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Frictional property comparisons of conventional and self-ligating lingual brackets according to tooth displacement during initial leveling and alignment

초기 레벨링 단계에서 치아 변위에 따른 일반 설측 브라켓과 자가결찰 설측 브라켓의 마찰력 특성 비교에 관한 연구

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ABSTRACT

Frictional property comparisons of conventional and self-ligating lingual brackets according to tooth displacement during initial leveling and alignment

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Objective: The purpose of this *in vitro* study was to evaluate the effects of tooth displacement on frictional properties when conventional ligating lingual brackets (7th Generation), conventional ligating lingual brackets with a narrow bracket width (STb), and self-ligating lingual brackets (In-Ovation L) were used with initial leveling and alignment wires.

Materials and methods: 7th Generation brackets, STb brackets, and In-Ovation L brackets were tested under three tooth displacement conditions: no displacement (control); a 2-mm palatal displacement (PD) of the maxillary right lateral incisor (MXLI); and a 2-mm gingival displacement (GD) of the maxillary right canine (MXC) (nine groups, n = 7 per group). A stereolithographic typodont system and artificial saliva were used. Static and kinetic frictional forces (SFF and KFF, respectively) were measured while drawing a 0.013-inch copper-nickel-titanium archwire through brackets at 0.5 mm/min for 5 minutes at 36.5° C.

Results: The In-Ovation L group exhibited lower SFF under control conditions and lower KFF under all displacement conditions than the 7th Generation and STb groups (all $P < 0.001$). No significant difference in SFF existed between the In-Ovation L and STb groups for a 2-mm gingival displacement of the MXC and 2-mm palatal displacement of the MXLI. A 2-mm gingival displacement of the MXC produced higher SFF and KFF than a 2-mm palatal displacement of the MXLI in all brackets (all $P < 0.001$).

Conclusion: STb brackets exhibited similar SFF and higher KFF than In-Ovation L brackets under tooth displacement conditions. Conventional ligating lingual brackets and ligation methods should be developed to produce SFF and KFF as low as those in self-ligating lingual brackets during the initial and leveling stage.

Keywords: frictional force, tooth displacement, initial leveling and alignment, lingual bracket

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I. INTRODUCTION

Lingual appliances were developed in the 1980s as an esthetic treatment option for adult orthodontic patients.[1-3] However, there are several disadvantages in using this technique such as longer chair time, tongue discomfort, speech problems, a relatively insufficient bonding area caused by the short clinical crown height of the lingual surface, variation of anatomy on the tooth lingual surface, shorter arch perimeter, reduced interbracket distance on the lingual side to the labial side, bowing effects, and finishing difficulty.[2,4-9] So, several modifications to lingual appliances have been introduced to overcome these disadvantages, including a low-profile bracket design for patient comfort, a narrow bracket width design to increase interbracket distance, a customized bracket base for variation in tooth surface anatomy, and self-ligating lingual brackets to reduce chair time.

Sliding resistance during tooth movement occurs between both lingual brackets and the archwire and between conventional labial brackets and the archwire. This has been attributed to bracket type, size and geometry of the bracket slot, size and alloy of the archwire, and method of ligation.[10-13] In cases with crowding, rotation, angulation, or vertical discrepancy, the initial leveling and alignment archwire is deflected and contacts the edges of the bracket slots.

Therefore, the effect of sliding resistance is important in the leveling and alignment stage as well as in the space closure stage.

While numerous studies have investigated the implications of friction between conventional labial brackets and archwires,[11,12,14-17] information about the frictional properties of lingual brackets is limited, and some drawbacks exist in experimental design and methodology. For example, one or several lingual brackets aligned in a straight line have been used to measure frictional force.[18,19] Consequently, it is necessary to perform an experiment using whole dentitions with initial malocclusion status to mimic actual clinical situations.

Currently, the lingual straight wire technique is used for lingual orthodontic treatment, which uses conventional ligating lingual brackets with narrow bracket widths.[20] Small-sized lingual brackets have narrow and shallow slots that make it extremely difficult to perform a double over-tie ligation, which is usually performed with uses conventional ligating lingual brackets.[21] However, few studies have compared frictional properties between uses conventional ligating lingual brackets with a narrow bracket width and self-ligating lingual brackets. Therefore, the purpose of this *in vitro* study was to evaluate the effects of tooth displacement on frictional properties when uses conventional ligating lingual brackets, uses conventional ligating lingual brackets with a narrow bracket width, and self−ligating lingual brackets were used with an initial leveling and alignment wire. The null hypothesis was that there is no significant difference in the effects of tooth displacement or lingual bracket type on static or kinetic frictional forces (SFF and KFF, respectively).

II. REVIEW OF LITERATURE

1. Characteristics of the lingual orthodontic treatment.

The lingual orthodontic treatment follows the same biological and mechanical principles with the labial orthodontic treatment. However, the lingual orthodontic treatment has a lot of different characteristics in accessibility and workability compared to the labial one.[1]

First, the relationship of the lingual tooth surfaces in the dentition is different from that of the labial tooth surfaces. Therefore, Fujita[1] suggested that the lingual archwire should be formed like a mushroom.

Second, irregularity of the lingual tooth surface, especially on the maxillary anterior teeth, and short clinical crown height of the lingual tooth surface make bracket bonding difficult compared to the labial tooth surface.[2,3]

Third, interbracket distances of the lingual appliances are shorter than the labial appliances. Moran[4] reported that the decreased interbracket distance in the lingual appliances made a wire approximately 3 times stiffer in the first- and second-order bends, and approximately one and half times stiffer in the third-order bend compared to the labial appliances. Since the interbracket distance of lingual brackets is shorter than that of labial brackets, it takes longer for leveling and alignment in the lingual appliances than the labial appliances.[5] Geron[6] described the contributing factors of difficulties at the finishing stage of treatment as follows: difficulty in precise bracket positioning, mechanical limitations of the lingual appliances, and the characteristics of adult patients seeking orthodontic treatment with lingual appliances. The lingual arch perimeter in the anterior segment is always shorter than the labial arch perimeter. Lombardo et al.[7] reported that because of the reduced interbracket distance, adoption of superelastic wires with smaller diameter was required in lingual mechanics compared to labial mechanics, in particular during the first phases of treatment. They suggested that the use of a lingual bracket with reduced mesiodistal dimensions could contribute to reduce the load on the teeth.[7]

Fourth, Khattab et al.[8] studied the effect of lingual appliance on speech performance and impairment. They reported that, although both labial and lingual appliances caused soft tissue irritation and chewing difficulty, the lingual appliance was more problematic than the labial one in terms of speech articulation.[8] The lingual appliance group had significantly higher scores, particularly in the immediate postplacement phase, compared to the labial appliance group.[8]

2. Friction in orthodontic appliances

Friction is classically described as the force acting tangentially at the surface of two bodies in contact when one body moves against the other.[22]

A distinction is made between static frictional force, the smallest force needed to start the motion, and kinetic frictional force, the force needed to resist the sliding motion of one solid object over another at a constant speed.[23] Although there has been some debate about whether static or kinetic friction is more important, kinetic friction is considered to be less important because the orthodontic sliding movement of a tooth or bracket on an archwire is a series of short steps rather than a continuous or constant motion. [11] From the clinical perspective, to overcome static frictional force between the bracket and the wire is a prerequisite for tooth movement and kinetic frictional force is still a factor during sliding mechanics.[11,23]

Friction in orthodontics is generated when the archwire slides through the bracket slot, which is called resistance-to-sliding.[22]

The resistance-to-sliding affects initial leveling and alignment as well as space closing stage in sliding mechanics.[22,24]

There are numerous studies to find the factors that affect friction between the brackets and the archwire. The factors are known as follows: (1) the material of the bracket and the archwire [11,12,14,15,], (2) bracket design and slot size [14,15,25,26], (3) archwire size and dimension [12,14,15], (4) method of ligation[13,27], (5) interbracket distance [12,14], (6) saliva [14, 24−26], (7) temperature [24], and (8) vibration condition.[16]

Several studies have reported that the self−ligating labial brackets showed lower friction than conventional ligating labial brackets.[11,12,14−17] Previous studies using a custom−designed typodont system were shown that frictional force was increased as tooth was displaced vertically or horizontally in conventional ligating and self−ligating labial brackets and archwire size and alloy type also affected friction between bracket and archwire.[11,12,16,17] However, there are a few studies about the frictional properties of the conventional and self−ligating lingual brackets.[13,18,19] In addition, information about frictional properties of these lingual brackets is controversial.[18,19] For examples, Ozturk Ortan et al.[19] investigated the frictional resistance resulting from a combination of the lingual orthodontic brackets (7th Generation, STb, Magic, and In−Ovation L) and stainless steel archwires at 0, 5, and 10 degrees of second−order angulation with three different size of archwire. They reported that Magic and In−Ovation L brackets showed lower frictional resistance when compared with 7th Generation and STb brackets and the lowest friction was found with In-Ovation L brackets and 0.016 inch archwires at 0 degrees angulation.[19] However, Lombardo et al.[13] examined the frictional resistance exerted by different lingual (7th Generation, STb, Magic, and In-Ovation L) and labial brackets (Mini-Mono, Mini Diamond, and G&H Ceramic), including both conventional and self-ligating designs. They reported that the STb bracket produced a significantly lower friction than the In-Ovation L bracket.[13]

3. Limitation of experimental designs in previous studies

Previous studies have limitations in experiment design as follows.[13,18,19] First, a straight wire was drawn thought one to three brackets. However, in clinical situation, an archwire contacts to brackets in whole dentitions according the arch curvature. It is necessary to perform an experiment using whole dentitions with initial malocclusion status to mimic clinical situations. To simulate malocclusion status, the stereolithographic typodont system was made in previous studies. [12,16,17] This typodont was comprised of a complete maxillary dentition fixed to an arch-shaped metal frame, which can be moved in the occluso-gingival (up and down) and labio-lingual (forward and backward) directions from the zero position to a maximum of 5 mm to produce an arbitrary displacement of the individual resin tooth.[12,16,17] Second, they examined frictional tests in room temperature and dry conditions. They did not consider the influence of saliva and a temperature of intraoral condition on the bracket-archwire interfaces and mechanical behavior of copper nickel-titanium wire.

4. Development of the lingual bracket system

Scuzzo et al.[20] explained the reason of development of the STb brackets and the lingual straight wire technique as follows: (1) to improve the comfort, speed, and reliability of lingual treatment, and (2) to overcome several limitations of the lingual mushroom-arch technique introduced by Fujita. Since the STb bracket has narrower mesiodistal width, it can increase the interbracket distance and thus reduce both the force transmitted by the archwire and the resistance-to-sliding.[20] The thinner bracket pad of STb bracket can place its slot much closer to the lingual tooth surface and increase the interbracket distance.[20] In addition, the STb brackets incorporate a 0.33mm passive-ligation step on each side of the bracket slot, which can reduce binding between ligatures and archwire, and friction when using .012" or .013" main wires.[20]

Recently, Scuzzo et al.[21] developed the passive self-ligating lingual brackets to minimize friction while providing light, continuous orthodontic force that can allow the teeth to move more smoothly.

III. MATERIALS AND METHODS

Three lingual bracket systems with equivalent slot dimension and insertion were selected. One type of conventional ligating lingual brackets (7th Generation; Ormco, Orange, CA, USA), one type of conventional ligating lingual brackets with a narrow bracket width (STb; Ormco), and one type of self-ligating lingual bracket (In-Ovation L; Dentsply GAC International, Islandia, NY, USA) were tested under three tooth displacement conditions: no displacement (control); a 2-mm palatal displacement of the maxillary right lateral incisor (MXLI); and a 2-mm gingival displacement of the maxillary right canine (MXC) (Figure 1). Therefore, a total of nine groups were created by the combination of these factors (n = 7 per group).

In this study, a stereolithographic typodont system used in previous studies[12,16,17] was refabricated. This typodont system had a full maxillary dentition fixed to an arch-shaped metal frame, which allowed each tooth to move in the occluso-gingival (up and down) and labio-palatal (forward and backward) directions from the ideal position to a maximum of 5 mm displacement to produce arbitrary displacement of each tooth.[12,16,17] At the zero position, all teeth were aligned in the ideal position according to an ovoid arch form (OrthoForm III-Ovoid, reference no. 701-723; 3M Unitek; Monrovia, CA, USA). Each tooth had its periodontal ligament space filled with Imprint™ II Garant™ Light Body Vinyl Polysiloxane Impression Material (3M ESPE; Seefeld, Germany), which emulates the mobility of human teeth and absorbs mechanical stress.[12,16,17]

The characteristics of the lingual brackets tested in this study are listed in Table 1. After the 7th Generation, STb, and In−Ovation L brackets were positioned with full−size preformed straight lingual archwire at the center of the lingual surface, customized resin bases for the brackets were fabricated by curing Transbond XT (3M Unitek). Then, the archwire was removed and individual transfer trays were made. To minimize wire−related bias, 0.013−inch copper−nickel−titanium (Cu−NiTi) preformed lingual archwires were used (STb straight wire small, 204−2101; Ormco).

For ligation of the maxillary anterior teeth, a double over−tie of powerchain was used for the 7th Generation group (Clear Generation II Power Chain, 639−0002; Ormco) and a single tie of elastic modules was applied to the STb group (AlastiK Easy−To−Tie Ligature; 3M Unitek) according to the manufacturer’ s guide.[20,21] For ligation of the maxillary posterior teeth, elastic modules (AlastiK Easy−To−Tie Ligature; 3M Unitek) were used in both conventional ligating lingual bracket groups (the 7th Generation and STb groups) according to the manufacturer’ s guide.[20,21] After the ligation of all brackets, a 3-minute waiting period was allowed to obtain reproducible amounts of stress relaxation and ligation force.[11,12,14,15,17] The self-ligating In-Ovation L brackets were closed with an active clip.

The typodont was then attached to a metal plate fixed to a mechanical testing machine (Model 4466; Instron, Canton, MA, USA). After artificial saliva (Taliva®; Hanlim Pharm. Co., Ltd., Seoul, Korea) was sprayed onto the bracket, the end of the archwire extruding from the maxillary right second molar tube was gripped with a custom-designed adaptor. SFF and KFF were measured while drawing the archwire through the brackets at a speed of 0.5 mm/min for 5 minutes. Tests were conducted in a chamber maintained at 36.5 ± 0.3° C (Figure 2).

After each test, the typodont system was immediately washed with distilled water and alcohol to remove the artificial saliva and then dried with an air syringe. Each group was tested seven times, and a new wire was used each time.

The definitions of SFF and KFF are presented in Figure 3. SFF was measured at the maximal point of the initial rise. KFF was calculated by averaging frictional forces from after the maximal point of the initial rise to the end of the test.[12,16,17]

A power analysis was performed to determine the sample size using a sample size determination program (version 2.0.1, Seoul National University Dental Hospital, Registration No. 2007-01-122-004453, Seoul, Korea). The values of mean and standard deviation derived from previous studies were used for the power analysis.[11,12,16,17] The Shapiro-Wilk test was performed to assess the normality of the distributions in the experimental groups. The existence of normal distributions was confirmed in all nine groups. The two-way analysis of variance (ANOVA) and Tukey's HSD (honest significant difference) post hoc test were performed to evaluate the interaction of tooth displacement and brackets with regard to SFF, KFF. A one-way analysis of variance (ANOVA) was used to further investigate the effect of tooth displacement type on the variables among lingual bracket type and the effect of lingual bracket type on the variables among tooth displacement type. If equal variances were assumed by the Levene's test, a one-way analysis of variance (ANOVA) with Tukey's HSD (honest significant difference) post hoc test was performed for the statistical analysis. When equal variances were not assumed by Levene's test, Welch's variance-weighted ANOVA with

Dunnett’s T3 post hoc test was used.

IV. RESULTS

SFF and KFF under conditions of no displacement (control) (Table 2,3 and Figure 4)

The 7th Generation group showed the highest SFF and KFF, followed by the STb group and the In-Ovation L group ($P < 0.001$).

SFF and KFF under conditions of a 2-mm palatal displacement of the MXLI (Table 2,3 and Figure 4)

The 7th Generation group showed the highest SFF and KFF, followed by the STb and In-Ovation L groups ($P < 0.001$). There was no significant difference between the STb and In-Ovation L groups in SFF. However, the STb group demonstrated higher KFF than the In-Ovation L group ($P < 0.001$).

SFF and KFF under conditions of a 2-mm gingival displacement of the MXC (Table 2,3 and Figure 4)

The same findings were observed with a 2-mm palatal displacement of the MXLI. The 7th Generation group demonstrated higher SFF and KFF than the STb and In-Ovation L groups ($P < 0.001$). There was no significant difference between the STb and In-Ovation L groups in SFF. However, the STb group showed higher KFF than the In-Ovation L group ($P < 0.001$).

Comparisons of SFF and KFF according to displacement type (Table 2, 3 and Figure 5)

In the 7th Generation group, a 2–mm palatal displacement of the MXLI was associated with significantly lower SFF and KFF than in the control group and with a 2–mm gingival displacement of the MXC (all $P < 0.001$). Interestingly, the control group exhibited higher SFF and KFF than a 2–mm palatal displacement of the MXLI (all $P < 0.001$). In addition, there was no significant difference in SFF between the control group and a 2–mm gingival displacement of the MXC.

In the STb group, a 2–mm gingival displacement of the MXC demonstrated higher SFF than the control group and a 2–mm palatal displacement of the MXLI ($P < 0.001$). Similarly, a 2–mm gingival displacement of the MXC produced the highest KFF, followed by a 2–mm palatal displacement of the MXLI and the control group ($P < 0.001$).

In the In–Ovation L group, the highest SFF and KFF were observed with a 2–mm gingival displacement of the MXC, followed by a 2–mm palatal displacement of the MXLI and the control group (all $P < 0.001$).

V. DISCUSSION

The present study showed that the In−Ovation L group produced lower SFF under conditions of no displacement (P < 0.001; Table 2, 3 and Figure 4) and lower KFF under all displacement conditions (the control group, 2 mm of palatal displacement of the MXLI, and 2 mm of gingival displacement of the MXC; all P < 0.001; Table 2,3 and Figure 4) than the 7th Generation and the STb groups. This might be attributed to differences in ligation methods and in the original and effective slot dimensions as follows. First, the In−Ovation L brackets use a self−ligating clip for ligation of the maxillary anterior and posterior teeth. However, the 7th Generation brackets use the double over−tie method, while STb brackets use a single−tie method for ligation of the maxillary anterior teeth. Both 7th Generation and STb brackets use the single−tie method for ligation of the maxillary posterior teeth. Second, when an archwire was placed in the 7th Generation and STb brackets, the effective slot width was increased over the original slot dimension because of elastomeric ligature material surrounding the bracket wings (Figure 6). However, the In−Ovation L brackets (self−ligating type) demonstrated no difference between the original and effective slot dimensions (Figure 6). Ozturk Ortan et al.[19] reported that the In−Ovation L bracket generated lower frictional force than the STb bracket, in agreement with the results of the present study (Table 2, 3 and Figure 4). However, Lombardo et al.[13] demonstrated that the STb bracket produced significantly lower friction than the In-Ovation L bracket. The reason for the disagreement between the results of their study and those of the present study seems to originate from differences in experimental design, and specifically the use of three anterior teeth and a straight archwire in the study by Lombardo et al.[13] rather than the whole maxillary dentition and preformed lingual archwire used in the present study.

The finding that the STb (conventional ligating lingual brackets with a narrow bracket width) group produced lower SFF and KFF than the 7th Generation (conventional ligating lingual brackets) group under all displacement conditions (the control group, 2 mm of palatal displacement of the MXLI, and 2 mm of gingival displacement of the MXC; all $P < 0.001$; Table 2, 3 and Figure 4) can be explained by the narrow bracket width and difference in ligation method. First, STb brackets have a narrower mesiodistal bracket width and thinner bracket pad than 7th Generation brackets, which increases the interbracket distance and thus reduces both the force transmitted by the archwire and resistance to sliding mechanics.[13,20] Second, STb brackets use a single-tie method for ligation of the maxillary anterior teeth. The double over-tie method for ligation of the maxillary anterior teeth used with 7th Generation brackets can generate more friction than the single-tie method used with STb brackets.

There was no significant difference in SFF between the In-Ovation L and STb groups for a 2-mm gingival displacement of the MXC and 2-mm palatal displacement of the MXLI (Table 2, 3 and Figure 7). Because of the incorporation of a 0.33-mm passive ligation step on each side of the STb bracket slot (Figure 6),[20] effective interbracket distances could be increased and critical contact angles might also be affected. This phenomenon might induce less deflection of the archwire and reduce the degree of binding and frictional forces between the archwire and bracket slot. Therefore, conventional ligating lingual brackets with a narrow bracket width and passive ligation step (STb) exhibited similar amounts of SFF as self-ligating lingual brackets (In-Ovation L) under conditions of tooth displacement.

In the present study, a 2-mm gingival displacement of the MXC produced higher SFF and KFF than a 2-mm palatal displacement of the MXLI and the control group among the 7^{th} Generation and the STb groups, and even in the In-Ovation L group (all $P < 0.001$, Tables 2, 3 and Figure 5). This seems to result from differences in the patterns of contact and degrees of binding between the archwires and bracket slots. In a 2−mm gingival displacement of the MXC, the 7^{th} Generation, STb, and In−Ovation L groups showed full contact between the archwire and gingival wall of the bracket slot of the MXLI and the maxillary first bicuspid, and between the archwire and the incisal wall of the bracket slot of the MXC, resulting in strong binding of the archwire within the bracket slot (Figure 7). However, in a 2−mm palatal displacement of the MXLI, these experimental groups demonstrated only partial contact between the archwire and the vertical wall of the bracket slot of the MXC and the maxillary central incisor, although full contact between the archwire and the vertical wall of the bracket slot was observed in the MXLI (Figure 7).

Interestingly, the 7^{th} Generation group produced lower SFF and KFF in a 2−mm palatal displacement of the MXLI than the control group (all $P < 0.001$; Table 2 and 3). The engagement of an archwire into the bracket slot of a palatally displaced MXLI produced an internal shear force in the wire from deflection, which might exceed the seating force of a double over−tie ligation, resulting in partial disengagement of the archwire from the bracket slot and eventual decreases in SFF and KFF than in the control group (Figure 7).

The STb group showed higher SFF in a 2−mm palatal displacement of the MXLI than the control group but there was no significant difference (Table 2 and 3). Due to the incorporation of a 0.33-mm passive ligation step on each side of the STb bracket slot (Figure 6),[20] less deflection of the archwire and reduced degree of binding between bracket slot and archwire might be happened under palatal displacement of the MXLI. So frictional forces between the archwire and bracket slot was slightly increased.

All experimental groups showed higher KFF than SFF, which was consistently found, even when the experiments were repeated several times. This phenomenon might be related to mechanical differences such as shorter arch perimeter, shorter interbracket distance, and smaller curvature of the anterior segment than the labial appliance.[4,9] These differences affect the load deflection characteristics of the wire, increase wire stiffness, and produce a higher binding force between the bracket and wire, resulting in a greater increase in KFF than SFF.[4,7]

This *in vitro* study exhibited new findings that the STb brackets can reduce SFF as effectively as the In-Ovation L brackets in a 2-mm gingival displacement of the MXC and a 2-mm palatal displacement of the MXLI. However, special precautions should be taken when interpreting the findings of this study because of several limitations.

First, the material used to emulate the periodontal ligament’s stress−absorbing mechanism could not truly replicate the biological tooth−periodontal ligament−bone complex.[28] Second, archwire movement can occur in various ways, and not strictly in a single direction in an intraoral situation. Third, different ligation methods were used for the maxillary anterior teeth with the conventional ligating lingual brackets. Therefore, it would be prudent to develop an experimental design improving on these drawbacks in further studies.

VI. CONCLUSION

- The null hypothesis was rejected.
- Since the STb brakcets exhibited similar SFF and higher KFF than the In-Ovation L brackets under conditions of tooth displacement, it is necessary to develop conventional-ligating lingual brackets and ligation methods that reduce SFF and KFF as effectively as self-ligating lingual brackets during the initial and leveling stage.

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Table 1. Characteristics of the lingual brackets and wires

Bracket					Ligation		Wire
Bracket type		Slot size (inch)	Slot orientation		Anterior	Posterior	Size (inch), type, and shape
			Anterior	Posterior			
Conventional ligating lingual bracket	7th Generation (Ormco, Orange, CA, USA)	0.018 x 0.025	Horizontal	Horizontal	Double overtie (Clear Generation II Powerchain, 639−0002, Ormco)	Single tie (AlastiK Easy−To−Tie Ligature, 3M Unitek)	0.013 inch Cu−NiTi preformed lingual straight wire (STb straight wire small, 204−2101, Ormco)
Conventional ligating lingual bracket with narrow bracket width	STb (Ormco, Orange, CA, USA)				Single tie (AlastiK Easy−To−Tie Ligature, 3M Unitek)		
Self−ligating lingual bracket	In−Ovation L (Dentsply GAC International, Islandia, NY, USA)				Active clip	Active clip	

Cu−NiTi, copper−NiTi

Table 2. Static frictional forces (cN) from a 2–mm palatal displacement (PD) of the maxillary right lateral incisor (MXLI) and 2–mm gingival displacement (GD) of the maxillary right canine (MXC)

	7th Generation		STb		In–Ovation L		Significance	
	Mean	SD	Mean	SD	Mean	SD	Bracket	Bracket x displacement
Control(no displacement) [B]	846.9	87.2	161.1	18.8	26.1	7.7	P<0.001*** IO < STb < 7G [D]	P<0.001***
PD of MXLI [B]	618.2	87.6	173.5	8.8	155.4	24.3	P<0.001*** IO < STb < 7G [D]	P<0.001***
GD of MXC [A]	905.2	47.1	297.8	83.2	235.6	67.1	P<0.001*** IO < STb < 7G [C]	P<0.001***
Significance Displacement	P<0.001*** PD<(Control, GD)		P<0.001*** (Control, PD)<GD		P<0.001*** Control<PD<GD			

Two–way ANOVA was performed.

[A] One–way analysis of variance (ANOVA)

[B] Welch s variance–weighted ANOVA

[C] A multiple comparison test was performed using Tukey’ s HSD.

[D] A multiple comparison test was performed using Dunnett’ s T3.

7G, 7th Generation; IO, In–Ovation L; ***, P < 0.001.

Table 3. Kinetic frictional forces (cN) from a 2−mm palatal displacement (PD) of the maxillary right lateral incisor (MXLI) and 2−mm gingival displacement (GD) of the maxillary right canine (MXC)

	7th Generation		STb		In−Ovation L		Significance	
	Mean	SD	Mean	SD	Mean	SD	Bracket	Bracket x displacement
Control (no displacement) [B]	1448.0	106.4	198.6	40.4	40.4	10.0	P<0.001*** IO < STb < 7G [D]	P<0.001***
PD of MXLI [B]	1200.5	56.4	261.0	22.8	179.9	22.8	P<0.001*** IO < STb < 7G [D]	P<0.001***
GD of MXC [A]	1913.0	74.4	573.6	31.8	464.8	48.1	P<0.001*** IO < STb < 7G [C]	P<0.001***
Significance Displacement	P<0.001*** PD<Control<GD		P<0.001*** Control<PD<GD		P<0.001*** Control<PD<GD			

Two−way ANOVA was performed.

[A] One−way analysis of variance (ANOVA)

[B] Welch's variance−weighted ANOVA

[C] A multiple comparison test was performed using Tukey's HSD.

[D] A multiple comparison test was performed using Dunnett's T3.

Control, no displacement; ***, P < 0.001.

FIGURE LEGENDS

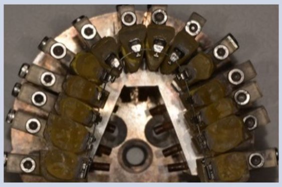
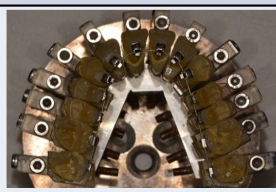
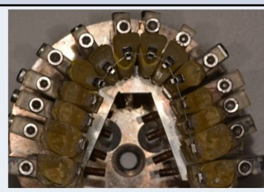
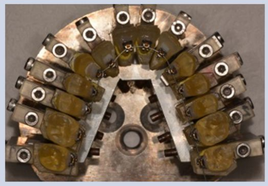
	Control (No displacement)	Gingival displacement of the maxillary right canine	Palatal displacement of the maxillary right lateral incisor
7^{th} Generation			
STb			
In-Ovation L			

Figure 1. The experimental set−ups used in this study.

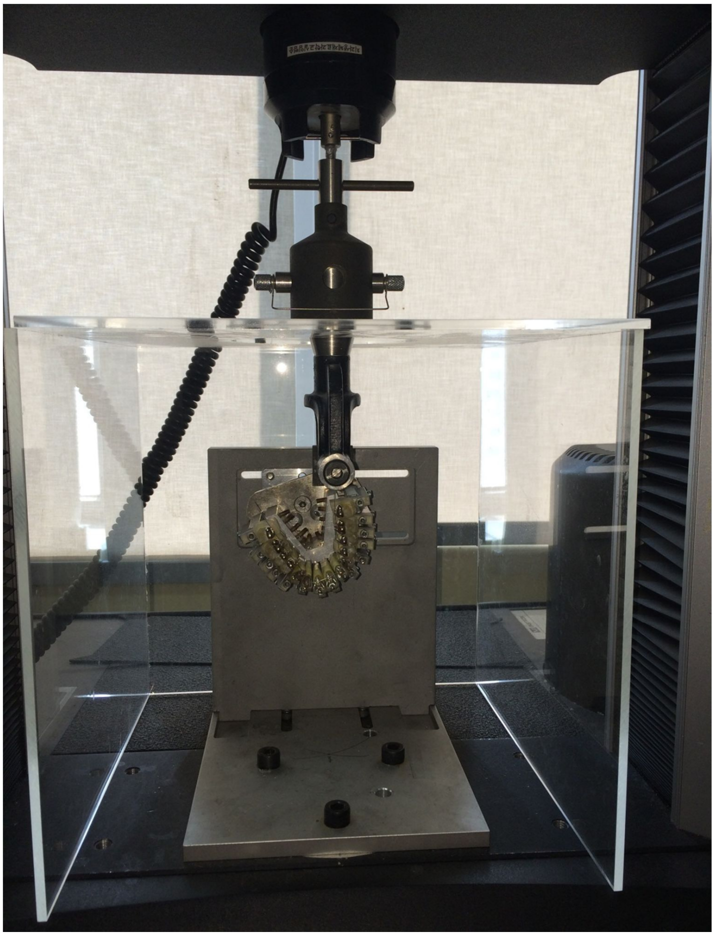


Figure 2. The stereolithographic typodont system and testing apparatus used in this study.

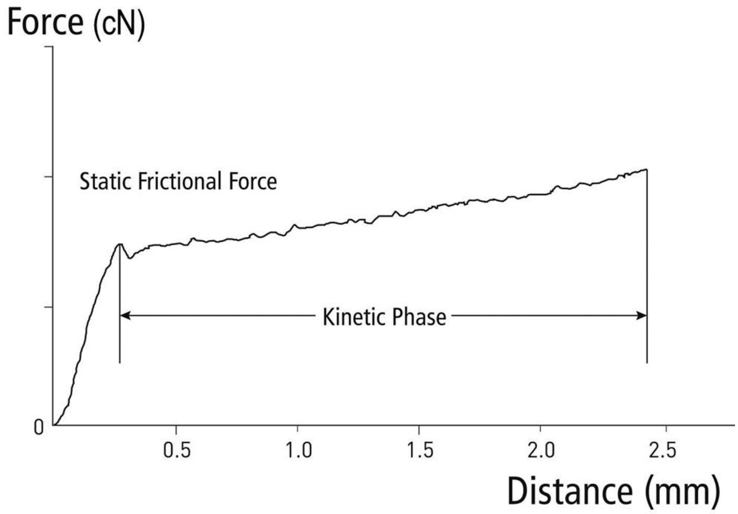
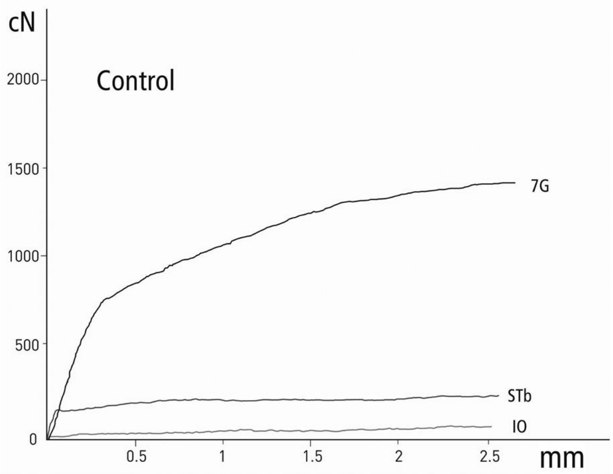
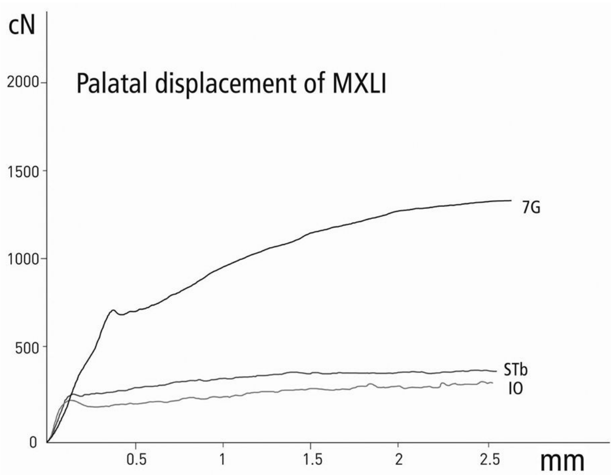


Figure 3. A diagram of the static and kinetic frictional forces.


cN
Control
2000
1500
1000
500
0
7G
STb
IO
0.5
1
1.5
2
2.5
mm


cN
Palatal displacement of MXLI
2000
1500
1000
500
0
7G
STb
IO
0.5
1
1.5
2
2.5
mm

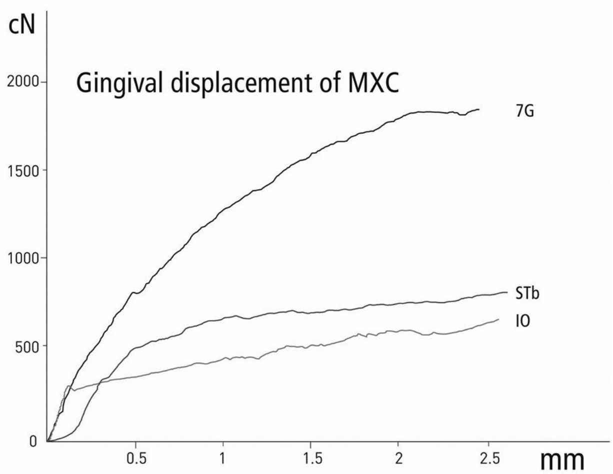

cN
Gingival displacement of MXC
2000
1500
1000
500
0
7G
STb
IO
0.5
1
1.5
2
2.5
mm

Figure 4. A comparison of frictional forces among the 7th Generation (7G), STb, and In-Ovation L (IO) groups. A. The control group (no displacement); B. a 2-mm palatal displacement of the maxillary right lateral incisor (MXLI); and C. a 2-mm gingival displacement of the maxillary right canine (MXC).

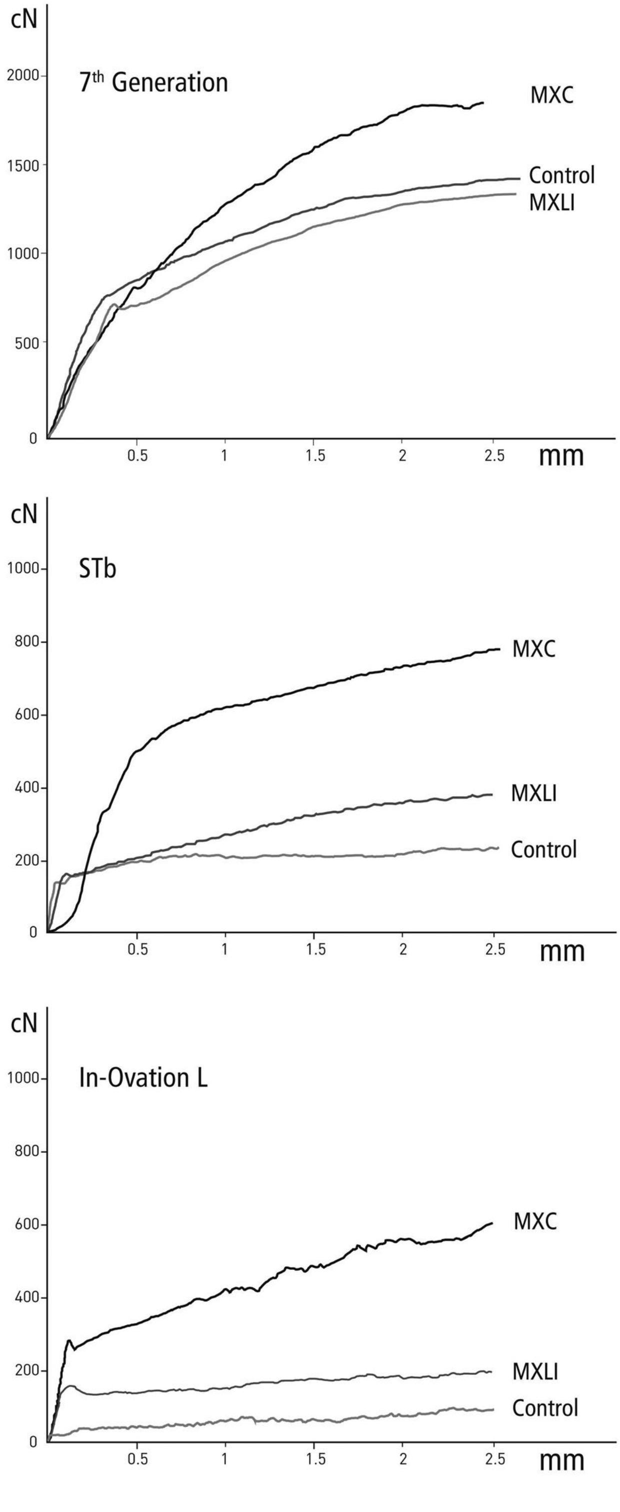

cN
7th Generation
2000
1500
1000
500
0
0.5
1
1.5
2
2.5
mm
MXC
Control
MXLI
cN
STb
1000
800
600
400
200
0
0.5
1
1.5
2
2.5
mm
MXC
MXLI
Control
cN
In-Ovation L
1000
800
600
400
200
0
0.5
1
1.5
2
2.5
mm
MXC
MXLI
Control

Figure 5. A comparison of frictional forces among the control group (no displacement), a 2−mm palatal displacement in the MXLI group, and a 2−mm gingival displacement in the MXC group. A. 7th Generation; B. STb; and C. In−Ovation L.

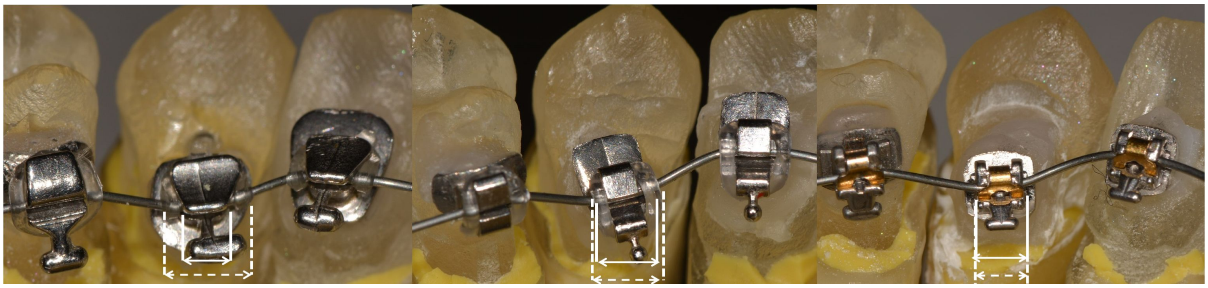


Figure 6. A comparison of original (solid lines) and effective slot dimensions (dotted lines) of brackets with a 2-mm gingival displacement of the MXC. From the left side, the 7th Generation, STb, and In-Ovation L brackets are shown. Original slot dimension: effective slot dimenstion; 7th Generation (2.30 mm: 3.66 mm), STb (2.50 mm: 3.15 mm), In-Ovation L (2.15 mm: 5003
2.15 mm)

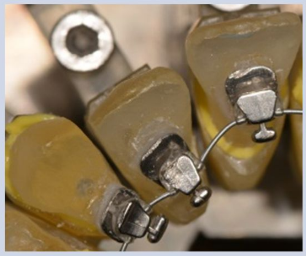
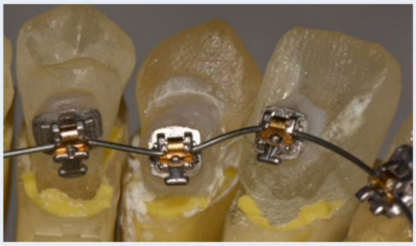
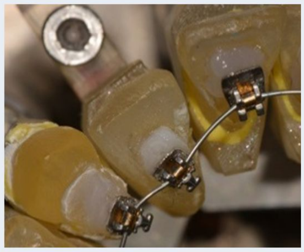
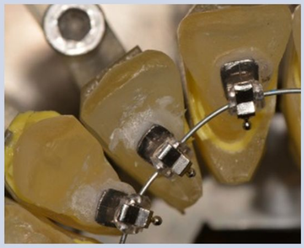
	Gingival displacement of the maxillary right canine	Palatal displacement of the maxillary right lateral incisor
7th Generation		
STb		
In-Ovation L		

Figure 7. Wire deflection from a 2−mm gingival displacement of the MXC and 2−mm palatal displacement of the MXLI.

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국문초록

초기 레벨링 단계에서 치아 변위에 따른 일반 설측 브라켓과 자가결찰 설측 브라켓의 마찰력 특성 비교에 관한 연구

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목적: 본 연구의 목적은 일반 설측 브라켓 (7^{th} Generation, Ormco, Orange, CA, USA), 브라켓 폭을 줄인 일반 설측 브라켓 (STb, Ormco)과 자가결찰 설측 브라켓 (In-Ovation L, Dentsply GAC International, NY, USA) 에서 레벨링과 배열용 나이타이 호선을 사용하였을 때 치아변위가 마찰력에 미치는 효과를 평가하기 위함이다.

연구재료 및 방법: 브라켓은 7^{th} Generation 결찰 설측 브라켓, STb 결찰 설측 브라켓과 In-Ovation L 자가결찰 설측 브라켓을 사용하였다. 치아의 변위는 상악 우측 측절치의 2 mm 구개측 변위 (palatal displacement), 상악 우측 견치의 2 mm 치은측 변위 (gingival displacement), 비변위 (대조군, control) 로 하여 총 9군으로 구성하였다. 치아의 치관, 치근, 치주인대의 형태를 Stereolithography apparatus (SLA) 공법으로 재현한 타이포돈트를 인스트론 (Model 4466, Instron, Canton, MA, USA) 에 고정시켰다. 브라켓 슬롯에 인공타액을 분사하고 0.013 inch Cu-NiTi호선을 삽입한 후 36.5° C 에서 호선을 0.5 mm/min의 속도로 5 분간 당기면서 정지마찰력 (static frictional force, SFF) 과 운동마찰력 (kinetic frictional force, KFF) 을 측정하였다. 정규성검정을 위해 Shapiro-Wilk 검정을 사용하였다. 치아 변위와 브라켓간의 상관관계를 위해 이원배치분석을 사용하였다. 치아변위와 브라켓 각각의 효과를 알아보기 위해 Levene 의 등분산 가정이 성립되면 일원배치분석 및 사후검정으로 Tukey' s HSD (honest significant difference) 를 사용하고 등분산 가정이 성립이 되지 않으면 Welch 일원배치분석 및 사후검정으로 Dunnett' s T3 방법을 사용하여 통계처리하였다.

결과: 이로부터 다음과 같은 결과를 얻었다.

(1) In−Ovation L 은 7^{th} Generation 과 STb 에 비해 비변위시 가장 낮은 정지마찰력이 보였으며 변위시에서도 가장 낮은 운동마찰력을 보였다. (P<0.001)

(2) 상악 측절치 2mm 구개측 변위와 상악 견치 2mm 치은측 변위시 In−Ovation L 과 STb 의 정지마찰력에서는 유의한 차이가 없었다 (P<0.001)

(3) 7^{th} Generation, STb 와 In−Ovation L 은 상악 측절치 2mm 구개측 변위보다 상악 견치 2mm 치은측 변위에서 높은 정지마찰력과 운동마찰력이 나타났다. (P<0.001)

결론: STb는 치아 변위시 In−Ovation L과 비슷한 정지마찰력을 나타내고 높은 운동마찰력을 나타내므로 초기 레벨링과 배열 단계에서 정지마찰력과 운동마찰력이 자가결찰 설측 브라켓 수준으로 낮아지도록 일반 설측 브라켓과 결찰 방법을 개발하는 것이 필요하다.

주요어: 마찰력, 치아 변위, 초기 레벨링, 설측브라켓

학번: 2004−30716