The effect of alveolar bone loss and miniscrew position on the tooth displacement during intrusion of maxillary anterior teeth : finite element analysis

Sun-Mi Cho

Graduate School

Yonsei University

Department of Dental Science

The effect of alveolar bone loss and miniscrew position on the tooth displacement during intrusion of maxillary anterior teeth : finite element analysis

A Dissertation Thesis
Submitted to the Department of Dental Science
and the Graduate School of Yonsei University
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy of Dental Science

Sun-Mi Cho

June 2015

This certifies that the dissertation thesis of

Sun-Mi Cho is approved.

Thesis Supervisor: Chung Ju Hwang

Hyung Seog Yu

Jung Yul Cha

Sang Jin Sung

Young Soo Cho

The Graduate School

Yonsei University

June 2015

감사의 글

교정과 수련을 끝내고 여러 해 만에 박사논문 연구를 진행하면서 아직 저의 배움이 많이 부족함을 느꼈고, 앞으로도 제자리에 머물지 않고 항상 노력하는 교정과 의사가 되어야겠다는 생각을 했습니다.

이 논문이 완성되기까지 지도와 격려를 아끼지 않으신 황충주 지도 교수님께 진심으로 감사드립니다. 그리고 바쁘신 가운데 논문 심사를 맡아주셔서 많은 관심과 조언으로 도움을 주셨던 유형석 교수님, 차정열 교수님, 성상진 교수님, 조영수 박사님께도 깊은 감사의 말씀을 올립니다. 또한 제가 교정학에 대한 학문적 소양을 기를 수 있도록 많은 가르침을 주신 박영철 교수님, 백형선 교수님, 김경호 교수님, 이기준 교수님, 정주령 교수님, 최윤정 교수님께도 깊이 감사드립니다. 박사 과정 동안 많은 도움을 주었던 수련 동기들에게도 이 지면을 빌어 감사의 마음을 전합니다.

마지막으로 사랑하는 나의 가족 - 언제나 든든한 삶의 버팀목이 되어주시는 존경하는 아버지와 무한한 사랑과 인내를 보여주시는 사랑하는 어머니, 언니보다 뛰어난 자랑스러운 내 동생 선영이, 그리고 여러 면에서 부족한 아내의 모든 것을 지지해주고 한결같은 사랑을 보여주는 사랑하는 남편 이승범, 내 인생의 보물인 사랑하는 아들 이서준에게도 진심을 담아 사랑과 감사의 인사를 전하며 이 기쁨을 함께 나누고 싶습니다.

2015년 6 월

조 선 미

Table of Contents

List of Figures ······ iii

List of Tables ······ iv

Abstract (English) ······ v

I. Introduction ······ 1

II. Materials and methods ······ 4

1. Finite element model construction ······ 4
2. Material properties ······ 6
3. Loading conditions and boundary conditions ······ 6
4. Solutions ······ 9
5. Graph analysis ······ 9

III. Results ······ 10

1. Displacement of anterior teeth without bone loss at 4 anterior teeth segment ······ 10
2. Displacement of anterior teeth with 2 mm bone loss at 4 anterior teeth segment ······ 12
3. Displacement of anterior teeth with 4 mm bone loss at 4 anterior teeth segment ······ 13
4. Displacement of anterior teeth without bone loss at 6 anterior teeth segment ······ 14
5. Displacement of anterior teeth with 2 mm bone loss at 6 anterior teeth segment ······ 15
6. Displacement of anterior teeth with 4 mm bone loss at 6 anterior teeth segment ······ 17

7. The changes of angulation of crown tip after intrusion ································ 19

8. Comparison of central incisor displacement according to bone loss ···················· 20

9. Comparison of lateral incisor displacement according to bone loss····················· 22

10. Comparison of canine displacement according to bone loss ··························· 24

11. The stress distribution on maxillary anterior teeth without bone loss ················ 26

12. The stress distribution on maxillary anterior teeth with 2 mm bone loss ············ 27

13. The stress distribution on maxillary anterior teeth with 4 mm bone loss ············ 28

14. Comparison of stress distribution after intrusion with 4 mm bone loss ·············· 29

IV. Discussion ··· 31

V. Conclusion ··· 42

References ··· 44

Abstract (Korean) ··· 50

List of Figures

Figure 1. 3 dimensional finite element models and coordination system 5

Figure 2. Force vectors for intrusion of 4 anterior teeth segment 8

Figure 3. Force vectors for intrusion of 6 anterior teeth segment 8

Figure 4. Sagittal view of displacement of anterior teeth without bone loss at 4 anterior teeth segment 11

Figure 5. Sagittal view of displacement of anterior teeth with 2 mm bone loss at 4 anterior teeth segment 12

Figure 6. Sagittal view of displacement of anterior teeth with 4 mm bone loss at 4 anterior teeth segment 13

Figure 7. Sagittal view of displacement of anterior teeth without bone loss at 6 anterior teeth segment 14

Figure 8. Sagittal view of displacement of anterior teeth with 2 mm bone loss at 6 anterior teeth segment 16

Figure 9. Sagittal view of displacement of anterior teeth with 4 mm bone loss at 6 anterior teeth segment 17

Figure 10. Displacements of central incisors in tooth local directions 21

Figure 11. Displacements of lateral incisors in tooth local directions 23

Figure 12. Displacements of canines in tooth local directions 25

Figure 13. Comparison of maximum compressive stress distribution in periodontal ligament 30

List of Tables

Table 1. Material properties ··· 6

Table 2. Position of hooks and miniscrews for intrusion of maxillary anterior teeth ··· 7

Table 3. The changes of angulation of crown after intrusion ··· 19

Table 4. Maximum compressive stresses of PDLs without bone loss ··· 26

Table 5. Maximum compressive stresses of PDLs with 2 mm bone loss ··· 27

Table 6. Maximum compressive stresses of PDLs with 4 mm bone loss ··· 28

Table 7. Displacement of crown tip at tooth axis direction ··· 37

Table 8. Displacement of crown tip at bucco-lingual direction··· 37

Abstract

The effect of alveolar bone loss and miniscrew position on the tooth displacement during intrusion of maxillary anterior teeth : finite element analysis

The purpose of this study was to investigate the intrusion pattern of maxillary anterior teeth according to alveolar bone height and miniscrew position. Finite element analysis was performed to simulate the movement pattern of maxillary anterior teeth under intrusion force. A standard three-dimensional finite element model was constructed, and varied the position of miniscrews and hooks after setting the alveolar bone loss in 0, 2, 4 mm. The applied intrusion force was 80 g for 4 anterior teeth, 100 g for 6 anterior teeth. The following results were observed:

1. Intrusion force applied at the archwire level induced initial labial tipping with intrusion of the anterior teeth (central incisor, lateral incisor, canine).

2. With reduced alveolar bone heights, under the same load, the study indicated an increase of tooth proclination.

3. Labial tipping of anterior teeth segment was reduced when retraction force was added to vertical intrusion force.

4. The amount of tooth displacement was larger in 6 anterior teeth more than 4 anterior teeth. In the case of canine, intrusion was increased but labial tipping was decreased.

5. Stress was concentrated at the apex than cervical area of PDL in all cases. And stress was also increased as bone loss increased.

6. When a miniscrew was inserted between two central incisors, high stress concentration was significant at the central incisors than other teeth. On the other hand, when miniscrews were inserted at distal to canines and intrusion force were applied at distal to lateral incisors, stress was the lowest and distributed evenly across all the teeth.

The results of this study indicate that it is thought to be able to induce initial tooth movement close to pure intrusion when miniscrews were inserted at distal to maxillary canines and intrusion force were applied at distal to lateral incisors.

Key words: maxillary anterior teeth intrusion, alveolar bone loss, miniscrew position, finite element analysis

The effect of alveolar bone loss and miniscrew position on the tooth displacement during intrusion of maxillary anterior teeth : finite element analysis

Department of Dental Science, Graduate School, Yonsei University

(Directed by Prof. Chung Ju Hwang, D.D.S., M.S., Ph.D.)

I. Introduction

The steadily growing desire to improve dentofacial esthetics has led to the increasing tendency for adult patients to undergo orthodontic treatment. Periodontal disease is common in adult dentitions. As inflammatory phenomena of multifactorial origin destroy periodontal tissue, some sequelae occur such as elongation and tipping and pathologic migration of teeth. As a result of pathologic tooth migration, occlusal trauma and periodontitis are mutually aggravated, resulting in greater loss of attachment, extrusion, and mobility of the displaced teeth (Serio FG et al., 1999; Rohatgi S et al., 2011). The most notable clinical sign of periodontal disease is seen in maxillary anterior region, including labial flaring, irregular spacing and extrusion of anterior teeth (Brunsvold MA, 2005; Feng X et al., 2005). Especially these problems occur in maxillary anterior region as they are not protected by occlusal forces and have no antero–posterior contacts to inhibit tooth migration.

Maxillary anterior teeth are an important area in esthetic view; patients affected by these problems often seek help from orthodontists (McKiernan EX et al., 1992;

Brunsvold MA, 2005). Orthodontic correction of pathologic migrated teeth can relieve occlusal trauma, stabilize the dentition, and improve the periodontal status as well as esthetic improvement (Gkantidis N et al., 2010; Derton N et al., 2011; Weston P et al., 2008; Diedrich PR 1996). To solve these problems, intrusion of anterior teeth is necessary in most cases. However, intrusion of periodontally extruded teeth is controversial (Serio FG et al., 1999; Weston P et al., 2008; Boyd RL et al., 1989). Recent studies have suggested that light intrusive forces can be used to correct pathologic extrusion and migration. Conventional methods for intrusion of maxillary anterior teeth were introduced by previous researchs (Burstone CJ 1977; Begg PR et al., 1977; Ricketts RM 1976; Greig DG 1983). The major disadvantages with these appliances include extrusion and tipping of posterior teeth, complicated wire bending and patient cooperation.

Recently, miniscrews as effective temporary anchorage devices have occupied an important role in producing various tooth movements, since anchorage control and patient cooperation are very critical in orthodontic field. Many authors have introduced methods using mini screws for intrusion of incisors and have reported statistically significant amounts of incisor intrusion with miniscrews (Kanomi R 1997; Melsen B & Verna C 2005). Direct intrusion method using mini screws has the advantage of being able to move the teeth effectively because that forms a force vector in the desired direction without the loss of anchorage. This means that orthodontists can easily control the position and direction of orthodontic force. However, the orthodontic force applied from the miniscrew is an external force in the whole force system. In other words, the direction of the force has a great influence on the movement pattern of the teeth. To move the teeth in a desired pattern, the appropriate direction of the force must be selected. Therefore, the relationship between the force direction and the movement pattern should be clarified (Park & Lee 2009).

Orthodontists dealing with periodontally compromised dentitions need to understand the altered biomechanics to render their treatments for the reduced periodontal tissue. For example, the center of resistance in periodontally compromised teeth moves to a more apical position, which requires that the moment/force ratio has to be adjusted (Cattaneo PM et al., 2008). When periodontally compromised patients undergo orthodontic treatment, tooth movements should be as well-targeted and well-controlled as possible under the application of light forces. They must take place within certain biological limits, and the biomechanics must be adapted to each patient. This necessitates modifications in the applied force system to produce the same movement as in a tooth with a healthy supporting structure.

The finite element analysis (FEA) has proved to be a valid and reliable technique for the calculation of the local state of deformation and loading of complex structures (Cattaneo, Dalstra et al. 2005). It is an approximation method, replacing a complex structure with an assemblage of simple elements interconnected at points called nodes. These elements can be assembled to represent any shape or defined model (Reddy JN 1984). Each element can be assigned with material properties that are determined by the clinical situation or model conditions, and forces are applied to simulate clinical loads. The experimental response to the applied forces or applied stress can then be visualized and calculated. FEA allows for detailed visualization of strength and stiffness where structures bend and twist, while indicating the distribution of displacements and stresses (Iseri et al., 1998). In orthodontics, FEA allows to find out the patterns of stress distribution and initial tooth movement visibly and quantitatively by constructing a three dimensional computer model and analyzing the stress, strain, moment that are generated when loaded.

The aim of this study is to observe the tooth movement patterns in intrusion of maxillary anterior teeth with miniscrews according to alveolar bone loss. For this purpose, orthodontic movements were simulated by using the finite element method.

II. Materials and methods

1. Finite element model construction

To calculate the tooth elements, tooth morphology was based on the 3D scanning of dental model produced by the sample survey of adults with normal occlusion (Model-i21D-400G, Nissin Dental Products, Kyoto, Japan). The position and axial inclination of teeth were considered on the basis of ideal occlusion of Andrews and arch form was fabricated according to broad arch form (Ormco®, Glendora, CA, USA) Curve of Spee and curve of Wilson were not considered. Long axis of the incisor was 60˚ inclined from the occlusal plane. The thickness of PDL was considered to be 0.25 mm and this thickness was constant around the root surface (Coolidge ED 1937). Average alveolar bond thickness on the labial and lingual sides was determined from 3D scanning of the same dental model. The morphology of the alveolar bone were modeled 1 mm above cemento-enamel junction (CEJ) following curvature of the CEJ in case of normal bone level (bone loss =0). Also each model has 2, 4 mm of alveolar bone loss. Alveolar bone loss were assumed to be even in bucco-lingual and mesio-distal direction. In 2 mm loss model, alveolar bone was 3 mm above CEJ, 4 mm loss model was 5 mm respectively. Brackets were made based on Microarch® (Tomy Co, Tokyo, Japan) and bracket slots were located on the facial axis of clinical crown (FACC) of individual teeth on the basis of Andrews plane. The arch wire was made from a 0.017*0.025 inch stainless steel wire, and brackets of the whole teeth were ligated firmly to the arch wire. The tooth, alveolar bone, PDL and brackets were all generated with 3D tetrahedral elements, and each tooth contacted with the adjacent teeth at the contact point.

The finite element model was made of two types; 4 anterior teeth segment and 6 anterior teeth segment. Overall conditions were the same but bilateral central incisors and lateral incisors were assumed to be combined as one unit in the 4 anterior teeth segment, and bilateral central incisors, lateral incisors and canines were assumed to be combined as one unit in the 6 anterior teeth segment. In other words, the difference is whether canines were included in the segment or not. In the segment, all teeth and the arch wire tie as oneunited body and the remaining posterior teeth were allowed to slide. The boundary condition between the arch wire and bracket was set to be no play. However, it was to allow for sliding freely (Figure 1). The miniscrew was assumed to be pure titanium with a Young's modulus of 110 GPa and a Poisson's ratio of 0.35 based on the existing literature. Miniscrews were assumed to be located 12 mm gingivally to the arch wire, midpoint between adjacent roots of teeth antero-posteriorly and just below the arch wire bucco-lingually. Bracket-tooth, bracket-archwire, and bone-miniscrew interfaces were defined as fully bonded surfaces.

The x-axis was set in the mesial direction, the y-axis was set in the labial direction, and the z-axis was set in the apical direction. And tooth local directions (mesio-distal, bucco-lingual, tooth axial direction) were set to analyze the movement patterns of individual tooth.

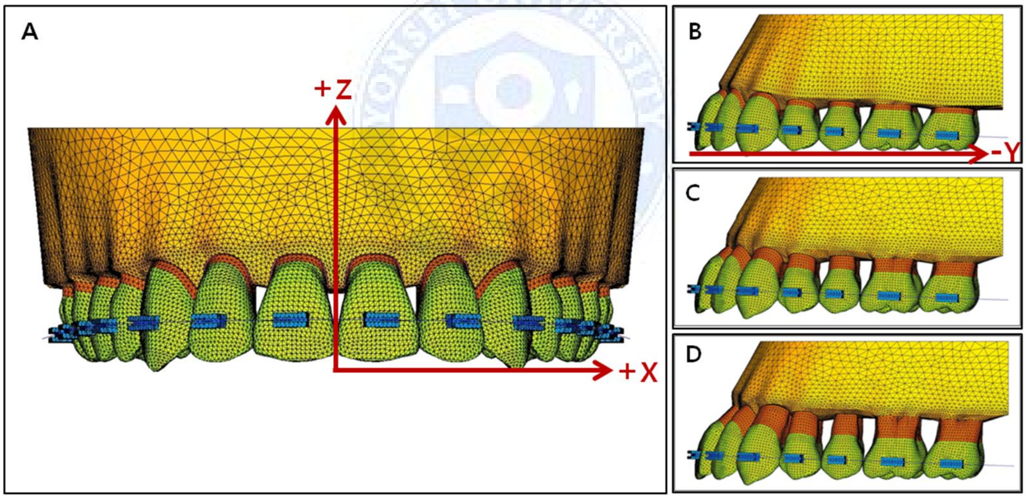


Figure 1. 3 dimensional finite element models and coordination system.

A, Maxillary teeth model; B, C and D, lateral view of model with 0, 2 and 4 mm alveolar bone loss respectively. X, mesio-distal (+) distal, (−) mesial direction; Y, labio-lingual (+) labial, (−) lingual direction; Z, superio-inferior (+) superior, (−) inferior direction.

2. Material properties

All materials were assumed to be homogeneous, isotropic, and linear-elastic. Applied properties for the each material were listed on Table 1. These properties were selected from other studies (Cobo, Sicilia et al. 1993; Cobo, Arguelles et al. 1996; Middleton, Jones et al. 1996; Cattaneo, Dalstra et al. 2005; Kanjanaouthai, Mahatumarat et al. 2012).

Table 1. Material properties

	Young’s modulus(MPa)	Poisson’s ratio
Periodontal ligament	5.0E-02	0.49
Alveolar bone	2.0E+03	0.30
Teeth	2.0E+04	0.30
Stainless steel	2.0E+05	0.30

3. Loading conditions and boundary conditions

For each 4 anterior teeth segment and 6 anterior teeth segment, the point and direction of intrusive force were applied by varying the location of the hooks and miniscrews (Table 2, Figure 2, 3). The magnitude of the intrusive force applied on the four upper incisors was initially suggested to be around 100 g (Burstone, 1977). On the other hand, Ricketts et al. (1979) proposed a magnitude of 125-160 g. In this study, for single force of inter-central incisors, 80 g of intrusive force was applied in 4 anterior teeth segment and 100 g in 6 anterior teeth segment. For bilateral force conditions, 40 g of intrusive force per side was applied in 4 anterior teeth segment and 50 g in 6 anterior teeth segment.

Table 2. Position of hooks and miniscrews for intrusion of maxillary anterior teeth

Condition	Position of hook	Position of miniscrew
1A	Between both central incisors	Between both central incisors
1B	Between central and lateral incisor	Between central and lateral incisor
1C	Between central and lateral incisor	Between lateral incisor and canine
1D	Between lateral incisor and canine	Between lateral incisor and canine
2A	Between both central incisors	Between both central incisors
2B	Between central and lateral incisor	Between central and lateral incisor
2C	Between central and lateral incisor	Between lateral incisor and canine
2D	Between lateral incisor and canine	Between lateral incisor and canine
2E	Between central and lateral incisors	Between canine and 1st premolar
2F	Between lateral incisor and canine	Between canine and 1st premolar

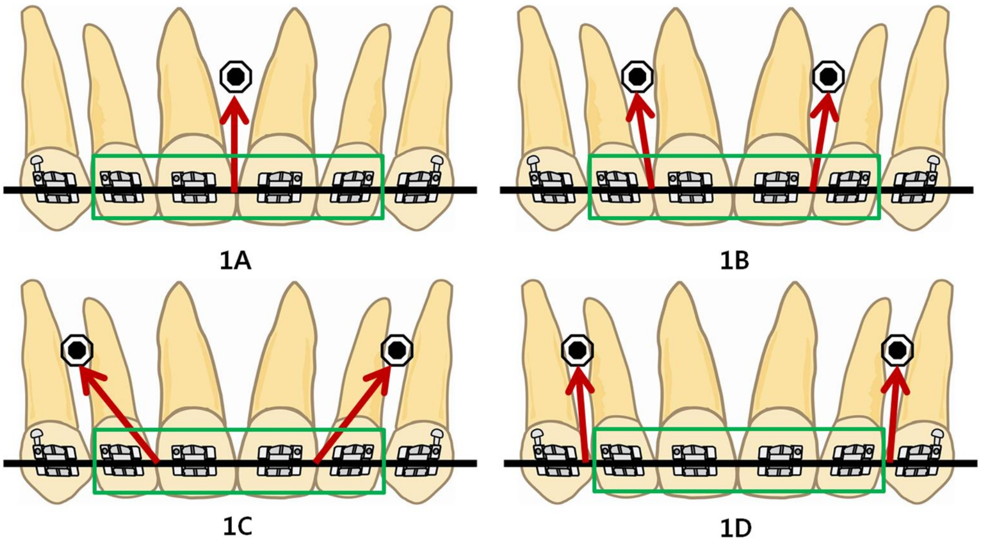


Figure 2. Force vectors for intrusion of 4 anterior teeth segment.

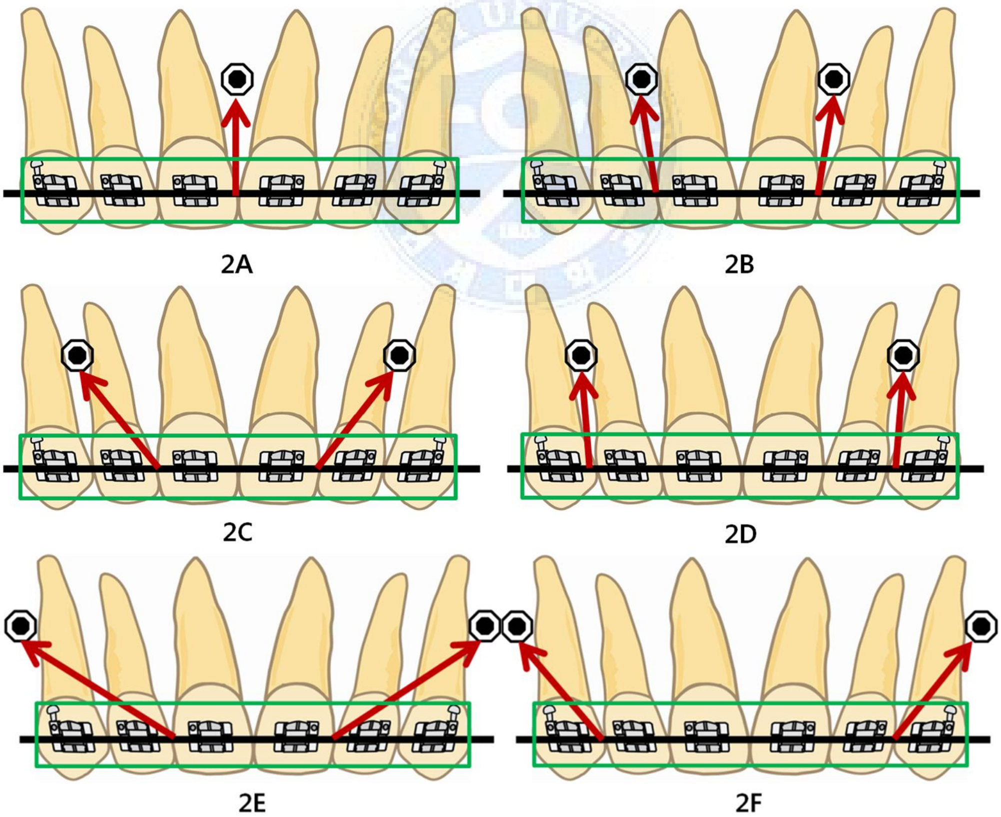


Figure 3. Force vectors for intrusion of 6 anterior teeth segment.

* The teeth in green box were assumed to be one unit.

4. Solutions

The analysis was performed with ANSYS software (version 12.0, ANSYS Inc., Canonsburg, PA, USA). By using the finite element method, the initial displacement of the anterior teeth and the stress distribution along the root surface were evaluated. To measure the displacement of the tooth under intrusive force, the nodes were selected at the midpoint of incisal edge and apex of each tooth, and the movements of nodes were considered as tooth movements. The displacement of nodes appeared through 3 directions(x, y, z axis) were calculated by obtaining the coordinates.

5. Graph analysis

In this study, we aimed to investigate the tooth displacement pattern of maxillary anterior teeth during intrusive movement. For this, the graphs were created, which initial location of each tooth on sagittal plane was displayed and later location after intrusive movement was displayed. And the angle between initial location and later location was measured, and the change of tooth angulation was calculated. In addition, the table which represented numerical amount of tooth displacement on each tooth was constructed.

III. Results

1. Displacement of anterior teeth without bone loss at 4 anterior teeth segment

Without bone loss, central incisor, lateral incisor, and canine moved as the graph showed in 4 conditions (1A, 1B, 1C, 1D) where the force directions were differently set (Figure 4). Although there was a slight difference in its degree, intrusion of anterior teeth did occur, accompanying uncontrolled tipping. Central incisor was the one with the largest intrusion amount among all the conditions except for 1D. In central incisor, 1A case was the most labially moved one, and its degree decreased towards 1B, 1C, and 1D in order. In lateral incisor, 1B case showed the largest intrusion amount, but there was no noticeable difference in 4 conditions since the rest 3 conditions showed similar level displacement. Canine intrusion occurred the most in 1D. In 1D case, the degree of canine intrusion was nearly similar to one another in central incisor, lateral incisor, and canine.

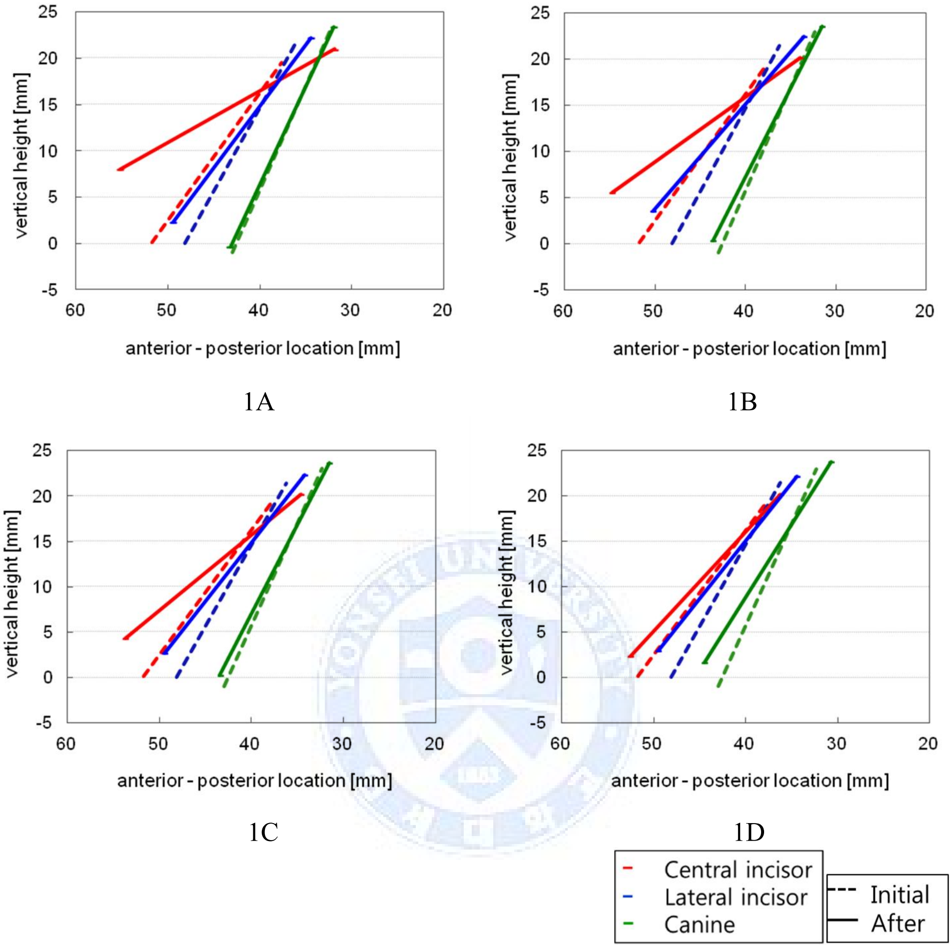


Figure 4. Sagittal view of displacement of anterior teeth without bone loss at 4 anterior teeth segment

* anterior-posterior location: distance from the distal surface of second molar

* The displacement is scaled up to 1000 fold for visibility.

2. Displacement of anterior teeth with 2 mm bone loss at 4 anterior teeth segment

With 2 mm bone loss, central incisor, lateral incisor, and canine moved as the graph showed in 4 conditions (Figure 5). Although there was a slight difference in its degree, intrusion did occur, accompanying uncontrolled tipping against each fiducial lines. Although the appearance of tooth movement was similar to without bone loss cases, the degree of labial tipping was larger.

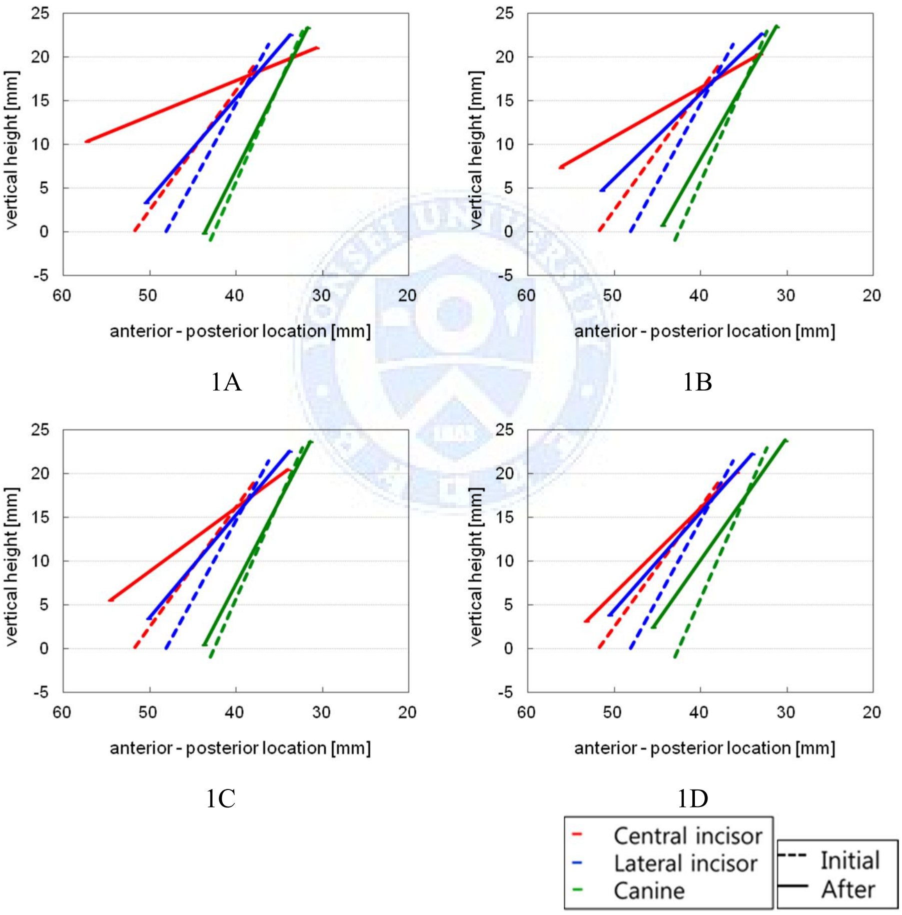


Figure 5. Sagittal view of displacement of anterior teeth with 2 mm bone loss at 4 anterior teeth segment

* anterior-posterior location: distance from the distal surface of second molar

* The displacement is scaled up to 1000 fold for visibility.

3. Displacement of anterior teeth with 4 mm bone loss at 4 anterior teeth segment

With 4 mm bone loss, central incisor, lateral incisor, and canine moved as the graph showed in 4 conditions (Figure 6). Although there was a slight difference in its degree, intrusion did occur, accompanying uncontrolled tipping against each fiducial lines. Although the appearance of tooth movement was similar to 0 or 2 mm bone loss cases, the degree of labial tipping movement was noticeable. However, the intrusion amount was larger than 0 and 2 mm cases as well.

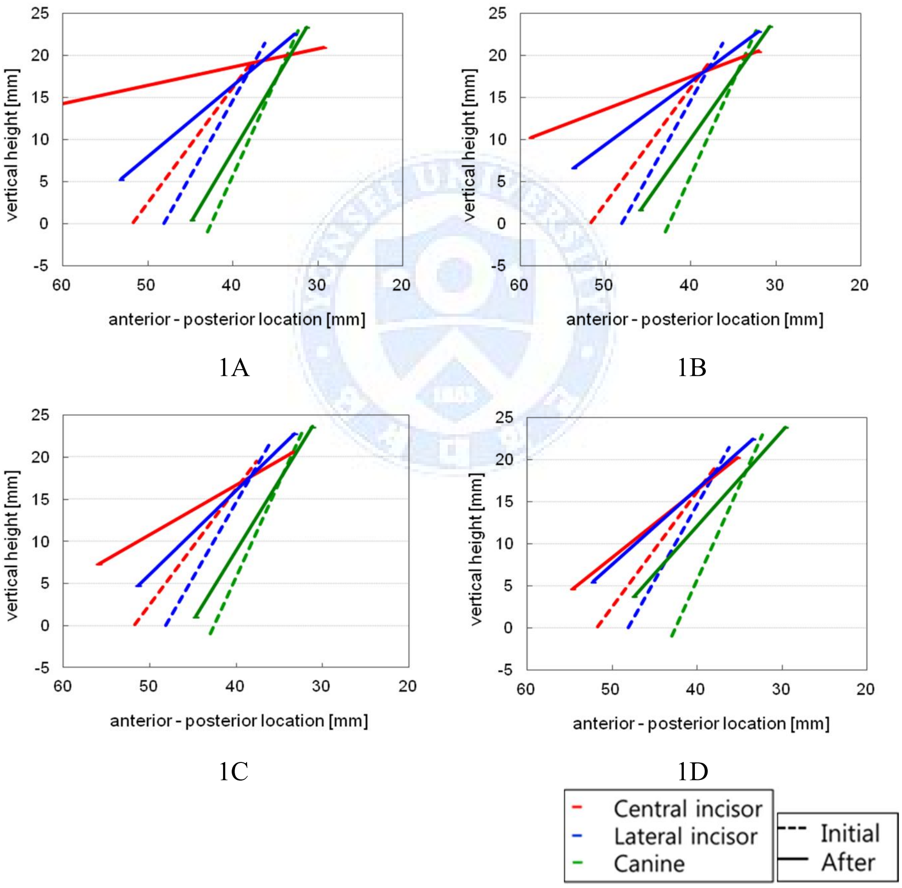


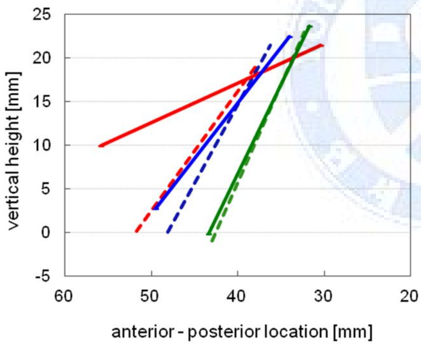
Figure 6. Sagittal view of displacement of anterior teeth with 4 mm bone loss at 4 anterior teeth segment

* anterior-posterior location: distance from the distal surface of second molar

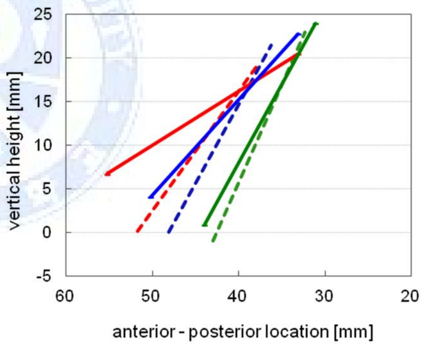
* The displacement is scaled up to 1000 fold for visibility.

4. Displacement of anterior teeth without bone loss at 6 anterior teeth segment

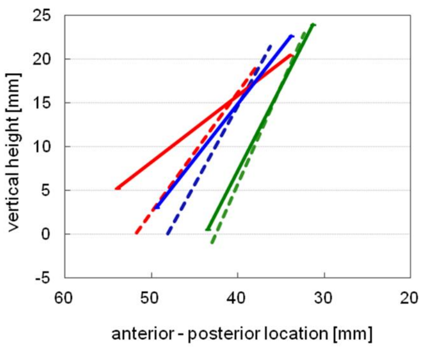
The appearance of tooth movement on sagittal plane when intrusion force was applied unto 6 anterior teeth segment was as follows. Without bone loss, intrusion occurred in all the cases of central incisor, lateral incisor, and canine, accompanying uncontrolled tipping in 6 conditions where the applied force directions were set differently (Figure 7). In 2A case, central incisor showed the most labial tipping, and its degree decreased in 2B, 2C, 2D, 2E, 2F in order.   In F case, the labial tipping tendency of anterior teeth was the least, yet the intrusion amount was the least as well. In lateral incisor case, 2B, 2C, and 2D conditions showed a relatively large amount of intrusion and labial movement. The displacement of canine occurred the most in 2D and 2F. 2E and 2F showed the displacement relatively similar to controlled tipping.



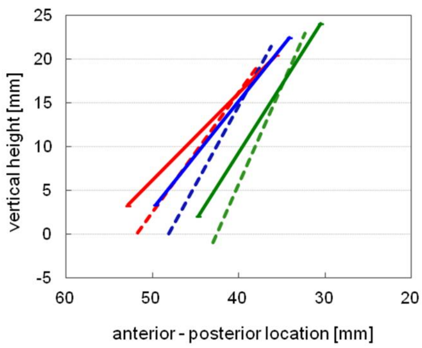
2A



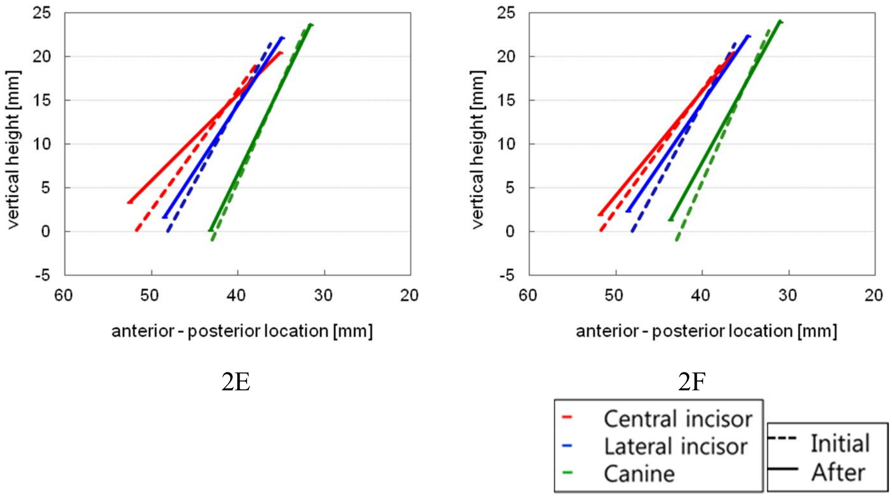
2B



2C



2D



2E 2F

Figure 7. Sagittal view of displacement of anterior teeth without bone loss at 6 anterior teeth segment

* anterior-posterior location: distance from the distal surface of second molar

* The displacement is scaled up to 1000 fold for visibility.

5. Displacement of anterior teeth with 2 mm bone loss at 6 anterior teeth segment

The appearance of tooth displacement in sagittal plane when intrusion force was applied unto 6 anterior teeth segment was as follows (Figure 8). With 2 mm bone loss, in 6 conditions in which the applied force directions were set differently, intrusion occurred in all the cases of central incisor, lateral incisor, and canine, accompanying the appearance of uncontrolled tipping. The overall appearance of tooth movement coincided with no bone loss case, yet the degree of labial tipping movement was larger.

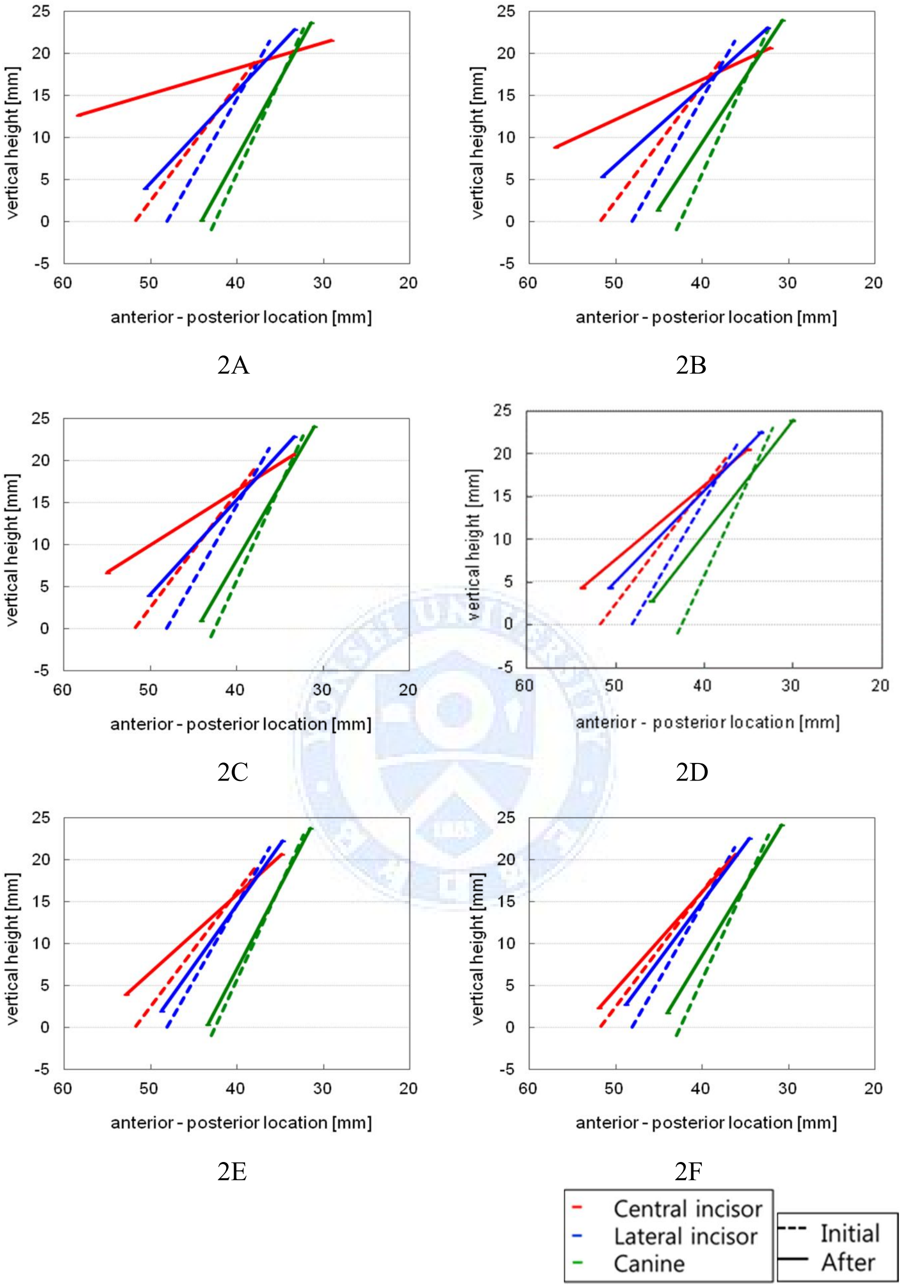


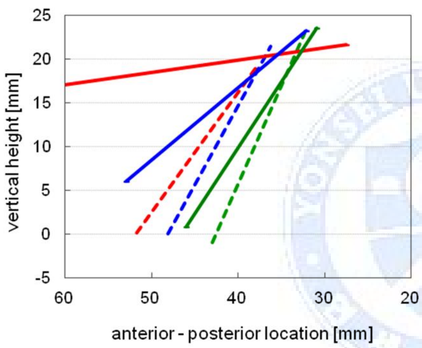
Figure 8. Sagittal view of displacement of anterior teeth with 2 mm bone loss at 6 anterior teeth segment

* anterior-posterior location: distance from the distal surface of second molar

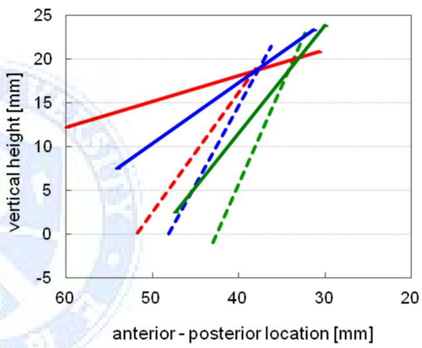
* The displacement is scaled up to 1000 fold for visibility.

6. Displacement of anterior teeth with 4 mm bone loss at 6 anterior teeth segment

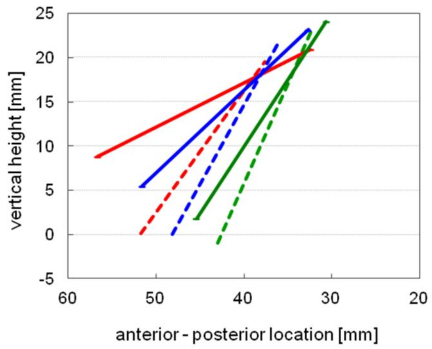
The appearance of tooth displacement in saggital plane when intrusion force was applied unto 6 anterior teeth segment was as follows (Figure 9). With 4 mm bone loss, in 6 conditions in which the applied force directions were set differently, intrusion occurred in all the cases of central incisor, lateral incisor, and canine against their fiducial lines, accompanying the appearance of uncontrolled tipping. The overall appearance of tooth movement coincided with bone loss 0 and 2 mm cases, yet the degree of labial tipping movement was larger.



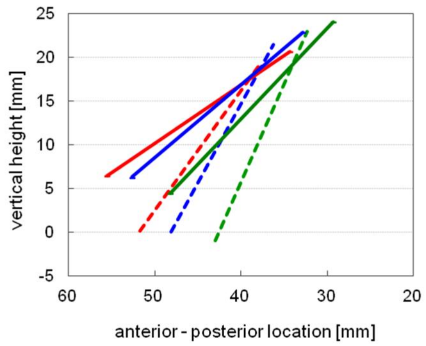
2A



2B



2C



2D

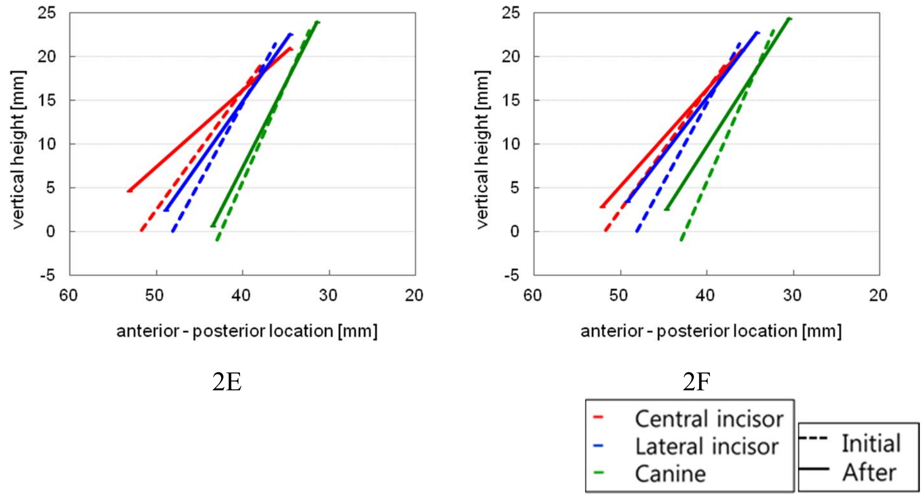


Figure 9. Sagittal view of displacement of anterior teeth with 4 mm bone loss at 6 anterior teeth segment

* anterior-posterior location: distance from the distal surface of second molar

* The displacement is scaled up to 1000 fold for visibility.

7. The changes of angulation of crown after intrusion

With 0, 2 and 4 mm bone loss, the changes of angulation of crown after intrusion on each tooth was shown in the following graph (Table 2). On sagittal plane, all of the central incisor, lateral incisor, and canine cases showed labial tipping movement appearance in which crown tip moved anterior to root tip. In central incisor, 1A and 2A showed the largest tipping amount, and the amount showed a decreasing tendency from 2A towards 2F. Lateral incisor showed a small tipping amount compared with that of central incisor, and the tipping amount was the largest in 1B and 2B. Canine showed a relatively larger tipping amount in 1D and 2D compared with central incisor and lateral incisor. In each case, each tooth showed a tendency that tipping amount increased as bone loss increased, and the increase amount was much larger when proceeding from 2 to 4 mm than when proceeding from 0 to 2 mm.

Table 3. The changes of angulation of crown tip after intrusion (°)

Group	Central incisor			Lateral incisor			Canine		
	0 mm	2 mm	4 mm	0 mm	2 mm	4 mm	0 mm	2 mm	4 mm
1A	26.9	36.1	51.5	7.9	12.1	21.9	1.6	3.2	6.6
1B	19.5	26.3	37.2	12.5	17.3	25.8	3.7	6.2	11.3
1C	14.4	18.6	24.8	8.7	11.7	16.4	3.0	4.1	7.1
1D	6.4	9.6	15.5	8.9	12.6	19.1	8.0	11.6	17.9
2A	32.9	43.9	60.1	9.0	13.8	22.9	2.2	4.6	10.3
2B	23.3	31.4	43.9	13.6	19.0	28.5	5.4	8.8	15.8
2C	17.1	22.1	29.7	9.5	12.7	18.5	3.7	5.6	9.9
2D	9.1	13.4	21.0	9.9	14.1	21.5	9.0	13.1	20.4
2E	9.5	11.1	13.0	4.4	5.3	6.5	2.4	2.9	3.7
2F	3.9	4.7	6.0	5.6	6.6	8.6	5.4	6.7	9.0

8. Comparison of central incisor displacement according to bone loss

With 0, 2 and 4 mm bone loss, central incisor (crown tip) showed the movement appearance as shown in the following graph in 4 anterior teeth segment and 6 anterior teeth segment (Figure 10). Without bone loss, first of all, 1A showed a more noticeable mesio-distal displacement than other conditions. Labial tilting movement and intrusion decreased from A towards D.

In 6 anterior teeth segment as well, 2A showed a markedly large mesio-distal displacement than other conditions. Labial tilting movement decreased from 2A towards 2F in sequential manner. The amount of intrusion also decreased from 2A towards 2D, but 2D exceptionally showed a smaller intrusion amount than 2E case. The movement appearances of central incisors were all the same in 3 cases (bone loss 0, 2 and 4 mm), and as bone loss increased, the tooth displacement amount increased in all the directions (mesio-distal, bucco-lingual, tooth axial).

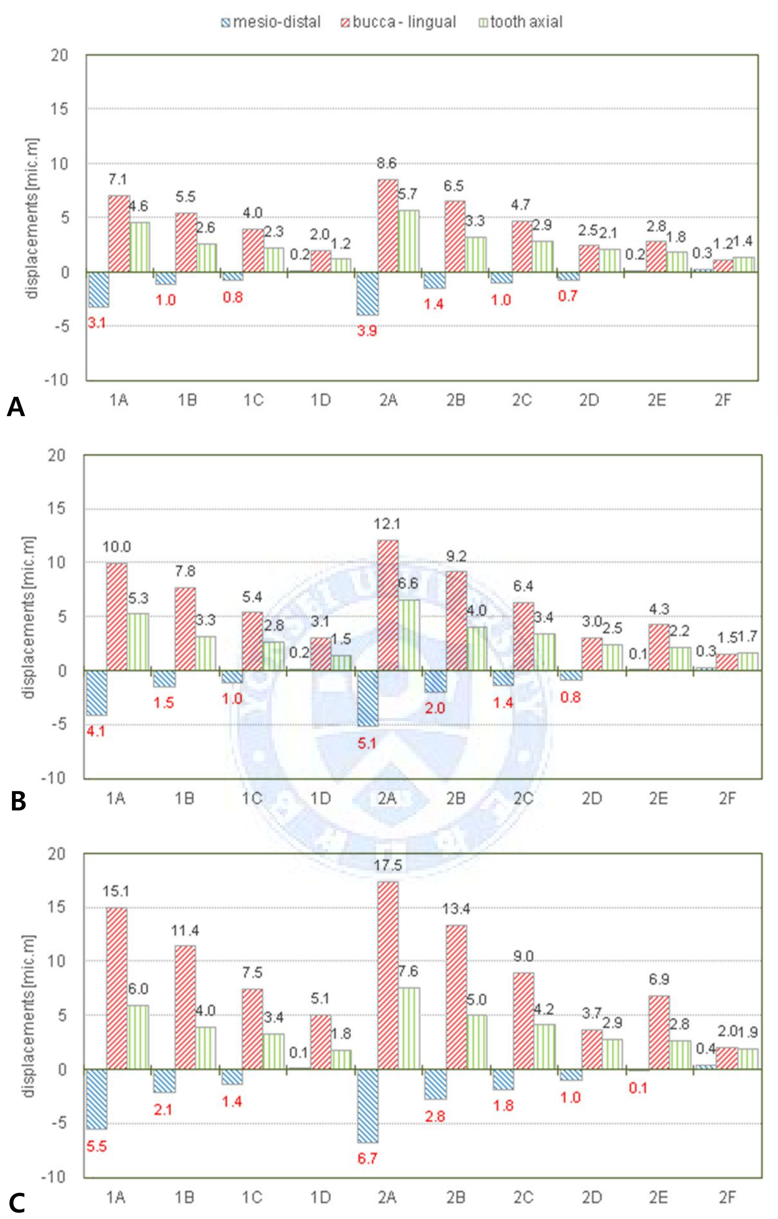


Figure 10. Displacements of central incisors in tooth local directions

A, 0 mm bone loss; B, 2 mm bone loss; C, 4 mm bone loss

9. Comparison of lateral incisor displacement according to bone loss

With 0, 2 and 4 mm bone loss, central incisor (crown tip) showed the movement appearance as shown in the following graph in 4 anterior teeth segment and 6 anterior teeth segment (Figure 11). In 4 anteior teeth segment, mesio-distal displacement was noticeable in 1A, 1B, ad 1C, compared with other conditions. Labial movement occurred markedly in 1B and 1D although there was no big difference, compared with central incisor. The intrusion amount on tooth axis direction was similar to that of labial tipping. In 6 anterior teeth segment as well, similar tooth movement was shown from 2A through 2D. In 2E and 2F, mesio-distal displacement amount was much smaller, compared with other conditions, and the degree of labial tipping also was moderate and thus controlled tipping appearance was shown. However, the intrusion amount was also small. The movement appearances of lateral incisors were all the same in 3 cases (bone loss 0, 2 and 4 mm), and as bone loss increased, the tooth displacement amount increased in all the directions (mesio-distal, bucco-lingual, and tooth axial). And its degree increased more when proceeding from 2 to 4 mm than when proceeding from 0 to 2 mm.

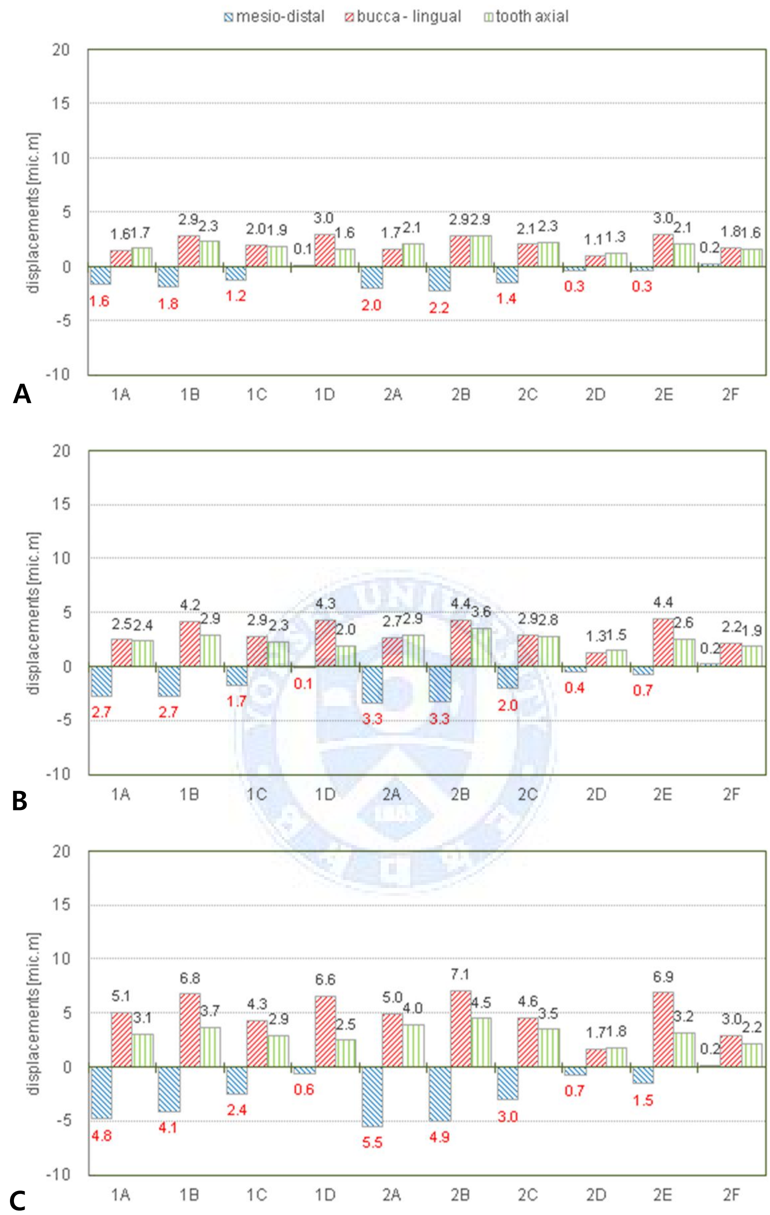


Figure 11. Displacements of lateral incisors in tooth local directions

A, 0 mm bone loss; B, 2 mm bone loss; C, 4 mm bone loss

10. Comparison of canine displacement according to bone loss

In canine case, mesio-distal displacement amount was not large. The amount of labial displacement and intrusion also was small, compared with those of central incisor or lateral incisor. In 1D and 2D, labial tipping and intrusion occurred the most. 1B and 2B, 1C and 2C conditions, although their force conditions were identical, showed somewhat different result. In 4 anterior teeth segment, labial tipping amount and intrusion amount were nearly similar to each other, yet in 6 anterior teeth segment, intrusion occurred more than labial tipping. The intrusion amount was the largest in 1D and 2D, and 2B and 2F also showed a considerable amount of axial intrusion.

As bone loss increased, the tooth displacement pattern became similarly increased, but its change amount was not as large as that of central incisor or lateral incisor.

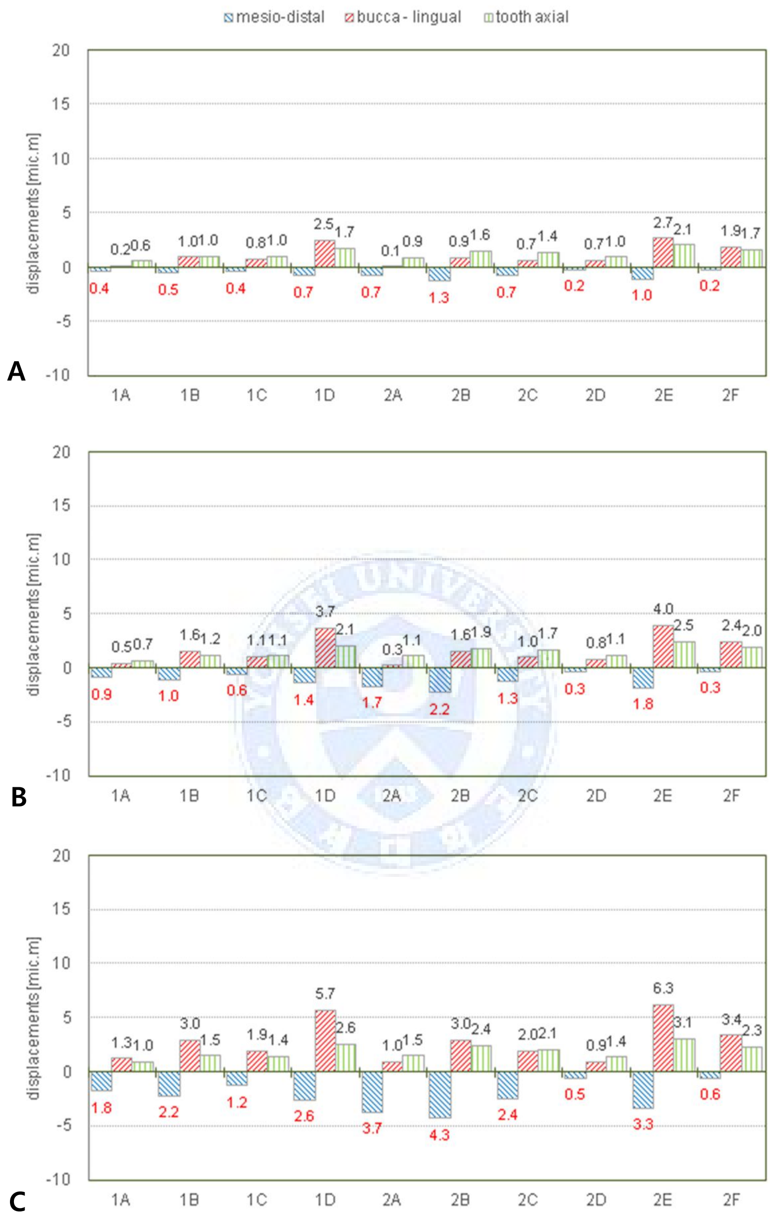


Figure 12. Displacements of canines in tooth local directions

A, 0 mm bone loss; B, 2 mm bone loss; C, 4 mm bone loss

11. The stress distribution on maxillary anterior teeth without bone loss

In all cases, more stress was applied unto apex than to cervical area of PDL. In 4 anterior teeth segment, stress was noticeably concentrated on central incisor in 1A, and the degree of stress decreased in central incisor, lateral incisor, canine in order in 1B and 1C. In 1D case, central incisor was the one with the least stress, and the same amount of stress was applied on lateral incisor and canine. In 6 anterior teeth segment as well, stress of central incisor was shown the most in 2A, and in lateral incisor, 2B was the one with the highest stress value. Canine was the one with relatively less stress. In 2F, stress was relatively evenly distributed on central incisor, lateral incisor, and canine (Table 3).

Table 4. Maximum compressive stresses of PDLs without bone loss (g/mm²)

Group	Central incisor		Lateral incisor		Canine	
	Apical	Cervical	Apical	Cervical	Apical	Cervical
1A	2.3	0.9	0.8	0.3	0.2	0.1
1B	1.4	0.6	1.1	0.5	0.4	0.2
1C	1.2	0.4	0.9	0.3	0.4	0.2
1D	0.5	0.2	0.8	0.4	0.8	0.4
2A	2.8	1.1	0.9	0.4	0.3	0.1
2B	1.7	0.7	1.3	0.5	0.6	0.2
2C	1.4	0.5	1.0	0.3	0.6	0.2
2D	0.8	0.3	0.9	0.4	0.9	0.4
2E	1.0	0.3	0.6	0.2	0.4	0.1
2F	0.5	0.1	0.7	0.2	0.7	0.3

12. The stress distribution on maxillary anterior teeth with 2 mm bone loss

When bone loss progressed up to 2 mm, stress amount increased more. In 1A and 2A as well, the stress which was concentrated on central incisor was noticeable, and in labial incisor, 1B and 2B showed the highest stress value. In 1D and 2F, stress was relatively evenly distributed (Table 4).

Table 5. Maximum compressive stresses of PDLs with 2 mm bone loss (g/mm^2)

Group	Central incisor		Lateral incisor		Canine	
	Apical	Cervical	Apical	Cervical	Apical	Cervical
1A	2.6	1.1	1.0	0.4	0.3	0.1
1B	1.7	0.7	1.3	0.6	0.5	0.3
1C	1.4	0.5	1.0	0.4	0.5	0.2
1D	0.7	0.3	0.9	0.4	0.9	0.5
2A	3.3	1.3	1.3	0.5	0.4	0.2
2B	2.1	0.9	1.6	0.6	0.8	0.4
2C	1.7	0.6	1.2	0.4	0.7	0.2
2D	1.0	0.4	1.1	0.5	1.1	0.5
2E	1.1	0.3	0.7	0.2	0.5	0.1
2F	0.6	0.2	0.8	0.2	0.8	0.3

13. The stress distribution on maxillary anterior teeth with 4 mm bone loss

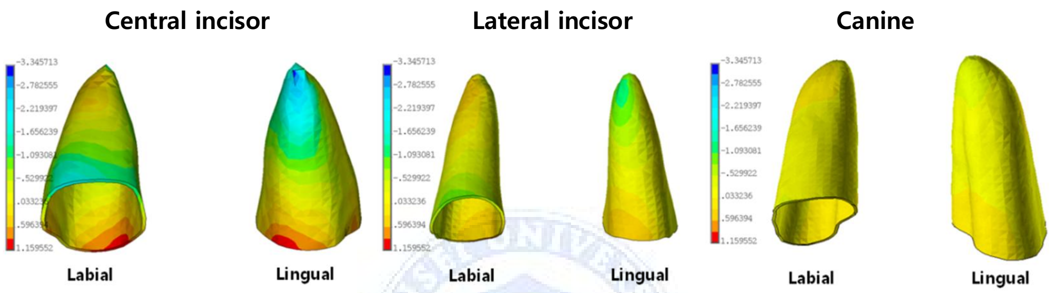
The stress distribution appearance was same as that of bone loss 0 and 2 mm, but the stress increase was outstanding. Similarly, stress concentration rate of central incisor was high in 1A and 2A, and relatively even stress distribution was shown in 1D and 2F (Table 5).

Table 6. Maximum compressive stresses of PDLs with 4 mm bone loss (g/mm²)

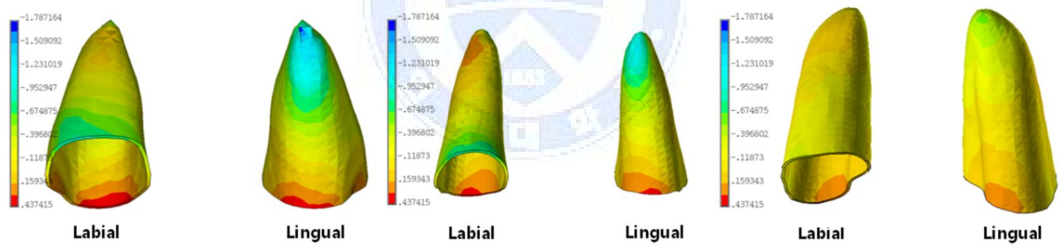
Group	Central incisor		Lateral incisor		Canine	
	Apical	Cervical	Apical	Cervical	Apical	Cervical
1A	3.2	1.1	1.4	0.6	0.4	0.2
1B	2.1	0.7	1.7	0.6	0.7	0.4
1C	1.7	0.4	1.3	0.4	0.6	0.3
1D	0.9	0.4	1.2	0.5	1.2	0.7
2A	3.9	1.2	1.7	0.7	0.6	0.3
2B	2.6	0.8	2.0	0.7	1.0	0.5
2C	2.0	0.5	1.5	0.4	0.8	0.3
2D	1.3	0.5	1.4	0.5	1.3	0.6
2E	1.2	0.2	0.8	0.2	0.6	0.1
2F	0.7	0.2	0.9	0.2	1.0	0.3

14. Comparison of stress distribution after intrusion with 4 mm bone loss

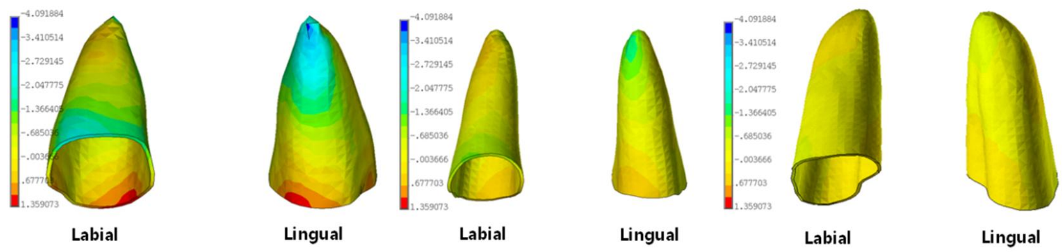
In 4 anterior teeth segment, stress difference between central incisor, lateral incisor, and canine was big in 1A, and relatively even stress distribution was shown in 1D. In 6 anterior teeth segment, stress difference was the biggest in 2A, and smallest in 2F.



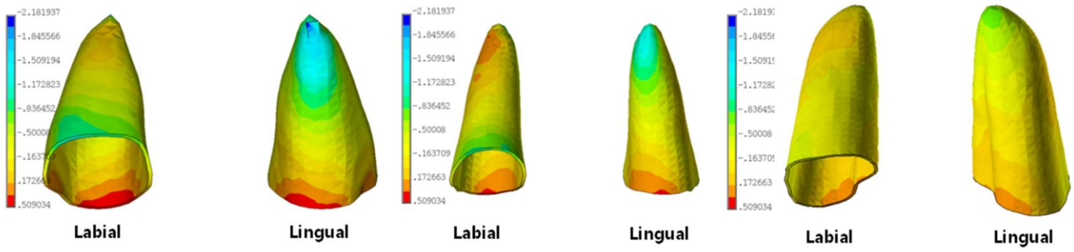
1A



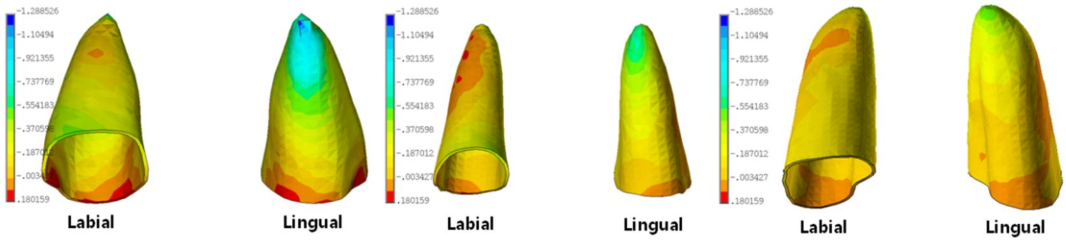
1D



2A



2D



2F

Figure 13. Comparison of maximum compressive stress distribution in periodontal ligament

* Blue color means high stresss distribution and red color means low stress distribution.

IV. Discussion

There is an ever-increasing concern for dentofacial esthetics in the adult population; hence, in contemporary dental care, an increasing number of adult patients are seeking orthodontic treatment. In this group of patients, the primary motivating factor is a desire to improve their dental appearance (McKiernan EX et al., 1992; Brunsvold MA, 2005). Majority of the adult orthodontic patients are accompanied with a co-existing periodontal pathology, resulting in pathologic migration, spacing, flaring and trauma from occlusion. Anterior teeth are especially prone to elongation since they are not protected by occlusal forces and have no antero-posterior contacts inhibiting migration (Melsen B et al. 1989). In addition, anterior tooth has one single root, and alveolar bone around anterior tooth is thin, so alveolar bone loss occurs easily. The maxillary central incisors are the most visible teeth during unstrained facial activities. They are also the most representatives of the mold design of the teeth and can be easily distinguished from the other teeth in oral cavity. So when pathologic migration occurs, patients recognize it seriously and want to fix that problem.

In cases of pathologic migration and extrusion, intrusive movement has been recommended to realign the teeth and improve clinical crown lengths and marginal bone levels (Cardaropoli, D et al. 2001). And correction of anterior deepbite also played an important role in the elimination of occlusal trauma. A shallow overbite can establish better incisal and canine guidance, which is important for stability of the occlusion. Furthermore, histologic studies suggest that orthodontic intrusion may lead to the formation of new connective tissue attachment (Melsen B 1986; Melsen B et al., 1988). At this time, light intrusive force and intrusion without tipping are two prerequisites to obtain new connective tissue attachment. If these prerequisites are satisfied, there will be no hyalinization in the marginal part of the periodontal ligament. Hyalinization has crucial importance for the result since retardation of the intrusive movements caused by hyalinization may well allow the epithelial downward growth to occur. Consequently if there is no hyalinization, new connective tissue attachment can be formed during the intrusion of the periodontally involved teeth (Melsen B et al., 1988).

Traditional methods for intrusion of maxillary anterior teeth were introduced by many scholars (Burstone CJ 1977; Begg PR et al., 1977; Ricketts RM 1976; Greig DG 1983). These mechanics frequently cause labial tipping of incisors, a situation which does not always give favorable treatment outcomes (Barton, 1972; Engel et al., 1980; Otto et al., 1980). Melsen et al. (1989) indicated that the segmented arch technique is the treatment of choice for patients with elongated incisors or periodontal bone loss. However, since these conventional arches are connected to the posterior teeth during intrusion, the presence of counteracting moments is frequently inevitable (Burstone, 2001).

But recently with remarkable development of orthodontic miniscrews, it became possible to simplify force system and move the targeted tooth predictably. Direct application of intrusive forces from miniscrews offers an efficient alternative to many conventional intrusion arches and true intrusion can be achieved. In patients with alveolar bone loss, increased demands are placed on clinicians for careful application of the force systems used in tooth movement. Because the reduced supporting PDL area and volume result in ever higher amounts of displacements in supporting structures of affected teeth for a given level of force and moment magnitude.

This study aimed to investigate the displacement of anterior teeth during intrusion according to alveolar bone loss by changing the position of miniscrews and hooks at the reproducible levels in clinical practice.

When intrusion force was applied unto 4 anterior teeth and 6 anterior teeth with the miniscrew and hook being differently positioned, central incisor, lateral incisor, and canine all underwent intrusion accompanying labial tipping movement. Yet, the degree of each labial tipping turned out to be different depending on the location of miniscrew and hook. In 1A case among four conditions (1A, 1B, 1C, 1D) where 4 anterior teeth were intruded as one segment, the effect upon central incisor was the largest since miniscrew was inserted in between both central incisors so that the force could be applied. They thus became more intruded than other teeth did, yet the degree of the labial tipping was also large as much as it was intruded. Looking at this result from a clinical perspective, it is not desirable that the force is applied as in the 1A case if periodontal health condition is not good. Because teeth could look more spaced or severely flared since the degree of the labial tipping is high even beyond that of intrusion, although it is desirable in a sense that anterior teeth are intruded significantly. The intrusion amount and labial tipping decreased from 1A towards 1D, and its degree was proportional to how far the location of the hook became from central incisor. In lateral incisor case, 1B was the one with the most intrusion, and the rest 3 cases showed similar amounts of intrusion. The degree of labial tipping was the largest in 1B and 1D showing similar values, and the labial tipping decreased in 1A where the miniscrew and hook were farthest from lateral incisor and in 1C where retraction force was added. It is considered, in 1C case, that the fact that a slight amount of retraction force was added stopped the labial tipping since the hook was located mesial to lateral incisor although the location of miniscrew was the same. In canine, 1D showed the largest amount of intrusion. This also is thought to be because the location of the hook is close to canine. In the case of labial tipping, the same correlation as in intrusion was shown. In canine, 1A underwent nearly no labial tipping, and 1D underwent labial tipping outstandingly. This is thought to be because a significant amount of direct force was applied since the hook was located right mesial to canine. As bone loss progressed, labial tipping and intrusion of teeth occurred more, and the overall tooth movement appearance was the same as that of no bone loss case. In all of the central incisor, lateral incisor, and canine case, the tooth displacement occurred more when bone loss progressed from 0 to 2 mm than when progressing from 2 to 4 mm. Canine was relatively less affected by the bone loss, compared with central and lateral incisor. The reason for this is considered that since canine is larger than central or lateral incisor, the resistance force against vertical pressure is also large. It was observed that the bone loss affected more on labial tipping than on intrusion.

2A case among 6 conditions (2A, 2B, 2C, 2D, 2E, 2F) where 6 anterior teeth were intruded as one segment was the one where a miniscrew was installed in between bilateral central incisors. In 2A, central incisor was the most intruded and also labially protruded one. The intrusion amount of central incisor gradually decreased in 2A, 2B, 2C, 2E, 2D and 2F in order. The reason why the intrusion amount is larger in 2C is that although 2C and 2E have a common feature that the hook is located distal to central incisor, the retraction force vector is larger in 2E. In lateral incisor, intrusion occurred significantly in 2B and 2C. In canine, intrusion occurred significantly in 2B and 2F. Labial tipping showed a similar tendency to that of intrusion. In central incisor, labial tipping decreased from 2A towards 2F. In lateral incisor, 2B and 2D showed the largest amount of labial tipping movement. There is one common feature that in both two conditions, the location of the hook is in between central incisor and lateral incisor. In canine, 2D showed a noticeable amount of labial tipping, compared with other conditions. This is thought to be because at the distal part of canine, retraction force was not added since only vertical force was applied on the arch. Also in 2F where the hook location was mesial to canine, a considerable amount of labial tipping occurred, but the amount was smaller than that of 2D. Overall, labial tipping tendency decreased from A towards F and its appearance was similar to controlled tooth movement although there was somewhat difference on each tooth. However, intrusion amount markedly decreased as well. In 2E, displacement pattern were similar to pure intrusion with few labial tipping since retraction force vector was added because the location of the miniscrew was in between the canine and first premolar, compared with 2B and 2C conditions where the hook location was the same.

Within the boundary of this study, minimal labial displacement of 6 anterior teeth was found when the hook was positioned distal to the lateral incisor and miniscrews were inserted between canine and first premolar (condition 2F), indicating almost controlled tipping with intrusion. This is thought to be because the force was applied by being closest to center of resistance (CR) among 6 anterior teeth. In other words, this implies that for a pure intrusion of 6 anterior teeth, the intrusion method using the miniscrew on the posterior side of canine and the hook on the distal side of lateral incisor is very effective. This result is very encouraging because treatment will be much more effectively done if 6 anterior teeth could be simultaneously intruded by a predictable method, since in most extrusion cases, canine intrusion is eventually necessary. When the same force was applied with 6 anterior teeth being intruded as one segment, the amount of anterior movement and the intrusion of anterior teeth turned out to be large in all cases as bone loss increased. And tooth displacement occurred more when bone loss progressed from 2 to 4 mm than when progressing from 0 to 2 mm as in 4 anterior teeth segment. Also, the difference of labial tipping turned out to be much larger than that of intrusion. It is thought that since posterior movement of CR is larger when bone loss is progressing from 2 to 4 mm than when progressing from 0 to 2 mm, anterior displacement of tooth turned out to be larger when going from 2 to 4 mm under the same force vector.

When comparing 4 anterior teeth segment and 6 anterior teeth, tooth movement was larger in 6 anterior teeth segment. When looking at the intrusion amount, central incisor and lateral incisor showed a result nearly proportional to the difference of the force size (80 g on 4 anterior teeth, and 100 g was applied on 6 anterior teeth segment). On the othder hand, in canine of 6 anterior teeth segment, the increase amount of intrusion was larger than the disparity between the two different sized forces. This is thought to be because it was hypothesized that in 4 anterior teeth segment case, canine was not connected to archwire and sliding was accepted, and in 6 anterior teeth segment, all of 6 anterior teeth including canine were connected to arch wire. In the case of labial tipping, central incisor showed a difference relatively proportional to the force size, yet lateral incisor showed a nearly no difference. In canine, labial tipping actually decreased, compared with 4 anterior teeth segment. This is thought to be because it was hypothesized that the archwire was tightly connected through canine.

The changes of angulation of crown after intrusion were analyzed. On sagittal plane, all of the central incisor, lateral incisor, and canine cases showed labial tipping movement appearance in which crown tip moved anterior to root tip. In each case, each tooth showed a tendency that tipping amount increased as bone loss increased. Central incisors in 1A and 2A showed the largest tipping amount, the amount were 51° in 1A, 60° in 2A with 4 mm bone loss. This support that vertical intrusion force through the miniscrew between both central incisors is not desirable, especially in periodontally compromised patients. In general, central incisor showed the largest labial tipping, followed by lateral incisor and canine. It was observed that the maximum tipping amount were 27° in central incisor, 12° in lateral incisor and 8° in canine at 4 anterior teeth segment without bone loss, while the maximum tipping amount were 33° in central incisor, 14° in lateral incisor and 9° in canine at 6 anterior teeth segment without bone loss. In 2 mm bone loss, the maximum tipping amount were 36° in central incisor, 17° in lateral incisor and 12° in canine at 4 anterior teeth segment, while the maximum tipping amount were 44° in central incisor, 19° in lateral incisor and 13° in canine at 6 anterior teeth segment. In 4 mm bone loss, the maximum tipping amount were 51° in central incisor, 26° in lateral incisor and 18° in canine at 4 anterior teeth segment, while the maximum tipping amount were 60° in central incisor, 28° in lateral incisor and 20° in canine at 6 anterior teeth segment. In summary, all teeth showed similarly small tipping in 1D and 2F. Especially, the tipping amount in 2F was significantly less than other conditions, representing controlled tipping near pure intrusion. When adding retraction force than just applying vertical intrusion force, the tipping amount decreased. Because adding retraction vector to intrusion force enable to apply the force close to CR.

Table 7. Displacement of crown tip at tooth axis direction (㎛)

Group	Central incisor			Lateral incisor			Canine		
	0 mm	2 mm	4 mm	0 mm	2 mm	4 mm	0 mm	2 mm	4 mm
1A	4.6	5.3	6.0	1.7	2.4	3.1	0.6	0.7	1.0
1B	2.6	3.3	4.0	2.3	2.9	3.7	1.0	1.2	1.5
1C	2.3	2.8	3.4	1.9	2.3	2.9	1.0	1.1	1.4
1D	1.2	1.5	1.8	1.6	2.0	2.5	1.7	2.1	2.6
2A	5.7	6.6	7.6	2.1	2.9	4.0	0.9	1.1	1.5
2B	3.3	4.0	5.0	2.9	3.6	4.5	1.6	1.9	2.4
2C	2.9	3.4	4.2	2.3	2.8	3.5	1.4	1.7	2.1
2D	1.8	2.2	2.8	2.1	2.6	3.2	2.1	2.5	3.1
2E	2.1	2.5	2.9	1.3	1.5	1.8	1.0	1.1	1.4
2F	1.4	1.7	1.9	1.6	1.9	2.2	1.7	2.0	2.3

Table 8. Displacement of crown tip at bucco-lingual direction (㎛)

Group	Central incisor			Lateral incisor			Canine		
	0 mm	2 mm	4 mm	0 mm	2 mm	4 mm	0 mm	2 mm	4 mm
1A	7.1	10.0	15.1	1.6	2.5	5.1	0.2	0.5	1.3
1B	5.5	7.8	11.4	2.9	4.2	6.8	1.0	1.6	3.0
1C	4.0	5.4	7.5	2.0	2.9	4.3	0.8	1.1	1.9
1D	2.0	3.1	5.1	3.0	4.3	6.6	2.5	3.7	5.7
2A	8.6	12.1	17.5	1.7	2.7	5.0	0.1	0.3	1.0
2B	6.5	9.2	13.4	2.9	4.4	7.1	0.9	1.6	3.0
2C	4.7	6.4	9.0	2.1	2.9	4.6	0.7	1.0	2.0
2D	2.8	4.3	6.9	3.0	4.4	6.9	2.7	4.0	6.3
2E	2.5	3.0	3.7	1.1	1.3	1.7	0.7	0.8	0.9
2F	1.2	1.5	2.0	1.8	2.2	3.0	1.9	2.4	3.4

When it comes to stress, more stress was concentrated on tooth apex area than on cervical area of PDL in all cases. As the displacement amount of tooth became larger, the stress also showed more tendency of increasing. Just as 1A or 2A, when the movement of central incisor was significantly large, stress was also concentrated on central incisor rather than other teeth. In 4 anterior teeth segment, stress was most evenly distributed on central incisor, lateral incisor, and canine when the miniscrew was inserted on the distal part of lateral incisor and vertical intrusion force was applied on the same location. In 6 anterior teeth segment, stress level was the lowest and was evenly distributed when the miniscrew was installed on the distal part of canine and the intrusion force was applied on the distal part of lateral incisor. When there is bone loss, PDL naturally diminishes, so smaller PDL surface should handle the stress caused by tooth movement. Therefore, it is physiologically desirable that lower stress is distributed evenly along the PDL.

The most important consideration is the location of CR of the targeted tooth or teeth while orthodontists try intrusive movement. Depending on the applied point and direction of the intrusion force, labial or lingual tipping may occur accompanied with intrusion. Especially when maxillary anterior teeth are flared and extruded due to periodontal problem, intrusive movement should be attempted with bodily movement or slightly linguoversion. A number of investigators have reported on the location of the CR of maxillary anterior teeth. In vitro studies using different methods such as the laser reflection technique and holographic interferometry (Dermaut & Vanden Buckle, 1986), photoelastic stress analysis (Matsui S et al., 2000), and the finite element method (Reimann S et al., 2007) as well as in vivo studies have been performed to determine the CR of the incisors (Sia S et al.,2007). The results show that the CR of the four incisor teeth lies 8-10 mm apical and 5-7 mm distal to the lateral incisors (Dermaut and Vanden Buckle, 1986; Matsui S et al., 2000; Turk T et al., 2005; Reimann S et al., 2007; Sia S et al., 2007). In addition, factors that alter the position of CR of anterior teeth are the shape of surrounding bone, root morphology, position of each tooth, and physiologic properties of periodontal attachment (Tanne K et al., 1991; Choy K et al., 2000; Park GH & Shon BW 1993; Ha MH & Son WS 2001).

As far as the vertical location of the CR of the anterior teeth is concerned, it was reported that the CR moves apically as the number of teeth increase (Vanden Bulcke et al., 1986; Vanden Bulcke et al., 1987; Woo & Park 1993). Woo and Park reported that the CR of maxillary 4 incisors was located at 37.4 % of the distance of the root length apical to the alveolar crest, the CR of 6 maxillary anterior teeth was located at 50.3 %. Min and Hwang investigated the change of location of CR according to alveolar height and root length, and they reported that the CR of 6 maxillary anterior teeth was located at 42.4 % apically from cemento-enamel junction (CEJ) of the averaged tooth of them, and CR moves 1.35 mm apically as alveolar bone loss occurs 2 mm (Min & Hwang 1999).

As far as the horizontal location of the CR of the anterior teeth is concerned, it was reported that CR moves posteriorly as alveolar bone loss occurs, and posteior movement of CR increases as alveolar bone loss increases (Sung et al., 2009). This result is thought to be caused by the decrease of alveolar bone support of the anterior part by alveolar bone diminishing because teeth and alveolar bone of the anterior part is tilted anteriorly. Also, Park and Yang said that posterior movement amount of CR is significant in 6 anterior teeth group, compared with 4 anterior teeth, and they mentioned that since canine is much larger than lateral incisor and the resistance force against vertical stress is thus much larger in canine, and canine is positioned antero-posteiorly just as posterior teeth do unlike lateral incisor which is positioned laterally just as central incisor does, looking at each locations within dental arch. This study was intended for the tooth with an average size of crown and root morphology and length and proclination. The location of CR can be changed by individual variation of crown size and root lengh and proclination, and therefore modification of force application may be necessary according to individual variation.

Bantleon states that 3 mm of alveolar bone loss causes 20 % of M/F ratio increment to maintain bodily movement (Bantleon 1997). And Siatkowski reports an increase of 38 % needed to produce bodily movement when 5 mm of marginal bone loss occurs (Siatkowski 1996). These results show the increase in percentage needed to maintain movement with different degrees of alveolar bone losses. Cobo et al state that with alveolar bone loss, CR can be located above the alveolar bone crest (Cobo et al., 1993). The reduced supporting PDL area and volume result in ever higher amounts of displacements in supporting structures of affected teeth for a given level of force and moment magnitude. Applied force and moment magnitudes must be reduced in proportion in order to maintain physiologically tolerable movements without further damage to these supporting structures.

In the view of this study, additional retraction force is necessary as well as intrusion force passing by center of resistance to achieve pure intrusion of maxillary anterior teeth. Especially in periodontally compromised adult patients, it should be considered that increase of retraction force is essential not only applying vertical intrusion force to obtain periodontal improvement through pure intrusion and minimize side effect.

During anterior intrusion with the segmented or the bioprogressive technique, the undesirable side effects occur in the posterior teeth. The posterior teeth are subjected to a vertical force, which tends to extrude them and a tip-back moment, which in the upper arch will steepen the occlusal plane (Burstone CJ 1977, Ricketts RM 1976). The loss of anchorage during anterior intrusion is primarily produced by the tip-back moment. This posterior moment generated in the sagittal plane is large because of the length of the moment arm, i.e. the distance from the incisor to the CR of the posterior teeth. In segmented arch mechanics, the posterior anchorage unit is generally stabilized by using heavy stainless steel archwires to counteract the moments produced during incisor intrusion (Matsui S et al.,2000). In this study, although not mentioned, when the intrusion force using miniscrews were applied to maxillary anterior teeth, counteractive moment of posterior teeth was hardly showed. It was a result unlike utility arches. This result is for two reasons. First, when using miniscrews, there was no direct engagement of utility arch to the posterior teeth. So a tip-back moment was not generated. Second, the whole dentition was stabilized by heavy stainless steel archwire.

The design of this study has some limitations. Firstly, the study intended to mathmatically visualize the initial displacement and stress distribution of PDL during intrusion using a FEA, so the results may not reflect exact clinical outcomes, which are influenced by the cumulative effects of continuous bone reactions and rebounding of the archwire related to secondary displacement of the teeth. In other words, it should be avoided to predict the ultimate clinical outcome by calculating initial response arithmetically. Secondly, there are other simulation conditions that were not taken into consideration, such as deformation of the bone tissue and brackets, occlusal force, and soft tissue pressure from perioral muscles and gingival fibers. Furthermore, other limitations of this study were the constant values used for the physical properties of the tissues, which would normally alter clinically through the histologic process, and the assumption that the periodontal membrane was homogeneous, isotropic, and uniform in thickness. These limitations can cause differences between clinical applications and simulation studies. Also, because of individual variations, it is impossible to simulate an exact mathematic model to validate each case. Recently there is an increasing use of 3D CT, this can be used for making individual tooth models and enables us to simulate the orthodontic tooth movement for each patient. And if 3D CT-assisted individual model is combined with finite element analysis software, this will be helpful for clinical treatment planning.

V. Conclusion

The purpose of this study was to investigate the intrusion pattern of maxillary anterior teeth according to alveolar bone height and miniscrew position. Finite element analysis was performed to simulate the movement pattern of maxillary anterior teeth under intrusion force. A standard three-dimensional finite element model was constructed, and varied the position of miniscrews and hooks after setting the alveolar bone loss in 0, 2, 4 mm. The applied intrusion force was 80 g for 4 anterior teeth, 100 g for 6 anterior teeth. The following results were observed:

1. Intrusion force applied at the archwire level induced initial labial tipping with intrusion of the anterior teeth (central incisor, lateral incisor, canine).

2. With reduced alveolar bone heights, under the same load, the study indicated an increase of tooth proclination.

3. Labial tipping of anterior teeth segment was reduced when retraction force was added to vertical intrusion force.

4. The amount of tooth displacement was larger in 6 anterior teeth more than 4 anterior teeth. In the case of canine, intrusion was increased but labial tipping was decreased.

5. Stress was concentrated at the apex than cervical area of PDL in all cases. And stress was also increased as bone loss increased.

6. When a miniscrew was inserted between two central incisors, high stress concentration was significant at the central incisors than other teeth. On the other hand, when miniscrews were inserted at distal to canines and intrusion force were applied at distal to lateral incisors, stress was the lowest and distributed evenly across all the teeth.

The results of this study indicate that it is thought to be able to induce initial tooth movement close to pure intrusion when miniscrews were inserted at distal to maxillary canines and intrusion force were applied at distal to lateral incisors.

References

Bantleon HP: Modified lingual lever arm technique: biomechanical considerations. In: Nanda R. Biomechanics in clinical orthodontics. Philadelphia: WB Saunders; 1997 p. 241.

Begg PR, Kesling PC: The differential force method of orthodontic treatment. Am J Orthod Dentofacial Orthop 71:1-39, 1977.

Boyd RL, Leggot PJ, Quinn RS, Eakle WS, Chambers DW: Periodontal implications of orthodontic treatment in adults with reduced or normal periodontal tissues versus those of adolescents. Am J Orthod Dentofacial Orthop 96:191-8, 1989.

Brunsvold MA: Pathologic tooth migration. J Periodontol 76:859-66, 2005.

Burstone CJ: Deep overbite correction by intrusion. Am J Orthod Dentofacial Orthop 72:1-22, 1977.

Burstone CJ: Biomechanics of deep overbite correction. Semin Orthod 7:26-33, 2001.

Cardaropoli D, Re S, Corrente G, Abundo R: Intrusion of migrated incisors with infrabony defects in adult periodontal patients. Am J Orthod Dentofacial Orthop 120:671-5, 2001.

Cattaneo, PM, Dalstra M, Melsen B: The finite element method: a tool to study orthodontic tooth movement. J Dent Res 84: 428-33, 2005.

Cattaneo PM, Dalstra M, Melsen B: Moment-to-force ratio, center of rotation, and force level: A finite element study predicting their interdependency for simulated orthodontic loading regimens. Am J Orthod Dentofacial Orthop 133:681-9, 2008.

Choy K, Pae EK, Park Y, Kim KH, Burstone CJ: Effect of root and bone morphology on the stress distribution in the periodontal ligament. Am J Orthod Dentofacial Orthop 117:98-105, 2000.

Cobo J, Sicilia A, Argüelles J, Suarez D, Vijande M: Initial stress induced in periodontal tissue with diverse degrees of bone loss by an orthodontic force: 3-dimensional analysis by means of the finite element method. Am J Orthod 104:448-54, 1993.

Cobo J, Arguelles J, Puente M, Vijande M: Dentoalveolar stress from bodily tooth movement at different levels of bone loss. Am J Orthod Dentofacial Orthop 110:256-62, 1996.

Cobo J, Sicilia A, Argüelles J, Suárez D, Vijande M: Initial stress induced in periodontal tissue with diverse degrees of bone loss by an orthodontic force: tridimensional analysis by means of the finite element method. Am J Orthod Dentofacial Orthop 104:448-54, 1993.

Coolidge ED: The thickness of human periodontal membrane. J Am Dent Assoc 24: 1260-70, 1937.

Dermaut LR, Vanden Bulcke MM: Evaluation of intrusive mechanics of the type "segmented arch" on a macerated human skull using the laser reflection technique and holographic interferometry. Am J Orthod 89:251-63, 1986.

Derton N, Derton R, Perini A, Gracco A, Fornaciari PA: Orthodontic treatment in periodontal patients: a case report with 7 years follow-up. Int Orthod 9:92-109, 2011.

Diedrich PR: Orthodontic procedures improving periodontal prognosis. Dent Clin North Am 40:875-87, 1996.

Feng X, Oba T, Oba Y, Moriyami K: An interdisciplinary approach for improved functional and esthetic results in a periodontally compromised adult patient. Angle Orthod 75:1061-70, 2005.

Gkantidis N, Christou P, Topouzelis N: The orthodontic periodontic interrelationship in integrated treatment challenges:a systematic review. J Oral Rehabil 37:377-90, 2010.

Greig DG: Bioprogressive therapy; overbite reduction with the lower utility arch. Br J Orthod 10:214-16, 1983.

Ha MH, Son WS: Three-dimensional finite element analysis on intrusion of upper anterior teeth by three-piece base arch appliance according to alveolar bone loss. Korean J Orthod 31:209-23, 2001.

Iseri H, Tekkaya AE, Oztan O, Bilgic S: Biomechanical effects of rapid maxillary expansion on the craniofacial skeleton, studied by the finite element method. Eur J Orthod. 20:347-56, 1998.

Kanjanaouthai A, Mahatumarat K, Techalertpaisarn P, Versluis A: Effect of the inclination of a maxillary central incisor on periodontal stress: finite element analysis. Angle Orthod 82: 812-19, 2012.

Kanomi R: Mini-implant for orthodontic anchorage. J Clin Orthod 31:763-7, 1997.

Matsui S, Caputo AA, Chaconas SJ, Kiyomura H: Center of resistance of anterior arch segment. Am J Orthod Dentofacial Orthop 118: 171-78, 2000

McKiernan EX, McKiernan F, Jones ML: Psychological profiles and motives of adults seeking orthodontic treatment. Int J Adult Orthod Orthognath Surg 7:187-98, 1992.

Melsen B: Tissue reaction following application of extrusive and intrusive forces to teeth in adult monkeys. Am J Orthod 89:469-75, 1986.

Melsen B, Agerbaek N, Eriksen J, Terp S: New attachment through periodontal treatment and orthodontic intrusion. Am J Orthod Dentofacial Orthop 94:104-16, 1988.

Melsen B, Agerback N, Markenstan G: Intrusion of incisors in adult patients with marginal bone loss. Am J Orthod Dentofacial Orthop 96:232-41, 1989.

Melsen B, Verna C: Miniscrew implants: the Aarhus anchorage system. Semin Orthod 11:24-31, 2005.

Middleton J1, Jones M, Wilson A: The role of the periodontal ligament in bone modeling: the initial development of a time-dependent finite element model. Am J Orthod Dentofacial Orthop 109: 155-62, 1996.

Min YG, Hwang CJ: A study about the change of locations of the center of resistance according to the decrease of alveolar bone heights and root lengths during anterior teeth retraction using the laser reflection technique. Korean J Orthod 29:165-81, 1999.

Park CK, Yang WS: A three-dimensional finite element analysis on the location of center of resistance during intrusion of upper anterior teeth. Korean J Orthod 27:259-72, 1997.

Park GH, Shon BW: The center of resistance of the maxillary anterior teeth segment in the horizontal plane during intrusion by using laser reflection technique. Korean J Orthod 23:619-32, 1993.

Park YC, Lee KJ: Biomechanical principles in miniscrew-driven orthodontic. In: Nanda R editor. Temporary anchorage devices in orthodontics. 2009, p. 93-144, St Louis: Mosby Elsevier.

Proffit W. Special considerations in comprehensive treatment for adults. In: Proffit W, Fields HW, editors. Contemporary orthodontics. 3rd ed. 2000, p. 644-74. St Louis: Mosby.

Reddy JN: An Introduction to the Finite Element Method. 1984.

Reimann S, Keilig L, Jäger A, Bourauel C: Biomechanical finite element investigation of the position of the centre of resistance of the upper incisors. Eur J Orthod 29:219-24, 2007.

Ricketts RM: Bioprogressive therapy as an answer to orthodontic needs. Part I. Am J Orthod 70:241-68, 1976.

Rohatgi S, Narula SC, Sharma RK, Tewari S, Bansal P: A study on clinical attachment loss and gingival inflammation as etiologic factors in pathologic tooth migration. Niger J Clin Pract 14:449-53, 2011.

Serio FG, Hawley CE: Periodontal trauma and mobility. Diagnosis and treatment planning. Dent Clin North Am 43:37-44, 1999.

Sia S, Kog Y, Yoshida N: Determining the center of resistance of maxillary anterior teeth subjected to retraction forces in sliding mechanics. Angle Orthod 77:999-1003, 2007.

Siatkowski RE: Optimal Orthodontic space closure in adult patients. Dent Clin North Am 40:837-73, 1996.

Sung SJ, Baik HS, Moon YS, Yu HS, Cho YS: A comparative evaluation of different compensating curves in the lingual and labial techniques using 3D FEM. Am J Orthod Dentofacial Orthop 123:441-50, 2003.

Sung SJ, Kim IT, Kook YA, Chun YS, Kim SH, Mo SS: Finite-element analysis of the shift in center of resistance of the maxillary dentition in relation to alveolar bone loss. Korean J Orthod 39:278-88, 2009.

Tanne K, Nagataki T, Inoue Y, Sakuda M, Burstone CJ: Patterns of initial tooth displacements associated with various root lengths and alveolar bone heights. Am J Orthod Dentofacial Orthop 100:66-71, 1991.

Turk T, Elekdag-Turk S, Dincer M: Clinical evaluation of the center of resistance of the upper incisors during retraction. Eur J Orthod 27:196–201, 2005.

Vanden Bulcke MM, Burstone CJ, Sachdeva RC, Dermaut LR: Location of the centers of resistance for anterior teeth during retraction using the laser reflection technique. Am J Orthod Dentofacial Orthop 91:375-84, 1987.

Vanden Bulcke MM, Dermaut LR, Sachdeva RC, Burstone CJ: The center of resistance of anterior teeth during intrusion using the laser reflection technique and holographic interferometry. Am J Orthod Dentofacial Orthop 90:211-20, 1986.

Weston P, Yaziz YA, Moles DR, Needleman I: Occlusal interventions for periodontitis in adults. Cochrane Database of Systematic Reviews, Issue 3. Art. No.: CD004968. doi: 10.1002/14651858.CD004968.pub2, 2008.

Woo JY, Park YC: Experimental study of the vertical location of the centers of resistance for maxillary anterior teeth during retraction using the laser reflection technique. Korean J Orthod 23:375-90, 1993.

국문요약

상악 전치 압하 시 미니스크류 위치와 치조골 소실이 치아 변위 양상에 미치는 영향 : 유한요소 분석

(지도교수 황충주)

연세대학교 대학원 치의학과

조 선 미

이 연구의 목적은 유한요소 분석법을 이용하여 상악 전치 압하 시 미니스크류 위치와 치조골 소실이 치아의 변위 양상에 미치는 영향을 조사하는데 있다.

상악 4전치와 6전치 분절에서 미니스크류와 훅의 위치를 다르게 하여 압하력을 적용하였을 때 치아의 초기 변위 양상을 분석하고자 상악 치아, 치주인대, 치조골에 대한 3차원 유한요소 모델을 제작하였다. 그리고 치조골 소실 높이는 0, 2, 4 mm로 설정하였다. 압하력은 4전치 분절에서는 80 g, 6전치 분절에서는 100 g으로 설정하였다. 본 연구를 통하여 다음과 같은 결과를 얻었다.

1. 상악 전치에 압하력을 가하였을 때 중절치, 측절치, 견치 모두 순측으로 경사이동을 보이면서 압하되었다.

2. 치조골 소실이 증가할수록 같은 압하력에 대해 전치의 순측 경사가 증가하였다.

3. 전치의 순측 경사는 수직 압하력에 후방 견인력을 첨가하였을 때 감소하는 것으로 나타났다.

4. 4전치 분절에 비해 6전치 분절의 치아 변위량이 더 많았다. 특히 견치의 경우, 6전치 분절에서 압하는 더 많이 되었으나 순측 경사는 감소했다.

5. 압하력을 가하였을 때 응력은 모든 경우에서 치주인대의 치경부보다 치근첨 부위에 집중되었으며, 골소실이 증가할수록 응력 역시 증가하는 경향을 보였다.

6. 양 중절치 사이에 미니스크류를 식립한 경우 중절치의 응력 집중이 다른 경우보다 현저히 나타났다. 반면, 상악 견치 후방에 미니스크류를 식립하고, 측절치 후방에서 압하력을 가하였을 때 응력이 모든 치아에 고르게 낮게 분포하였다.

이상의 연구 결과를 토대로 상악 전치의 압하가 요구되는 과개교합 증례에서 상악 견치 후방에 미니스크류를 식립하고 측절치 후방에서 압하력을 가하였을 때 상악 전치의 순수한 압하에 가까운 초기 치아 이동을 유도할 수 있을 것으로 생각된다.

핵심이 되는 말: 상악 전치 압하, 치조골 소실, 미니스크류 위치, 3차원 유한요소