

Frictional property comparisons of conventional and self-ligating lingual brackets according to tooth displacement during initial leveling and alignment: an *in vitro* mechanical study

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Objective: We evaluated the effects of tooth displacement on frictional force when conventional ligating lingual brackets (CL-LBs), CL-LBs with a narrow bracket width, and self-ligating lingual brackets (SL-LBs) were used with initial leveling and alignment wires. **Methods:** CL-LBs (7th Generation), CL-LBs with a narrow bracket width (STb), and SL-LBs (In-Ovation L) 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 exhibited lower SFF under control conditions and lower KFF under all displacement conditions than the 7th Generation and STb (all $p < 0.001$). No significant difference in SFF existed between the In-Ovation L and STb for a 2-mm GD of the MXC and 2-mm PD of the MXLI. A 2-mm GD of the MXC produced higher SFF and KFF than a 2-mm PD of the MXLI in all brackets (all $p < 0.001$). **Conclusions:** CL-LBs with narrow bracket widths exhibited higher KFF than SL-LBs under tooth displacement conditions. CL-LBs and ligation methods should be developed to produce SFF and KFF as low as those in SL-LBs during the initial and leveling stage. [Korean J Orthod 2016;46(2):87-95]

Key words: Frictional force, Tooth displacement, Initial leveling and alignment, Lingual bracket

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INTRODUCTION

Lingual appliances were developed in the 1980s as an esthetic treatment option for adult orthodontic patients.¹⁻³ However, there are several disadvantages to 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, variations in anatomy on the tooth lingual surface, shorter arch perimeter, reduced interbracket distance on the lingual side versus the labial side, bowing effects, and finishing difficulty.^{2,4-9} Therefore, 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 variations in tooth surface anatomy, and self-ligating lingual brackets for reduced 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.¹⁰⁻¹⁴ In cases with crowding, rotation, angulation, or vertical discrepancy, the initial leveling and alignment archwire is usually 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.

Although numerous studies have investigated the implications of friction between conventional labial

brackets and archwires,^{11,12,15-18} information about the frictional properties of lingual brackets is still 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.^{19,20} Therefore, it is necessary to perform an experiment using whole dentitions with initial malocclusion statuses to mimic clinical situations.

Currently, the lingual straight wire technique is used for lingual orthodontic treatment, which uses conventional ligating lingual brackets (CL-LBs) with narrow bracket widths.²¹ 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 CL-LBs.²² However, few studies have compared frictional properties between CL-LBs with a narrow bracket width and self-ligating lingual brackets. Therefore, the purpose of this *in vitro* mechanical study was to evaluate the effects of tooth displacement on frictional properties when CL-LBs, CL-LBs 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).

MATERIALS AND METHODS

Three lingual bracket systems with equivalent slot sizes and orientations were selected. One type of CL-LB (7th Generation; Ormco, Orange, CA, USA), one type of

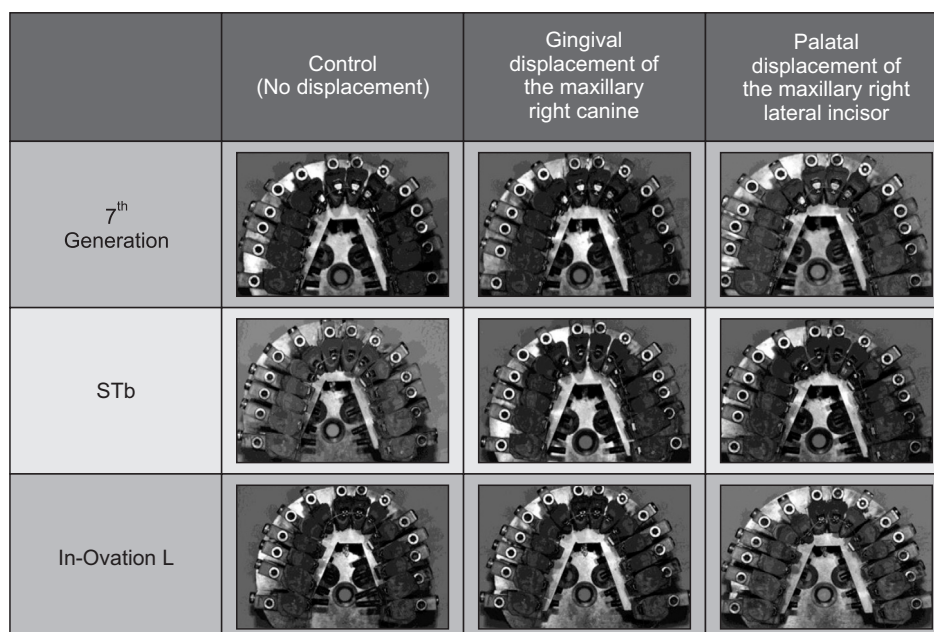


Figure 1. The experimental set-ups used in this study. 7th Generation and STb: Ormco, Orange, CA, USA; In-Ovation L: GAC, Dentsply Corp., York, PA, USA.

CL-LB with a narrow bracket width (STb; Ormco), and one type of self-ligating lingual bracket (In-Ovation L; GAC, Dentsply Corp., York, PA, 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^{12,17,18} 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-lingual (up and down) and labio-palatal (forward and backward) directions. 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.^{12,17,18}

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.^{21,22} For ligation of the maxillary posterior teeth, elastic modules (AlastiK Easy-To-Tie Ligature; 3M Unitek) were used in both CL-LB groups (the 7th Generation and STb groups) according to the manufacturer's guide.^{21,22} After the ligation of all brackets, a 3-minute waiting period was allowed to obtain reproducible amounts of stress relaxation and ligation force.^{11,12,15,16,18} Since the In-Ovation L bracket was self-ligating, it was 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

Table 1. Characteristics of the lingual brackets and wires

	Bracket		Ligation		Wire		
	Bracket type	Slot size (inch)	Slot orientation				
			Anterior	Posterior			
Conventional ligating lingual bracket	7th Generation*	0.018 × 0.025	Horizontal	Horizontal	Double overtie (Clear Generation II Powerchain, 639-0002)*	Single tie (AlastiK Easy-To-Tie Ligature) [†]	0.013 inch Cu-NiTi preformed lingual straight wire (STb straight wire small, 204-2101)*
Conventional ligating lingual bracket with narrow bracket width	STb*				Single tie (AlastiK Easy-To-Tie Ligature) [†]		
Self-ligating lingual bracket	In-Ovation L [†]				Active clip	Active clip	

Cu-NiTi, Copper-nickel-titanium.

*Ormco, Orange, CA, USA; [†]GAC, Dentsply Corp., York, PA, USA; [‡]3M Unitek, Monrovia, CA, USA.

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 $36.5 \pm 0.3^\circ\text{C}$ (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.

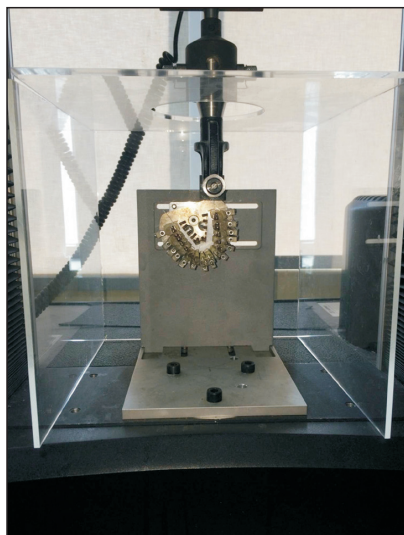


Figure 2. The stereolithographic typodont system and testing apparatus used in this study.

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.^{12,17,18}

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 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. If equal variances were assumed by the Levene's test, a one-way analysis of variance (ANOVA)

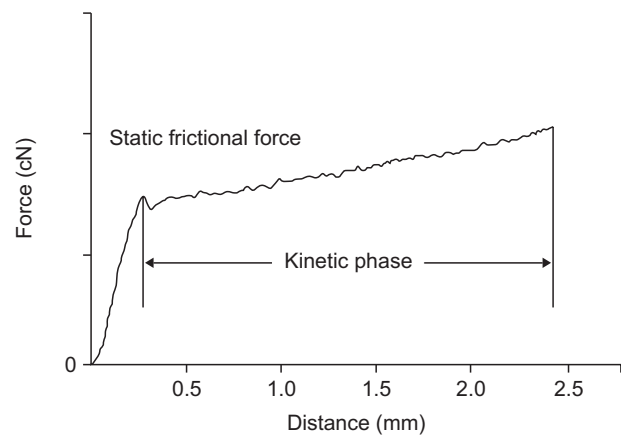


Figure 3. A diagram of the static and kinetic frictional forces.

Table 2. Static and kinetic frictional forces (cN) from a 2-mm palatal displacement of the maxillary right lateral incisor and 2-mm gingival displacement of the maxillary right canine

Frictional force according to displacement	Conventional ligating lingual bracket (7th Generation)	Conventional ligating lingual bracket with narrow bracket width (STb)	Self-ligating lingual bracket (In-Ovation L)	Significance	Multiple comparison
Static					
Control (no displacement) [†]	846.9 ± 87.2	161.1 ± 18.8	26.1 ± 7.7	$p < 0.001$	IO < STb < 7G [§]
2 mm PD of MXLI [†]	618.2 ± 87.6	173.5 ± 8.8	155.4 ± 24.3	$p < 0.001$	(IO, STb) < 7G [§]
2 mm GD of MXC*	905.2 ± 47.1	297.8 ± 83.2	235.6 ± 67.1	$p < 0.001$	(IO, STb) < 7G [‡]
Kinetic					
Control (no displacement) [†]	1,448.0 ± 106.4	198.6 ± 40.4	40.4 ± 10.0	$p < 0.001$	IO < STb < 7G [§]
2 mm PD of MXLI [†]	1,200.5 ± 56.4	261.0 ± 22.8	179.9 ± 22.8	$p < 0.001$	IO < STb < 7G [§]
2 mm GD of MXC*	1,913.0 ± 74.4	573.6 ± 31.8	464.8 ± 48.1	$p < 0.001$	IO < STb < 7G [‡]

Values are presented as mean ± standard deviation.

7th Generation (7G) and STb: Ormco, Orange, CA, USA; In-Ovation L (IO): GAC, Dentsply Corp., York, PA, USA.

*One-way analysis of variance (ANOVA); [†]Welch's variance-weighted ANOVA; [‡]multiple comparison test was performed using Tukey's HSD; [§]multiple comparison test was performed using Dunnett's T3.

PD, Palatal displacement; MXLI, the maxillary right lateral incisor; GD, gingival displacement; MXC, the maxillary right canine.

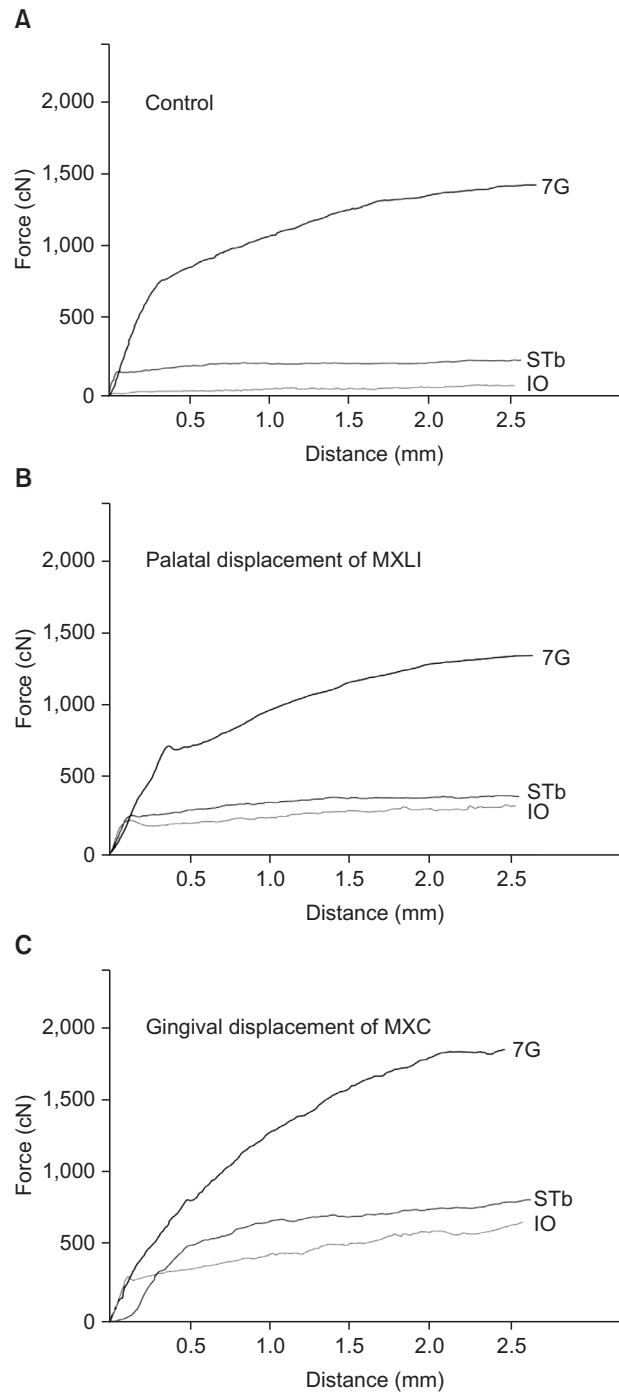


Figure 4. A comparison of frictional forces among the 7th Generation (7G), STb, and In-Ovation L (IO) groups. **A**, The control group (no displacement); **B**, a 2-mm palatal displacement of the maxillary right lateral incisor (MXLI); and **C**, a 2-mm gingival displacement of the maxillary right canine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

7th Generation and STb: Ormco, Orange, CA, USA; In-Ovation L: GAC, Dentsply Corp., York, PA, USA.

with Tukey's honest significant difference (HSD) *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.

RESULTS

SFF and KFF under conditions of no displacement (control)

The 7th Generation group showed the highest SFF and KFF, followed by the STb group and the In-Ovation L group ($p < 0.001$; Table 2 and Figure 4).

SFF and KFF under conditions of a 2-mm palatal displacement of the MXLI

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 ($p < 0.001$; Table 2 and Figure 4).

SFF and KFF under conditions of a 2-mm gingival displacement of the MXC

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 ($p < 0.001$; Table 2 and Figure 4).

Comparisons of SFF and KFF according to displacement type

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 $p < 0.001$; Table 3 and Figure 5). 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

Table 3. Comparisons of static and kinetic frictional forces according to displacement type

Frictional force	Conventional ligating lingual bracket (7th Generation)*	Conventional ligating lingual bracket with narrow bracket width (STb)*	Self-ligating lingual bracket (In-Ovation L)†
	Comparison‡	Significance	Significance
Static	2 mm PD of MXLI < (Control, 2 mm GD of MXC)	(Control, 2 mm PD of MXLI) < 2 mm GD of MXC	Control < 2 mm PD of MXLI < 2 mm GD of MXC
Kinetic	2 mm PD of MXLI < Control < 2 mm GD of MXC	Control < 2 mm PD of MXLI < 2 mm GD of MXC	Control < 2 mm PD of MXLI < 2 mm GD of MXC

PD, Palatal displacement; MXLI, the maxillary right lateral incisor; Control, no displacement; GD, gingival displacement; MXC, the maxillary right canine.

*One-way analysis of variance (ANOVA); †Welch's variance-weighted ANOVA; ‡multiple comparison test was performed using Tukey's HSD; §multiple comparison test was performed using Dunnett's T3.

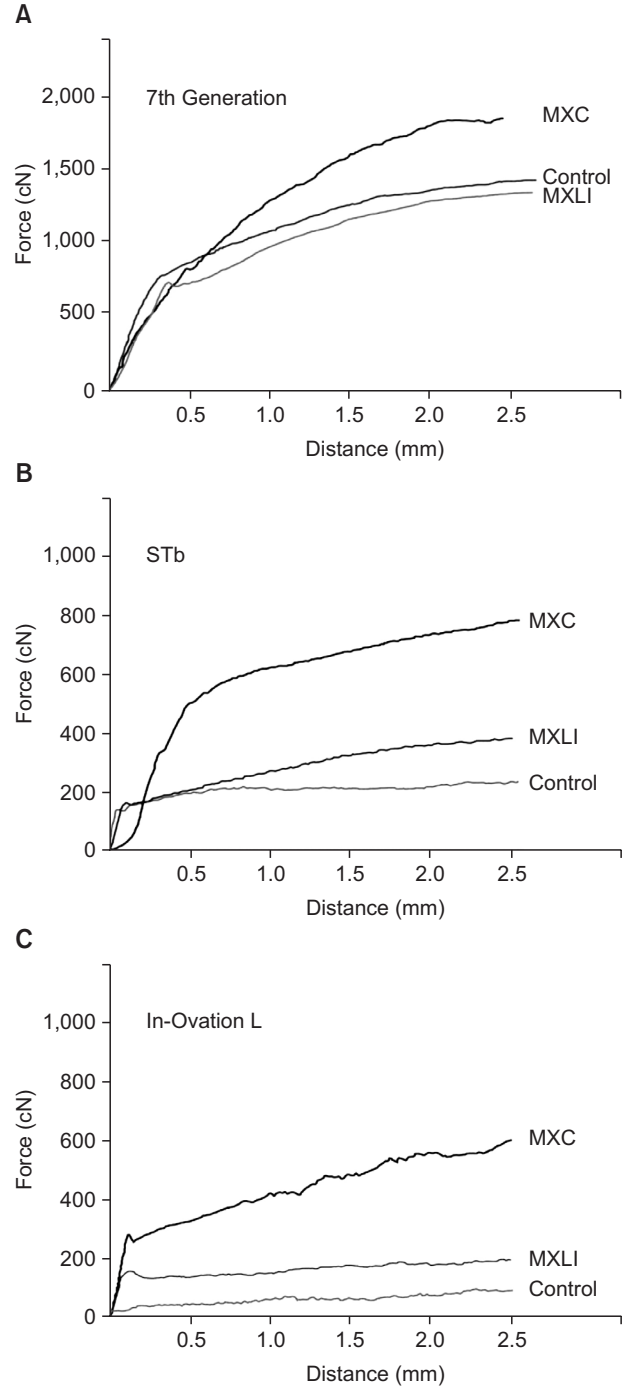


Figure 5. A comparison of frictional forces among the control group (no displacement), a 2-mm palatal displacement in the maxillary right lateral incisor (MXLI) group, and a 2-mm gingival displacement in the maxillary right canine (MXC) group. **A**, 7th Generation (Ormco, Orange, CA, USA); **B**, STb (Ormco); and **C**, In-Ovation L (GAC, Dentsply Corp., York, PA, USA).

MXC, followed by a 2-mm palatal displacement of the MXLI and the control group (all $p < 0.001$).

DISCUSSION

The present study showed that the self-ligating lingual bracket (In-Ovation L) group produced lower SFF under conditions of no displacement ($p < 0.001$; Table 2 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 and Figure 4) than the CL-LB groups (7th Generation and STb). 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.²⁰ 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 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

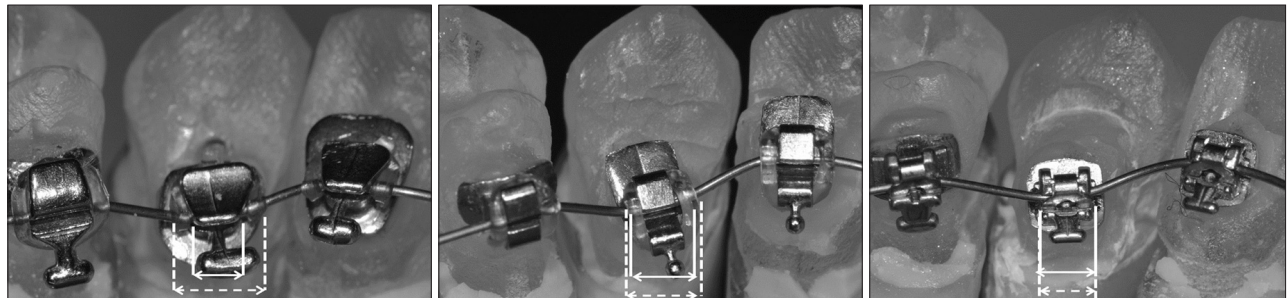


Figure 6. A comparison of original (solid lines) and effective slot dimensions (dotted lines) of brackets with a 2-mm gingival displacement of the maxillary right canine. From the left side, the 7th Generation (Ormco, Orange, CA, USA), STb (Ormco), and In-Ovation L brackets (GAC, Dentsply Corp., York, PA, USA) are shown.

	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 maxillary right canine and 2-mm palatal displacement of the maxillary right lateral incisor.

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 (CL-LBs with a narrow bracket width) group produced lower SFF and KFF than the 7th Generation (CL-LBs) 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 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.^{13,21} 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 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),²¹ 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, CL-LBs 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 CL-LBs (7th Generation and STb), and even in a self-ligating lingual bracket (In-Ovation L) (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 7th 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 7th 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 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).

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 CL-LBs with narrow bracket widths can reduce SFF as effectively as self-ligating lingual 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.²³ 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 CL-LBs. Therefore, it would be prudent to develop an experimental design improving on these drawbacks in further studies.

CONCLUSION

The null hypothesis was rejected.

Since conventional-ligating lingual brackets with a narrow bracket width exhibited higher KFF than self-ligating lingual 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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