Evaluation of different self ligationg brackets in leveling vertically displaced canine using 3D FEA

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Evaluation of different self ligationg brackets in leveling vertically displaced canine using 3D FEA

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This certifies that the dissertation of

Yoon Hee Kwon is approved.

Thesis supervisor

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The Graduate School

Yonsei University

June 2012

감사의 글

이 박사 학위 논문이 완성되기까지 부족한 저를 지도해주시고 세심한 배려를 아끼지 않으신 은사 황 충주 교수님께 진심으로 감사드립니다.

교수님 덕분에 논문의 시작과 완성이 가능하였기에 다시 한번 마음속 깊이 감사드립니다. 그리고 많은 조언과 격려를 해주시며 부족한 논문의 심사를 맡아주신 성 상진 교수님, 이 기준 교수님, 차 정열 교수님께도 감사의 마음을 전하며 특히 실험과 논문의 완성을 위해 물심 양면 도움을 아끼지 않으신 조 영수 박사님 정말 감사합니다. 또한 마무리를 잘할 수 있게 도와주신 백 형선 교수님, 박 영철 교수님, 김 경호 교수님 및 여러 은사님들께 고개숙여 존경과 감사의 마음을 전합니다.

믿음과 격려로 지금의 제가 있을수 있게 해주신 부모님과 시부모님께도 사랑하고 감사하다는 말씀을 올리고 싶고 무엇보다 제가 논문을 완성하기까지 힘든 시간을 묵묵히 인내해주고 용기와 격려를 준 남편 조 상범과 제 가장 귀한 보물인 아들 조 준기에게 이 박사 논문을 바칩니다.

2012년 6월 저자 권 윤희

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ABSTRACT

Evaluation of different self-ligationg brackets in leveling vertically displaced canine using 3D FEA

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In this study, self-ligation brackets of active and passive type were bonded to canines which were vertically displaced at 1.0 mm, 2.0 mm and 3.0 mm superior to occlusal plane respectively, and metal bracket was bonded as control group. When initial orthodontic force was applied, stress at the tooth and its surrounding alveolar bone were observed from lateral, longitudinal and vertical direction. This study is to investigate on the differences of the stress distribution according to the type of self-ligation brackets and the differences from the metal bracket as the control group by comparing them using finite element analysis.

At 1.0 mm above the occlusal plane, vertical stress was the largest in smart clip bracket, and then clippy-c bracket and metal bracket in order, and vertical displacement was the largest in smart clip bracket and the smallest in metal bracket proportionally to the stress. At 2.0 mm above the occlusal plane, vertical stress was the largest in clippy-c bracket, and then smart clip bracket and metal bracket in order, and vertical displacement showed the value proportional to the stress just as in the 1.0mm case. At 1.0 mm and 2.0 mm above the occlusal plane, self-ligation bracket was more advantageous than metal bracket because the vertical stress and vertical displacement of self-ligation bracket was large. At 3.0 mm above the occlusal plane, vertical stress was the largest in smart clip bracket, and then metal bracket and clippy-c bracket in order, and vertical displacement was the largest in smart clip and the smallest in clippy-c bracket proportionally to the vertical stress. At 3.0 mm above the occlusal plane, self-ligation bracket was not always more advantageous because the vertical displacement of clippy-c bracket was the smallest at 3.0 mm superior point. The size of vertical stress and vertical displacement were proportional to each other, and it was that more vertical movement was not always gained in self-ligation bracket and was depending on bracket system.

Key words : self- ligation bracket, passive, active, conventional metal bracket

Stress, clippy-c bracket, smart- clip bracket

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I. INTRODUCTION

What is the effective treatment is a major concern in contemporary orthodontics. The primary step for fixed orthodontic treatment is correct alignment and leveling of teeth, and the efficiency of this process is related to many variables.

Tooth movement in the alveolar bone is based on the reaction of periodontal tissue to orthodontic force. The success of tooth movement depends on the vitality and the reaction of cell and connective tissue. Orthodontists can influence directly on biological reaction by selecting bracket and arch wire.

Tooth movement is accomplished by transfer orthodontic force of arch wire to the bracket. And then frictional force is produced between bracket and arch wire which are contacting to each other. Stoner[1] reported that a large amount of orthodontic force disappeared by friction. Kwak[2] stated that when applying orthodontic force clinically, the amount of the force disappeared by friction must be taken into consideration. Therefore, as a mechanical factor affecting the speed of tooth movement, frictional force should be taken into consideration.

According to Min et al. [3], Hwang et al. [4], Sung et al. [5], Ko et al.[6], and Lee et al. [7], it was said that the factors affecting the friction include the material of bracket and arch wire, the surface condition of arch wire, the bracket slot size, the cross section and torque of arch wire, ligation method, the distance between brackets, and the saliva so on. Especially, Shivapuja et al.[8] said that it depended on the ligation method a lot.

Brackets are divided into ligation and self-ligation type by the ligation method of archwire. Conventional ligation bracket could not avoid the increase of friction because of ligation wire or elastic ring not to slip out of archwire from the slot. In order to reduce the friction, self-ligation bracket with a mechanical device which the bracket slot could to be closed without wire was invented from the 1930s [9], but it was not widely used. And various self-ligationg brackets are being developed and being popularized gradually.

According to Shivapuja et al.[8], self-ligation bracket became possible to apply the lighter force due to the decrease of friction. And according to Turnbull et al.[10] and Harradine[11], shortening of the total treatment period became possible due to a physiological and fast movement of teeth. In clinical point of view, the treatment efficiency is increased and arch wire can be inserted to the whole teeth even at initial stage, and visiting interval became longer. Self-ligation brackets are divided into active type and passive type depending on the shape of the self-ligation part and the condition in which force is applied to arch wire. Active type has a clip attachment and passive type has a slide attachment. In passive type, ligation force is not applied to the wire because a slide covers the bracket slot only. According to Vouduuris[12]and Berger[13], active types are divided into two cases where force is applied to the wire or not depending on whether the clip is active or passive. In this study, self-ligation brackets of active and passive type were bonded to canines which were vertically displaced at 1.0 mm, 2.0 mm and 3.0 mm above the occlusal plane respectively, and metal bracket was bonded as control group. When initial orthodontic force was applied, stress at the tooth and its surrounding PDL were observed from lateral, longitudinal and vertical direction. The purpose of this study is to investigate on the differences of the stress distribution according to the type of self-ligation brackets in leveling vertically displaced canine and the differences from the metal bracket as the control group using finite element analysis.

The methods to analyze the stress where orthodontic force is applied on tooth are holography , strain gauge, photo elastic and finite element method, and so on. Holograhy method was introduced by Danis Grabe in 1947, and Burstone et al.[15] used it in the segmented arch study, but it has a disadvantage not to measure a large stress. Photo-elastic method is a method in which the pattern and the size of stress can be seen visually through isochromatics formed on the model by converting a mechanical internal stress of machine into a visible light form.[16] However, there are disadvantages: difficulty in model formation, complexity of results analysis, and the fact that only difference of relative stress can be observed.

Finite element analysis started to improve rapidly due to computer science since Hrennikoff and McHenry tried it by using a simple one-dimensional element in the early 1940s, and it was used in industrial analysis and planning. Finite-element method was used not only the research of structural mechanics but also medical and dental field widely. Especially, it has been used for analysis of the appliance, stress distribution, and research on growth in orthodontics. Tanne[17] researched the stress distribution of initial periodontal tissue to which orthodontic force was applied by making 3-dimensional model of central incisor, canine, and premolar, and Kim[18] did a research on the stress distribution in the initial stage of canine distal movement and Lim[19] did when tipping, torquing force were applied to composite and ceramic brackets, and Park[20] did when crowded dentition were treated with .014 NiTi wire using finite element method. Finite element analysis in orthodontics has been used mostly to the objects being placed in their original position when apply the orthodontic force,

The advantages of finite element analysis are that a mechanical analysis is possible in the object with complex shape, and the weight condition can be easily changed and repeated reconstruction is easy. Therefore, in this study, using finite-element analysis is the most appropriate method for the stress distribution study of self-ligation bracket that has very small, complex, and delicate difference.

Studies on anti-frictional resistance between self-ligation brackets and arch wire such as Lee[14] have been done, but studies on the stress which is formed at the tooth and around alveolar bone when orthodontic force is applied to self-ligation bracket are rare. Thus, in this study, the stress distributed on the PDL when orthodontic force was applied was observed by bonding various self-ligation brackets to vertically displaced canines.

II. MATERIALS AND METHODS

1. Bracket modeling

Two types of self-ligation brackets were used as experimental group, and one conventional ligation metal bracket was used as control group.

As active type, clippy-c bracket (Clippy-C, Tomy, Tokyo, Japan) was modeled, and smart clip bracket (Smart Clip, 3M Unitek, Monrovia, Calif) was modeled as passive type. Non self ligating .022 x .028 slot metal bracket (Micro-arch, Tomy, Tokyo, Japan) was modeled as control group (Table 1). Orthodontic wire used in the stress analysis was .016 NiTi.

Table 1. Bracket characteristics and prescription

	Clippy-C	Smart Clip	Micro- arch
Manufacturer	Tomy	3M Unitek	Tomy
Type	Active self ligating	Passive SL	Conventional
Material	Ceramic bracket	Metal bracket	Metal bracket
Slot size	0.022	0.022	0.022

2. Method

A. 3 D modeling of tooth, PDL and alveolar bone

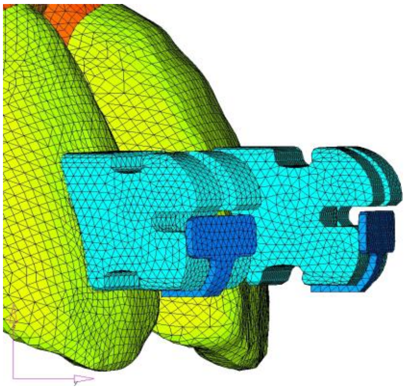
The 3 D shape of model should be digitized for finite elements analysis of tooth and alveolar bone. For this purpose, a tooth model (Nissin Dental Products, Kyoto, Japan) was made by the 3 D laser scanning of adult normal occlusion sample and the curve of the tooth surface was shown in numerical value.

The dental arch form was arranged in accordance to broad arch form of Ormco company (California, USA), and Andrew's prescription[21] was applied to inclination and angulation of each teeth. Using the shape of the arrangement of teeth measured as mentioned above, the whole curve which composed the surface of teeth was formed and they were divided into finite elements of 0.5 mm length again.

Thickness of PDL was modeled uniformly to 0.25 mm based on the research by Coolidge[22] and Kronfeld[23], and the alveolar bone was assumed as normal condition, and it was formed following the curve of cement enamel junction at 1.0 mm below.

For the modeling of bracket, the real bracket was directly measured using micrometer and the inside of the bracket slot was indirectly measured by making an epoxy resin molded specimen. 3 types of brackets, clippy-c bracket, smart clip bracket and metal bracket, of canine were modeled, and 9 models in total were made at 1.0 mm, 2.0 mm, and 3.0 mm above the occlusal plane (Figure 1). The measurements of each parts of the bracket were embodied to solid models using CAD, the curvature of the bracket was analysized by finite element method. A tetrahedron element is used for tooth and bracket, and beam element is used for arch wire. Between arch wire and interior surface of bracket slot, contact element was applied and transformation of the arch wire in the slot was embodied. Clearance between arch wire and bracket is made as initial displacement amount of the respective contact element. Extrusive force on the canine by arch wire and reaction of the adjacent teeth are computed after mathematizing the condition that the contact area of bracket to arch wire is inserted and canine surface for bracket should maintain the same position after transformation.

The canine bracket was initially set to locate with holding the undeformed wire. Proper constraint equations were applied to achieve the extrusion effect by the canine bracket. Six pairs of points on the bracket and crown adhering surfaces were designated to the constraint positions, of which the deformed coordinates after adhering coincides each other.



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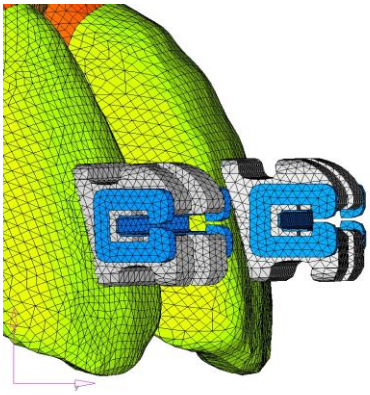

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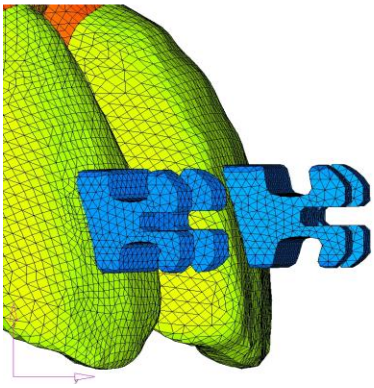

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Figure 1. Model of the clippy-c bracket (A), smart clip bracket (B), metal bracket (C)

B. Mechanical property

Tooth, alveolar bone, alveolar periosteum and arch wire were assumed to be linear elasticity of isotropy and homogeneity, and Young's modulus and Poisson's ratio were given for physical properties of each component based on the previous study Tanne et al[27] and Sung et al[26] 's research (Table 2).

Table 2. Material properties

	Young's modulus (g/mm^2)	Poisson's ratio
Periodontal ligament	5.0	0.49
Alveolar bone	2.0E+05	0.3
Teeth	2.0E+06	0.3
Ceramic	8.5E+05	0.28
Stainless steel	2.0E+07	0.3
NiTi	1.2E+07	0.3

C. Boundary condition

The maxillary canines vertically displaced in 1.0 mm, 2.0 mm and 3.0 mm above the occlusal plane were moved downward using the elasticity of arch wire and relative positions of the bracket and arch wire were made coincided without any direct load or displacement.

In this procedure, mechanical contact algorithm is applied between bracket and arch wire because arch wire does not get separated from inside of the bracket slot. Because the clearance between slot and wire are considered automatically, the frictional force varies according to the brackets.

Therefore, in the procedures of this analysis, should be considered both the contact non-linear where the contact point of bracket and arch wire and the large transformation non-linear where a significant movement of the bracket of canine and should be collected all the non-linear solutions.

III. RESULTS

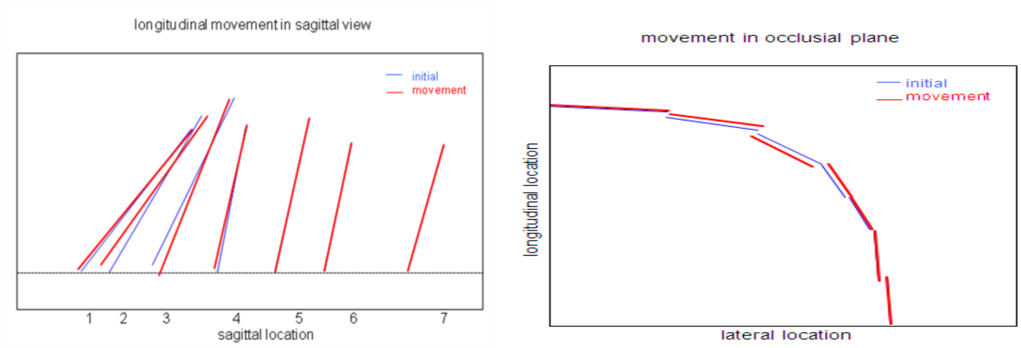
1. When orthdontic force was applied at 1.0 mm above the occlusal plane

A. Rotation

Clippy-C bracket, smart clip bracket, metal bracket were bonded to canine located 1.0mm superior to occlusal plane, and the rotation of the 3 models to which orthodontic force was applied was observed in sagittal and occlusal direction.

As canine moved downward, it showed a lingually tilted rotation in sagittal plane. The rotations of canine observed in sagittal plane were 0.143°, 0.150°, and 0.145° according to clippy-c bracket, smart clip bracket, metal bracket. There was no significant difference between brackets, but clippy-c bracket (active type) showed the smallest value and the smart clip bracket (passive type) showed the largest value (Figure 2) (Table 3, 4, 5). Canine to be bonded smart clip bracket showed the largest lingual rotation, and canine with clippy-c bracket showed the smallest as canine moved inferiorly. On the contrary, rotation of lateral incisor occurred in labial direction. The tooth to which smart clip bracket was bonded showed the largest labial tilting, and the one with clippy-c bracket showed the smallest tilting.

The rotation of canine observed in occlusal plane was in mesio-distal direction, and the differences of 0.053°, 0.045°, 0.039° were shown in brackets respectively. The mesio-distal rotation was the largest in the clippy-c bracket, and the smallest in the metal bracket which was more than 20% lower than that of clippy-c bracket (Figure2) (Table3, 4, 5). Seeing the pattern of the rotation on occlusal plane, it was shown that metal brackets moved almost parallel, and the distal rotation of canine was largest in clippy-c bracket.



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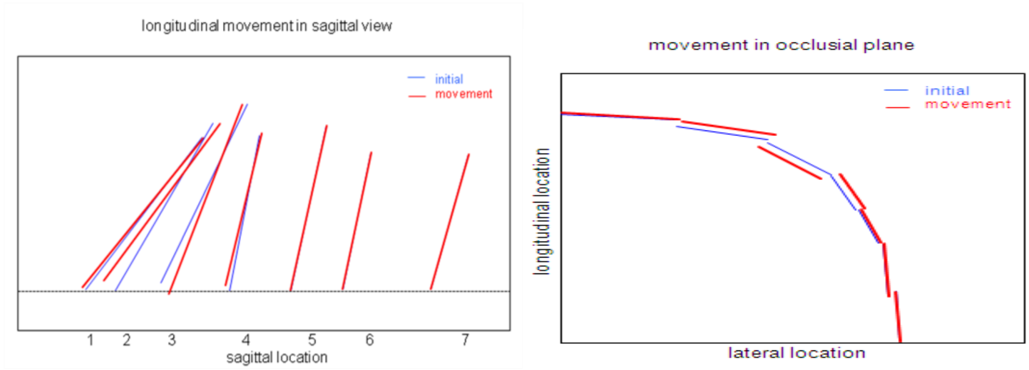

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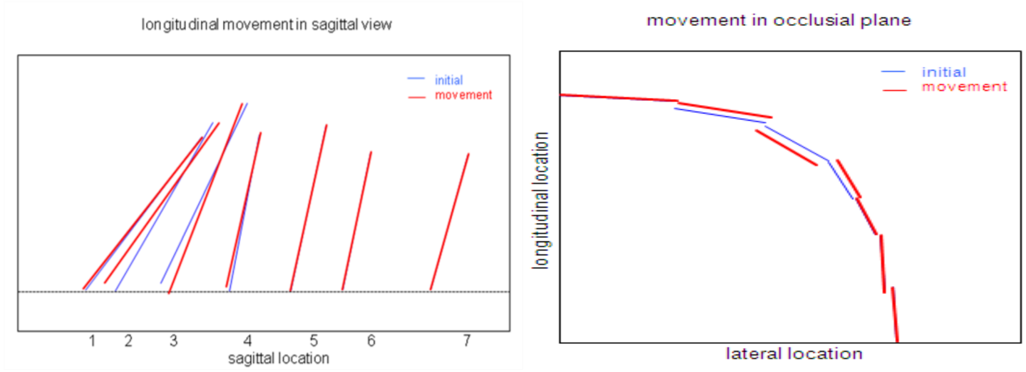

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Figure 2. Rotation in sagittal (Lt) and occlusal (Rt) view at 1.0 mm above the occlusal plane of clippy-c bracket (A), smart clip bracket (B), metal bracket (C)

B. Displacement

Clippy-c bracket, smart clip bracket and metal bracket were bonded to canine located 1.0mm superior to occlusal plane, and the movement of canine in three models to which orthodontic force was applied was observed.

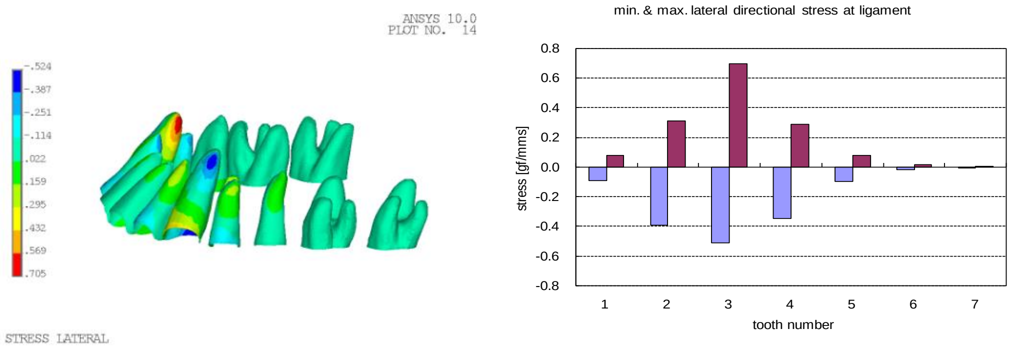
Anterior and posterior (A-P) displacement were 0.03 mm in clippy-c bracket, 0.036 mm in smart clip bracket and 0.037 mm in metal bracket. In the case of smart clip and metal bracket, there was large distal displacement and it was approximately 20% larger than that of clippy-c bracket. Longitudinal (B-L) displacement, lingual movement were 0.031 mm in clippy-c bracket, 0.034 mm in smart clip bracket and 0.033 mm in metal bracket. In clippy-c bracket, lingual movement was small although the difference was not significant compared to other brackets, and smart clip bracket's movement was the largest. Vertical displacement, vertico-inferior direction, was the same large amount of 0.042 mm in clippy-c bracket and smart clip bracket and it was shown that metal bracket was little effective (Table 3, 4, 5). When moving canine located 1.0mm superior to occlusal plane, canine with clippy-c, active self-ligation bracket, showed larger vertical displacement and smaller A-P and B-L displacement than others.

C. Stress

In the case of lateral stress (A-P direction), maximum tensile stress of 0.705

gf/mm^2, 0.706 gf/mm^2, 0.667 gf/mm^2 were produced according to brackets. The largest stress of canine was in smart clip bracket, almost the same as that of clippy-c bracket, and the smallest was in metal bracket (Figure 3). Metal bracket showed the smallest lateral stress and the largest posterior movement, and smart clip bracket showed the largest lateral stress and posterior movement similar to that of metal bracket. It is assumed that there is no significant correlation between lateral stress and displacement seeing at the above result.

In the case of longitudinal stress (B-L direction), the maximum stresses of 0.802 gf/mm^2, 0.77 gf/mm^2, and 0.717 gf/mm^2 were developed according to brackets. The stress was the largest in clippy-c bracket and the smallest in metal bracket. Stress distribution showed similar patterns in all brackets (Figure 4). In the case of vertical stress, the maximum stresses of 0.837 gf/mm^2, 0.858 gf/mm^2 and 0.82 gf/mm^2 were developed according to brackets. The stress was the largest in smart clip bracket and the smallest in metal bracket. Compared to others, vertical stress distribution has difference that the maximum stress region is not the root apex but the upper 1/3 root (Figure 5). Metal bracket showed a small stress and also a small amount of vertical displacement, and smart clip bracket showed a large stress and a large vertical displacement. so it is assumed there is significant correlation between vertical stress and displacement. Self-ligation bracket showed a larger stress than metal bracket. And smart clip (passive type) bracket's stress were large than clippy-c bracket at vertical and lateral direction.



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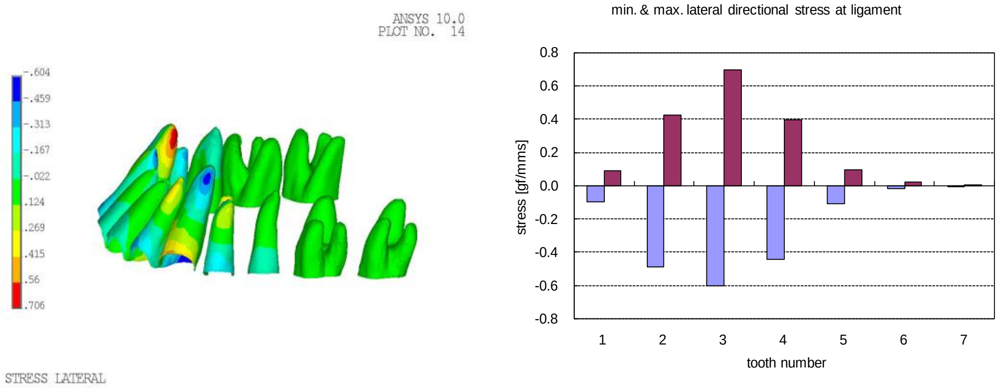

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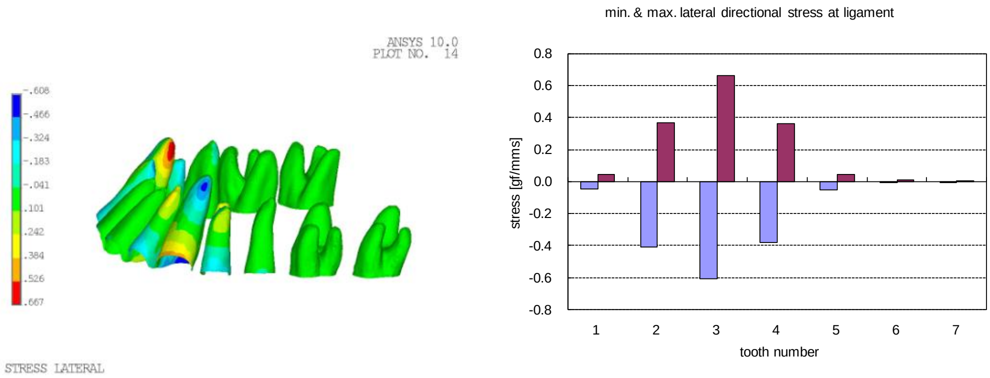

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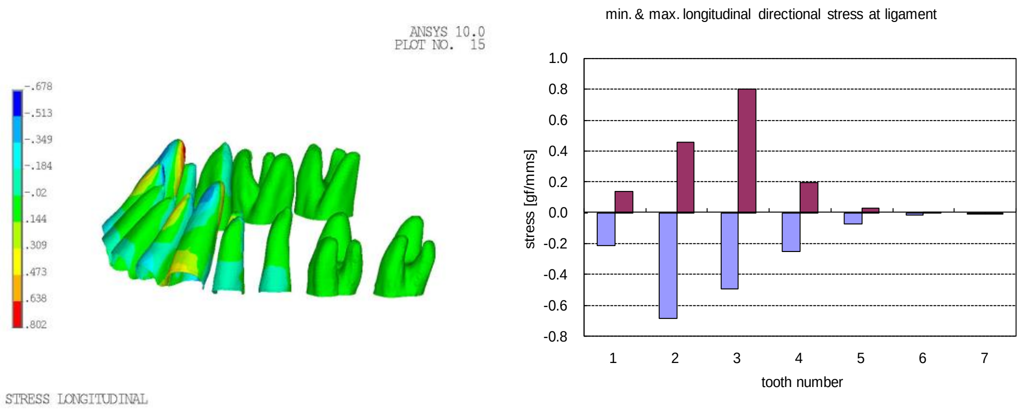
Figure 3. Lateral stress at periodontal ligament of clippy-c bracket (A), smart clip bracket (B), metal bracket (C) (1.0 mm above)



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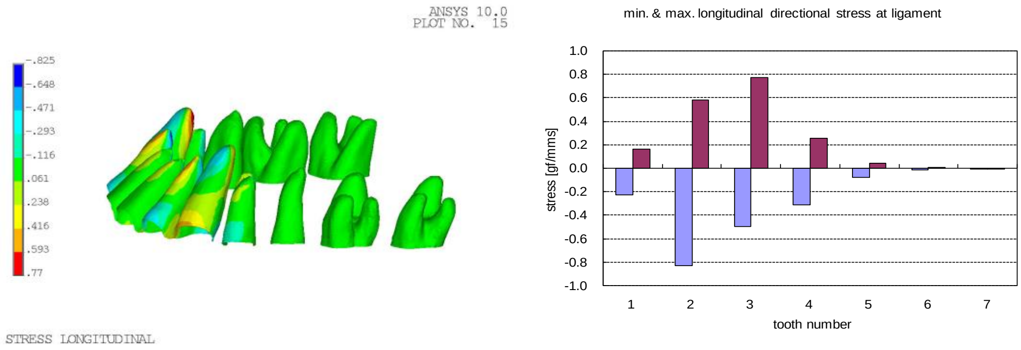

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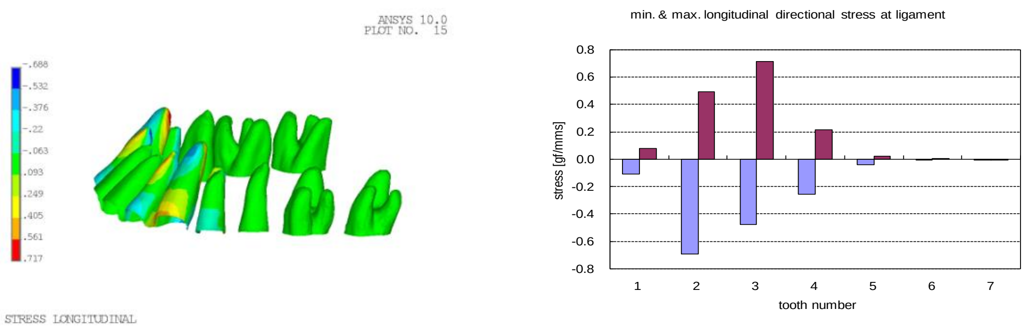

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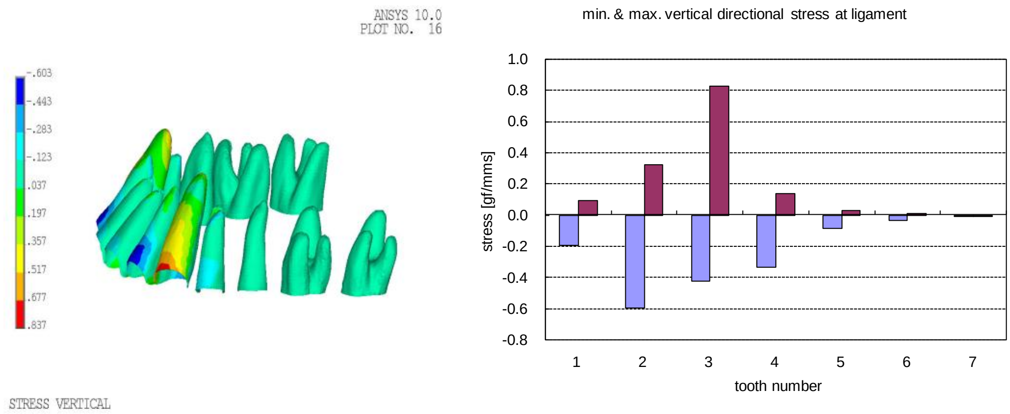
Figure 4. Longitudinal stress at periodontal ligament of clippy-c bracket (A) smart clip bracket (B), metal bracket (C) (1.0 mm above)



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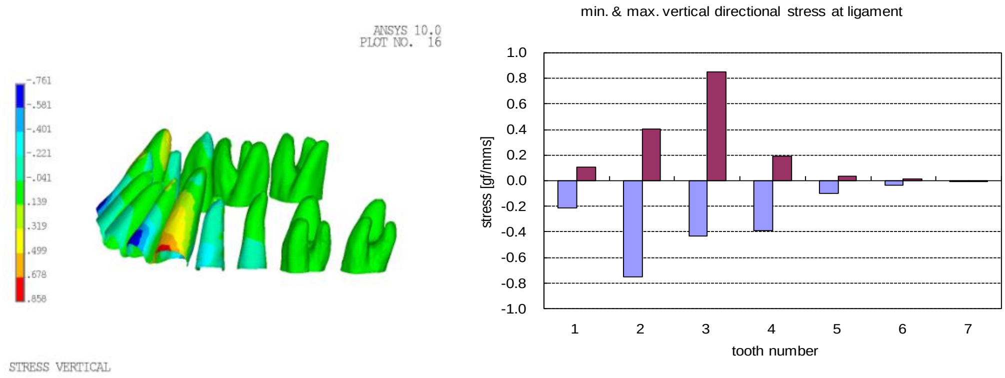

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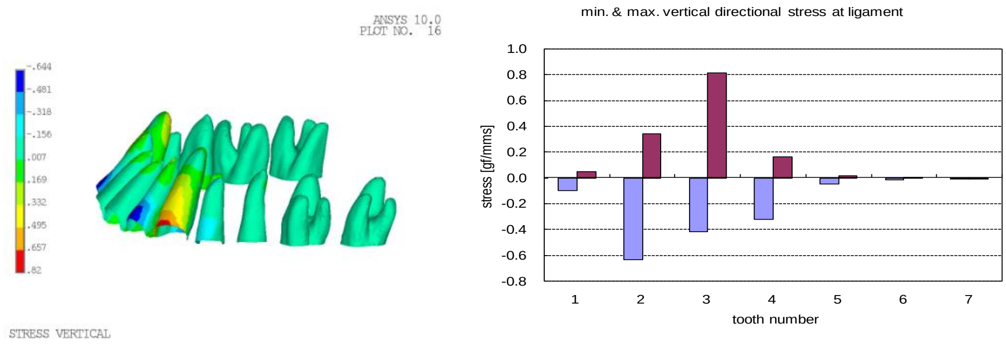

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Figure 5. Vertical stress at periodontal ligament of clippy-c bracket (A), smart clip bracket (B), metal bracket (C) (1.0 mm above)

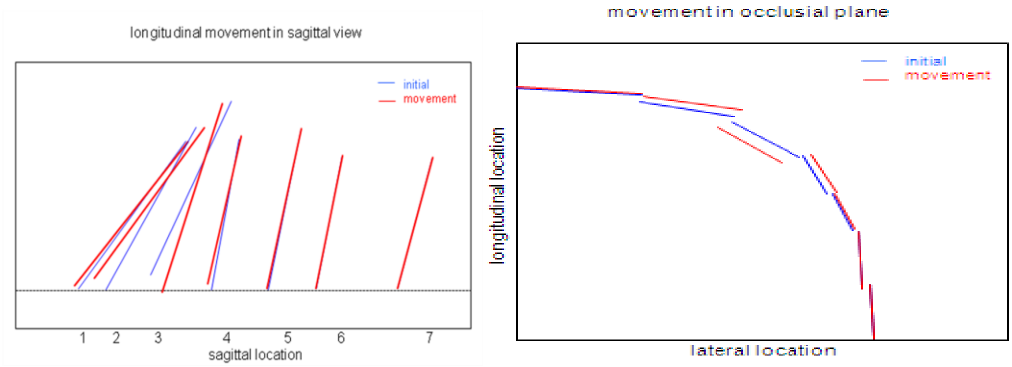
2. When orthodontic force was applied at 2.0 mm above the occlusal plane

A. Rotation

The lingual rotation of canine observed from sagittal plane were 0.353°, 0.346° and 0.317°, and it was the smallest in metal bracket. Although there was no significant difference between self-ligation brackets, but clippy-c bracket, the smallest lingual rotation at 1.0mm above the occlusal plane, showed the largest lingual rotation (Figure 6) (Table 6,7,8). When compared to the value at 1.0 mm, the lingual rotations were increased to 246%, 230%, 218%, more than twice respectively.

The rotation of canine observed from occlusal plane occurred in distal direction, and metal bracket showed the smallest and clippy-c bracket showed the largest value, more than 50% increased amount than metal bracket. They were increased more than twice up to 246%, 230% and 218% than 1.0 mm superior case (Figure 6) (Table 6, 7, 8).

When orthodontic force was applied to canine located at 2.0 mm above the occlusal plane, all the brackets showed lingual rotation on their sagittal planes, and unlike the 1.0 mm case, clippy-c bracket (active type self-ligation bracket) showed the largest lingual tilting. In occlusal plane, rotation in distal direction occurred and self-ligation bracket's rotation increased more than metal bracket just as in 1.0 mm superior case.



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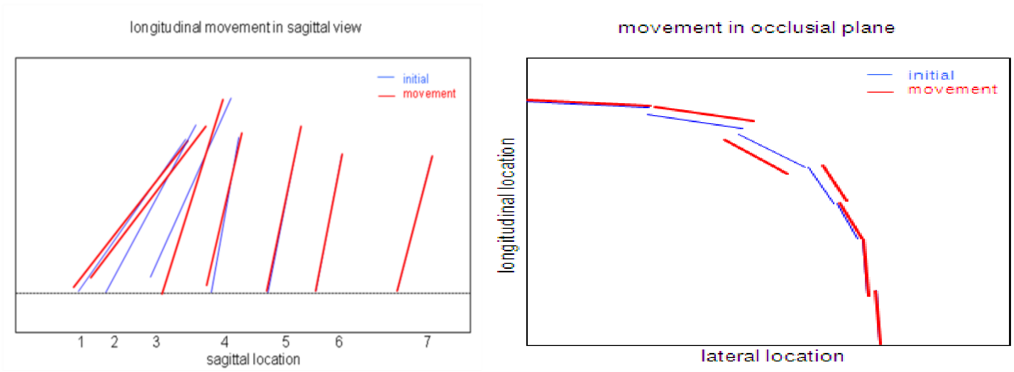

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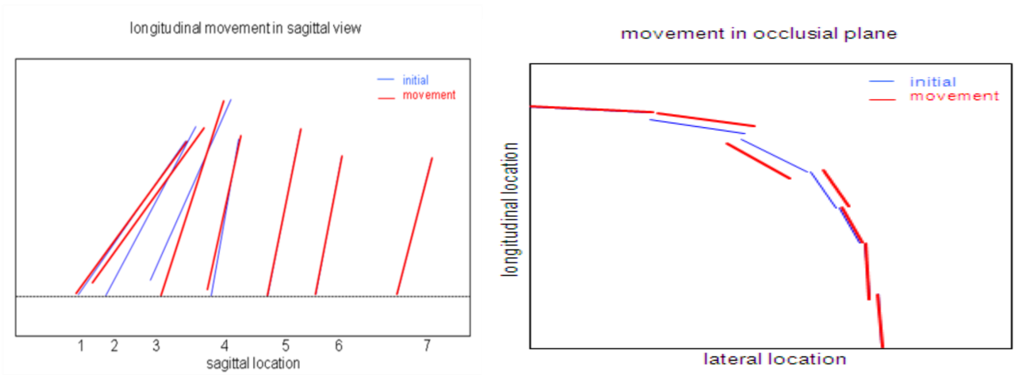

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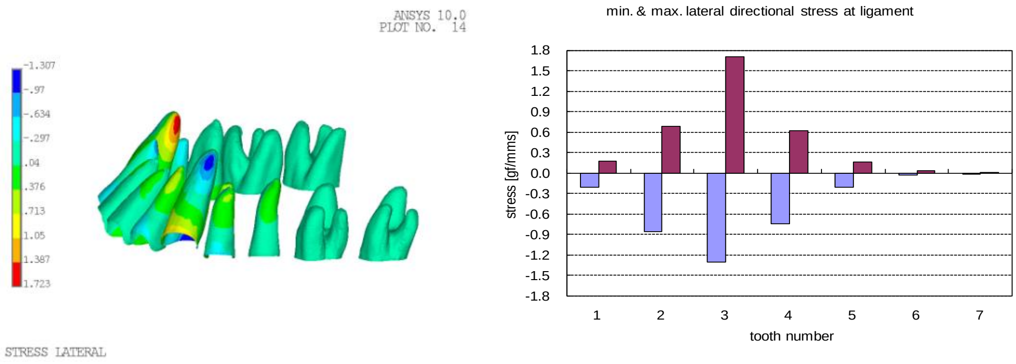
Figure 6. Rotation in sagittal (Lt) and occlusal (Rt) view at 2.0 mm above the occlusal plane of clippy-c bracket (A), smart clip bracket (B), metal bracket (C)

B. Displacement

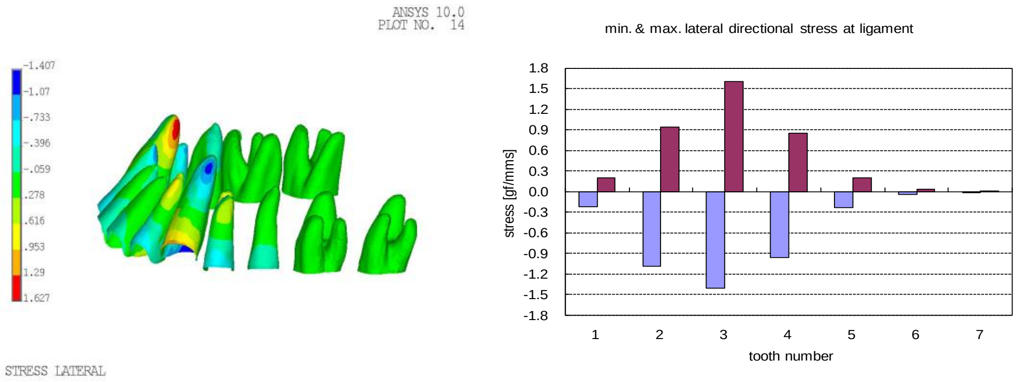
In anterior-posterior (A-P) displacement, 0.077 mm in clippy-c bracket, 0.085 mm in smart clip bracket and 0.081 mm in metal bracket were shown. Just like the 1.0 mm case, clippy-c bracket showed a small posterior movement. In longitudinal (B-L) displacement, 0.077 mm in clippy-c bracket, 0.078 mm in smart clip bracket and 0.078 mm in metal bracket were shown. Unlike the 1.0mm case, metal bracket showed the smallest value. The vertical displacement were 0.11 mm in clippy-c bracket, 0.10 mm in smart clip bracket and 0.093 mm in metal bracket. It found that self-ligation bracket was more effective in vertical displacement (Table 6, 7, 8).

C. Stress

In the case of lateral stress (A-P direction), the maximum stress of 1.723 gf/mm^2, 1.627 gf/mm^2 and 1.46 gf/mm^2 were produced in clippy-c bracket, smart clip bracket and metal bracket. The stress of self-ligation bracket was enlarged compared to metal bracket (Figure 7). In the case of longitudinal stress (B-L direction), the maximum stress of 1.941 gf/mm^2, 1.77 gf/mm^2 and 1.567 gf/mm^2 were produced according to the brackets (Figure 8). In the case of vertical stress, the result of 2.059 gf/mm^2 and 1.984 gf/mm^2, 1.797 gf/mm^2 were shown at 2.0 mm superior to occlusal plane. Clippy-c bracket showed the largest value, and the increase was up to 245% (Figure 9) compared to 1.0 mm case. The stress of metal bracket was relatively small (approx. 10%), and it showed an unfavorable result in vertical displacement.



A



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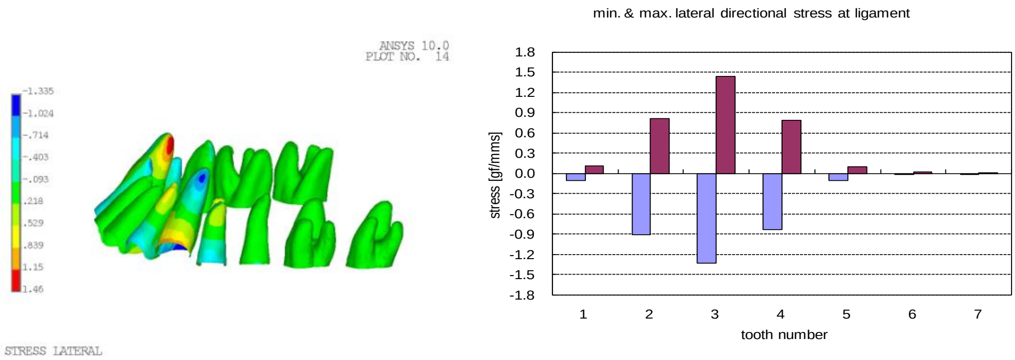
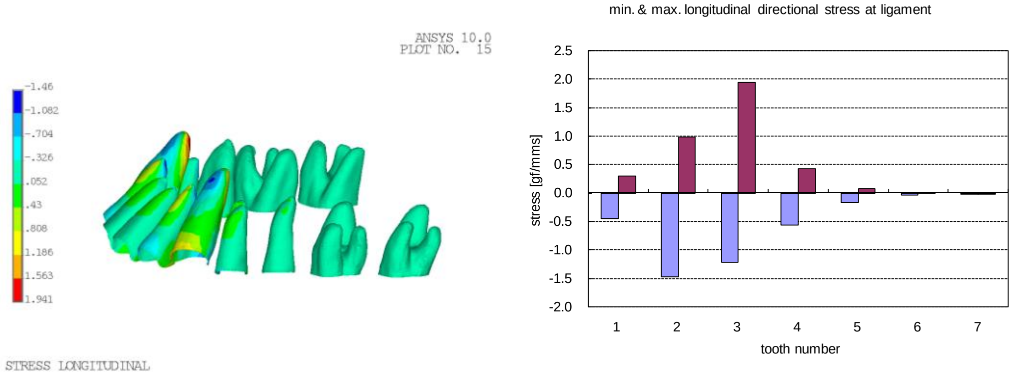


C

Figure 7. Lateral stress at periodontal ligament of clippy-c bracket (A), smart clip bracket (B), metal bracket (2.0 mm above)



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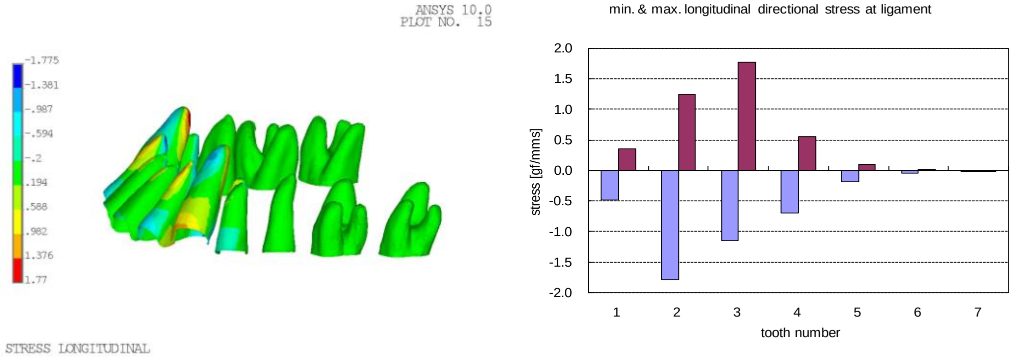
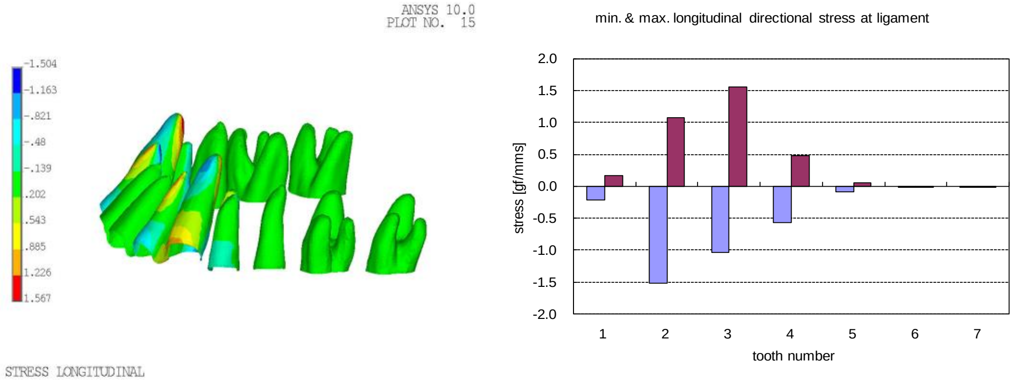


B



C

Figure 8. Longitudinal stress at periodontal ligament of clippy-c bracket (A), smart clip bracket (B), metal bracket (C) (2.0 mm above)

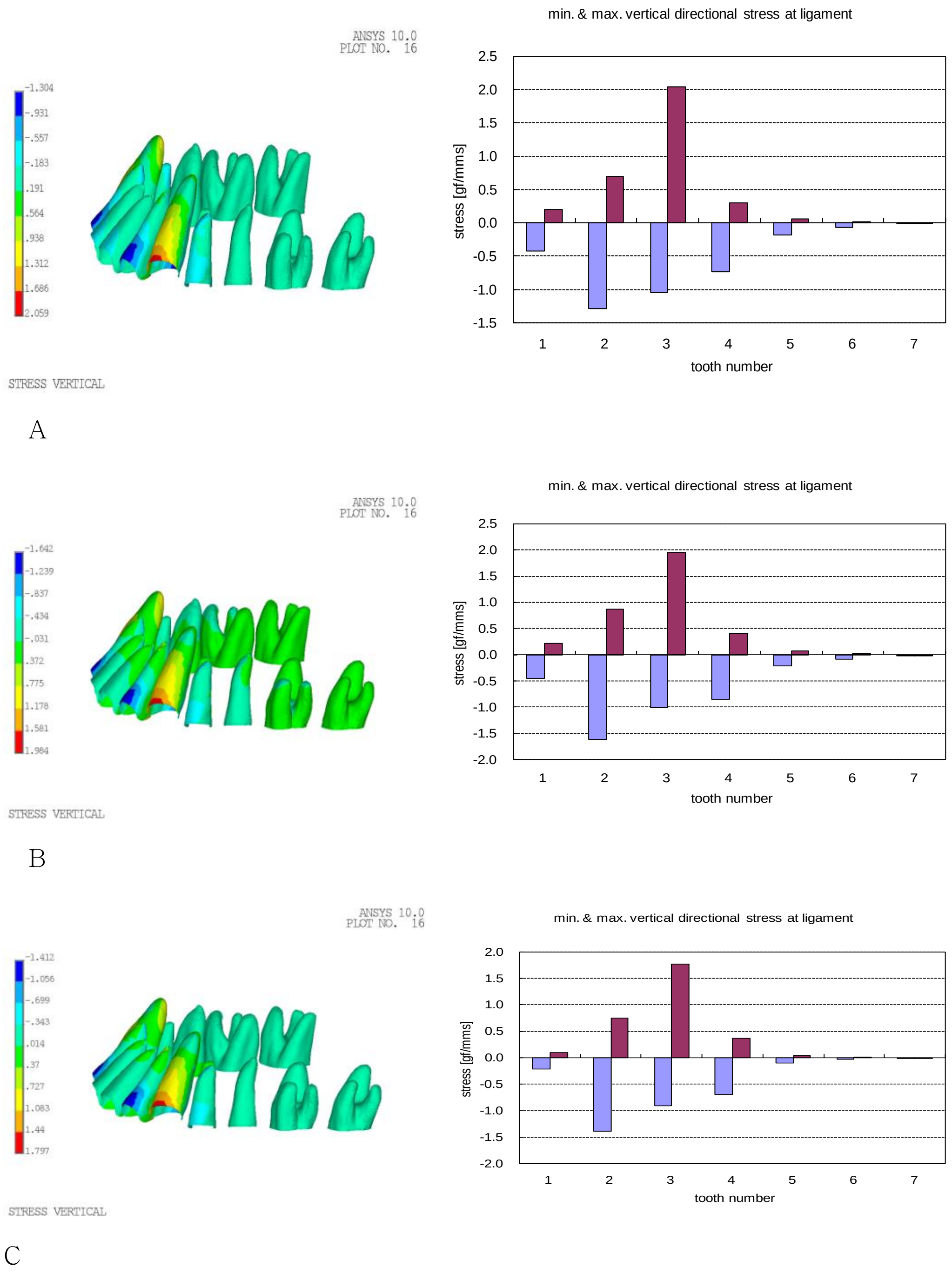


Figure 9. Vertical stress at periodontal ligament of clippy-c bracket (A), smart clip bracket (B), metal bracket (C) (2.0 mm above)

3. When orthodontic force was applied at 3.0 mm above the occlusal plane

A. Rotation (Figure 10) (Table 9, 10, 11).

The lingual rotation of canines observed from sagittal plane were 0.153°, 0.159° and 0.150° at 3.0 mm superior to occlusal plane. The lingual rotation was increased a lot at 2.0 mm , but decreased at 3.0 mm above the occlusal plane, and thus the value was similar to 1.0mm case. Metal bracket showed the smallest lingual tilting and smart clip bracket showed the largest, but there was no significant difference between self-ligation brackets

Rotation from the occlusal plane was in mesio-distal direction, 0.067°, $0.035^{p,}$, and 0.019° at 3.0 mm , and decreased more than 2.0 mm case. The distal rotation of smart clip and metal bracket was decreased more than 1.0 mm case , so they moved parallel. Clippy-c bracket showed the largest and metal bracket showed the smallest just as in 1.0 mm and 2.0 mm cases

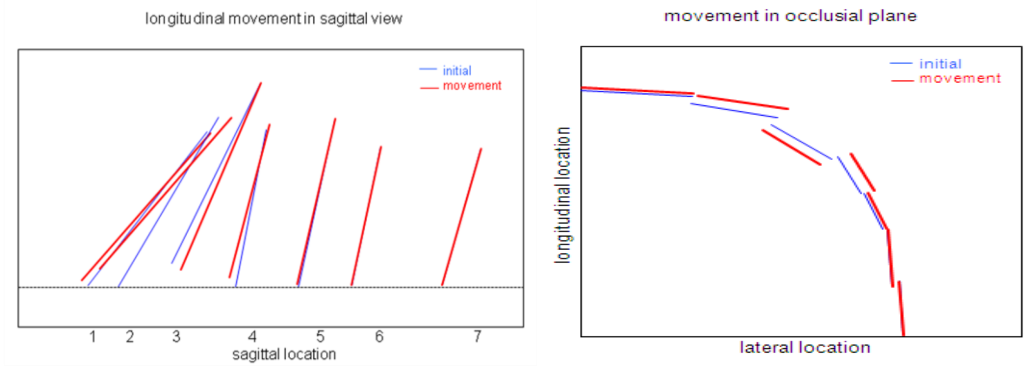
B. Displacement (Table 9, 10, 11)

At the antero-posterior (A-P) displacement, at 3.0 mm superior to occlusal plane, 0.05 mm in clippy-c bracket, 0.058 mm in smart clip bracket and 0.057

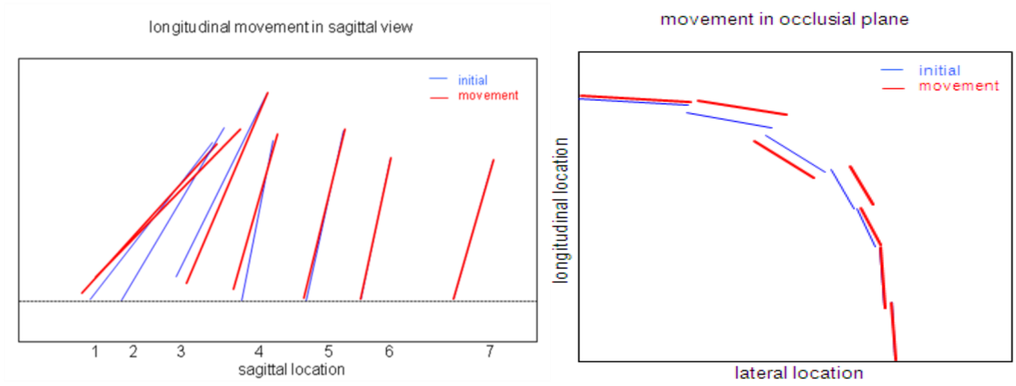
mm in metal bracket were shown, and these results were decreased a lot compared to 2.0 mm case, and clippy-c bracket showed the smallest value.

At the longitudinal (B-L) displacement, 0.058 mm in clippy-c bracket, 0.06 mm in smart clip bracket and 0.055 mm in metal bracket were shown. At 3.0 mm superior to occlusal plane, metal bracket showed the smallest value and self-ligation bracket showed the largest.

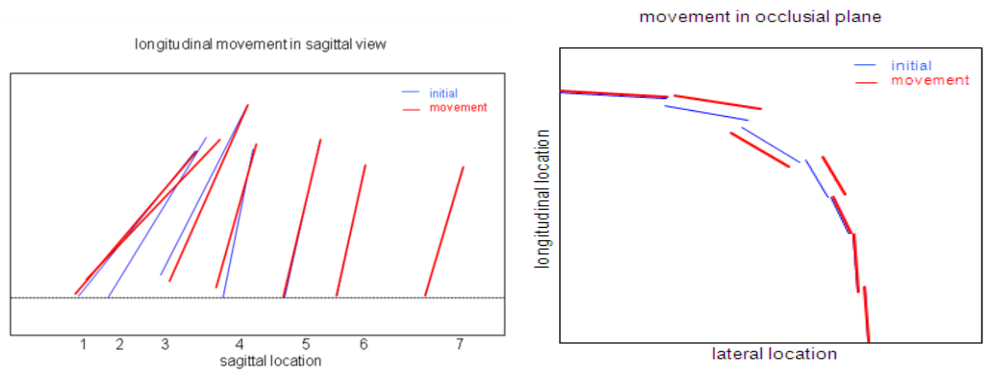
At the vertical displacement, at 3.0 mm superior to occlusal plane, 0.037 mm in clippy-c bracket, 0.040 mm in smart clip bracket and 0.038 mm in metal bracket were shown. Self-ligation bracket was effective in vertical displacement at 1.0 mm and 2.0 mm superior to occlusal plane, but did not show a significant difference at 3.0 mm. Self ligation bracket, clippy-c and smart clip bracket , did not show a significant difference in A-P and vertical displacement but show the increased bucco-lingual movement compared to metal bracket.



A



B



C

Figure 10. Rotation in sagittal (Lt) and occlusal (Rt) view at 3.0 mm above the occlusal plane of clippy-c bracket (A), smart clip bracket (B), metal bracket (C)

C. Stress

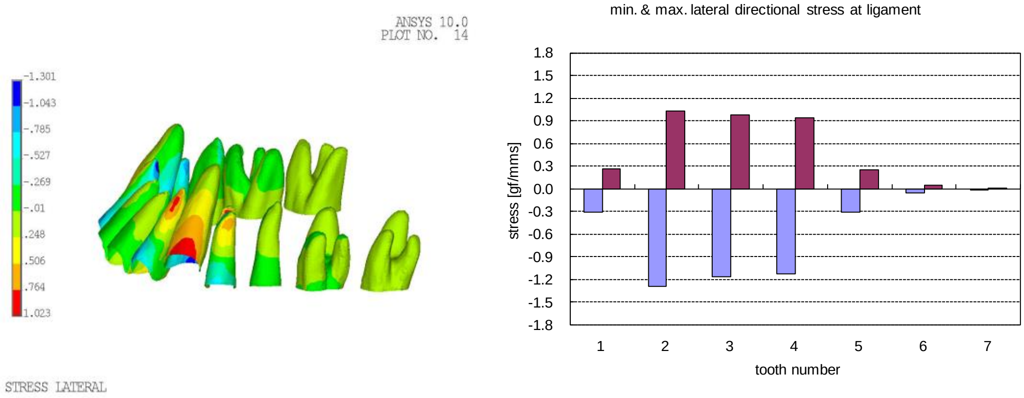
Looking into lateral stress, maximum stress 1.023 gf/mm^2,1.404 gf/mm^2, 1.222 gf/mm^2 in according to the brackets, were shown at 3.0 mm above the occlusal plane, and were decreased overall compared to 2.0 mm. The largest was in smart clip bracket, and the smallest in clippy-c bracket. In the smart clip bracket, the maximum stress was large, but the stress distribution was narrow. In other words, stress distribution in which a large stress was focused on the narrow portion. In the clippy-c bracket, its maximum stress was the smallest, but its distribution area was relatively larger (Figure 11). The maximum stress was concentrated at the lingual root apex in the case of 1.0 mm and 2.0 mm, but at the upper third of the root in the 3.0 mm case.

In the case of longitudinal stress (B-L direction), at 3.0mm superior to occlusal plane, maximum stress of 1.492 gf/mm^2, 1.393 gf/mm^2 and 1.215 gf/mm^2 were produced according to the order of the brackets. The maximum stress of smart clip bracket is smaller than clippy-c bracket, but it is more widely distributed, and thus B-L displacement of smart clip bracket is shown to be the largest. On the contrary, clippy-c bracket's B-L displacement is smaller than smart clip bracket because the large maximum longitudinal stress of clippy-c bracket is focused on the small portion only and then small sized stress (1.083

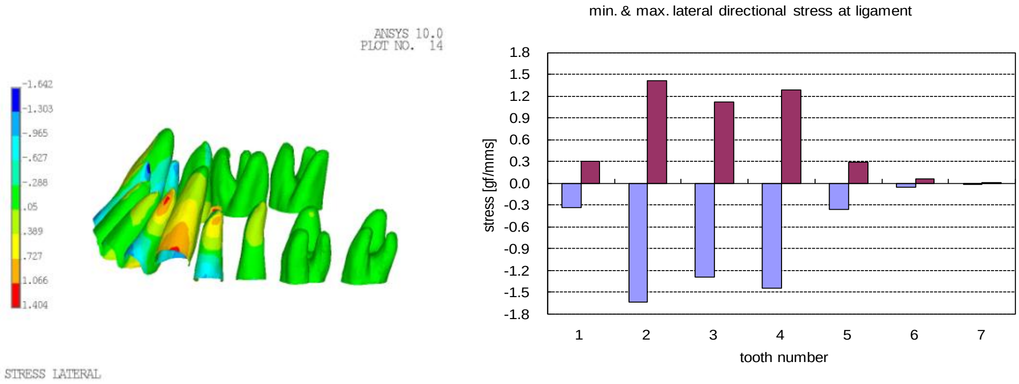
gf/mm^2) is largely distributed on the rest. The most significant differences, compared to the 2.0 mm case, were that overall stress decrease, and the change of stress distribution from root apex to the labial upper third of the root and a larger stress to lateral incisor than canine (Figure 12).

In the case of vertical stress, 1.057 gf/mm^2, 1.32 gf/mm^2, and 1.128 gf/mm^2의 were shown at 3.0 mm superior to occlusal plane according to the order of the brackets, and stress distribution patterns were similar to one another. In clippy-c bracket, it showed small stress than metal bracket, and then the vertical diplacement small was small too.

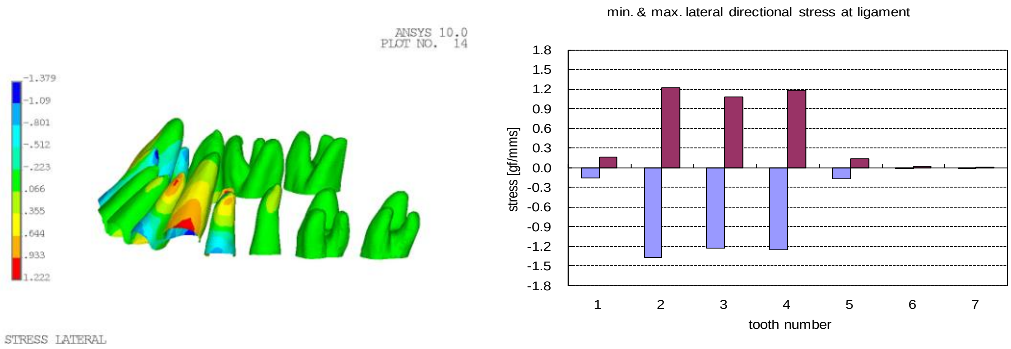
Overall, the vertical stress at 3.0 mm was decreased compared to the 2.0 mm case, and the vertical displacement was decreased more than 1.0 mm case (Figure 13).



A

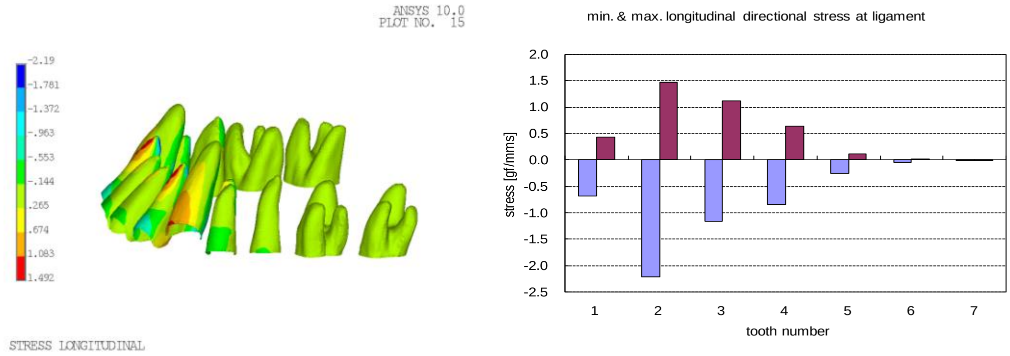


B

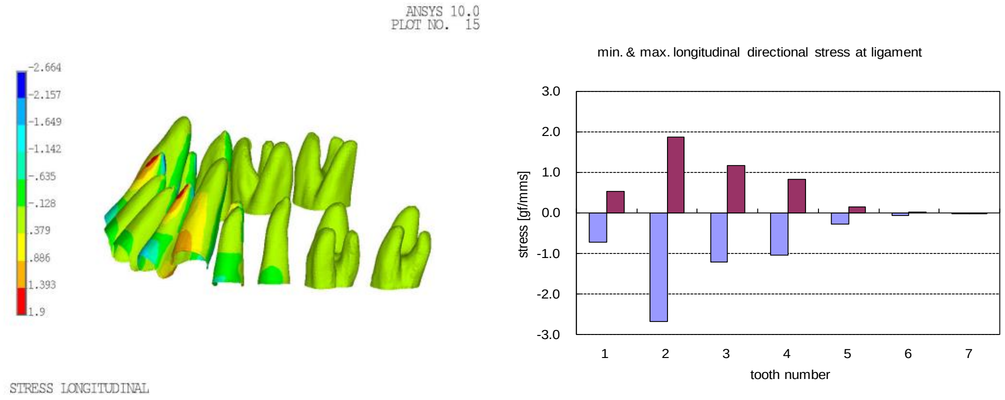


C

Figure 11. Lateral stress at periodontal ligament of clippy-c bracket (A), smart clip bracket (B), metal bracket (C) (3.0 mm above)



A



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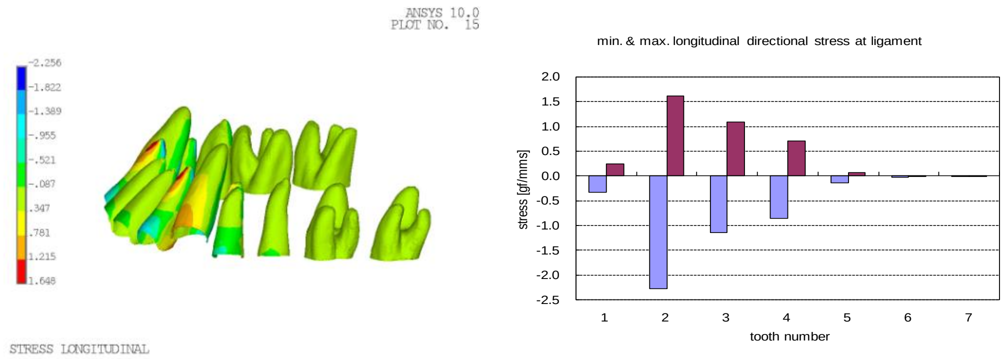

C

Figure 12. Longitudinal stress at periodontal ligament of clippy-c bracket (A), smart clip bracket (B), metal bracket (C) (3.0 mm above)

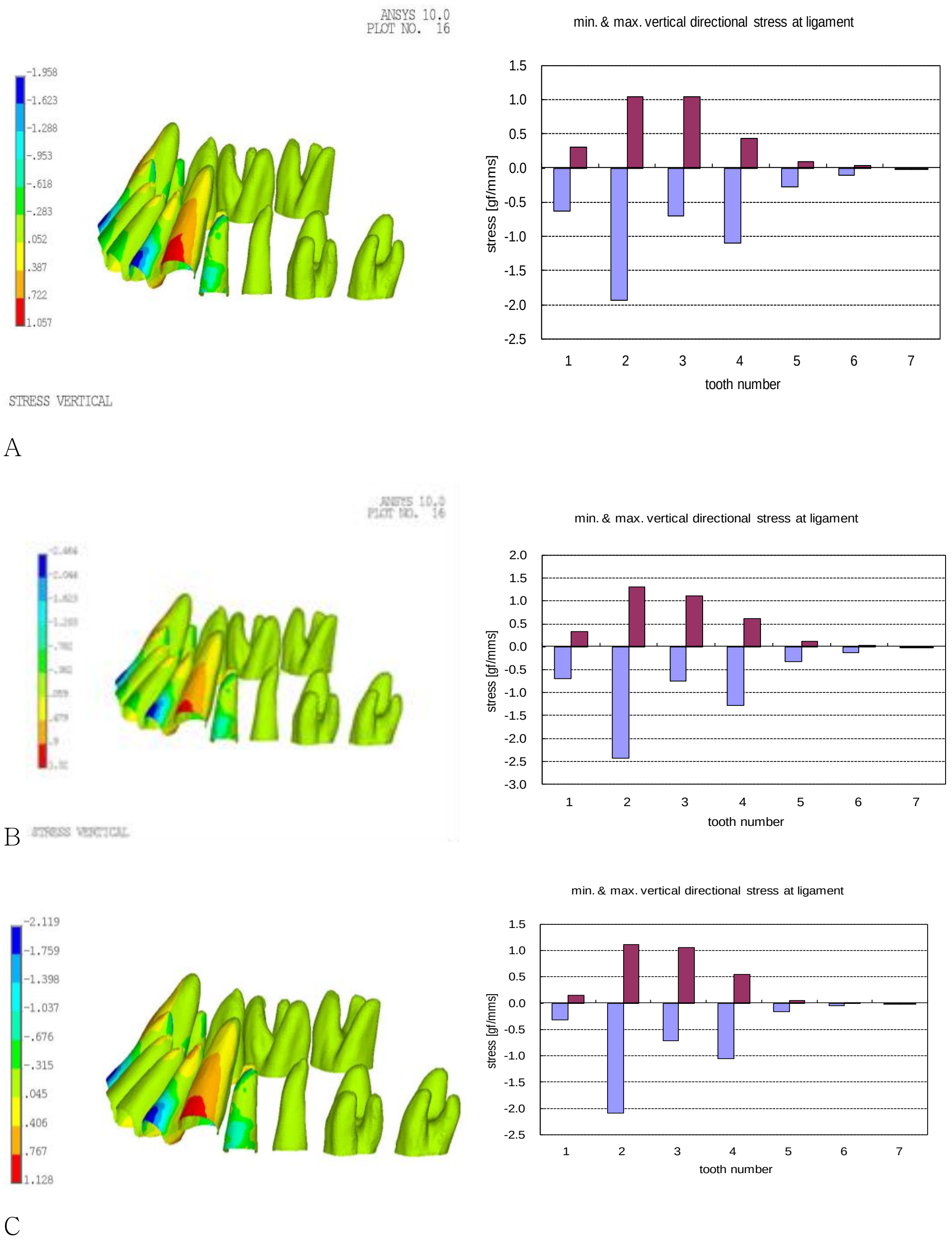

Figure 13. Vertical stress at periodontal ligament of clippy-c bracket (A), smart clip bracket (B), metal bracket (C) (3.0 mm above)

IV. DISCUSSION

This study of the alignment of vertically displaced canine is about the initial movement which occurs in periodontal ligament. If orthodontic force is applied to tooth, stress is produced in periodontal tissue and it reaches the equilibrium in 2 minutes, and strain proportional to the stress is occured in periodontal ligament, and it makes physiological changes such as bone absorption at pressure side and bone formation at tension side[26], and thus tooth movement is gained. Initial movement of tooth in periodontal ligament is called a primary displacement[27], and the after tooth movement by bone remodeling is called a secondary displacement, and secondary movement can be predicted by primary displacement.[28]

Primary displacement can be analyzed by investigating the stress distribution in periodontal ligament, and it had been done histologically in the past. Industrial theory for stress analysis was started to introduce in 1917 by Fish[29]. In 1963 Haack[30] used 2-dimensional model and in 1965 Geigel[31] used 3-dimensional model, and in 1971 Davidian[32] did a research on the force distribution of maxillary central incisor using a computer model. There are holography method, strain gauge method, photo-elasticity method, finite element method and so on in industrial methods for stress analysis caused from orthodontic force.

Finite element analysis is done by subdividing the object into element which is a basic unit through computer and by modeling it after that. The property of the real object is reflected on the analysis by substituting the physical value of each structure in the process of modeling. The intended solution is gained by entering various applied forces, the material property and the boundary conditions.[33] The real object and force are idealized by various assumptions through differential equation, and finite element analysis is one of the mathematical approximate solutions to solve the answer of differential equation.[34] Finite element method has been used in orthodontics, the analysis of an appliance, stress distribution, growth change and so on. Matsui[35]analyzed the stress by making 2-dimensional models of maxillary molrs and face bow. Matsuura[36] did an analysis by connecting a fixed appliance and tooth-PDL-alveolar bone model, and various retraction springs by making 2-dimensional model of maxillary canine. Domestically, Sung[37] used 3-dimensional finite element analysis on canine movement in labial and lingual orthodontic treatment, and Kim[18] researched the stress distribution of tooth and supporting tissue during initial stage of canine distal movement by using finite element method. Lim[19] evaluated the stress distribution at the metal slot of composite or ceramic bracket when tipping and torque force were applied using finite element method. Park[20] did a research on the pattern of transformation at crowded dentition was treated with 014 NiTi wire by setting constraint equation differently using finite element analysis and in the non-extraction orthodontic treatment of anterior crowding dentition, the alignment effect of the crowding dentition is that the roller boundary condition shows higher effective movement (movement/unit force) and lower level of teeth moment than the fixed boundary condition. In consideration of the binding condition between brackets and arch wires, it can be hypothesized the fixed boundary condition reflects the ligation bracket and the roller boundary condition reflects the self-ligation bracket. So the self-ligation bracket is clinically more effective than the ligation bracket in view of the alignment effect.

In the periodontal ligament, stress cause to move the tooth is located at upper third of the root, the site considered to be a center of resistance of canine. This is the same phenomenon regardless of the component of the stress. Although the distribution pattern that a large stress was occurred on the root apex is shown, this cannot be a primary cause of tooth movement because it was just the root apex area became narrower and thus the force became concentrated at the apex. There were many researches on the center of resistance, Burstone[38,39] said that the center was located in approximately 40% of the tooth around cervical area in 2 -dimensional model, but reported that it was located in approximately 33% area after using 3-dimensional experimental model of central incisor. Nikolil[40,41] who used 2-dimensional model of canine said that it was located in approximately 48 % area, and Tanne[42,43] who used finite element method said that it was located in approximately 24 % area. Choy et al.[44] who used 2-dimensional analysis model of maxillary canine reported that it was located in approximately 42% area around cervical area, and Smith[45] said that center of resistance was located between 1/3 and 1/2 of long axis of tooth in single rooted tooth, and it was located in 1.0 - 2.0 mm below the furcation area in multiple rooted tooth. The reasons why the results are different like this are the location of the resistance center is not clear, and the location changes by the shape and size of tooth, condition of alveolar bone and its surrounding periodontal tissue, neighboring tooth and the applied force as well. And results can be different depending on how well the real tooth environment was reconstructed and how accurately the measurement was done, because it is difficult to measure the tooth movement in vivo.

Orthodontic force is transferred to tooth through brackets, and it is assumed that the stress applied to tooth and periodontal tissue will be different depending on the bracket materials such as metal, ceramic, resin and so on and ligation method (whether it is a conventional bracket or self-ligation bracket). Self-ligation bracket is assumed to reduce the friction because it has an appliance to engage a wire into the bracket slot for itself and thus a ligation force can be reduced.[29] Self-ligation bracket began to be introduced as an edgewise attachment called “ Russell Lock’’[46] in 1935, and Speed bracket in 1980, Time in 1994, Damon SL in 1996, Twinlock in 1998, Damon 2 and In-Ovation in 2000, Damon 3 and smart clip in 2004 were introduced. Recently, esthetic bracket such as clippy-c bracket and Damon clear were introduced. Self-ligation brackets are divided into two types which are passive type and active type according to its mechanical device for the closure of edgewise slot, and ligation force is not applied in passive type because the slide in the passive type only covers the bracket slot.[12] Active type is divided into two cases that force is applied to the wire, or not depending on the clip is active or passive.[12,13]

The advantages of self-ligation bracket introduced by the manufacturing company are as follows. Friction is low because ligation is not needed, and tooth movement is possible with light force, and chair time and treatment period become shortened because tooth movement is less painful and fast. But in the study by Mile et al.[47] on the initial arrangement between Damon 2 and conventional twin bracket, Damon 2 bracket was not shown more effective or less painful. And according to the study on friction of 4 kinds of self-ligation brackets and 4 kinds of conventional metal brackets by Reicheneder et al.[48], it cannot be said that there is a less friction in self-ligation bracket because the friction varies depending on the wire size. According to the study on friction between self-ligation bracket and conventional bracket by Ehsani et al.[49], small round wire showed low friction, but there is no proof that a large rectangular wire could be said to have a low friction. There are many studies on the friction of self-ligation bracket, but also there are lots of controversy.

According to Ogata et al.[50], reduced friction could be an advantage to tooth and surrounding tissue because orthodontic force cannot reach an optimal force because of the friction between bracket and wire, and there needs a more strong force.[10] Whether a large stress was applied to periodontal tissue due to low friction of self-ligation bracket or not was looked into in this study. As self-ligation brackets, clippy-c bracket (active) and smart clip bracket (passive) were used, and not only the difference between self-ligation bracket and conventional metal bracket but also the difference between self-ligation brackets themselves were looked into.

Moving pattern of canine was not only to vertical direction but also was 3-dimensional (lateral, longitudinal and vertical). The lateral (A-P) displacement of canine was the smallest with clippy-c bracket at all position, and the largest with metal bracket at 1.0 mm above the occlusal plane, and smart clip bracket at 2.0 mm, 3.0 mm. A-P displacememt and lateral stress always are not proportional to each other considering the fact that the largest stress was formed at clippy-c bracket at 2.0 mm but the smallest stress was at clippy-c bracket at 1.0 mm,3.0 mm above the occlusal plane, too. But, it was assumed that A-P displacement was not gained by lateral stress only considering the fact that lateral stress at 1.0 mm, 2.0 mm was limited to the root apex. Lateral stress of canine at 3.0 mm above the occlusal plane was located at upper 1/3 of root, canine with clippy-c bracket showed the smallest stress (1.023 gf/mm^2) and the smallest tooth movement (0.05 mm), and canine with smart clip bracket showed the largest stress (1.404 gf/mm^2) and the largest tooth movement (0.058 mm). It can be said that lateral displacement and lateral stress are proportional to each other at 3.0mm above the occlusal plane. Seen from these results, it cannot be said that A-P displacement of self-ligation bracket is smaller than metal bracket because smart clip bracket (passive type) showed the largest lateral stress and displacement and clippy-c bracket (active type) showed the smallest values. It was assumed that using clippy-c bracket (active type) would be advantageous for the prevention of tipping because the smaller the A-P movement.

Looking into longitudinal (B-L) displacement, clippy-c bracket showed the smallest movement (0.031 mm) at 1.0mm, and metal bracket showed the smallest movements(0.072 mm, 0.055 mm) at 2.0mm and 3.0mm, and smart clip bracket showed the largest displacement was at all positions. A-P and vertical displacement of self-ligation bracket is similar to metal bracket but B-L displacement of self-ligation bracket is larger than metal bracket. On the other hand, clippy-c bracket showed the largest longitudinal maximum stress (0.802

gf/mm^2, 1.941 gf/mm^2, 1.492 gf/mm^2) at all 1.0, 2.0, 3.0 mm above the occlusal plane and the smart clip bracket showed the second-largest value. In the case of 3.0mm above occlusal plane, longitudinal stress was located not at the root apex but at upper 1/3 of the root, and the maximum stress of metal bracket was the smallest (1.215 gf/mm^2) and the B-L displacement was also the smallest. Although maximum B-L stress of smart clip bracket was smaller than clippy-c bracket, B-L displacement of smart clip was the largest because the stress was more widely distributed relatively. So it was found not only the maximum stress but also the stress distribution area should be considered in proportional relationship between displacement and stress. When canine move downward, lingual movement was the smallest in metal bracket and the largest in smart clip bracket, so it was assumed that self-ligation bracket is unfavorable in torque control.

Looking into vertical stress, in 1mm above the occlusal plane case, there was few difference in size and distribution of the stress between the brackets although the stress was little larger in self-ligation bracket. In 2.0 mm above the case as well, the stress distribution between brackets were similar, but the stress were relatively larger (approx. 10%) in self-ligation bracket than metal bracket. In 3mm above case, the stress distribution patterns were all similar between brackets but the stress of smart clip bracket was largest, and clippy-c bracket was smallest. Vertical displacement was proportional to vertical stress. At 1.0 mm, 2.0 mm superior points, self-ligation bracket showed larger vertical movement than metal bracket, and at 3.0 mm superior point, smart clip bracket (passive type) showed the largest vertical movement and clippy-c bracket (active type) showed the smallest vertical movement.

In clippy-c bracket, vertical tensile stress of 0.84 gf/mm^2, 2.06 gf/mm^2 and 1.06 gf/mm^2 were formed respectively at canine above the occlusal plane. In the 2.0 mm above case, vertical stress increased more than twice of the 1.0 mm case, up to 245%, and the vertical stress distribution showed a similar pattern, decrease as closer to the apex. Canine vertical displacement was 0.045 mm in 1.0 mm case and 0.11 mm in 2.0 mm respectively, and this result coincide that the vertical stress increase up to 244% at 2.0 mm. It could be assumed that the vertical stress was increased, and vertical displacement pattern was maintained similar from 1.0 mm to 2.0 mm above the occlusal pattern. In the 3.0 mm case, vertical tensile stress was decreased to 51%, almost the half of the 2.0 mm's, and vertical displacement was decreased from 0.11 mm to 0.037 mm sharply (approx. 34%). In the 2.0 mm above the occlusal plane case, the vertical tensile stress was large at upper root 1/3, but hardly was formed or sharply decreased toward the apex. However in the 3.0 mm case, the stress distribution was relatively even along the whole root surface and 0.22 gf/mm^2 stress was formed at the apex although the maximum vertical stress was small. The reason for this can be judged by the surrounding alveolar bone became thicker at 3.0mm above the occlusal plane, and thus vertical movement of canine become difficult at 3.0 mm case. Opposite to the above result, in the lateral incisor at 3.0 mm case, vertical compressive stress was 1.96 gf/mm^2 which was 151% increased value compared to 1.30 gf/mm^2 at 2.0 mm case, and the change of stress formed is sharper than that of the 2.0 mm intrusion case. The pattern like this was similarly shown not only in lateral incisor next to canine but also in first premolar.

The size of the vertical stress at 1.0 mm above the occlusal plane was the largest in smart clip bracket, and then clippy-c bracket and metal bracket in order, and vertical displacement was the largest in smart clip bracket and the smallest in metal bracket proportionally to the stress. At 2.0 mm above the occlusal plane, the size of vertical stress was the largest in clippy-c bracket, and then smart clip bracket and metal bracket in order, and vertical displacement showed the value proportional to the stress just as in the 1.0 mm case. At 1.0 mm and 2.0 mm superior points, self-ligation bracket was advantageous over metal bracket sine vertical stress and vertical displacement of self-ligation bracket was large as well. At 3.0 mm superior point, the size of vertical stress was the largest in smart clip bracket, and then metal bracket and clippy-c bracket in order, and vertical displacement also was the largest in smart clip bracket and the smallest in clippy-c bracket. So, self-ligation bracket was not always more advantageous because the vertical displacement of clippy-c bracket, active type self-ligation bracket, was the smallest at 3.0 mm superior point. In clinical point of view, what is called an optimal force is the one that causes the optimal cellular reaction in periodontal ligament and thus moves the tooth with speed without causing discomforts to patient. Therefore, it could be inappropriate to calculate mathematically the various structure and reaction of body. Finite element method has an advantage that stress analysis is possible by simplifying the component and structure of material, although there is a disadvantage that it is not an real analysis because the experiment was not directly done with specimen. So it is considered that the result of finite element method is affected by many factors that accuracy of the modeling, numbers and arrangement of elements and so on.

V. CONCLUSIONS

The purpose of this study was to examine the difference of self-ligation bracket, clippy-c bracket (active type) and smart clip bracket (passive type), from conventional metal bracket by bonding to canines located at 1.0 mm, 2.0 mm and 3.0 mm above the occlusal plane. Not only the difference from metal bracket but also the difference between self-ligation brackets were looked into. As a result of the study in which the correlation between displacement of canine which occurs 3-dimensionally (lateral, longitudinal and vertical) was also researched, the conclusions as follows were drawn.

1. At 1.0 mm above the occlusal plane, vertical stress was the largest in smart clip bracket, and then clippy-c bracket and metal bracket in order, and vertical displacement was the largest in smart clip bracket and the smallest in metal bracket proportionally to the stress.
2. At 2.0 mm above the occlusal plane, vertical stress was the largest in clippy-c bracket, and then smart clip bracket and metal bracket in order, and vertical displacement showed the value proportional to the stress just as in the 1.0mm case.

3. At 1.0 mm and 2.0 mm above the occlusal plane, self-ligation bracket was more efficient than metal bracket because the vertical stress and vertical displacement of self-ligation bracket was large.

4. At 3.0 mm above the occlusal plane, vertical stress was the largest in smart clip bracket, and then metal bracket and clippy-c bracket in order, and vertical displacement was the largest in smart clip and the smallest in clippy-c bracket proportionally to the vertical stress.

5. At 3.0 mm above the occlusal plane, self-ligation bracket was not always more advantageous because the vertical displacement of clippy-c bracket was the smallest at 3.0 mm superior point.

6. The size of vertical stress and vertical displacement were proportional to each other, and it was that more vertical movement was not always gained in self-ligation bracket and was depending on bracket system.

APPENDICES

Table 3. Clippy-C bracket, that the orthodontic force was exerted at 1.0 mm above the occlusal plane

Tooth	Position	Displacements (mm)			Rotations(°)	
		Ux	Uy	Uz	Sagittal	Occlusal
Central incisor	Tip	-7.3E-04	-7.4E-03	-1.9E-03	-0.056	0.006
	Apex	9.7E-04	1.2E-02	1.2E-02		
	Distal	6.5E-04	8.6E-03	1.0E-02		
	Mesial	7.7E-04	9.6E-03	1.1E-02		
Lateral incisor	Tip	-9.7E-03	-2.4E-02	-7.8E-04	-0.160	0.048
	Apex	1.3E-02	3.4E-02	3.5E-02		
	Distal	8.9E-03	2.4E-02	3.0E-02		
	Mesial	1.1E-02	3.0E-02	3.2E-02		
Canine	Tip	2.2E-02	2.4E-02	-7.0E-03	0.143	-0.053
	Apex	-3.0E-02	-3.1E-02	-4.5E-02		
	Distal	-1.9E-02	-2.0E-02	-4.0E-02		
	Mesial	-2.5E-02	-2.4E-02	-3.8E-02		
1st premolar	Tip	-1.2E-02	-6.4E-03	9.8E-03	-0.050	0.006
	Apex	2.0E-02	1.0E-02	1.9E-02		
	Distal	1.6E-02	7.5E-03	1.8E-02		
	Mesial	1.6E-02	7.7E-03	1.4E-02		
2nd premolar	Tip	-3.9E-03	-1.7E-03	2.0E-03	-0.012	0.007
	Apex	5.4E-03	2.3E-03	4.9E-03		
	Distal	3.7E-03	1.6E-03	4.5E-03		
	Mesial	4.6E-03	1.9E-03	3.8E-03		
1st molar	Tip	-4.3E-04	-1.5E-04	1.0E-03	-0.001	0.000
	Apex	8.8E-04	1.9E-04	9.3E-04		
	Distal	6.5E-04	1.3E-04	8.7E-04		
	Mesial	6.5E-04	1.3E-04	4.0E-04		
2nd molar	Tip	1.2E-06	1.9E-06	6.6E-06	0.000	0.000
	Apex	6.1E-06	6.3E-06	7.3E-06		
	Distal	5.2E-06	5.6E-06	7.4E-06		
	Mesial	6.3E-06	5.3E-06	3.4E-06		

Table 4. Smart Clip bracket, that the orthodontic force was exerted at 1.0 mm above the occlusion plane

Tooth	Position	Displacements (mm)			Rotations(°)	
		Ux	Uy	Uz	Sagittal	Occlusal
Central incisor	Tip	-8.9E-04	-7.9E-03	-2.5E-03	-0.064	0.006
	Apex	1.4E-03	1.4E-02	1.3E-02		
	Distal	1.0E-03	1.0E-02	1.1E-02		
	Mesial	1.1E-03	1.1E-02	1.2E-02		
Lateral incisor	Tip	-1.3E-02	-3.0E-02	-3.4E-03	-0.210	0.051
	Apex	2.0E-02	4.6E-02	4.4E-02		
	Distal	1.4E-02	3.4E-02	3.7E-02		
	Mesial	1.7E-02	4.0E-02	4.0E-02		
Canine	Tip	2.3E-02	2.3E-02	-3.8E-03	0.150	-0.045
	Apex	-3.6E-02	-3.4E-02	-4.5E-02		
	Distal	-2.4E-02	-2.3E-02	-3.9E-02		
	Mesial	-3.0E-02	-2.7E-02	-3.7E-02		
1st premolar	Tip	-1.5E-02	-7.8E-03	1.1E-02	-0.065	0.006
	Apex	3.0E-02	1.3E-02	2.3E-02		
	Distal	2.3E-02	1.0E-02	2.2E-02		
	Mesial	2.4E-02	1.0E-02	1.8E-02		
2nd premolar	Tip	-4.6E-03	-1.8E-03	1.9E-03	-0.013	0.008
	Apex	7.2E-03	2.7E-03	5.5E-03		
	Distal	5.1E-03	1.9E-03	4.9E-03		
	Mesial	6.1E-03	2.2E-03	4.3E-03		
1st molar	Tip	-5.0E-04	-1.6E-04	1.2E-03	-0.001	0.000
	Apex	1.3E-03	2.4E-04	1.0E-03		
	Distal	1.0E-03	1.8E-04	9.5E-04		
	Mesial	1.0E-03	1.8E-04	3.5E-04		
2nd molar	Tip	4.3E-06	6.7E-06	1.5E-05	0.000	0.000
	Apex	1.7E-05	2.2E-05	1.8E-05		
	Distal	1.5E-05	2.0E-05	1.9E-05		
	Mesial	1.6E-05	2.0E-05	5.9E-06		

Table 5. Metal bracket, that the orthodontic force was exerted at 1.0 mm above the occlusion plane

Tooth	Position	Displacements(mm)			Rotations(°)	
		Ux	Uy	Uz	Sagittal	Occlusal
Central incisor	Tip	-4.4E-04	-3.7E-03	-1.3E-03	-0.030	0.003
	Apex	7.3E-04	6.5E-03	6.2E-03		
	Distal	5.3E-04	5.0E-03	5.3E-03		
	Mesial	5.9E-04	5.4E-03	5.5E-03		
Lateral incisor	Tip	-1.1E-02	-2.5E-02	-3.8E-03	-0.180	0.037
	Apex	1.7E-02	4.0E-02	3.7E-02		
	Distal	1.3E-02	3.0E-02	3.1E-02		
	Mesial	1.5E-02	3.4E-02	3.3E-02		
Canine	Tip	2.2E-02	2.2E-02	-2.4E-03	0.145	-0.039
	Apex	-3.7E-02	-3.3E-02	-4.2E-02		
	Distal	-2.5E-02	-2.3E-02	-3.7E-02		
	Mesial	-3.0E-02	-2.6E-02	-3.5E-02		
1st premolar	Tip	-1.3E-02	-6.3E-03	9.1E-03	-0.054	0.005
	Apex	2.7E-02	1.1E-02	1.9E-02		
	Distal	2.1E-02	8.6E-03	1.8E-02		
	Mesial	2.1E-02	8.8E-03	1.5E-02		
2nd premolar	Tip	-2.2E-03	-8.3E-04	8.5E-04	-0.006	0.004
	Apex	3.6E-03	1.3E-03	2.6E-03		
	Distal	2.6E-03	8.9E-04	2.3E-03		
	Mesial	3.1E-03	1.0E-03	2.0E-03		
1st molar	Tip	-1.9E-04	-6.1E-05	4.5E-04	0.000	0.000
	Apex	5.6E-04	8.4E-05	3.9E-04		
	Distal	4.3E-04	6.1E-05	3.5E-04		
	Mesial	4.2E-04	6.5E-05	1.1E-04		
2nd molar	Tip	8.2E-07	7.1E-07	3.9E-06	0.000	0.000
	Apex	4.2E-06	2.6E-06	4.0E-06		
	Distal	3.6E-06	2.3E-06	4.0E-06		
	Mesial	4.1E-06	2.1E-06	2.1E-06		

Table 6. Clippy-C bracket, that the orthodontic force was exerted at 2.0 mm above the occlusal plane

Tooth	Position	Displacements(mm)			Rotations(°)	
		Ux	Uy	Uz	Sagittal	Occlusal
Central incisor	Tip	-2.1E-03	-1.6E-02	-4.0E-03	-0.121	0.020
	Apex	3.1E-03	2.5E-02	2.6E-02		
	Distal	2.1E-03	1.8E-02	2.1E-02		
	Mesial	2.5E-03	2.1E-02	2.4E-02		
Lateral incisor	Tip	-2.2E-02	-5.2E-02	-1.6E-03	-0.345	0.113
	Apex	2.9E-02	7.3E-02	7.7E-02		
	Distal	2.0E-02	5.1E-02	6.3E-02		
	Mesial	2.6E-02	6.4E-02	7.0E-02		
Canine	Tip	5.5E-02	5.8E-02	-1.5E-02	0.353	-0.124
	Apex	-7.7E-02	-7.7E-02	-1.1E-01		
	Distal	-4.9E-02	-5.0E-02	-9.8E-02		
	Mesial	-6.4E-02	-6.1E-02	-9.3E-02		
1st premolar	Tip	-2.5E-02	-1.4E-02	2.1E-02	-0.113	0.012
	Apex	4.4E-02	2.3E-02	4.0E-02		
	Distal	3.3E-02	1.7E-02	3.8E-02		
	Mesial	3.5E-02	1.7E-02	3.1E-02		
2nd premolar	Tip	-8.4E-03	-4.0E-03	4.2E-03	-0.029	0.015
	Apex	1.2E-02	5.7E-03	1.1E-02		
	Distal	7.9E-03	3.9E-03	9.9E-03		
	Mesial	9.8E-03	4.5E-03	8.2E-03		
1st molar	Tip	-9.3E-04	-3.3E-04	2.2E-03	-0.002	0.000
	Apex	1.9E-03	3.8E-04	2.0E-03		
	Distal	1.4E-03	2.5E-04	1.8E-03		
	Mesial	1.4E-03	2.5E-04	8.6E-04		
2nd molar	Tip	-2.1E-06	-4.4E-06	6.2E-07	0.000	0.000
	Apex	-3.0E-06	-1.4E-05	-1.9E-06		
	Distal	-3.2E-06	-1.3E-05	-2.9E-06		
	Mesial	-1.5E-06	-1.4E-05	3.2E-06		

Table 7. Smart Clip bracket, that the orthodontic force was exerted at 2.0 mm above the occlusal plane

Tooth	Position	Displacements(mm)			Rotations(°)	
		Ux	Uy	Uz	Sagittal	Occlusal
Central incisor	Tip	-2.7E-03	-1.7E-02	-5.3E-03	-0.137	0.023
	Apex	4.5E-03	2.9E-02	2.9E-02		
	Distal	3.2E-03	2.1E-02	2.3E-02		
	Mesial	3.7E-03	2.5E-02	2.6E-02		
Lateral incisor	Tip	-2.9E-02	-6.4E-02	-7.2E-03	-0.451	0.123
	Apex	4.4E-02	9.9E-02	9.6E-02		
	Distal	3.2E-02	7.2E-02	7.8E-02		
	Mesial	3.8E-02	8.6E-02	8.8E-02		
Canine	Tip	5.4E-02	5.4E-02	-8.3E-03	0.346	-0.101
	Apex	-8.5E-02	-7.8E-02	-1.0E-01		
	Distal	-5.7E-02	-5.3E-02	-9.1E-02		
	Mesial	-6.9E-02	-6.2E-02	-8.6E-02		
1st premolar	Tip	-3.2E-02	-1.8E-02	2.4E-02	-0.148	0.012
	Apex	6.4E-02	3.0E-02	5.0E-02		
	Distal	5.0E-02	2.3E-02	4.7E-02		
	Mesial	5.1E-02	2.4E-02	3.8E-02		
2nd premolar	Tip	-9.9E-03	-4.5E-03	4.1E-03	-0.033	0.015
	Apex	1.5E-02	6.7E-03	1.2E-02		
	Distal	1.1E-02	4.8E-03	1.1E-02		
	Mesial	1.3E-02	5.4E-03	9.0E-03		
1st molar	Tip	-1.1E-03	-3.4E-04	2.6E-03	-0.003	0.000
	Apex	2.9E-03	5.2E-04	2.3E-03		
	Distal	2.2E-03	3.8E-04	2.0E-03		
	Mesial	2.2E-03	3.9E-04	7.6E-04		
2nd molar	Tip	8.2E-06	1.3E-05	3.0E-05	0.000	0.000
	Apex	3.4E-05	4.3E-05	3.6E-05		
	Distal	3.0E-05	3.8E-05	3.7E-05		
	Mesial	3.3E-05	3.8E-05	1.2E-05		

Table 8. Metal bracket, that the orthodontic force was exerted at 2.0 mm above the occlusal plane

Tooth	Position	Displacements(mm)			Rotations(°)	
		Ux	Uy	Uz	Sagittal	Occlusal
Central incisor	Tip	-1.6E-03	-7.6E-03	-2.6E-03	-0.063	0.014
	Apex	2.8E-03	1.4E-02	1.3E-02		
	Distal	2.1E-03	9.8E-03	1.0E-02		
	Mesial	2.3E-03	1.2E-02	1.3E-02		
Lateral incisor	Tip	-2.4E-02	-5.4E-02	-8.4E-03	-0.395	0.088
	Apex	3.9E-02	8.8E-02	8.2E-02		
	Distal	2.9E-02	6.5E-02	6.7E-02		
	Mesial	3.4E-02	7.6E-02	7.4E-02		
Canine	Tip	4.9E-02	4.8E-02	-5.0E-03	0.317	-0.084
	Apex	-8.1E-02	-7.2E-02	-9.3E-02		
	Distal	-5.6E-02	-5.0E-02	-8.1E-02		
	Mesial	-6.6E-02	-5.7E-02	-7.7E-02		
1st premolar	Tip	-2.8E-02	-1.4E-02	2.0E-02	-0.123	0.010
	Apex	5.9E-02	2.5E-02	4.3E-02		
	Distal	4.6E-02	2.0E-02	3.9E-02		
	Mesial	4.7E-02	2.0E-02	3.3E-02		
2nd premolar	Tip	-4.6E-03	-2.3E-03	1.7E-03	-0.017	0.006
	Apex	7.5E-03	3.5E-03	5.6E-03		
	Distal	5.4E-03	2.5E-03	5.1E-03		
	Mesial	6.2E-03	2.8E-03	4.0E-03		
1st molar	Tip	-4.1E-04	-1.3E-04	9.5E-04	-0.001	0.000
	Apex	1.2E-03	1.8E-04	8.1E-04		
	Distal	9.1E-04	1.3E-04	7.3E-04		
	Mesial	8.8E-04	1.4E-04	2.4E-04		
2nd molar	Tip	1.3E-06	8.2E-07	7.1E-06	0.000	0.000
	Apex	7.9E-06	3.2E-06	6.9E-06		
	Distal	6.8E-06	2.7E-06	6.7E-06		
	Mesial	7.7E-06	2.5E-06	3.8E-06		

Table 9. Clippy-C bracket, that the orthodontic force was exerted at 3.0 mm above the occlusion plane

Tooth	Position	Displacements(mm)			Rotations(°)	
		Ux	Uy	Uz	Sagittal	Occlusal
Central incisor	Tip	-3.1E-03	-2.4E-02	-5.9E-03	-0.182	0.030
	Apex	4.7E-03	3.8E-02	3.9E-02		
	Distal	3.2E-03	2.7E-02	3.2E-02		
	Mesial	3.8E-03	3.2E-02	3.6E-02		
Lateral incisor	Tip	-3.3E-02	-7.8E-02	-2.2E-03	-0.519	0.169
	Apex	4.4E-02	1.1E-01	1.2E-01		
	Distal	3.0E-02	7.7E-02	9.5E-02		
	Mesial	3.9E-02	9.7E-02	1.1E-01		
Canine	Tip	1.9E-04	1.2E-03	2.1E-03	0.153	-0.067
	Apex	-5.0E-02	-5.8E-02	-3.7E-02		
	Distal	-3.8E-02	-4.6E-02	-3.3E-02		
	Mesial	-4.6E-02	-5.2E-02	-3.0E-02		
1st premolar	Tip	-3.7E-02	-2.2E-02	3.2E-02	-0.171	0.019
	Apex	6.6E-02	3.4E-02	6.0E-02		
	Distal	5.0E-02	2.6E-02	5.8E-02		
	Mesial	5.3E-02	2.7E-02	4.6E-02		
2nd premolar	Tip	-1.3E-02	-6.0E-03	6.4E-03	-0.043	0.023
	Apex	1.7E-02	8.7E-03	1.6E-02		
	Distal	1.2E-02	6.0E-03	1.5E-02		
	Mesial	1.5E-02	7.0E-03	1.2E-02		
1st molar	Tip	-1.4E-03	-4.8E-04	3.3E-03	-0.003	0.000
	Apex	2.8E-03	6.5E-04	3.0E-03		
	Distal	2.1E-03	4.6E-04	2.8E-03		
	Mesial	2.1E-03	4.5E-04	1.3E-03		
2nd molar	Tip	5.1E-06	-1.9E-06	1.2E-05	0.000	0.000
	Apex	1.3E-05	1.6E-05	1.6E-05		
	Distal	1.1E-05	1.3E-05	1.7E-05		
	Mesial	1.5E-05	1.2E-05	3.6E-06		

Table 10. Smart Clip bracket, that the orthodontic force was exerted at 3.0 mm above the occlusion plane

Tooth	Position	Displacements(mm)			Rotations(°)	
		Ux	Uy	Uz	Sagittal	Occlusal
Central incisor	Tip	-4.1E-03	-2.5E-02	-8.0E-03	-0.206	0.034
	Apex	6.9E-03	4.4E-02	4.3E-02		
	Distal	4.9E-03	3.2E-02	3.5E-02		
	Mesial	5.5E-03	3.7E-02	4.0E-02		
Lateral incisor	Tip	-4.3E-02	-9.5E-02	-1.1E-02	-0.678	0.184
	Apex	6.6E-02	1.5E-01	1.4E-01		
	Distal	4.8E-02	1.1E-01	1.2E-01		
	Mesial	5.8E-02	1.3E-01	1.3E-01		
Canine	Tip	1.1E-03	1.5E-03	2.5E-03	0.159	-0.035
	Apex	-5.8E-02	-6.0E-02	-4.0E-02		
	Distal	-4.7E-02	-4.8E-02	-3.6E-02		
	Mesial	-5.1E-02	-5.1E-02	-3.2E-02		
1st premolar	Tip	-4.9E-02	-2.7E-02	3.6E-02	-0.223	0.018
	Apex	9.6E-02	4.6E-02	7.6E-02		
	Distal	7.5E-02	3.5E-02	7.1E-02		
	Mesial	7.7E-02	3.6E-02	5.7E-02		
2nd premolar	Tip	-1.5E-02	-6.7E-03	6.1E-03	-0.051	0.023
	Apex	2.3E-02	1.0E-02	1.8E-02		
	Distal	1.6E-02	7.3E-03	1.6E-02		
	Mesial	1.9E-02	8.3E-03	1.4E-02		
1st molar	Tip	-1.6E-03	-5.1E-04	3.8E-03	-0.004	0.000
	Apex	4.3E-03	8.0E-04	3.3E-03		
	Distal	3.3E-03	5.8E-04	3.0E-03		
	Mesial	3.2E-03	6.0E-04	1.1E-03		
2nd molar	Tip	7.1E-06	2.8E-06	1.5E-05	0.000	0.000
	Apex	2.2E-05	2.9E-05	2.0E-05		
	Distal	2.0E-05	2.5E-05	2.1E-05		
	Mesial	2.2E-05	2.4E-05	1.5E-06		

Table 11. Metal bracket, that the orthodontic force was exerted at 3.0 mm above the occlusion plane

Tooth	Position	Displacements(mm)			Rotations(°)	
		Ux	Uy	Uz	Sagittal	Occlusal
Central incisor	Tip	-2.4E-03	-1.1E-02	-3.9E-03	-0.095	0.021
	Apex	4.3E-03	2.1E-02	2.0E-02		
	Distal	3.1E-03	1.5E-02	1.5E-02		
	Mesial	3.5E-03	1.8E-02	1.9E-02		
Lateral incisor	Tip	-3.6E-02	-8.1E-02	-1.2E-02	-0.593	0.132
	Apex	5.9E-02	1.3E-01	1.2E-01		
	Distal	4.4E-02	9.8E-02	1.0E-01		
	Mesial	5.1E-02	1.1E-01	1.1E-01		
Canine	Tip	1.4E-03	1.5E-03	2.4E-03	0.150	-0.019
	Apex	-5.7E-02	-5.5E-02	-3.8E-02		
	Distal	-4.6E-02	-4.6E-02	-3.4E-02		
	Mesial	-4.9E-02	-4.7E-02	-3.0E-02		
1st premolar	Tip	-4.3E-02	-2.1E-02	3.0E-02	-0.185	0.015
	Apex	8.8E-02	3.8E-02	6.4E-02		
	Distal	6.9E-02	3.0E-02	5.9E-02		
	Mesial	7.1E-02	3.0E-02	4.9E-02		
2nd premolar	Tip	-7.0E-03	-3.5E-03	2.6E-03	-0.026	0.010
	Apex	1.1E-02	5.3E-03	8.4E-03		
	Distal	8.2E-03	3.9E-03	7.8E-03		
	Mesial	9.4E-03	4.3E-03	6.1E-03		
1st molar	Tip	-6.1E-04	-1.9E-04	1.4E-03	-0.001	0.000
	Apex	1.8E-03	3.1E-04	1.2E-03		
	Distal	1.4E-03	2.3E-04	1.1E-03		
	Mesial	1.3E-03	2.4E-04	3.5E-04		
2nd molar	Tip	4.9E-06	-1.3E-06	7.8E-06	0.000	0.000
	Apex	1.4E-05	1.1E-05	1.0E-05		
	Distal	1.2E-05	9.3E-06	1.1E-05		
	Mesial	1.5E-05	8.6E-06	6.8E-07		

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국 문 요 약

수직 변위된 견치의 초기 배열에서 다양한 자가 결찰 브라켓을 사용시 나타나는 응력 분포에 대한 유한 요소 분석

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본 연구에서는 교합 평면을 기준으로 1.0 mm, 2.0 mm, 3.0 mm 상방으로 수직 변위된 상악 견치에 능동형과 수동형의 자가 결찰 브라켓을 각각 장착하고 대조군으로 결찰 브라켓인 메탈 브라켓을 장착하였다. 초기 교정력이 가해졌을 때 lateral, longitudinal, vertical 방향에서 치아와 그 주변 치조골에 발생되는 응력을 관찰하였다. 자가 결찰 브라켓의 종류에 따른 응력 분포의 차이와 대조군인 메탈 브라켓과의 응력 분포 차이를 유한요소 해석으로 비교해 다소의 지견을 보고하는 바이다. 교합면 1.0 mm 상방에서 수직 응력의 크기는 smart clip bracket, clippy−c bracket, 메탈 브라켓의 순서였으며 하방 이동량도 응력에 비례해 smart clip bracke t 이 가장 크고 메탈 브라켓이 가장 작았다. 교합면 2.0 mm 상방에서는 수직 응력의 크기는 clippy−c bracket, smart clip bracket, 메탈 브라켓의 순서였으며 하방 이동량도 1.0 mm 와 마찬가지로 응력에 비례한 수치를 보였다. 1.0 mm, 2.0mm 상방에서는 자가 결찰 브라켓의 수직 응력이 크고 하방 이동량도 커

메탈 브라켓에 비해 유리하였다. 3.0 mm 상방에서는 수직 응력의 크기가 smart clip bracket, 메탈 브라켓, clippy-c bracket 의 순서였고 하방 이동량도 수직 응력에 비례해 smart clip bracket 이 가장 크고 clippy-c 브라켓이 가장 작았다. 3.0 mm 에서는 능동형 자가 결찰 브라켓의 하방이동이 가장 적었기 때문에 자가 결찰 브라켓이 항상 유리하다고 할 수는 없었다.

수직 응력의 크기와 수직 이동은 비례하였으며 자가 결찰 브라켓이 항상 많은 수직 이동이 일어나지는 않았다.

핵심되는 말 : 자가결찰 브라켓, 수동형, 능동형, 일반 메탈브라켓, 응력, 유한요소,