the values in the T1 and T2 stages. SD represents standard deviation; *, P<.05; †, P<.01; ‡, P<.001.

The ratio of the changes in the alveolar bone area was computed as follows: [amount of the changes in the alveolar bone area (T2-T1, △T) / amount of the alveolar bone area at T1 stage].

Table 2. Expanded.

Maxillary canines (N = 69)						Comparison of the amounts of change during T1 and T2 and ratio among the maxillary anterior teeth in the levels of each side			
T1		△T		△T/T1 ratio	*P-value*[a]	amount		ratio	
Mean	SD	Mean	SD			*P-value*[b]	*Multiple comparison*	*P-value*[b]	*Multiple comparison*
1.16	0.89	0.64	2.67	0.54	0.0517	0.0532		0.4769	
1.29	1.10	0.40	1.82	0.31	0.0694	0.2844		0.2765	
2.09	3.29	-0.10	3.73	-0.05	0.8162	0.8276		0.1731	
4.54	4.21	0.94	6.21	0.20	0.2144	0.6358		0.7221	
3.27	2.43	-1.57	2.11	-0.48	<0.0001‡	0.2629		0.0054†	(2,1)<3
13.01	6.09	-2.29	6.44	-0.18	0.0043†	0.0373*	(1,2)<(2,3)	0.0190*	(1,2)<3
31.54	11.70	-8.25	13.51	-0.26	<0.0001‡	0.4048		0.0244*	(2,1)<3
47.82	18.16	-12.10	18.66	-0.25	<0.0001‡	0.3900		0.0005†	(2,1)<3

[b] One-way ANOVA with Duncan's multiple comparison test was performed to assess the differences in the amount (T2-T1, △T) and ratio (ΔT/T1) of change in the cervical, middle, apical, and total levels. SD represents standard deviation; *, P<.05; †, P<.01; ‡, P<.001.

Table 3. Comparison of the palatal to labial alveolar bone area ratio between the T1 and T2 stages in each tooth and the amounts of change during the T1 and T2 stages among the maxillary anterior teeth.

Palatal / labial alveolar bone area ratio	Maxillary central incisors (N = 66)					Maxillary lateral incisors (N = 69)				
	T1		T2		*P-value*[a]	T1		T2		*P-value*[a]
	Mean	SD	Mean	SD		Mean	SD	Mean	SD	
cervical	2.75	4.41	0.56	1.23	0.0003‡	2.18	2.26	0.29	0.75	<0.0001‡
middle	3.66	3.20	1.51	2.13	<0.0001‡	6.71	10.86	4.83	21.95	0.4468
apical	9.38	15.03	4.63	6.17	0.0170*	23.19	43.91	10.47	31.01	0.0290*
total	4.37	3.15	2.42	2.42	<0.0001‡	11.55	34.02	5.21	12.04	0.1699

[a] Paired t-test was performed.

SD represents standard deviation; *, P<.05; ‡, P<.001.

The palatal to labial alveolar bone area ratio in the cervical, middle, apical, and total levels was calculated as follows: palatal alveolar bone area / labial alveolar bone area.

Table 3. Expanded

Maxillary canines (N = 69)					Comparison of the amounts of change during T1 and T2 among the maxillary anterior teeth
T1		T2		*P-value* [a]	
Mean	SD	Mean	SD		*P-value* [b]
3.30	4.43	3.49	17.11	0.9224	0.2649
15.43	16.15	13.83	27.48	0.7221	0.9899
38.29	55.39	30.09	48.94	0.4575	0.6778
14.87	10.92	15.01	24.21	0.9663	0.3535

[b] One-way ANOVA with Duncan's multiple comparison test was performed.

Table 4. Comparison of the amount and ratio of the vertical bone level of the alveolar bone between the T1 and T2 stages in each tooth and the amounts of change during the T1 and T2 stages among the maxillary anterior teeth

Vertical bone level			Maxillary central incisors (N = 66)				
			T1		△T		*P-value*[a]
			Mean	SD	Mean	SD	
Labial side		Amount (mm)	1.67	0.75	0.20	0.65	0.0136*
		Ratio (%)	13.88	6.52	1.64	5.78	0.0015†
Palatal side		Amount (mm)	1.30	0.51	3.65	2.65	<0.0001‡
		Ratio (%)	10.91	4.97	29.32	20.63	<0.0001‡
Comparison of the values between labial and palatal sides	*P-value*[c]	Amount (mm)	<0.0001‡		<0.0001‡		
		Ratio (%)	<0.0001‡		<0.0001‡		

[a] Paired t-test was performed to compare the values in the T1 and T2 stages.

[c] Independent t-test was performed.

SD means standard deviation; *, P<.05; †, P<.01; ‡, P<.001.

The ratio of the vertical alveolar bone level was computed as follows: [(amount of the vertical loss of the alveolar bone / root length)X100].

Table 4. Expanded.

Maxillary lateral incisors (N = 69)					Maxillary canines (N = 69)					Comparison of the amounts of change during T1 and T2 among the maxillary anterior teeth	
T1		△T		*P-value*[a]	T1		△T		*P-value*[a]		
Mean	SD	Mean	SD		Mean	SD	Mean	SD		*P-value*[b]	Multiple comparison
2.52	2.30	0.62	1.92	0.0095†	3.31	3.14	1.35	3.80	0.0042†	0.0271*	(1,2)<(2,3)
24.58	24.34	4.94	15.79	0.0341*	21.1	21.91	8.33	23.1	0.0005‡	0.0671	
1.52	1.06	4.42	3.09	<0.0001‡	1.75	1.22	2.42	2.05	<0.0001‡	0.0001‡	3<(1,2)
12.92	9.92	36.05	25.04	<0.0001‡	11.29	8.25	15.32	12.99	<0.0001‡	<0.0001‡	3<(1,2)
<0.0001‡		<0.0001‡			0.0012†		0.0528				
<0.0001‡		<0.0001‡			0.0012†		0.0410*				

[b] One-way ANOVA with Duncan's multiple comparison test was performed.

Table 5. Comparison of root resorption in terms of root length and root area between the T1 and T2 stages in each tooth, and the amounts of change during the T1 and T2 stages among the maxillary anterior teeth

	Maxillary central incisors (N = 66)					Maxillary lateral incisors (N = 69)				
	T1		T2		*P-value*[a]	T1		T2		*P-value*[a]
	Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Root length	12.33	1.44	11.26	1.52	<0.0001‡	12.28	1.93	11.14	1.83	<0.0001‡
Root area	55.87	11.07	52.32	10.74	<0.0001‡	55.06	9.19	51.64	9.26	<0.0001‡

[a] Paired t-test was performed.

SD represents standard deviation; ‡, P<.001.

Table 5. Expanded.

Maxillary canines (N=69)					Comparison of the amounts of change during T1 and T2 among the maxillary anterior teeth
T1		T2		*P-value*[a]	
Mean	SD	Mean	SD		*P-value*[b]
15.79	1.49	14.91	1.60	<0.0001‡	0.2198
85.24	11.94	82.48	11.89	<0.0001‡	0.3445

[b] One way ANOVA test were performed.

Table 6. Comparison of the prevalence of dehiscence in the cervical area between the labial and palatal sides in each tooth and among the maxillary anterior teeth in each side at the T2 stage

		Maxillary central incisors (N = 66)		Maxillary lateral incisors (N = 69)		Maxillary canine (N = 69)		*P*-value
		Incidence	percentage	Incidence	percentage	Incidence	percentage	
Labial side	cervical	1	2%	10	14%	8	12%	0.0251*
	middle	1	2%	11	16%	9	14%	-
	apical	2	3%	13	19%	12	18%	-
Palatal side	cervical	44	67%	47	68%	21	32%	<0.0001‡
	middle	8	12%	22	32%	0	0%	-
	apical	1	2%	2	3%	0	0%	-
Comparison of the prevalence of dehiscence in the cervical area between the labial and palatal sides	*P*-value	<0.0001‡		<0.0001‡		0.0066†		

Crosstab analysis was performed. *, P<.05; †, P<.01; ‡, P<.001.
If the alveolar bone area covering the root decreased to zero at the T2 stage, it was considered as dehiscence.

국문 초록

CBCT를 이용한 상악전치부 후방이동에 따른 상악전치부 치조골 및 치근의 변화 평가

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목 적: 본 연구는 최대 고정원을 이용하여 군집(en−masse) 후방 견인 후, 상악전치부 치조골 면적, 수직 치조골 높이, 치근 길이 및 면적의 변화를 평가하기 위함이다.

방 법: 골격성 I 급 치아치조전돌 성인 여성 환자 37 명을 대상으로, 상악 제 1 소구치 발거 후, 최대고정원으로 후방 견인을 시행하였다. 치료 전(T1)과 공간 폐쇄 후(T2), 콘빔형 전산화단층사진 (cone beam computed tomograms, CBCT)을 촬영하여, 상악 중절치(N = 66), 상악 측절치 (N = 69), 상악 견치 (N = 69)를 대상으로 개개 치아의 치관 형태와 치아 장축을 기준으로 삼차원 중첩을 시행하였다. 치근의 수직 길이를 3 등분하여, 치경부, 중간, 치근단 부위의 치조골 면적 및 치조골 수직 높이, 치근 길이, 치근 면적, 열개(dehiscence)의 유병률을 평가하고 통계처리 하였다.

결 과: 이로부터 다음과 같은 결과를 얻었다.

1. 구개측에서 상악 중절치, 측절치, 견치 모두, 모든 영역에서 유의한 치조골 면적의 감소를 보였다. 상악 중절치와 측절치는 견치보다 더 높은 치조골 면적의 감소율을 보였다. 순측에 대한 구개측 치조골 면적 비율은 상악 중절치와 측절치에서 감소하였다. 상악중절치와 측절치는 구개측에서 순측보다 치조골의 수직 높이가 더 크게 감소하였다.

2. 상악중절치, 측절치 견치 모두 구개측에서 순측보다 열개(dehiscence)의 유병률이 더 높게 나타났다. 상악 중절치의 순측 열개 유병률과 상악 견치의 설측 열개 유병률이 유의하게 낮았다.
3. 상악 중절치, 측절치, 견치 모두 치근 면적 및 치근 길이 감소가 유의하게 나타났으나 치아 간 차이는 없었다.

결 론: 골격성 I 급 양악치아치조 전돌 증례에서, 최대 고정원을 이용한 상악 전치부 군집 후방 견인 시, 상악 중절치와 측절치의 구개측 치조골 면적, 수직 치조골 높이, 치근 길이 및 면적의 유의한 감소를 보였다.

주요어: 치조골; 치근; 상악전치부; 군집 후방이동; 발치공간 폐쇄; 삼차원 CBCT

학 번: 2010-31199