Evaluation of alveolar bone remodeling around maxillary and mandibular central incisors during orthodontic extraction treatment using Conebeam CT

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감사의 글

박사학위를 연세대학교 치과대학에서 받을 수 있게 되어 감개무량합니다. 부족함이 많은 논문을 자상하고 꼼꼼히 지도하고 가르쳐주신 유형석 지도교수님으로부터 학문에 대한 자세뿐 아니라 인격적인 면까지 많은 점을 배울 수 있었습니다. 논문과 학위가 끝이 아니라, 앞으로도 교수님께 많은 가르침을 구하는 제자가 되겠습니다. 심사기간 동안 세련된 매너와 유쾌한 대화로 격려해주신 백형선 교수님, 논문을 세밀하게 검토해 주셔서 미흡한 부분을 보완할 수 있도록 지도해 주신 황충주 교수님, 논문을 심사 받으며 처음 뵈었지만 따뜻하게 조언해주시고 배려해주신 최성호 교수님, 김기덕 교수님께 깊은 존경과 감사의 마음을 바칩니다.

뵐 때마다 인자한 웃음으로 인사를 받아주시는 박영철 교수님께 존경의 마음을 전하며, 부족한 논문에 관심을 갖고 조언해주신 김경호, 이기준, 차정열, 정주령 교수님께도 깊이 감사 드립니다.

논문을 쓰는 동안 기술적 조언을 해주신 Anatomage 사의 김기현 이사님과 Vatech 사의 정동수 대리님, 통계에 도움을 주신 예방치과 이은송 조교님께 더불어 고마움을 표합니다.

수업을 받고 논문을 쓰는 동안 학문에 정진할 수 있도록 용기를 주고 응원해주신 어머니와 장인, 장모님께 사랑하며 감사하다는 말씀 올립니다. 하늘나라에서 기뻐해주실 아버지의 은혜는 항상 감사 드립니다. 논문이 완성되는 동안 자신감을 심어주고, 가장 든든한 힘이 되어준 아내 정재현과 우리 두 사람이 가장 사랑하는 보물들인 쌍둥이 딸 초영이 초원이에게 이 박사논문을 바칩니다.

2013 년 6 월 저자 김 일 곤

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Abstract

Evaluation of alveolar bone remodeling around maxillary and mandibular central incisors during orthodontic extraction treatment using Conebeam CT

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(Directed by Professor **Hyung Seog Yu**, DDS.,M.S., Ph.D.)

This study was conducted on adult patients who underwent orthodontic extraction treatment. Lateral cephalometric X-ray and Cone Beam Computed Tomography (CBCT) were conducted on the subjects before and after treatment. The buccal and palatal alveolar bone thickness of maxillary and mandibular central incisors at the 3 mm, 6 mm, and 9 mm apical levels from CEJ, the distance from CEJ to the buccal and palatal alveolar crestal bone, and the buccal and palatal alveolar bone area from CEJ to 9BT level were measured, and the changes in the measurement variables before and after treatment were analyzed. The subjects were divided into the tipping and torque groups according to the movement of anterior teeth observed in lateral cephalometric X-ray, followed by intra-group analysis and correlation analysis. The results of this study were as follows.

1. After orthodontic extraction treatment, the 6BT and 9BT of the maxilla ($p<0.01$)($p<0.001$) and the 6BT and 9BT of the mandible ($p<0.05$)($p<0.001$) significantly increased. Meanwhile, the PT at 3 mm, 6 mm, and 9 mm apical levels from CEJ and PABA significantly decreased in both maxilla and mandible ($p<0.001$).

2. After orthodontic extraction treatment, the BABL decreased by 0.22 mm ($p<0.01$), and the PABL decreased by 3.83 mm ($p<0.001$) in the maxilla. Meanwhile, the BABL decreased by 2.59 mm ($p<0.01$), and the PABL decreased by 5.82 mm ($p<0.001$) in the mandible.

3. In the case of Torque group, in the maxilla and mandible, the 6BT ($p<0.01$) and the 9BT ($p<0.001$) significantly increased, whereas the 3PT, 6PT, and 9PT significantly decreased in both maxilla and mandible ($p<0.001$). The PABL ($p<0.001$) in the maxilla and the BABL and PABL ($p<0.01$)($p<0.001$) in the mandible significantly decreased. BABA in the maxilla ($p<0.01$) and mandible ($p<0.05$) significantly increased and PABA in the maxilla ($p<0.001$) and mandible ($p<0.001$) significantly decreased.

4. In the case of Tipping group, no significant difference in the BT was found in the maxilla, but the 3BT ($p<0.001$) decreased and 9BT ($p<0.05$) increased in the mandible. 3PT, 6PT ($p<0.001$) and 9PT ($p<0.01$) significantly decreased in the maxilla and 3PT ($p<0.05$) and 6PT ($p<0.01$) significantly decreased in the mandible. In addition, BABL and PABL in the maxilla ($p<0.05$)($p<0.001$) and mandible ($p<0.001$) significantly decreased. PABA ($p<0.001$) in the maxilla and BABA ($p<0.01$) and PABA ($p<0.01$) in the mandible significantly decreased.

5. After orthodontic extraction treatment, the change of the axis of maxillary and mandibular incisors and the root movement were highly correlated with the alveolar bone thickness and area.

In orthodontic extraction treatment for adults who have reduced alveolar regeneration compared to adolescents, incisors movement type should be determined considering alveolar bone thickness and periodontal condition before treatment. In the maxilla, as the resorption of the buccal alveolar bone is insignificant, and that of the palatal alveolar bone is significant but in the mandible the resorption of both buccal and palatal alveolar bone is significant. So, mandibular incisor retraction plan should be more carefully established.

Key words : CBCT, Orthodontic extraction treatment, Central incisor, Anterior teeth retraction, Alveolar bone resorption, Alveolar bone thickness, Alveolar bone area, Alveolar bone remodeling.

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I. INTRODUCTION

In orthodontic treatment, the maintenance or improvement of the health status of the periodontal tissue is as important as the achievement of aesthetic and functional goals. Studies have been actively conducted to determine the optimal force to minimize possibilities of root resorption, recession of periodontal tissue, dehiscence and fenestration of alveolar bone during orthodontic treatment.[1] Teeth move via alveolar bone remolding during orthodontic treatment. The health status of the alveolar bone is important for the prediction of teeth movement during orthodontic treatment and for the maintenance of the stability after orthodontic treatment. In addition, alveolar bone height plays a critical role in the determination of the center of resistance of the anterior teeth during orthodontic treatment. If the height of the alveolar bone is changed during the treatment, the change of the center of resistance should be also considered in the process of the maintenance or improvement of the axis.

In a study using lateral cephalometric X-ray under assumption that the alveolar bone undergoes physiological remodeling during orthodontic treatment, which is based on the conventional thinking that the bone traces tooth movement during orthodontic treatment, tooth movement vs alveolar bone remodeling was reported to be a ratio of 2:1.[2] In another study, the alveolar bone was formed and stably maintained via orthodontic treatment that moved the canine to the location of the lateral incisor in the case of lateral incisor missing.[3]

Orthodontic treatment utilizes a remodeling process that is responsive to the stress applied to the teeth of the alveolar bone. The resorption of the alveolar bone occurs by osteoclasts in the region where the compressive force is applied to the tooth, and the formation of the alveolar bone occurs by osteoblasts in the region where the tensile force is applied to the tooth, via which tooth movement occurs. However, this remodeling process varies depending on age.[4] In adolescent patients, alveolar bone regeneration is somewhat expected after tooth movement. However, alveolar bone regeneration in adults is less expected compared to adolescent patients.[5] None the less, many adults undergo orthodontic treatment with premolar extraction in order to solve bimaxillary protrusion for aesthetic purposes. Furthermore, as miniscrew implants have been commonly used for anchor reinforcement in the orthodontic area, the retraction of anterior teeth for improvement of protrusion was further maximized, leading to tooth movement that is significantly larger compared to the past situation.

In adults, periodontal condition is more disadvantageous compared to adolescents, but more retraction is required in many cases. Thus, it is important to examine the health condition of the alveolar bone before treatment, and to assess the remodeling of the alveolar bone during the treatment. For the improvement of protrusion in adults, the treatment goal is to the retraction of anterior teeth after premolar extraction. However, if orthodontic treatment focuses on aesthetic and functional aspects by maximizing the retraction of anterior teeth and ignoring periodontal condition in adults with significantly low bone regeneration, tooth movement that exceeds alveolar bone housing occurs, which may result in the loss of periodontal support.

2-dimensional lateral cephalometric X-rays have been conventionally used for the establishment and assessment of orthodontic treatment. However, 3-dimensional evaluation has been conducted due to the common use of CBCT.[6] It was difficult to quantitatively analyze maxillary and mandibular incisors individually via analysis using a 2–dimensional X-ray, but the quantitative analysis of individual teeth was enabled via CBCT.[7] As the 3-dimensional axis of individual teeth can be accurately determined and reproduced via CBCT, the measurement of the tooth and alveolar bone before and after treatment can be performed for each tooth, and reproducibility and consistency can be maintained.

The purpose of this study was to investigate alveolar bone remodeling around maxillary and mandibular central incisors during orthodontic extraction treatment in adults. Changes in the thickness and area of the buccal and lingual alveolar bone around maxillary and mandibular central incisors were measured and compared using CBCT in order to assess the relationship of central incisor movement and axial change with alveolar bone remodeling.

II. MATERIALS AND METHODS

1. Subject selection and lateral cephalometric X-ray and CBCT

Lateral cephalometric X-ray and Cone Beam Computed Tomography *Implagraphy SC 8X5* (FOV: 8 cm X 5 cm, Voxel Size : 0.22 mm, Vatech, Seoul, Korea) were obtained from patients who visited the author's clinic for orthodontic treatment for a diagnostic purpose. They were also obtained from the patients after the completion of orthodontic treatment for post treatment evaluation. Among the aforementioned patients, 35 adult patients who satisfied the following criteria according to the results of clinical and radiologic examination were selected as the subjects of this study.

a. Patient visited the clinic due to protrusion and undergone orthodontic treatment after extracting four premolars (upper, lower, right, left)
b. Patient had a crowding of maxillary and mandibular incisors ≤ 4 mm
c. Patient had not undergone prosthodontic treatment or endodontic treatment of central incisors.
d. Patient whose dental growth had been completed without orthodontic treatment
e. Patient had not root resorption or periodontal inflammation

1) Subject selection

A total of 35 subject had a mean age of 22 years and 10 months, and they consisted of 5 men (mean 21 years and 11 months) and 30 women (mean 22 years and 9 months). The subjects underwent space closure with 022 Roth prescription SWA bracket using Sliding Mechanic. Miniscrew implants were implanted on maxillary molar area, which were used as an anchor. The mean treatment period was 34 months.

2) Lateral cephalometric X-ray and CBCT

Before and after treatment, lateral cephalometric X-ray and CBCT were performed on the subjects in a posture of Natural Head Position (NHP) by referring to vertical and horizontal guidelines. Digital lateral cephalometric X-ray and CBCT data were obtained using Implagraphy SC 8X5 (FOV: 8 cm X 5 cm, Voxel Size : 0.22 mm)(Vatech Inc.). The data of the digital lateral cephalometric X-ray were analyzed via tracing and superimposition using QuickCeph® Studio (Quick Ceph Systems, San Diego, CA), and CBCT DICOM Data were analyzed using a 3-D analysis software, “OnDemand 3D” (Cybermed, Seoul, Korea).

2. Measurement method

1) Measurement using lateral cephalometric X-ray

Each horizontal reference plane that has the best reproducibility was used to assess the movement of maxillary and mandibular incisors. As for the maxilla, the palatal plane was used as a reference plane, and the vertical line that passes the ANS was used as a reference line to assess the posterior retraction of maxillary incisors. The vertical movement was measured via the shortest distance from the palatal plane. As for the mandible, the mandibular plane was used as a reference plane, and the vertical line that passes Pogonion was used as a reference line to assess the posterior retraction of mandibular incisors. The vertical movement was measured via the shortest distance from the mandibular plane (Table 1)(Figure 1).

Table 1. Variables of cephalometric analysis

Variables	Explanation
Maxilla	
1 to SN	Upper Incisors angle to Sella-Nasion Plane
1 to PP	Upper Incisors angle to Palatal Plane
U1RPP	Distance between Upper Incisor Root Apex and Palatal plane
U1IPP	Distance between Upper Incisor Crown Tip and Palatal plane
U1RAV	Distance between Upper Incisors Root Apex and Perpendicular line to Palatal plane through ANS
U1IAV	Distance between Upper Incisors Crown tip and Perpendicular line to Palatal plane through ANS
Mandible	
IMPA	IMPA
L1IPV	Distance between Lower Incisors Crown tip and Perpendicular line to Mandibular plane through Pogonion
L1RPV	Distance between Lower Incisors Root Apex and Perpendicular line to Mandibular plane through Pogonion
L1IMP	Distance between Lower Incisor Crown Tip and Mandibular plane
L1RMP	Distance between Lower Incisor Root Apex and Mandibular plane

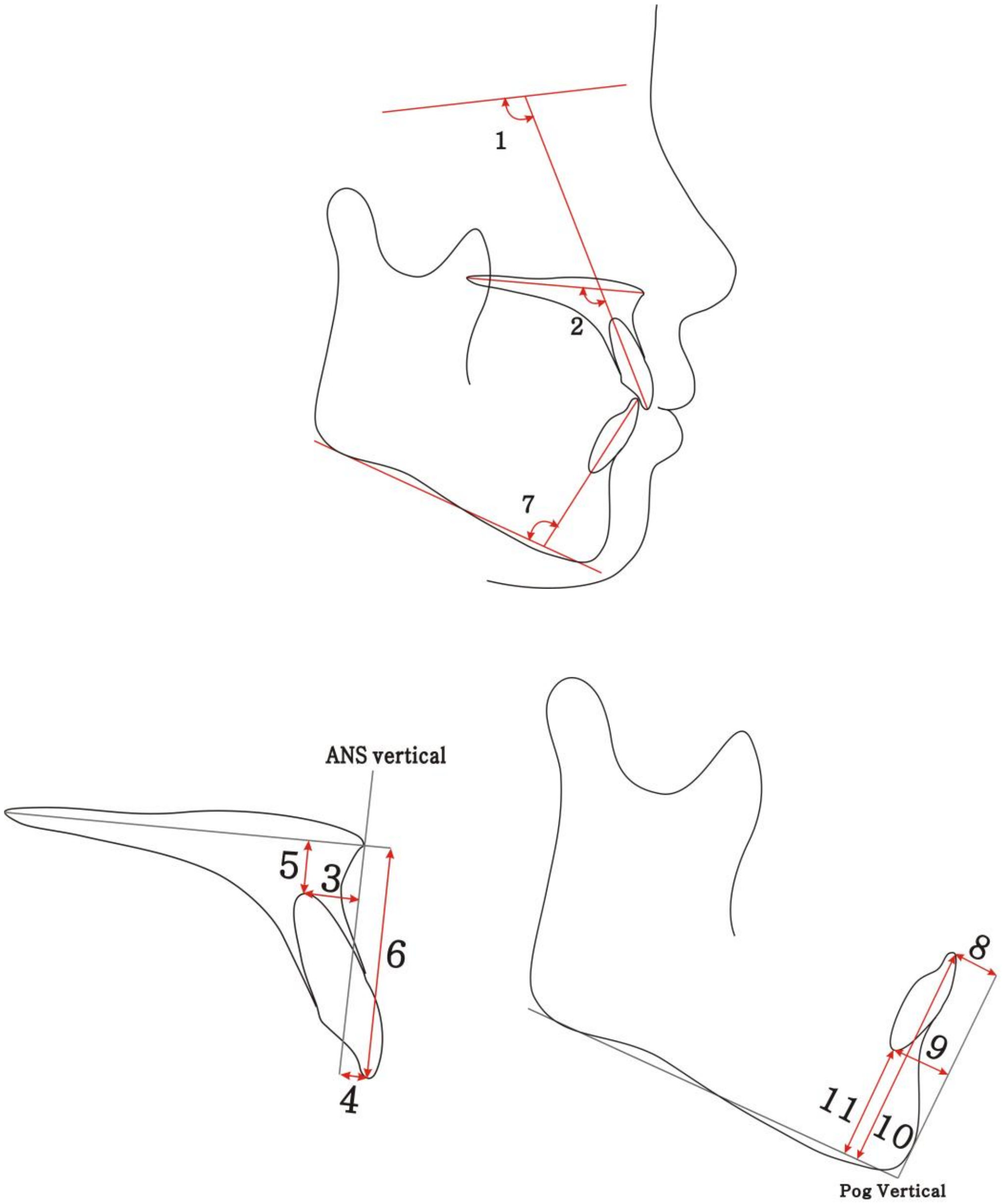
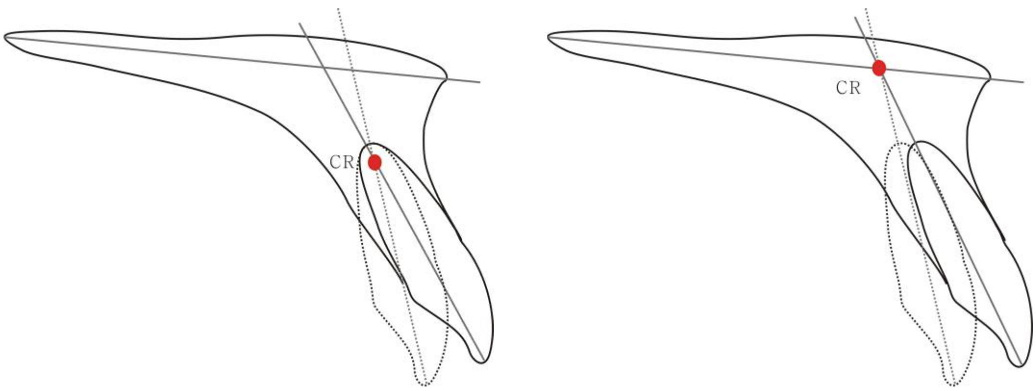


Figure 1. Reference planes and variables on the lateral cephalometric x-ray

1. 1 to SN, 2. 1 to PP, 3. U1RPP, 4. U1IPP, 5. U1RAV,

6. U1IAV, 7. IMPA, 8. L1IPV, 9. L1RPV, 10. L1IMP, 11. L1RMP

In case where the center of rotation was present in the inside of the tooth depending on the type of maxillary and mandibular incisor movement, it was classified into the Tipping Group (Tip-Group) where tipping movement mainly occur. In case where the center of rotation was present in the outside of the tooth, it was classified into the Torque Group (Trq-Group) where bodily movement mainly occurs.[8] Then, alveolar remodeling was investigated according to the tooth movement type of maxillary and mandibular central incisors (Table 2)(Figure 2).



Tip-Group Trq-Group

Figure 2. Classification of Tip-Group and Trq-Group

Table 2 . Subjects of Tip-Group and Tor-Group

Group	N
Maxilla	
Mx Tip	18
Mx Trq	17
Mandilble	
Mn Tip	15
Mn Trq	20

2) Measurement using CBCT

After maxillary and mandibular incisors were selected as the subjects of this study, the following variables were measured by setting the long axis along the pulp cavity as a reference line to determine the sagittal long axis of individual teeth (Table 3)(Figure 3, 4)

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1) Buccal and palatal bone thickness at 3 mm, 6 mm, and 9 mm apical levels from CEJ (3BT, 3PT, 6BT, 6PT, 9BT, 9PT)
2) Distance from CEJ to buccal alveolar crestal bone, Distance from CEJ to palatal alveolar crestal Bone (BABL,PABL)
   - Expressed in ***negative distance*** from the point of origin(CEJ) to help understand the decrease in the measurements to the deterioration.
3) Buccal alveolar bone area from buccal alveolar crest to 9BT level, Palatal alveolar bone area from palatal alveolar crest to 9PT level (BABA, PABA)

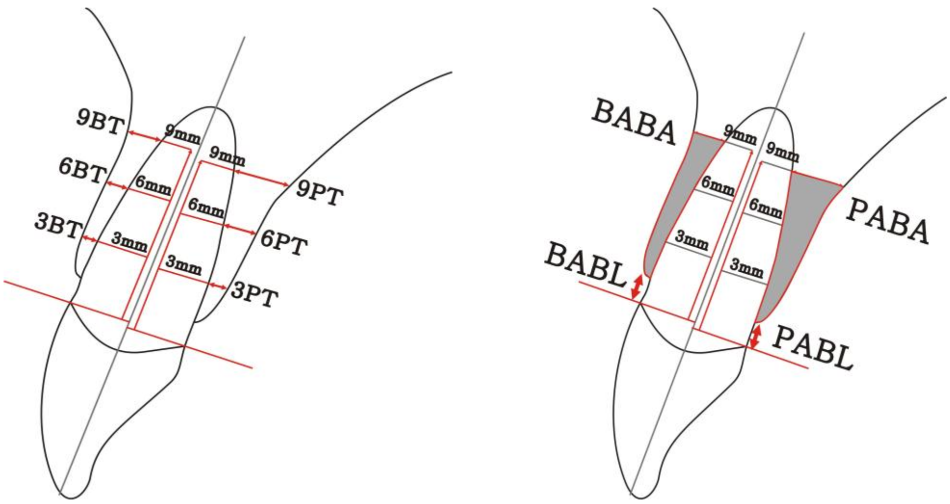

Figure 3.1. Variables on the CBCT 2D MPR Sagittal view

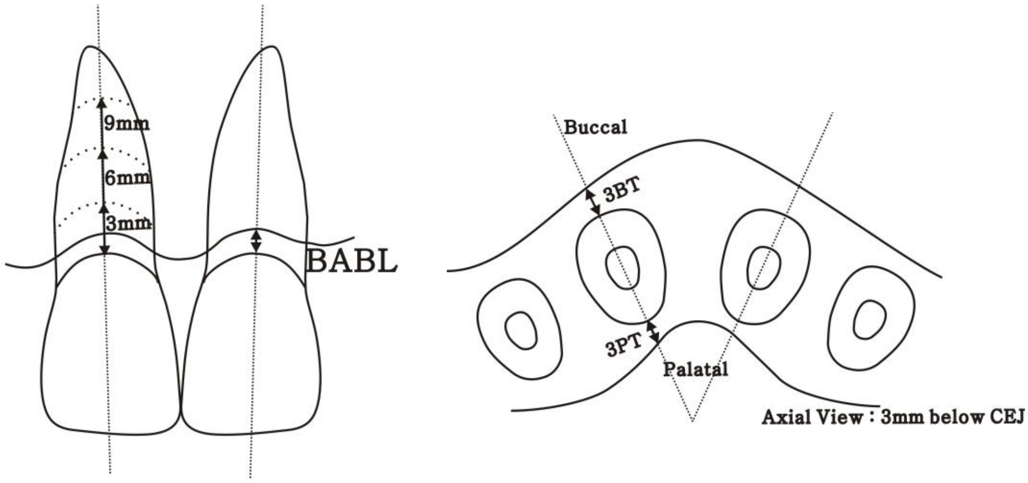

Figure 3.2. Variables on the CBCT 2D MPR Coronal & Axial view

Table 3. Variables of CBCT analysis

	Explanation
3BT	Buccal bone Thickness at the 3 mm apical level from CEJ
3PT	Palatal bone Thickness at the 3 mm apical level from CEJ
6BT	Buccal bone Thickness at the 6 mm apical level from CEJ
6PT	Palatal bone Thickness at the 6 mm apical level from CEJ
9BT	Buccal bone Thickness at the 9 mm apical level from CEJ
9PT	Palatal bone Thickness at the 9 mm apical level from CEJ
BABL	Distance from CEJ to Buccal Alveolar Crestal Bone
PABL	Distance from CEJ to Palatal Alveolar Crestal Bone
BABA	Buccal Alveolar Bone Area from Buccal Alveolar Crest to 9BT level
PABA	Palatal Alveolar Bone Area from Palatal Alveolar Crest to 9PT level

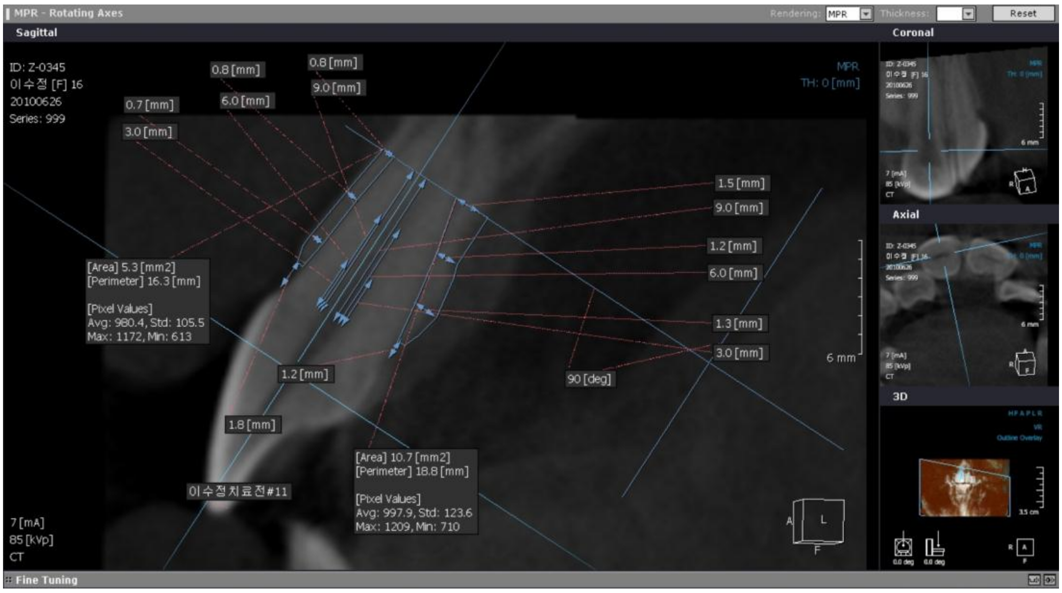

Figure 4.1. CBCT analysis of #11 before Treatment (T1)

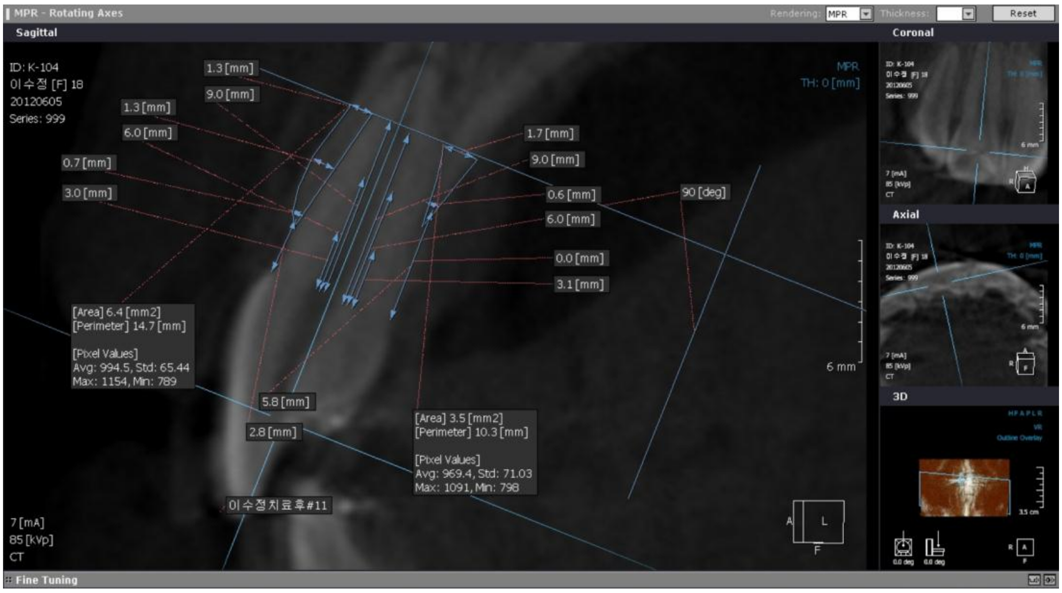

Figure 4.2. CBCT analysis of #11 after Treatment (T2)

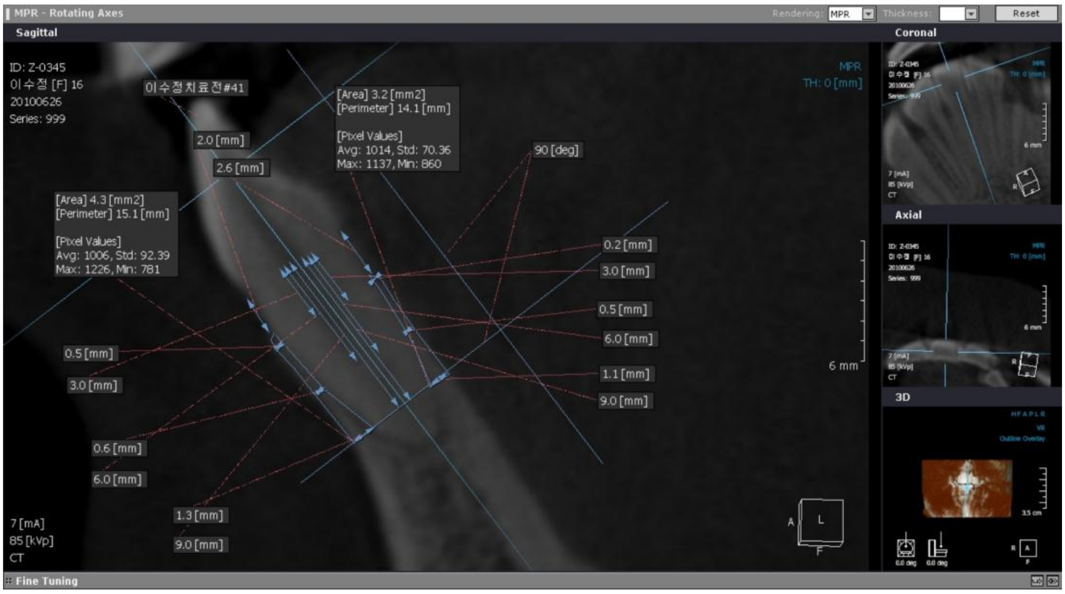

Figure 4.3. CBCT analysis of #41 before Treatment (T1)

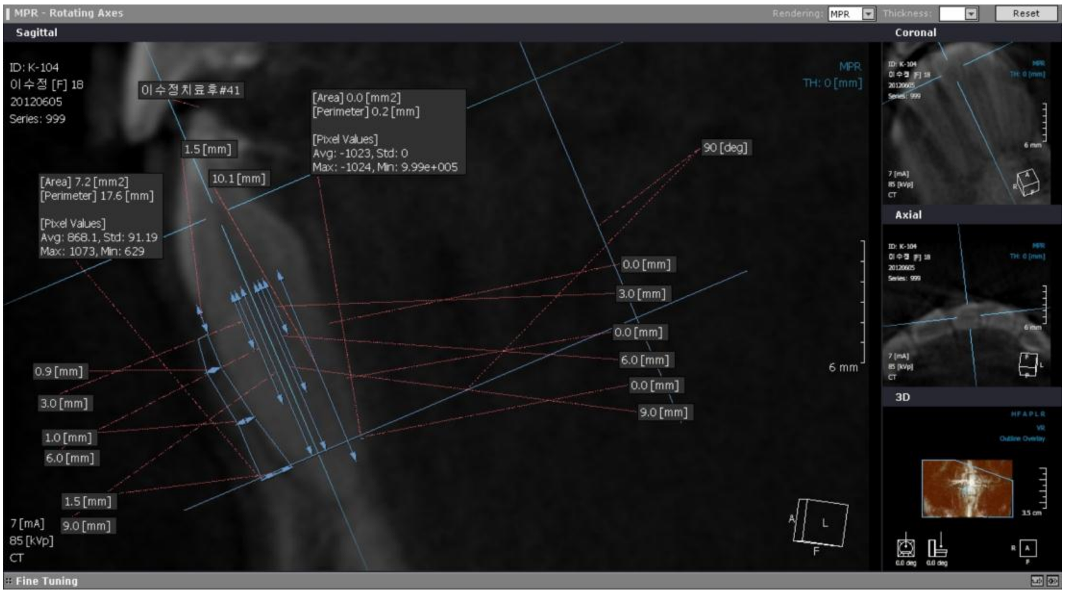

Figure 4.4. CBCT analysis of #41 after Treatment (T2)

3. Statistical analysis of the measured variables

The measurement and analysis of the obtained data was conducted by a single person. The obtained data were statistically analyzed using SPSS.

1) Intra-examiner error testing

Paired t-test was conducted.

2) Results of lateral cephalometric X-ray on the whole subjects

Paired t-Test was conducted.

3) Results of lateral cephalometric X-ray according to Tip-Trq group classification

Levene test was conducted for testing significant difference.

3) Results of CT analysis

Paired t-Test was conducted.

4) Results of CT analysis according to Tip-Trq group classification

Levene test was conducted for testing significant difference

5) Analysis of the correlation between lateral cephalometric X-ray and CT data

Pearson correlation was conducted.

6) Analysis of the correlation between lateral cephalometric X-ray and CT data according to Tip-Trq group classification

Pearson correlation was conducted.

III. RESULTS

1. Intra-examiner error testing

For the assessment of the reliability of the measured values, five samples were randomly collected, and then measured again by a single person using the same method at an interval of one week. The result of paired t-test showed no significant difference ($p>0.05$).

2. Results of lateral cephalometric X-ray on the total subjects

The mean and standards deviation was measured before (T1) and after treatment (T2). A paired t-test was conducted to test the significance of changes in the angle and vertical and horizontal movement of maxillary and mandibular central incisors before and after treatment (Table 4). After the treatment, both maxillary and mandibular central incisors were inclined lingually, and the proclination of the anterior teeth significantly decreased. As for inclination of the maxillary central incisors, the $\underline{1}$ to SN was 11.13^{o} inclined lingually and the $\underline{1}$ to PP was 11.02^{o} inclined lingually ($p<0.001$). The crown tip and root apex were retracted 5.22 mm and 0.99 mm posteriorly, respectively ($p<0.001$)($p<0.01$). As for change in the vertical movement of the maxillary central incisors before and after treatment, the crown tip was 0.54 mm extruded, and the root apex was 0.83 mm intruded ($p<0.05$).

The mandibular central incisors were 9.69^{o} lingually inclined after treatment ($p<0.001$). The crown tip was retracted 5.12 mm posteriorly, and the root apex was retracted 2.01 mm posteriorly ($p<0.001$). Compared to the status before the treatment, the crown tip was 2.06 mm intruded ($p<0.001$), and the root apex was 2.21 mm intruded after the treatment ($p<0.01$).

Table 4. Comparison of Changes of Central lncisor before and after treatment in cephalometry

	T1(Before Tx)		T2(After Tx)		**ΔT(T2-T1)**		p-
Variables	Mean	SD	Mean	SD	Mean	SD	value
Maxilla							
1 to SN(^{o})	110.25	3.93	99.13	5.84	-11.12	4.07	***
1 to PP(^{o})	120.38	4.04	109.36	5.55	-11.02	4.04	***
U1RAV(mm)	-7.30	1.77	-8.30	2.30	-1.00	1.56	**
U1IAV(mm)	4.49	2.32	-0.72	2.76	-5.21	1.33	***
U1RPP(mm)	10.57	2.13	9.74	2.61	-0.83	1.27	*
U1IPP(mm)	30.74	2.32	31.28	2.58	0.54	1.42	*
Mandible							
IMPA(^{o})	100.22	7.67	90.53	7.53	-9.69	5.63	***
L1IPV(mm)	-6.21	3.31	-11.34	3.67	-5.13	1.92	***
L1RPV(mm)	-9.51	1.53	-11.52	2.13	-2.01	1.37	***
L1IMP(mm)	43.68	3.02	41.62	2.98	-2.06	1.09	***
L1RMP(mm)	24.41	2.84	22.29	2.89	-2.22	1.47	**

(* p<0.05 , ** p<0.01, *** p<0.001)

3. Results of lateral cephalometric X-ray according to Tip-Trq Group classification

A Levene test was conducted to test the variables measured before (T1) and after treatment (T2). After the mean and standard deviation of the variables were obtained, changes in the angle and vertical and horizontal movement of the maxillary and mandibular central incisors before and after treatment were tested for their significance (Table 5).

The maxillary anterior teeth were 12.77^o and 12.86^o lingually inclined against the SN plane and palatal plane in the Tip-Group ($p<0.001$), whereas they were 7.39^o and 7.56^o lingually inclined against SN plane and palatal plane in the Trq-Group ($p<0.001$). The crown tip of the maxillary incisors was retracted 4.85 mm posteriorly in the Tip-Group, whereas it was retracted 5.28 mm posteriorly in the Trq-Group ($p<0.001$). As for root apex movement, no significant difference in the root apex movement before and after treatment was found in the Tip-Group, but the root apex was retracted 2.34 mm posteriorly in the Trq-Group ($p<0.001$). As for vertical movement, the crown tip of the Tip-Group was 0.99 mm extruded, which was statistically significant ($p<0.01$).

The mandibular anterior teeth were 12.15^o lingually inclined in the Tip-Group ($p<0.001$), whereas they were 7.3^o lingually inclined in the Trq-Group ($p<0.001$). As for the movement of the crown tip of the mandibular anterior teeth, the crown tip was 4.82 mm posteriorly retracted in the Tip-Group, whereas it was 5.24 mm posteriorly retracted in the Trq-group ($p<0.001$). As for the movement of the root apex of the mandibular anterior teeth, the root apex was 0.84 mm posteriorly retracted in the Tip-Group ($p<0.01$), whereas it was 2.96 mm posteriorly retracted in the Trq-Group ($p<0.001$). As for the vertical movement of the crown tip of the mandibular anterior teeth, the crown tip was 1.97 mm intruded in the Tip-Group ($p<0.001$), whereas it was 2.11 mm intruded in the Trq-Group ($p<0.001$). As for the vertical movement of the crown tip, the crown tip was 1.79 mm intruded in the Tip-Group ($p<0.01$), but no significant difference was found in the Trq-group.

Table 5. Comparison of Changes of Central Incisor before and after treatment of Tip-Group and Trq-Group in cephalometry

Variables	Group	T1(Before Tx) Mean	T1(Before Tx) SD	T2(After Tx) Mean	T2(After Tx) SD	**ΔT(T2-T1)** Mean	**ΔT(T2-T1)** SD	p-value
Maxilla								
1 to SN(^{o})	Tip	109.59	4.57	96.73	5.94	-12.86	3.24	***
	Trq	108.88	4.08	101.32	6.02	-7.56	4.33	***
1 to PP(^{o})	Tip	120.96	4.57	108.19	6.46	-12.77	3.30	***
	Trq	117.68	3.39	110.29	5.78	-7.39	4.19	***
U1RAV(mm)	Tip	-6.63	1.98	-6.57	1.67	0.06	1.11	NS
	Trq	-6.67	1.67	-9.01	2.21	-2.34	1.50	***
U1IAV(mm)	Tip	5.17	2.44	0.32	3.25	-4.85	1.20	***
	Trq	3.64	2.05	-1.64	2.12	-5.28	1.70	***
U1RPP(mm)	Tip	10.77	2.33	10.51	2.58	-0.26	2.04	NS
	Trq	11.53	2.46	11.21	2.03	-0.32	2.07	NS
U1IPP(mm)	Tip	30.42	2.52	31.41	2.58	0.99	1.32	**
	Trq	31.22	1.88	31.14	2.63	-0.08	1.29	NS
Mandilbe								
IMPA(^{o})	Tip	101.49	7.28	89.34	6.73	-12.15	4.92	***
	Trq	98.44	8.19	91.05	8.98	-7.3	5.84	***
L1IPV(mm)	Tip	-5.14	3.29	-9.96	3.43	-4.82	1.74	***
	Trq	-7.04	3.28	-12.28	3.74	-5.24	2.19	***
L1RPV(mm)	Tip	-8.91	1.37	-9.75	1.33	-0.84	0.76	**
	Trq	-9.54	1.89	-12.49	1.82	-2.96	1.20	***
L1IMP(mm)	Tip	43.17	3.54	41.20	3.33	-1.97	0.94	***
	Trq	44.17	2.65	42.06	2.74	-2.11	1.32	***
L1RMP(mm)	Tip	24.47	2.84	22.68	2.89	-1.79	1.48	**
	Trq	25.12	3.42	24.06	2.32	-1.07	2.71	NS

(* p<0.05 , ** p<0.01, *** p<0.001)

4. Results of CBCT analysis

1) CBCT analysis of the maxillary central incisors

After the posterior retraction of the maxillary central incisors, no significant difference in the buccal bone thickness at the 3 mm apical level from CEJ was found, but significant differences in the changes in the other variables were found. The buccal bone thickness at the 6 mm apical level from CEJ (6BT) increased by +0.22 mm (+24 %)($p<0.01$), and the buccal bone thickness at the 9 mm apical level from CEJ (9BT) increased by +0.52 mm (+54 %)($p<0.001$). The palatal bone thickness at 3 mm (3PT), 6 mm (6PT), and 9 mm (9PT) apical level from CEJ decreased by - 0.93 mm ~ - 1.43 mm (-29 % ~ -74 %). The 6PT decreased by -1.43 mm, which showed the largest decrease, but the decreased percentage of the thickness at 3 mm apical level from CEJ was -74 %, which was the largest decrease percentage ($p<0.001$). As for changes in the vertical length of the alveolar bone, the BABL decreased by -0.22 mm (-14 %)($p<0.01$), and the PABL decreased by -3.83 mm (-309 %)($p<0.001$). As for changes in the alveolar bone area, the BABA increased by +1.27 mm^2 (+19 %)($p<0.05$), but the PABA decreased by -7.81 mm^2 (-55 %)($p<0.001$). (Table 6)(Figure 5)

Table 6. Comparison of the CBCT Variables related to Maxillary Central Incisors.

Mx Incisor	T1(n=70)		T2(n=70)		ΔT(T2-T1)		ΔT/T1 ratio	p-value
	Mean	SD	Mean	SD	Mean	SD		
3BT(mm)	0.93	0.28	0.93	0.42	0.00	0.39	0.00	NS
3PT(mm)	1.33	0.52	0.34	0.42	-0.99	0.52	-0.74	***
6BT(mm)	0.91	0.31	1.13	0.46	0.22	0.41	0.24	**
6PT(mm)	2.27	1.19	0.84	0.87	-1.43	1.15	-0.63	***
9BT(mm)	0.97	0.38	1.49	0.71	0.52	0.64	0.54	***
9PT(mm)	3.16	1.06	2.23	1.47	-0.93	0.93	-0.29	***
BABL(mm)	-1.57	0.47	-1.79	0.63	-0.22	0.45	-0.14	**
PABL(mm)	-1.24	0.41	-5.07	3.10	-3.83	3.04	-3.09	***
BABA(mm^2)	6.54	1.87	7.81	3.07	1.27	2.89	0.19	*
PABA(mm^2)	14.23	5.17	6.42	5.27	-7.81	4.70	-0.55	***

(* $p<0.05$, ** $p<0.01$, *** $p<0.001$)

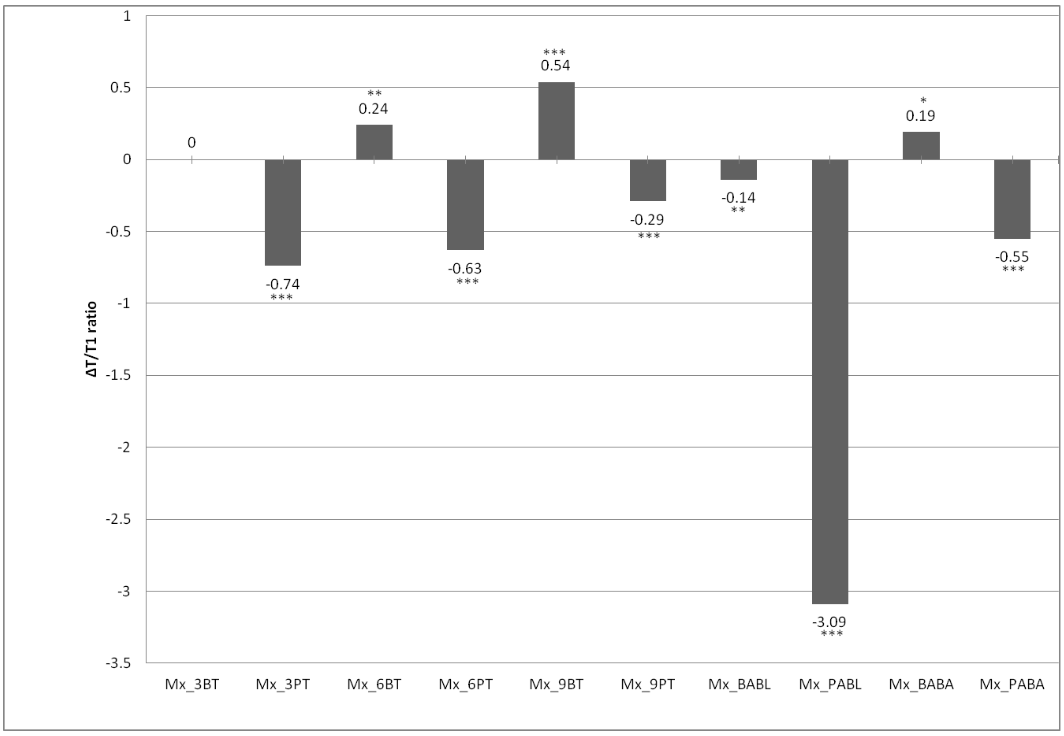

Figure 5. ΔT/T1 ratio of Maxillary Incisors

2) CBCT analysis of the mandibular central incisors

After the posterior retraction of the mandibular central incisors, no significant difference in the change in the buccal bone thickness at the 3 mm (3BT) apical level from CEJ was found. However, the buccal bone thickness at the 6 mm (6BT) apical level from CEJ increased by +0.40 mm (+87 %)($p<0.05$), and the buccal bone thickness at 9 mm (9BT) apical level from CEJ increased by +1.04 mm (+104 %), which showed significant differences ($p<0.001$).

The palatal alveolar bone thickness at the 3 mm (3PT), 6 mm (6PT), and 9 mm (9PT) apical level from CEJ decreased significantly ranging -0.63 ~ -0.99 mm (-55 % ~ -88 %) ($p<0.001$). The thickness at the 9 mm apical level from CEJ decreased by -0.99 mm (-55 %), which was the largest decrease amount, but the thickness at the 3 mm apical level from CEJ decreased by -88 %, which was the largest decrease percentage.

As for changes in the vertical ABL, the BABL decreased by -2.59 mm (-175 %)($p<0.001$), and the PABL decreased by -5.82 mm (-285 %)($p<0.001$). As for changes in the alveolar area, no significant difference in the BABA was found, but the PABA decreased by -5.47 mm^2 (-75 %)($p<0.001$). (Table 7)(Figure 6)

Table 7. Comparison of the CBCT Variables related to Mandibular incisors.

Mn Incisor	T1(n=70)		T2(n=70)		ΔT(T2-T1)		ΔT/T1 ratio	p-value
	Mean	SD	Mean	SD	Mean	SD		
3BT(mm)	0.70	0.57	0.50	0.70	-0.20	0.83	-0.29	NS
3PT(mm)	0.72	0.55	0.09	0.41	-0.63	0.68	-0.88	***
6BT(mm)	0.46	0.17	0.86	1.11	0.40	1.07	0.87	*
6PT(mm)	1.07	0.48	0.23	0.71	-0.84	0.60	-0.79	***
9BT(mm)	1.00	0.53	2.04	1.57	1.04	1.35	1.04	***
9PT(mm)	1.79	0.77	0.80	1.19	-0.99	0.86	-0.55	***
BABL(mm)	-1.48	0.47	-4.07	2.53	-2.59	-2.55	-1.75	**
PABL(mm)	-2.04	0.50	-7.86	2.39	-5.82	-2.44	-2.85	***
BABA(mm^2)	4.84	1.04	5.89	5.50	1.05	4.97	0.22	NS
PABA(mm^2)	7.33	2.60	1.86	4.39	-5.47	3.54	-0.75	***

(* p<0.05 , ** p<0.01, *** p <0.001)

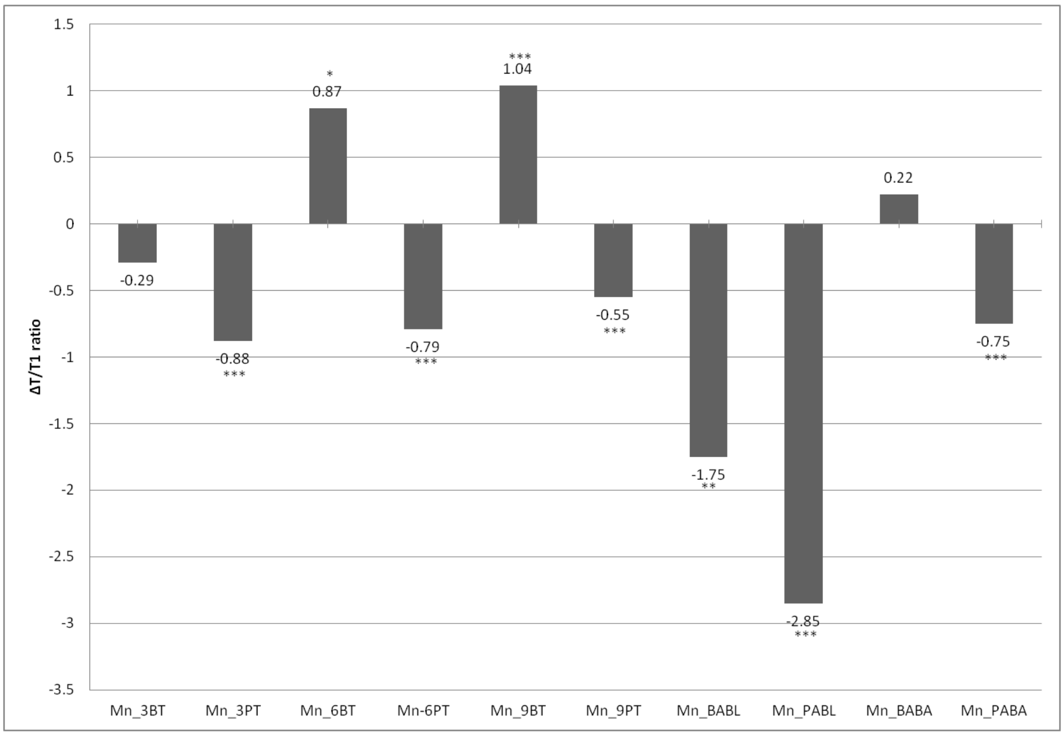

Figure 6. ΔT/T1 ratio of Mandibular incisors

5. Analysis of CT data according to Tip-Trq Group classification

1) CBCT analysis of the maxillary central incisors according to group classification

No significant difference in the buccal bone thickness at the 3 mm (3BT-Tip), 6 mm (6BT-Tip), and 9 mm (9BT-Tip) apical level from CEJ was found in the Tip-Group. Meanwhile, the palatal bone thickness at the 3 mm (3PT-Tip), 6 mm (6PT-Tip), and 9 mm (9PT-Tip) apical level from CEJ decreased by -0.95 mm (70 %), -1.45 mm (-58 %)($p<0.001$), and -0.73 mm (-87 %), respectively($p<0.01$). On the other hand, no significant difference in the buccal bone thickness at the 3 mm (3BT-Trq) apical level from CEJ was found in the Trq-Group. However, the buccal bone thickness at the 6 mm (6BT-Trq), and 9 mm (9BT-Trq) apical level from CEJ increased by 0.37 mm (39 %) ($p<0.01$) and 0.85 mm (82 %)($p<0.001$), respectively, in the Trq-Group. The palatal bone thickness at the 3 mm (3PT-Tip), 6 mm (6PT-Tip) and 9 mm (9PT-Tip) apical level from CEJ decreased by -0.95 mm (-70%), -1.45 mm (-58 %), and -0.73 mm (-22 %), respectively, in the Tip-Group ($p<0.001$). The palatal bone thickness at the 3 mm (3PT-Trq), 6 mm (6PT-Trq), and 9 mm (9PT-Trq) apical level from CEJ decreased by -1.04 mm (-80 %), -1.42 mm (-70 %), and -1.14 mm (-38 %), respectively, in the Trq-Group ($p<0.001$).

The BABL decreased by -0.28 mm (-18 %) ($p<0.05$), whereas the PABL decreased by -2.56 mm (-213 %) in the Tip-Group ($p<0.001$). Meanwhile, no significant difference in the BABL was found, but the PABL decreased by -5.15 mm (-396 %) in the Trq-Group. As for changes in the alveolar bone area, no significant difference in the BABA was found, but the PABA decreased by -7.48 mm^2 (-50 %) in the Tip-Group ($p<0.001$). The BABA increased by

2.14 mm^2 (31 %) ($p<0.01$) whereas the PABA decreased by -8.16 mm^2 (-61 %) in the Trq-Group($p<0.001$). (Table 8)(Figure 7)

Table 8. Comparison of Alveolar Bone Changes around Maxillary Central Incisor before and after treatment of Tip-Group and Trq-Group in CBCT

Mx Incisor	Group	T1		T2		ΔT(T2-T1)		ΔT/T1	p-
		Mean	SD	Mean	SD	Mean	SD	ratio	value
3BT	Tip	0.89	0.29	0.81	0.47	0.07	0.43	0.08	NS
(mm)	Trq	0.97	0.27	1.05	0.34	0.08	0.33	0.08	NS
3PT	Tip	1.36	0.49	0.41	0.39	-0.95	0.47	-0.70	***
(mm)	Trq	1.30	0.56	0.26	0.45	-1.04	0.59	-0.80	***
6BT	Tip	0.87	0.31	0.96	0.48	0.09	0.38	0.10	NS
(mm)	Trq	0.94	0.32	1.31	0.39	0.37	0.41	0.39	**
6PT	Tip	2.49	1.48	1.04	0.65	-1.45	1.40	-0.58	***
(mm)	Trq	2.04	0.74	0.62	1.03	-1.42	0.85	-0.70	***
9BT	Tip	0.91	0.42	1.10	0.60	0.20	0.41	0.22	NS
(mm)	Trq	1.04	0.33	1.89	0.61	0.85	0.68	0.82	***
9PT	Tip	3.28	1.00	2.55	1.21	-0.73	0.87	-0.22	**
(mm)	Trq	3.03	1.14	1.89	1.68	-1.14	0.97	-0.38	***
BABL	Tip	-1.60	0.55	-1.88	0.70	-0.28	0.50	-0.18	*
(mm)	Trq	-1.56	0.39	-1.69	0.57	-0.13	0.39	-0.08	NS
PABL	Tip	-1.20	0.37	-3.76	2.00	-2.56	1.99	-2.13	***
(mm)	Trq	-1.30	0.44	-6.45	3.50	-5.15	3.44	-3.96	***
BABA	Tip	6.11	1.88	6.58	2.96	0.47	2.82	0.08	NS
(mm^2)	Trq	6.98	1.80	9.12	2.67	2.14	2.79	0.31	**
PABA	Tip	14.99	4.73	7.51	4.20	-7.48	3.99	-0.50	***
(mm^2)	Trq	13.42	5.65	5.26	6.12	-8.16	5.46	-0.61	***

(* $p<0.05$, ** $p<0.01$, *** $p<0.001$)

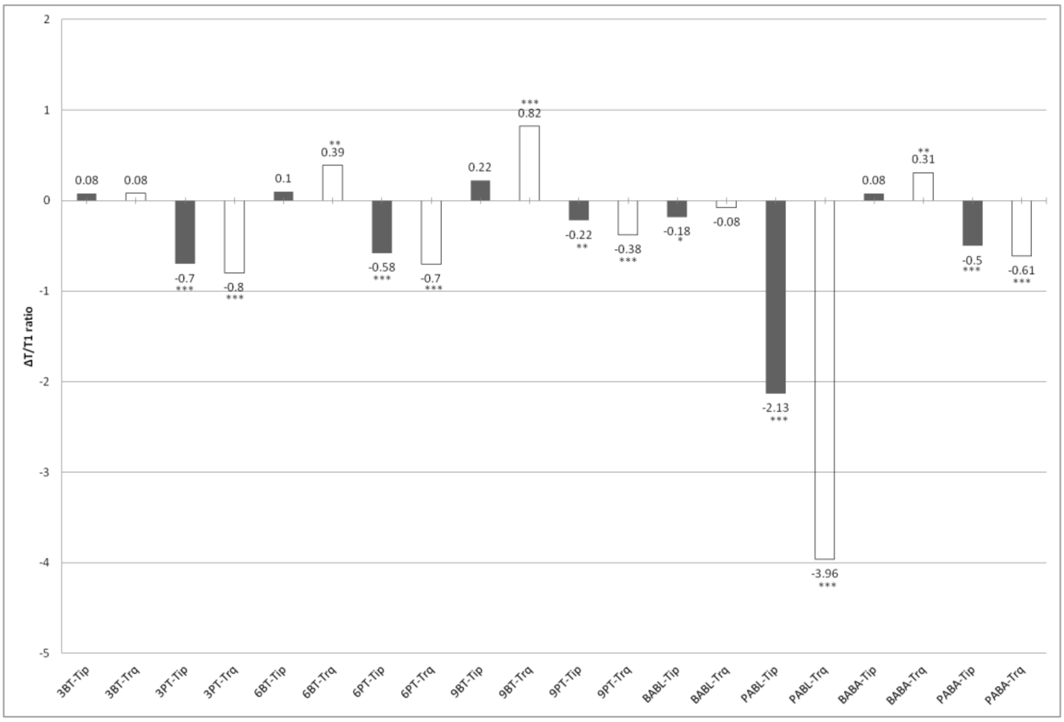

Figure 7. ΔT/T1 ratio of Alveolar Bone around Mx. Central incisor of Tip-Group and Trq-Group in CBCT

2) CBCT analysis of the mandibular central incisors according to group classification

In the Tip-Group, the buccal bone thickness at the 3 mm apical level from CEJ (3BT-Tip) decreased by -0.41 mm (-71 %)($p<0.001$), but no significant difference was found at the 6 mm apical level from CEJ (6BT-Tip). The buccal bone thickness at the 9 mm (9BT-Tip) apical level from CEJ increased by +0.40 mm (+41 %)($p<0.05$). In the Trq-Group, no significant difference in the buccal bone thickness at the 3 mm (3BT-Trq) apical level from CEJ was found, but the buccal bone thickness at the 6 mm (6BT-Trq) and 9 mm (9BT-Trq) apical level from CEJ increased by +0.61 mm (+124 %)($p<0.01$) and +1.51 mm (+145 %), respectively ($p<0.001$). In the Tip-Group, the palatal bone thickness at the 3 mm (3PT-Tip) and 6 mm (6PT-Tip) apical level from CEJ decreased by -0.69 mm (-78 %)($p<0.05$) and -0.76 mm (-61 %)($p<0.01$), respectively, but no significant difference was found at the 9 mm (9PT-Tip) apical level from CEJ was found. Meanwhile, in the Trq-Group, the palatal bone thickness at the 3 mm (3PT-Trq), 6 mm (6PT-Trq), and 9 mm (9PT-Trq) apical level from CEJ decreased by -0.6 mm (-100 %)($p<0.001$), -0.90 mm (-96 %), and -1.42 mm (-87 %) , respectively ($p<0.001$).

In the Tip-Group, the BABL decreased by -3.65 mm (-237 %)($p<0.001$), whereas the PABL decreased by -4.24 mm (-198 %)($p<0.001$). Meanwhile, in the Trq-Group, the BABL decreased by -1.79 mm (-124 %)($p<0.01$), whereas the PABL decreased by -6.99 mm (-354 %)($p<0.001$). As for changes in the alveolar bone area, the BABA decreased by -1.66 mm^2 (-36 %)($p<0.01$), and the PABA decreased by -4.72 mm^2 (-57 %)($p<0.01$) in the Tip-Group. Meanwhile, the BABA increased by +3.08 mm^2 (61 %)($p<0.05$), but the PABA decreased by -6.05 mm^2 (-90 %)($p<0.001$) in the Trq-Group. (Table 9)(Figure 8)

Table 9. Comparison of Alveolar Bone Changes around Mandibular Central Incisor before and after treatment of Tip-Group and Trq-Group in CBCT

Mn Incisor	Group	T1		T2		ΔT(T2-T1)		ΔT/T1	p-
		Mean	SD	Mean	SD	Mean	SD	ratio	value
3BT	Tip	0.58	0.21	0.17	0.26	-0.41	0.23	-0.71	***
(mm)	Trq	0.78	0.74	0.75	0.82	-0.03	1.06	-0.04	NS
3PT	Tip	0.88	0.79	0.19	0.62	-0.69	1.02	-0.78	*
(mm)	Trq	0.60	0.24	0.00	0.03	-0.60	0.22	-1.00	***
6BT	Tip	0.41	0.13	0.54	1.22	0.13	1.22	0.32	NS
(mm)	Trq	0.49	0.18	1.10	0.98	0.61	0.92	1.24	**
6PT	Tip	1.25	0.58	0.49	1.03	-0.76	0.84	-0.61	**
(mm)	Trq	0.94	0.36	0.04	0.11	-0.90	0.32	-0.96	***
9BT	Tip	0.96	0.52	1.36	0.84	0.40	0.71	0.41	*
(mm)	Trq	1.04	0.55	2.55	1.81	1.51	1.53	1.45	***
9PT	Tip	2.01	0.90	1.58	1.46	-0.43	0.93	-0.21	NS
(mm)	Trq	1.63	0.63	0.21	0.36	-1.42	0.50	-0.87	***
BABL	Tip	-1.54	0.45	-5.19	2.09	-3.65	2.02	-2.37	***
(mm)	Trq	-1.44	0.49	-3.23	2.56	-1.79	2.65	-1.24	**
PABL	Tip	-2.14	0.41	-6.39	2.65	-4.24	2.54	-1.98	***
(mm)	Trq	-1.97	0.56	-8.96	1.44	-6.99	1.58	-3.54	***
BABA	Tip	4.57	0.81	2.91	1.97	-1.66	1.91	-0.36	**
(mm^2)	Trq	5.04	1.17	8.12	6.26	3.08	5.60	0.61	*
PABA	Tip	8.14	2.97	3.42	6.20	-4.72	4.87	-0.57	**
(mm^2)	Trq	6.73	2.18	0.68	1.67	-6.05	2.04	-0.90	***

(* $p<0.05$, ** $p<0.01$, *** $p<0.001$)

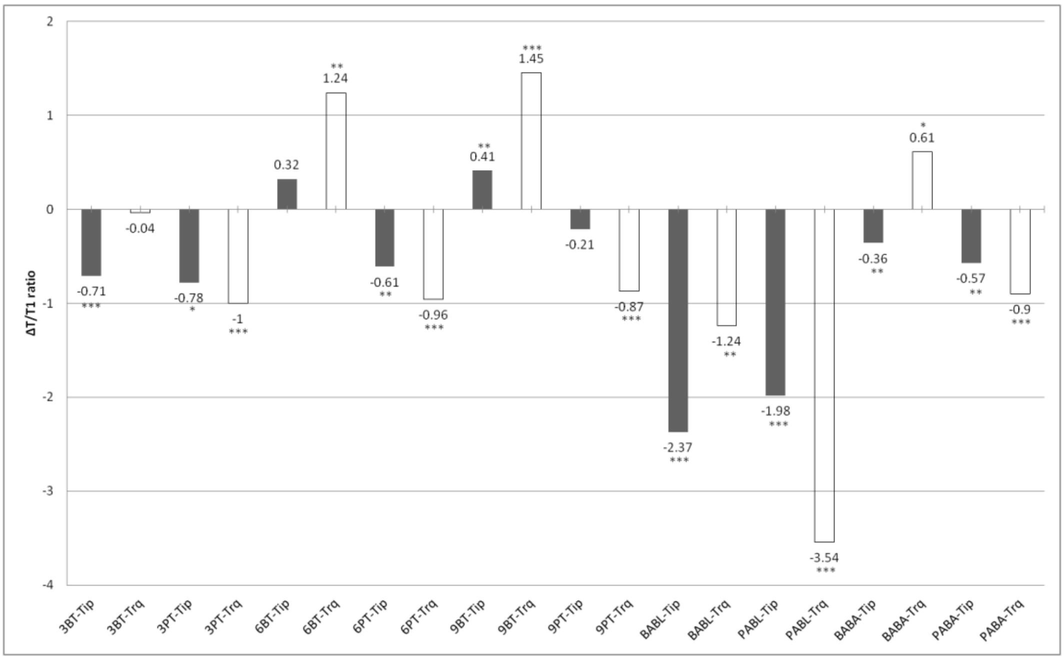

Figure 8. ΔT/T1 ratio of Alveolar Bone around Mn. Central incisor of Tip-Group and Trq-Group in CBCT

6. Relationship between variables of lateral cephalometric X-ray and CBCT variables

1) Relationship between variables of lateral cephalometric X-ray and CBCT variables in the maxillary central incisors

As for the relationship with the maxillary central incisors, the change in the angle of the maxillary central incisors was highly correlated with root movement. The palatal inclination of the maxillary central incisors had a strongly positive correlation with the changes in the buccal alveolar bone thickness at the 3 mm (p<0.05), 6 mm (p<0.01), and 9 mm (p<0.01) apical level form CEJ, and had a weakly positive correlation with the change in the buccal alveolar bone area (p<0.05). The root apex of the anterior teeth rather than the crown tip had a correlation with more CBCT variables. The posterior retraction of the root apex was positively correlated with the changes in the buccal bone thickness at 6 mm (p<0.05) and 9 mm (p<0.01) apical level from CEJ. Also, the posterior retraction of the root apex was negatively correlated with the PABL (p<0.05) and positively correlated with the buccal alveolar bone area (p<0.01). The extrusion of the crown of maxillary incisors was negatively correlated with the BABL (p<0.01). (Table10)

Table 10. Correlation between Alveolar bone change and Maxillary incisor retraction.

Maxilla	3BT	3PT	6BT	6PT	9BT	9PT	BABL	PABL	BABA	PABA
1 to SN(^{o})	.366*	-.142	.431**	.021	.547**	-.304	.089	-.236	.346*	-.210
1 to PP(^{o})	.336*	-.172	.412*	-.036	.558**	-.356*	.118	-.263	.346*	-.257
U1RAV(mm)	.245	-.202	.390*	-.074	.618**	-.300	.202	-.415*	.348*	-.163
U1IAV(mm)	-.109	-.032	-.036	-.046	.093	.120	.147	-.115	.015	.132
U1RPP(mm)	-.283	-.195	-.087	.037	-.075	-.284	-.294	-.208	-.154	-.293
U1IPP(mm)	-.320	-.144	-.206	.074	-.282	-.199	-.377*	-.131	-.268	-.189

(* p<0.05 , ** p<0.01)

2) Relationship between variables of lateral cephalometric X-ray and CBCT variables in the mandibular central incisors

As for the relationship with the mandibular central incisors, the lingual inclination of the mandibular central incisors was correlated with the alveolar bone thickness at the 9 mm apical level form CEJ; positive correlation with the BT ($p<0.01$) and negative correlation with the PT ($p<0.01$). The palatal inclination of the mandibular central incisors was negatively correlated with the PABL ($p<0.05$) and positively correlated with the BABA ($p<0.05$), but was uncorrelated with the changes in the PABA. The palatal movement of the mandibular incisor root was significantly correlated with the alveolar bone thickness at the 9 mm apical level form CEJ; positive correlation with the buccal bone thickness ($p<0.05$), and negative correlation with the palatal bone thickness ($p<0.01$). The palatal movement of the incisor root was strongly correlated with the decreased PABL ($p<0.01$), and positively correlated with the buccal bone area ($p<0.05$). (Table 11)

Table 11. Correlation between Alveolar bone change and Mandibular incisor retraction.

Mandible	3BT	3PT	6BT	6PT	9BT	9PT	BABL	PABL	BABA	PABA
IMPA(^{o})	.084	-.179	.087	-.146	.439**	-.542**	.299	-.353*	.390*	-.270
L1IPV(mm)	.033	.187	.010	.026	-.232	.232	-.135	.042	-.201	.145
L1RPV(mm)	.199	.039	.273	-.180	.424*	-.510**	.280	-.470**	.395*	-.202
L1IMP(mm)	-.111	-.119	-.170	.087	-.326	.024	-.007	.065	-.285	.012
L1RMP(mm)	-.201	-.075	-.350*	.003	-.295	-.055	-.209	-.162	-.285	-.117

(* $p<0.05$, ** $p<0.01$)

7. Correlation between the variables of lateral cephalometric X-ray and the variables of CBCT according to Tip-Trq group classification

1) Correlation between maxillary central incisors

The change of the axis of the maxillary central incisors was correlated with the 9PT-Tip, and the 1 to PP was negatively correlated with the PABA ($p<0.05$). The extrusion of the crown tip of the Trq-Group was negatively correlated with the 9PT-Trq ($p<0.05$). (Table 12)

Table 12. Correlation between Alveolar bone change and Maxillary incisor of Tip-Group and Trq-Group .

Maxilla		3BT	3PT	6BT	6PT	9BT	9PT	BABL	PABL	BABA	PABA
1 to SN	Tip	.296	-.331	.346	-.199	.318	-.532*	-.028	-.219	.271	-.462
(^{o})	Trq	.221	.222	.060	.321	.180	.018	-.142	.246	.033	-.017
1 to PP	Tip	.300	-.437	.353	-.272	.406	-.631**	-.059	-.245	.316	-.578*
(^{o})	Trq	.141	.264	.004	.312	.135	.015	-.162	.237	-.018	-.006
U1RAV	Tip	-.020	-.035	.034	-.359	.032	-.137	-.064	-.247	-.007	-.225
(mm)	Trq	.050	-.225	.315	-.240	.349	-.401	-.180	-.247	.182	-.269
U1IAV	Tip	-.336	.282	-.338	-.004	-.165	.392	.038	.217	-.229	.298
(mm)	Trq	.061	-.311	.134	-.214	-.209	-.070	.249	-.218	.171	-.024
U1RPP	Tip	-.138	-.235	-.015	.258	.116	-.270	.008	-.010	.083	-.225
(mm)	Trq	.044	.154	-.237	.209	.083	.116	.137	.024	-.095	.088
U1IPP	Tip	-.230	-.134	-.086	.392	-.234	-.008	-.327	-.305	-.144	-.062
(mm)	Trq	-.396	-.251	-.092	-.462	-.044	-.651*	-.469	-.450	-.257	-.383

(* $p<0.05$, ** $p<0.01$)

2) Correlation between variables of mandibular central incisors

The change of the axis of the mandibular central incisors was negatively correlated with the 9PT-Tip ($p<0.05$), and positively correlated with the 9BT-Trq ($p<0.05$). In addition, the change of the axis was positively correlated with the increased BABA ($p<0.05$). The retraction of the mandibular root was positively correlated with the increased PABA of the Trq-Group ($p<0.05$). (Table 13)

Table 13. Correlation between Alveolar bone change and Mandibular incisor of Tip-Group and Trq-Group

Mandible		3BT	3PT	6BT	6PT	9BT	9PT	BABL	PABL	BABA	PABA
IMPA	Tip	.210	-.459	-.261	-.226	.188	-.633*	.175	-.261	.287	-.249
(^{o})	Trq	-.002	-.119	.440	-.051	.542*	-.289	.213	.055	.461*	-.325
L1IPV	Tip	-.301	.363	.263	-.016	-.059	.316	-.306	.249	-.254	.029
(mm)	Trq	.036	.324	-.285	.195	-.420	.281	-.148	-.025	-.358	.462*
L1RPV	Tip	-.122	-.105	.226	-.427	.263	-.132	-.197	.069	.114	-.381
(mm)	Trq	.043	.081	.207	.012	.187	-.166	.147	-.115	.161	-.021
L1IMP	Tip	-.097	-.157	.042	.239	-.323	.226	.035	.182	-.150	.212
(mm)	Trq	-.115	-.189	-.338	-.130	-.366	-.188	-.023	-.010	-.290	-.244
L1RMP	Tip	-.367	.007	-.401	-.233	.276	-.051	-.122	-.490	-.097	-.298
(mm)	Trq	.164	.266	.063	-.036	.116	-.171	-.070	.075	.028	.142

(* p<0.05 , ** p<0.01)

IV. DISCUSSION

To meet the aesthetic desire of many Asian patients who have alveolar protrusion of maxillary and mandibular teeth via protrusion improvement, the posterior retraction of maxillary and madibular incisors after premolar extraction has been commonly performed. The result of this method is predictable.[9] Orthodontic treatment is increasingly conducted on adults compared to the past. However, as alveolar remodeling during orthodontic treatment significantly differs between adult and adolescent patients, the excessive posterior retraction of incisors may cause the dehiscence or fenestration of the alveolar bone in adults who have reduced alveolar remodeling ability. [10,11]

If the goal of orthodontic treatment emphasizes aesthetic and function without considering periodontal condition, it may raise a concern about stability after treatment. Thus, many researchers recommend that the excessive posterior retraction of maxillary and mandibular incisors that may cause alveolar bone damage should be avoided.[2, 11] In a study using lateral cephalometric X-ray, Vardimon et al.[2] suggested that the ratio of alveolar remodeling to tooth movement should be 2:1. However, that study had limitations of adolescent subjects, a small sample number, and the use of 2D cephalometric images. Accordingly, this study was conducted to investigate alveolar remodeling in adults using both lateral cephalometric X-ray and CBCT.

For the maximization of the posterior retraction of incisors, miniscrew implants have been commonly used as an efficient device for anchor reinforcement in orthodontic treatment.[12, 13] Thus, the posterior retraction of the incisors was controlled using a miniscrew implant in the maxillary molars of the subjects in this study. In a study that measured alveolar remodeling of incisors using cephalometric X-ray and CBCT in patients who underwent space closure using the miniscrew implant after premolar extraction. Ahn et al.[14] reported that the axis of the maxillary incisors was 10.42^{o} lingually inclined, and the crown tip and root apex were 5.66 mm and 0.63 mm posteriorly retracted, respectively. Meanwhile, this study showed that the axis of the maxillary incisors was 11.13^{o} and 11.02^{o} lingually inclined against the SN plane and palatal plane, respectively, and the crown tip and root apex were 5.22 mm and 0.83 mm posteriorly retracted, which were similar to the result of the study conducted by Ahn et al.[14] In addition, in this study, the axis of the mandibular incisors was 9.69^{o} lingually inclined against the IMPA, and the crown tip and root apex were 5.12 mm and 2.01 mm posteriorly retracted.

With the common utilization of CBCT in orthodontic treatment, studies that investigated alveolar remodeling using 3D VR images have been conducted, and the results of these studies were reported to be relatively accurate.[6,15,16] However, Ising et al.[17] reported that the accuracy of 2D MPR images was high when dehiscence of alveolar bone was analyzed using CBCT. Gauthier et al.[18] compared the outcome of surgically assisted RME before and after treatment using 2D MPR images. Lund et al.[15] reported that CBCT was useful for the observation of alveolar change and root resorption during orthodontic treatment. In this study, the 3-D long axis was set for maxillary and mandibular right and left central incisors to reproduce the measurement area of the alveolar bone before and after treatment, and then the alveolar remodeling at the 3 mm, 6 mm, and 9 mm apical level from CEJ was analyzed using 2D MPR images. Before the common use of CBCT in dentistry, studies on alveolar remodeling during orthodontic extraction treatment had already been conducted. However, due to the limitation of 2D lateral cephalometric X-ray, it was difficult to analyze changes of individual teeth and alveolar bone. Various studies have been conducted to investigate alveolar remodeling before and after orthodontic treatment using CBCT. In a previous study, the root was divided into three parts, and alveolar bone thickness was analyzed in these three parts. However, as root resorption during orthodontic treatment may occur regardless of its significance, the reference point of a three-part measurement may be changed due to the shortened root after treatment. This change, in turn, may affect the alveolar bone thickness and area around the measured sites. Thus, in this study, the regions at the 3 mm, 6 mm, and 9 mm apical levels from CEJ were selected as the reference line to avoid the influence of root resorption.

Nowzari et al.[19] reported that less than 3 % of adult patients had a buccal alveolar bone thickness of anterior teeth of ≥2 mm. Braut et al.[20] reported that approximately 90 % of adult patients had a buccal alveolar bone thickness of maxillary anterior teeth of ≤1 mm and had no alveolar bone at the 4 mm apical level from CEJ in 27~32 % of incisors. Ghassemian[21] reported that buccal alveolar bone thickness at the 3 mm apical level from CEJ was approximately 1.41 mm in the incisors of adult men, and that a precaution should be given upon implant installation. In this study, the buccal bone thickness of the maxilla at the 3 mm, 6 mm, and 9 mm apical levels from CEJ was all less than 1.0 mm before treatment. However, after the posterior retraction of incisors via orthodontic extraction treatment, the buccal alveolar bone thickness increased, which resulted in a significant increase in the 6BT and 9BT. The Torque group showed a significant difference in the 6BT and 9BT before and after treatment, whereas the Tipping group showed no significant difference in the buccal bone thickness before and after treatment. In a study using spiral CT, Sarikaya et al.[22] reported that in the comparison of alveolar change before and after the posterior retraction of maxillary teeth, no change was observed in the buccal alveolar bone, but a significant resorption occurred in the palatal alveolar bone. The result of this study also showed that a significant resorption occurred in the palatal alveolar bone. The most significant resorption occurred in the alveolar area at the 3 mm apical level from CEJ, and the least significant resorption occurred at the 9 mm apical level from CEJ, which were consistent with the result of the study conducted by Ahn et al.[14]. Hwang et al.[8] conducted a study where subjects were divided into the Tipping and Torque groups according to tooth movement and their anterior alveolar remodeling was compared using lateral cephalometric X-ray after the posterior retraction of maxillary incisors in orthodontic extraction treatment. This study also divided the subjects into the two groups for analysis, and the result showed that the maxillary and mandibular palatal bone thickness decreased more in the Trq group than in the Tip group. Richman[10] suggested that CBCT should be conducted to assess the alveolar bone during orthodontic treatment as the dehiscence of the alveolar bone occurs commonly in adults and proposed radiographic supporting bone index(RSBI) for assessing alveolar condition.

Adults have an increased risk of periodontal disease compared to adolescents. Fuhrmann[23] reported that the dehiscence and fenestration of the alveolar bone and root resorption that occur during orthodontic treatment were closely related to the periodontal condition of the first medical check.

In a study that analyzed 79 Cl I and 80 Cl II div. 1 patients, Evangelista et al.[12] reported that the dehiscence of the alveolar bone and the fenestration of the root occurred in 51.09 % and 36.51 %, respectively, of the total 4319 teeth, and that their morbidity increased by 35 % in the Cl I patients compared to the Cl II patients. Hsu et al.[24] reported that the bone mineral density of the alveolar bone around the maxillary central incisors decreased by 25.8 ~ 29.0 % after orthodontic treatment. In this study, as shown in the maxillary case, the 6BT and 9BT significantly increased in the mandible. However, the resorption ratio of the alveolar bone was higher in the lingual alveolar bone of the mandible compared to the maxilla. As for change in the alveolar bone area, the buccal alveolar bone area increased by 19 % in the maxilla and 22 % in the mandible, which showed a similar increase. Meanwhile, the palatal alveolar bone area decreased by 55 % in the maxilla and 75 % in the mandible. This difference in the resorption of the alveolar bone between the maxilla and mandible is likely to be attributable to the fact that the maxillary palatal alveolar bone has thickened alveolar bone width around the root, which makes it resistant against orthodontic force, but the mandibular alveolar bone is thinner and longer than the maxillary alveolar bone. In the maxilla, the BABL decreased by -0.22 mm (-14 %), but the PABL significantly decreased by -3.83 mm (-309 %). Meanwhile, in the mandible, the BABL and PABL decreased by -2.59 mm (-175 %) and -5.82 mm (-285 %), both of which showed a significant decrease. This is likely attributable to the fact that the mandible has dense bone and the narrow alveolar bone width has lower remodeling ability compared to the maxilla. In the maxilla, the BABL insignificantly decreased in both Tipping and Torque groups. However, the PABL significantly decreased in both groups, and the decreased amount was larger in the Trq group than in Tip group. Meanwhile, in the mandible, both BABL and PABL significantly decreased in both groups. This indicates that the resorption of the alveolar bone occurs more in the mandible than in the maxilla during orthodontic extraction treatment.

Baumgaertel et al.[25] reported a small systemic error in the CBCT measurements method. Because of the difference between real volume and voxel volume, the software might actually have measured the distance between the midpoints of the voxels. In this study, the voxel size of CBCT was 0.22 mm. If measurements were made from the center of the voxel, half of the voxel would not have been included in the measurement on either side. This would lead to CBCT measurements that are 0.22 mm smaller than real caliper measurements. If the alveolar bone thickness was thinner than 0.22 mm, the measurements would be 0. This result might overemphasize the bone resorption after orthodontic treatment. So the resorption ratio or pattern is more meaningful rather than absolute number of measurements presented in this study.

During the posterior retraction of maxillary incisors in orthodontic extraction treatment, the center of resistance is a very important factor for controlling the dental axis. According to the result of a study on the center of resistance of maxillary incisors[26, 27], the center of resistance of maxillary anterior teeth were reported to be positioned at 13.5 mm toward the root from the incisal tip of maxillary central incisors and 14.0 mm posteriorly. However, Min et al.[27] and Sung et al.[29] reported that as the PABL of the maxillary incisors decreased during space closure after extraction, the center of resistance of the incisors was also shifted to the root apex. Thus, if the extracted space is closed while maintaining the dental axis, it should be considered that the resorption of the palatal alveolar bone and the change of the center of resistance occur at the same time during space closure.

Strahm et al.[30] reported that as buccal alveolar generation is unlikely to occur by the anterior retraction of mandibular incisors in children with a mean age of 9 years, the limited alveolar bone thickness of the mandible should be taken into account during orthodontic treatment. Gracco[31] and Wonglamsam et al.[32] reported that alveolar bone thickness varied according to vertical facial type, and that the maximum thickness was observed in the short face and the minimum thickness was observed in the long face. In the establishment of orthodontic extraction treatment plan in adults, the limited movement of teeth and the weak resistance of the alveolar bone due to the narrow alveolar bone width of mandibular incisors should be considered during the determination of the posterior retraction amount of mandibular incisors in the long face. Thus, a treatment plan that compromises the goal of aesthetic improvement and periodontal condition should be established during the determination of the posterior retraction of incisors. As the resorption of the palatal alveolar bone is influenced more by bodily movement than by tipping movement, controlled tipping rather than bodily movement is recommended if alveolar bone width is thin.

In the correlation of variables of lateral cephalometric X-ray and variables of CBCT, the linguoversion of the maxillary incisors was positively correlated with the 3BT, 6BT, and 9BT, but negatively correlated with the 9PT. In addition, it was positively correlated with the BABA. The movement of the incisor root rather than the movement of the incisor crown had a correlation with more CBCT variables. The root movement was positively correlated with the BT. In addition, it was positively correlated with the increased PABA and BABL and the decreased PABL and BABL. The correlation also showed that the resorption of the palatal alveolar bone was more affected by tipping movement than by bodily movement.

In the cases of madibular incisors, the linguoversion of the incisors was positively correlated with the 9BT and negatively correlated with the PT. In addition, it was negatively correlated with the PABL and positively correlated with the BABA. The movement of the incisor root rather than the movement of the incisor crown had a correlation with more CBCT variables. The posterior movement of the root was positively correlated with the 9BT, and negatively correlated with the PT. In addition, it was correlated with the decreased PABL and the increased BABA.

It was reported that bone mineral density decreased in the region of tooth movement during orthodontic tooth movement.[33] In this study, the PABA decreased by 55 % after the posterior retraction of maxillary incisors, whereas the BABA decreased by 75 % after the posterior retraction of mandibular incisors. Considering that calculus significantly occurs in the mandibular palatal incisors and that periodontitis frequently occurs in the anterior teeth of the mandible in adults, the significant resorption of the palatal alveolar bone after orthodontic treatment provides a status subject to periodontitis. Thus, in the establishment of orthodontic extraction treatment plan, the posterior retraction of the mandible rather than the posterior retraction of the maxilla should be more carefully determined. Furthermore, the removal of calculus and preventive treatment of periodontitis should be required for madibular incisors at a regular basis after orthodontic treatment.

3D CBCT images were obtained in this study. However, as the automatic deduction of teeth from the alveolar bone is not accurate even using the most recently released software, the 3D volume of the alveolar bone was not measured. Instead, the analysis was conducted using the 2D MPR images. If the accuracy of CBCT is improved and an algorithm, via which the software accurately deducts teeth from the alveolar bone, is developed, changes in the alveolar volume during alveolar remodeling could be accurately analyzed. In addition, as the data of CBCT obtained before and after treatment was used in this study, alveolar remodeling might change 2~3 years after treatment. Thus, a further long-term study is required to investigate the range of alveolar remodeling by the recovery ability of the alveolar bone.

V. CONCLUSION

This study was conducted on 35 adult patients (5 men and 30 women) who underwent orthodontic treatment after extracting four premolars due to protrusion. CBCT data were obtained from the subjects before and after treatment. The alveolar bone thickness at the 3 mm, 6 mm, and 9 mm apical levels from CEJ was compared between before and after treatment. The correlation of the variables of CBCT analysis and those of lateral cephalometric X-ray was analyzed. The subjects were divided into the tipping and torque groups according to the movement of anterior teeth shown in lateral cephalometric X-ray, followed by analysis within the groups and correlation analysis. The results of this study were as follows.

1. After orthodontic extraction treatment, the 6BT and 9BT of the maxilla ($p<0.01$) ($p<0.001$) and the 6BT and 9BT of the mandible ($p<0.05$)($p<0.001$) significantly increased. Meanwhile, the PT at 3 mm, 6 mm, and 9 mm apical levels from CEJ and PABA significantly decreased in both maxilla and mandible ($p<0.001$).

2. After orthodontic extraction treatment, the BABL decreased by 0.22 mm ($p<0.01$), and the PABL decreased by 3.83 mm ($p<0.001$) in the maxilla. Meanwhile, the BABL decreased by 2.59 mm ($p<0.01$), and the PABL decreased by 5.82 mm ($p<0.001$) in the mandible.

3. In the case of Torque group, in the maxilla and mandible, the 6BT ($p<0.01$) and the 9BT ($p<0.001$) significantly increased, whereas the 3PT, 6PT, and 9PT significantly decreased in both maxilla and mandible ($p<0.001$). The PABL ($p<0.001$) in the maxilla and the BABL and PABL ($p<0.01$)($p<0.001$) in the mandible significantly decreased. BABA in the maxilla ($p<0.01$) and mandible ($p<0.05$) significantly increased and PABA in the maxilla ($p<0.001$) and mandible ($p<0.001$) significantly decreased.

4. In the case of Tipping group, no significant difference in the BT was found in the maxilla, but the 3 BT ($p<0.001$) decreased and 9BT ($p<0.05$) increased in the mandible. 3PT, 6PT ($p<0.001$) and 9PT ($p<0.01$) significantly decreased in the maxilla and 3PT ($p<0.05$) and 6PT ($p<0.01$) significantly decreased in the mandible. In addition, BABL and PABL in the maxilla ($p<0.05$)($p<0.001$) and mandible ($p<0.001$) significantly decreased. PABA ($p<0.001$) in the maxilla and BABA ($p<0.01$) and PABA ($p<0.01$) in the mandible significantly decreased.

5. After orthodontic extraction treatment, the change of the axis of maxillary and mandibular incisors and the root movement were highly correlated with the alveolar bone thickness and area.

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국문요약

발치교정치료시 Cone Beam CT를 이용한 상하악 중절치부위 치조골 리모델링의 평가

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본 연구에서는 발치교정치료를 종료한 성인을 대상으로 치료 전, 후의 측모두부규격 방사선 사진과 CBCT를 촬영하여, 상, 하악 중절치의 CEJ로부터 3 mm, 6 mm, 9 mm 하방 부위 순측, 설측 치조골 두께와 CEJ로부터 치조골 상연까지의 거리, 치조골 상연으로부터 CEJ 9 mm 하방 부위 수준까지의 치조골의 면적 등을 계측하였다. 치료 전, 후의 변화를 측정 비교하였고, 측모두부방사선 규격사진 상의 전치의 치아이동 양상에 따라 Tipping 군과 Torque 군으로 분류한 뒤, 각 군별 치아이동 양상과 군별 CBCT 계측과의 상관관계 분석을 시행하여 다음과 같은 결론을 얻었다.

1. 발치교정치료 후 상악 순측의 CEJ 6 mm 하방 부위($p<0.01$), 9 mm 하방 부위($p<0.001$)와 하악 순측의 CEJ 6 mm 하방 부위($p<0.05$), 9 mm 하방 부위($p<0.001$)의 치조골 두께는 유의성 있게 증가한 반면, 상악 구개측 및 하악 설측에서는 CEJ 3 mm, 6 mm, 9 mm 하방 부위에서 모두 치조골 두께와 면적이 유의성 있게 감소하였다($p<0.001$).

2. 발치교정치료 후, 상악 순측에서는 치조골 높이가 평균 0.22 mm 감소한 반면($p<0.01$), 구개측에서는 3.83 mm 감소하였고($p<0.001$), 하악 순측에서는 2.59 mm 감소한 반면($p<0.01$), 설측에서는 5.82 mm 감소하였다 ($p<0.001$).

3. Torque 군의 경우, 순측의 치조골 두께가 상악과 하악의 CEJ 6 mm 하방 부위($p<0.01$)와 9 mm 하방 부위($p<0.001$)에서 모두 유의한 증가를 보여준 반면, 설측은 상, 하악의 CEJ 3 mm, 6 mm, 9 mm 하방 모든 부위에서 유의한 감소를 나타내었다($p<0.001$). 치조골 높이는 상악 구개측($p<0.001$)과 하악 순측($p<0.01$), 설측($p<0.001$)에서 유의성 있게 낮아졌고, 치조골 면적은 상, 하악 순측에서는 유의성 있게 증가한 반면($p<0.01$)($p<0.05$), 상, 하악 설측에서는 유의성 있게 감소하였다 ($p<0.001$).

4. Tipping 군의 경우, 순측의 치조골 두께가 상악에서는 유의한 변화가 없었으나, 하악의 CEJ 3 mm 부위에서는 유의한 감소를($p<0.001$) 그리고, 9 mm 부위에서는 유의한 증가가($p<0.05$) 나타났다. 설측의 치조골 두께는 상악의 경우 CEJ 3 mm, 6 mm($p<0.001$), 9 mm($p<0.01$) 하방 부위에서는 유의하게 감소하였고, 하악에서는 CEJ 3 mm($p<0.05$), 6 mm($p<0.01$) 하방 부위에서 유의하게 감소하였다. 치조골 높이는 상악 순측($p<0.05$), 구개측($p<0.001$) 그리고, 하악 순측, 설측($p<0.001$) 모든 부위에서 유의성 있게 낮아졌다. 치조골 면적은 상악 구개측($p<0.001$)과 하악 순측, 설측($p<0.01$) 에서 유의성 있게 감소하였다.

5. 발치교정치료 시 상, 하악 전치의 각도변화와 치근의 이동거리가 치조골 두께 변화 및 치조골 면적변화와 높은 상관성을 보여주었다.

치조골의 재생능력이 청소년에 비해 떨어지는 성인의 발치교정치료는 치료 전 치조골의 두께, 치조골의 건강 등을 고려하여 치아이동의 형태를 결정해야 하며, 상악에서는 순측은 흡수가 미약한 반면, 구개측의 치조골 흡수가 현저하지만 하악에서는 순, 설측 모두에서 치조골의 흡수양상이 현저한 만큼 하악에서의 치아이동 계획 수립 시 더욱 신중해야 한다.

Key words : CBCT, 발치교정치료, 중절치, 전치 후방 견인, 치조골 흡수, 치조골 두께, 치조골 면적, 치조골 리모델링.