치의학박사 학위논문

Effect of Placing Passive Self-Ligating Brackets on the Posterior Teeth on Reduction of Frictional Force in Sliding Mechanics

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사용 시 마찰력 감소의 효과에 관한 연구

2016년 8월

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Abstract

Effect of Placing Passive Self-Ligating Brackets on the Posterior Teeth on Reduction of Frictional Force in Sliding Mechanics

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OBJECTIVE: The purpose of this *in vitro* study was to investigate the static frictional forces (SFF) and kinetic frictional forces (KFF) in sliding mechanics of hybrid bracket systems that involve placing a conventional-ligating bracket (CB) or active self-ligating bracket (ASLB) on the maxillary anterior teeth (MXAT) and a passive SLB (PSLB) on the maxillary posterior teeth (MXPT).

MATERIALS AND METHODS: The samples consisted of two thoroughbred types (Group 1, Anterior-CB + Posterior-CB; Group 2, Anterior-ASLB + Posterior-ASLB) and four hybrid types (Group 3, Anterior-CB + Posterior-PSLB-type 1; Group 4, Anterior-CB + Posterior-PSLB-type 2; Group 5, Anterior-ASLB + Posterior-PSLB-type 1; Group 6, Anterior-ASLB + Posterior-PSLB-type 2) (N = 13 per group). After maxillary dentition alignment and maxillary first premolars removal in the stereolithographically−made typodont system, a 0.019 × 0.025−inch stainless steel wire was drawn through the right quadrant of the maxillary arch at 0.5 mm/min for 5 min. The SFF and KFF were measured with an Instron and statistical analyses were performed.

RESULTS: Four different categories of SFF and KFF were observed among six groups (all $P < 0.001$). Group 1 demonstrated the highest SFF and KFF; Groups 4 and 3 were second and third highest, respectively. The fourth category included Groups 2, 5, and 6. Placing PSLBs on the MXPT resulted in significant SFF and KFF reductions in cases with CBs on the MXAT, but not in cases with ASLBs on the MXAT.

CONCLUSION: These data is expected to aid in the development of a hybrid bracket system that enables low−friction sliding of an archwire through the MXPT.

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Keywords : frictional force, hybrid bracket system, sliding mechanics, conventional−ligating brackets, self−ligating brackets

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I. INTRODUCTION

Friction between the bracket slot and archwire is one of the most important factors to be considered in sliding mechanics.[1] Self-ligating brackets (SLBs) are known to produce less friction than conventional-ligating brackets (CBs).[2-10] In general, SLBs are categorized as active type (ASLB) or passive type (PSLB).

PSLBs are known to produce less friction than ASLBs.[11-14] However, Badawi et al.[15] reported that ASLBs are more effective in torque expression than PSLBs, and lower friction might be disadvantageous to torque expression. In addition, Rinchuse and Miles[16] proposed a hybrid combination of CBs or ASLBs in the anterior segment and PSLBs in the posterior segment to take advantage of these properties. Afterwards, Paik et al.[17] introduced a variation of the hybrid system for premolar extraction cases called Hybrid Sliding Mechanics for Low Friction (HSM/LF): a combination of CBs on the anterior teeth, PSLBs on the second premolars, and conventional tubes on the first and second molars.

Although CBs and SLBs have been widely used, few previous studies have evaluated the frictional force in hybrid combinations of CBs, ASLBs, and PSLBs associated with sliding mechanics. Therefore, the purpose of this *in vitro* study was to investigate the static (SFF) and kinetic frictional forces (KFF) in the sliding mechanics of hybrid bracket systems that place a CB or ASLB on the maxillary anterior teeth and PSLB on the maxillary posterior teeth. The null hypothesis was that there was no significant difference in SFF and KFF in sliding mechanics between the thoroughbred and hybrid bracket groups.

II. REVIEW OF LITERATURE

1. Friction in Sliding Mechanics

Presence of friction (resistance to sliding) in the fixed orthodontic appliances is unavoidable and well recognized by the clinician.[1] Friction is described as an opposing and parallel force when one surface moves over another.[5] There are two types of friction: SFF and KFF.[5] The force to be overcome to initiate movement is SFF, and the force encountered during motion is KFF.[5]

Friction are generated at the bracket-archwire interface during leveling/aligning as well as space closure.[5] In order to move a tooth along an archwire the applied force needs to overcome the friction within the system.[9] These forces, however, can overpower the archwire and result in unwanted distortion and deformation of the wire, leading to unwanted side effects on the teeth.[9] For examples, friction is often held accountable for slowing down the rate of tooth movement and potentially causing loss of anchorage.[3] Therefore, it is necessary to reduce the friction at the bracket-archwire interface.[3] Information about the friction between orthodontic brackets and archwire is important for improving the effectiveness of orthodontic treatment.[14]

2. Self-ligating Brackets

SLBs seem to be gaining more and more popularity in contemporary orthodontics.[3] Compared with CBs, SLBs are known to increase tooth movement efficiency due to their improved frictional characteristics.[3] However, considerable variation exists between commercially available bracket types in terms of their mechanical, geometric, and material-related specifications, and this would be expected to affect their frictional performance.[3]

Contemporary SLBs can be classified as active or passive, based on the mode of self-ligation.[5] ASLBs have a spring clip that contacts with archwire and functions as the fourth wall of the bracket slot.[5] PSLBs have a movable labial slide that creates a hollow tube inside the bracket after closure of the slide.[5]

2-1. Friction in Conventional-ligating Brackets and Self-ligating Brackets

The ligation method can significantly influence friction between the bracket and archwire.[6] Several studies have shown that SLBs result in a significant reduction in friction compared with CBs.[2-10] Conventional ligation methods using stainless steel ligature wires or polymeric O-rings apply a pushing force on the archwire into the slot, thus increasing friction.[6]

Shivapuja and Berger[2] reported that SLBs [Activa ("A" Company, Johnson & Johnson, San Diego, CA, USA), Edgelock (Ormco, Glendora, CA, USA) and SPEED (Strite Industries, Cambridge, Ontario, Canada)] demonstrated a low friction. Krishnan et al.[5] showed that SLBs [Damon SL II (Sybron Dental Specialties Ormco, Orange, CA, USA), In-ovation (GAC International, Islandia, NY, USA), Smart Clip (3 M Unitek, Monrovia, CA, USA), and Time (American orthodontics, Sheboygan, WI, USA)] exhibited significantly lower SFF and KFF than CBs in all combinations of archwire alloys. Cordasco et al.[6] reported that the *in vitro* set-up of three vertically displaced brackets showed significantly lower friction for passive self-ligation compared to elastic or metallic ligation. Voudouris et al.[7] concluded that the SLBs generally exhibited the lowest friction irrespective of the bracket material and the wire size, and that CBs exhibited consistently higher friction. Huang et al.[10] showed PSLBs are associated with lower SFF or KFF than those of ASLBs or CBs. Pizzoni et al.[11] demonstrated that the SLBs had a markedly lower friction that CBs at all angulations when one SLB slides against a wire.

The low friction found with SLBs is clinically relevant for early alignment and sliding retraction of canines.[7] Light force application might also contribute to the potential prevention of root resorption and anchorage loss.[7]

2-2. Friction in Active and Passive Self-ligating Brackets

The self-ligating design (passive versus active) appeared to be the primary variable responsible for resistance to movement generated in SLBs.[3] With a small-sized archwire used in the alignment stage, there was no difference in friction between active and passive self-ligating systems.[9] However, with increasing archwire dimensions the active clips produced greater contact with the archwires, resulting in increase in friction.[9] In general, PSLBs are known to produce significantly less friction than ASLBs.[11-14]

Pizzoni et al.[11] reported that PSLB [Damon SL bracket (A-Company Europe, Amersfoort, Netherlands)] exhibited a significantly lower friction than ASLB [SPEED (Strite Industries, Cambridge, Ontario, Canada)] with respect to all wire types (stainless steel and beta titanium in two different dimensions, 0.018 and 0.017 × 0.025 inches).

Stefanos et al.[14] evaluated the friction between ASLB and PSLB of the maxillary right first premolar and 0.019 × 0.025 inch stainless steel archwire during sliding mechanics by using an orthodontic sliding simulation device. ASLBs [In-Ovation R, In-Ovation C (both, GAC International, Bohemia, NY, USA), and SPEED (Strite Industries, Cambridge, Ontario, Canada)], and PSLBs [SmartClip (3M Unitek, Monrovia, CA, USA), Synergy R (Rocky Mountain Orthodontics, Denver, CO, USA), and Damon 3MX (Ormco, Orange, CA, USA)] with 0.022 inch slots were used.[14] The Damon 3MX brackets had significantly the lowest mean SFF (8.6 g) and SPEED brackets exhibited the highest mean SFF (83.1 g).[14] The other brackets were ranked as follows, from highest to lowest, In-Ovation R, In-Ovation C, SmartClip, and Synergy R.[14] They confirmed that PSLBs have lower SFF and KFF compared with ASLBs when coupled with 0.019 × 0.025 inch stainless steel wire.[14]

However, this reduction in friction may come at the cost of decreased control compared to active ligating systems.[3, 5] If a bracket shows less friction in sliding mechanics with 0.019 × 0.025 inch stainless steel wire, it might be difficult to fully express the bracket's prescription during finishing stage.[14] In the study of Stefanos et al.[14], SPEED bracket generated the highest SFF and KFF. Therefore, SPEED brackets might not favor sliding mechanics.[14] On the contrary, SPEED brackets could more favorably express the bracket prescription if used with 0.019 × 0.025 inch stainless steel wire.[14]

3. Hybrid Bracket System

The selection of brackets should be based on the desired clinical outcome.[14] Low friction might be desired during leveling and aligning but could be inappropriate for expressing the torque in the bracket or achieving other objectives of finishing and detailing.[14] However, high friction might be desired for expressing torque in the bracket or finishing and detailing but be inappropriate for the leveling and aligning stages of treatment.[14]

Badawi et al.[15], in their study on the torque expression of SLBs, reported that the torque expression of Damon2 and SmartClip brackets followed characteristics of PSLBs, which torque started to be expressed at an angle of 15° of torsion. However, SPEED and In-Ovation brackets showed characteristics of ASLBs with a start of torque expression at an angle of 7.5°.[15] The range of clinically effective torque (5 to 20 Nmm) was expressed at 15° to 31° of torsion for the ASLBs, and at 22.5° to 34.5° of torsion for the PSLBs.[15] Therefore, the range of clinically useful torsion in ASLBs was larger than that in PSLBs (16° for the ASLBs and 12° for the PSLBs) and the meaningful torque control can only be achieved when torsion in the wire is higher than 15° and 22.5° for ASLBs and PSLBs, respectively.[15] Therefore, ASLBs are considered to be more effective in torque expression than PSLBs.[15]

Rinchuse and Miles[16] proposed a hybrid system in which various combinations of CBs, ASLBs, and PSLBs with the same slot size could be integrated into the patient's treatment. For example, SLBs could be used for space closing or regaining where low friction is needed.[16]

Paik et al.[17] have introduced a variation of the hybrid system for treatment of the first premolar extraction cases, called Hybrid Sliding Mechanics for Low Friction (HSM/LF) - a combination of CBs on the anterior teeth, PSLBs on the second premolars, and conventional tubes on the first and second molars. They reported that the HSM/LF has produced good results in two cases that is necessary with controlled tipping of the anterior teeth with maximum retraction.[17]

4. Limitations of experimental design in the previous studies

The validity of experimental design of friction in some previous studies is questionable.[16] Frank and Nikolai[1] simulated canine retraction for evaluating friction but they used an experiment design that the wire moved straight through the segment consisted of three teeth as viewed from an occlusal perspective. In numerous studies,[2,3,7,9-11,13,14] only one bracket was mounted on an acrylic cylinder or bonded to typodont tooth. Other studies measured friction using several brackets aligned straightly, rather than aligned according to the arch form. [5,6,12] Only a few studies have included the whole dentition, aligned according to arch form, to measure friction.[1,4,8]

Although the friction in CBs and SLBs has been widely studied, there was no study that has evaluated the frictional force in hybrid combinations of CBs, ASLBs, and PSLBs associated with sliding mechanics.

Ⅲ. MATERIALS AND METHODS

Teeth and typodont system

The stereolithographically (SL)-made typodont system, which can align the dentition according to arch form and malocclusion state, was used in this study (Figure 1-A).[8,18] Using computed tomography (CT) data, a three-dimensional (3D) virtual tooth model with root and periodontal ligament (PDL) space was designed to emulate a stress-absorbing mechanism and 3D structures were fabricated out of 3D virtual model using the Viper^{TM} Pro SLA® System (3D Systems Corporation, Valencia, CA, USA). The PDL space was filled with Imprint^{TM} II Garant^{TM} Light Body Vinyl Polysiloxane Impression Material (3M ESPE, Seefeld, Germany), which effectively reproduces the mobility of human teeth. Periotest (Siemens AG, Bensheim, Germany) revealed normal values in the mobility of the typodont teeth.[8,18-20]

All teeth were aligned in their ideal positions according to the Broad Arch Form® (SDS Ormco, Glendora, CA, USA). For the evaluation of frictional force in sliding mechanics during extraction space closure, the maxillary first premolar was removed from the typodont (Figure 1-A). When the archwire is pulled distally on one side, binding can occur on the opposite side.[5] Therefore, to minimize the effect of binding on the opposite side caused by pulling forces, Henao and Kusy[21] used half of the maxillary arch for frictional force measurement. In this study, the frictional force was measured in the right quadrant of the maxillary arch.

Various combinations of CBs, ASLBs, and PSLBs

The brackets tested in this study comprised one type of CB, one type of ASLB, and two types of PSLBs (Table 1). All brackets had a 0.022 inch slot.

The samples consisted of two thoroughbred types (Group 1, Anterior-CB + Posterior-CB; Group 2, Anterior- ASLB + Posterior-ASLB) and four hybrid types (Group 3, Anterior-CB + Posterior-PSLB-type 1; Group 4, Anterior-CB + Posterior-PSLB-type 2; Group 5, Anterior-ASLB + Posterior-PSLB-type 1; Group 6, Anterior-ASLB + Posterior-PSLB-type 2) (N = 13 per group, Table 1). The thoroughbred types (Groups 1 and 2) consisted of the same type of bracket from the same production company. The hybrid types (Groups 3 to 6) consisted of one type of CB or ASLB for proper torque control of the maxillary anterior teeth and two types of PSLBs for friction reduction at the maxillary posterior teeth during en masse retraction.

Sliding mechanics

Each bracket was bonded on the facial axis point[22] of the SL-made typodont tooth using Transbond XT (3M Unitek). While bonding the brackets, a 0.021 × 0.028 inch stainless steel (SS) wire (Broad Arch Form, DS Ormco) was placed to align the bracket slot and molar tube and to prevent any rotation, misalignment, or improper tipping/torque of the bracket that could influence unwanted friction during measurement.[4,8] The 0.021 × 0.028 inch SS wire was then removed from the bracket slot.

To simulate sliding mechanics for en masse retraction, 0.019 × 0.025 inch SS archwire (Broad Arch Form, SDS Ormco) was pulled distally from the most distal tube. In this study, the archwire length was half of a full archwire with a 90° bend at the anterior end as not to slip the archwire through the brackets or tubes during testing.

For the CBs, after ligation with elastic modules (Unistick Ligatures®, American Orthodontics, Sheboygan, WI, USA), a 3 minutes waiting period allowed a reproducible amount of stress relaxation to occur.[4,8,18,21,23]

Measurement of frictional force

The typodont was then attached to a custom-made metal plate that was fixed to a mechanical testing machine (Model 4466, Instron, Canton, MA, USA; Figure 1-B). A custom-designed adaptor gripped the distal end of the archwire, which was extruded from the second molar tubes. A 0.019 × 0.025 inch SS wire was drawn through the brackets and tubes at a speed of 0.5 mm/minute for 5 minutes in a dry state and at room temperature.

In this experiment, each combination was tested 13 times with new wires and brackets of the same type to eliminate the influence of wear between the wire and bracket slot. A total of 78 tests were conducted. After each test, the testing machine was stopped, the wire-bracket unit was removed, and a new assembly was placed. Both SFF and KFF were calculated by the same method used in previous studies.[4,8,18]

Statistical analysis

The sample size determination was made from a power analysis using the Sample Size Determination Program ver. 2.0.1 (Seoul National University Dental Hospital, registration number 2007-01-122-004453, Seoul, South Korea). Independent and paired *t* tests, a one-way analysis of variance (ANOVA), and Duncan's multiple comparison test were performed in the statistical analysis.

IV. RESULTS

Comparisons of static and kinetic frictional force (cN) in each group

There was a significant difference between SFF and KFF in the CB thoroughbred group (Group 1), Anterior-CB + Posterior-PSLB-type 1 group (Group 3), Anterior-CB + Posterior-PSLB-type 2 group (Group 4), and Anterior-ASLB + Posterior-PSLB-type 1 group (Group 5) (Groups 1, 3, and 5, $P < 0.05$; Group 4, $P < 0.01$; Table 2). However, the ASLB thoroughbred group (Group 2) and Anterior-ASLB + Posterior-PSLB-type 2 group (Group 6) did not exhibit a significant difference between SFF and KFF (Table 2).

Comparisons of static and kinetic frictional forces (cN) between the thoroughbred and hybrid bracket groups

When the thoroughbred groups (Groups 1 and 2) were compared, the CB thoroughbred group (Group 1) exhibited significantly higher SFF and KFF values than the ASLB thoroughbred group (Group 2) (all $P < 0.001$, Table 3).

When the Anterior-CB groups (Groups 1, 3, and 4) were compared, the Anterior-CB + PSLB-type 1 group (Group 3) exhibited lower SFF and KFF values than the CB thoroughbred group (Group 1) (all $P < 0.01$, Table 3). However, there was no significant difference in SFF and KFF between the Anterior-CB + Posterior-PSLB-type 1 group (Group 3) and the Anterior-CB + Posterior-PSLB-type 2 group (Group 4), or between the CB thoroughbred group (Group 1) and the Anterior-CB + Posterior-PSLB-type 2 group (Group 4) (Table 3).

When the Anterior-ASLB groups (Groups 2, 5, and 6) were compared, there was no significant difference in SFF and KFF among the ASLB thoroughbred group (Group 2), Anterior-ASLB + Posterior-PSLB-type 1 group (Group 5), and Anterior-ASLB + Posterior-PSLB-type 2 group (Group 6) (all $P > 0.05$, Table 3).

When the overall groups (Groups 1 through 6) were compared, four different categories were observed among the six groups in terms of SFF and KFF (all $P < 0.001$, Table 3). The CB thoroughbred group (Group 1) had the highest SFF and KFF values among all groups (Table 3). The Anterior-CB + Posterior-PSLB-type 2 group (Group 4) and Anterior-CB + Posterior-PSLB-type 1 group (Group 3) exhibited the second and third highest values, respectively (Table 3). These findings indicate that the placement of PSLBs on the maxillary posterior teeth with CBs on the maxillary anterior teeth (Groups 3 and 4) can significantly reduce SFF and KFF compared with the CB thoroughbred group (Group 1). The fourth category included the ASLB thoroughbred group (Group 2), Anterior-ASLB + Posterior-PSLB-type 1 group (Group 5), and Anterior-ASLB + Posterior-PSLB-type 2 group (Group 6) (Table 3). This finding indicates that placing PSLBs on the maxillary posterior teeth in conjunction with ASLBs on the maxillary anterior teeth did not significantly reduce SFF and KFF more than in the ASLB thoroughbred group (Group 2).

V. DISCUSSION

There has been consistent agreement that SLBs exhibit lower friction than CBs when coupled with small round archwires.[2,4,8, 21,24,25] However, for large rectangular archwires, there seems to be controversy. Henao and Kusy[21,23] insisted that the friction of SLBs coupled with large rectangular archwires was not lower than that of CBs. In a systemic review, Ehsani et al.[24] claimed there was no sufficient evidence that SLBs with large rectangular wires produced lower friction than CBs in the presence of tipping and/or torque or in arches with considerable malocclusion. Ehsani et al.[24] explained that rectangular wires increased friction, even in SLBs, because filling the bracket slots with heavy rectangular wires might minimize differences between the SLBs and CBs.

ASLBs are known to be more effective than PSLBs in torque expression.[15] However, there are still some controversies surrounding this issue. For example, Major et al.[26] reported that the torque plays in ASLBs and PSLBs were virtually indistinguishable and that there was no significant difference in torque expression from a clinical perspective at angles of twist smaller than 24°. In addition, Brauchli et al.[27] claimed that the influence of the ligature method (conventional ligation, active self-ligation, or passive self-ligation) on torque expression was minimal and that slot dimensions were more important in the transmission of torque. Therefore, it is necessary to investigate the torque expression of SLBs with more sophisticated methodology.

To accurately measure the frictional force of SLBs and CBs with large rectangular wires, the experimental conditions should be similar to a clinical situation for en masse retraction. Therefore, the brackets must be aligned using 0.021 × 0.028 inch SS wire to avoid improper rotation, in-and-out, tipping, and torque that could result in unwanted friction during measurements.[4,8,28]

Numerous studies have evaluated the friction using a rectangular wire in one or several brackets in a straight form.[3,6,9,10,14,29-32] However, it would be better to place the brackets according to a specific arch form to investigate the effect of curvature on frictional properties. Therefore, in this study, the SL-made typodont system, which can align the dentition according to arch form and malocclusion state, was used.

In this study, the CB thoroughbred group (Group 1) showed significantly higher SFF and KFF values than the ASLB thoroughbred group (Group 2) (1018.8 cN vs. 466.1 cN for SFF; 955.5 cN vs. 461.5 cN for KFF; all $P < 0.001$, Tables 2 and 3). This result is consistent with those of previous studies.[4,11-14,23,25,32] The finding that the Anterior-CB + Posterior-PSLB-type 2 group (Group 4) and Anterior-CB + Posterior-PSLB-type 1 group (Group 3) exhibited the second and third highest SFF and KFF values (860.6 cN and 818.5 cN for Group 4; 691.4 cN and 677.8 cN for Group 3; Tables 2 and 3) seemed to result from differences in the brackets. The Posterior-PSLB-type 1 and Posterior-PSLB-type 2 groups had different mesiodistal widths of the brackets and tubes (in the maxillary second premolars, first molars, and second molars), bracket designs (sliding door vs. clip on the maxillary second premolars and first molars), bracket slot material compositions (metal bracket and metal slot vs. ceramic bracket and metal slot in the maxillary second premolars), and bracket slot surface roughness (Table 1). Therefore, further studies are necessary to consider these characteristics in the evaluation of friction.

The reason that there was no significant difference in SFF and KFF among the ASLB thoroughbred group (Group 2), Anterior-ASLB + Posterior-PSLB-type 1 group (Group 5), and Anterior-ASLB + Posterior-PSLB-type 2 group (Group 6) (466.1 cN, 453.9 cN, and 414.5 for SFF; 461.5 cN, 447.4 cN, and 410.8 cN for KFF, all $P > 0.05$; Tables 2 and 3) was likely because the ASLB already has a smaller friction than the CB. Since the CB thoroughbred group (Group 1) resulted in significantly higher friction than the other groups (Tables 2 and 3), a bracket change from a CB to a PSLB on the posterior teeth could significantly reduce friction (-31.2% in Group 3 and -15.5% in Group 4 for SFF; -29.1% in Group 3 and -14.3% in Group 4 for KFF compared to Group 1; all $P < 0.01$; Figure 2). However, the friction of the ASLB thoroughbred group (Group 2) were lower than those in the CB thoroughbred group (Group 1) (Tables 2 and 3). Therefore, a bracket change from an ASLB to a PSLB on the posterior teeth may not result in a significant reduction in friction (-2.6% in Group 3 and -11.1% in Group 4 for SFF; -3.1% in Group 3 and -11.0% in Group 4 for KFF compared with Group 1; all $P > 0.05$; Figure 2). In summary, the type of hybrid bracket system placed on the maxillary anterior and posterior teeth (CB-PSLB or ASLB-PSLB) can affect the degrees of reduction in SFF and KFF compared with a thoroughbred bracket system (CB or ASLB).

The finding that the Anterior-CB + Posterior-PSLB-type 1 group (Group 3) exhibited lower SFF and KFF values than the CB thoroughbred group (Group 1) (all $P < 0.01$, Tables 2 and 3) might be similar to a case report by Paik et al.,[17] who introduced hybrid sliding mechanics for low friction (a combination of CBs on the anterior teeth, PSLBs on the second premolars, and conventional tubes on the first and second molars).

In the near future, hybrid bracket systems using CBs, ASLBs, and PSLBs can be adopted in clinics according to the orthodontist's intention. Further studies are necessary to investigate the effects of the PDL material and elastic module stress relaxation method on the level of friction. Moreover, it is necessary to consider the influence of torque on friction according to bracket type in the anterior region (CB and ASLB) with respect to bracket type in the posterior region (PSLB and ASLB).

VI. CONCLUSIONS

- Placing PSLBs on the maxillary posterior teeth resulted in significant reductions in SFF and KFF in cases with CBs on the maxillary anterior teeth, but not in cases with ASLBs on the maxillary anterior teeth; thus the null hypothesis was rejected.
- These data might be used to guide the development of a hybrid bracket system that enables low-friction sliding of an archwire through the maxillary posterior teeth.

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FIGURE LEGENDS

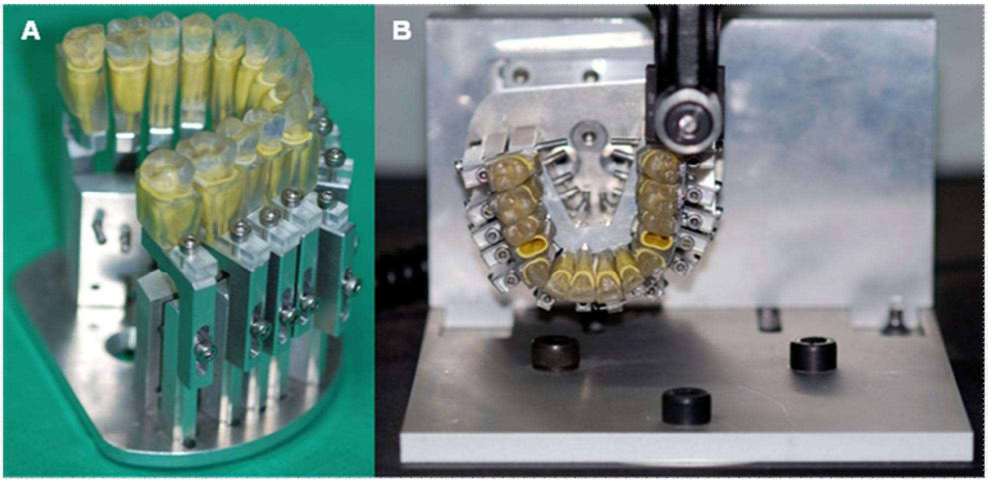
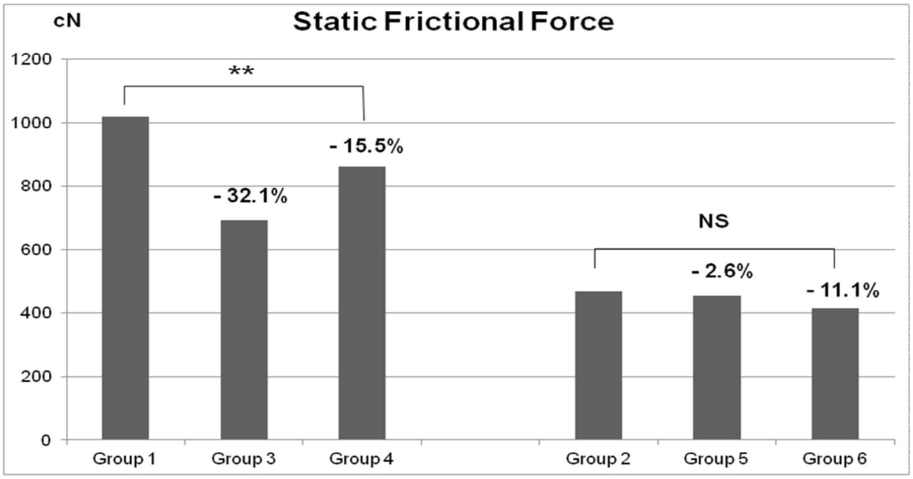


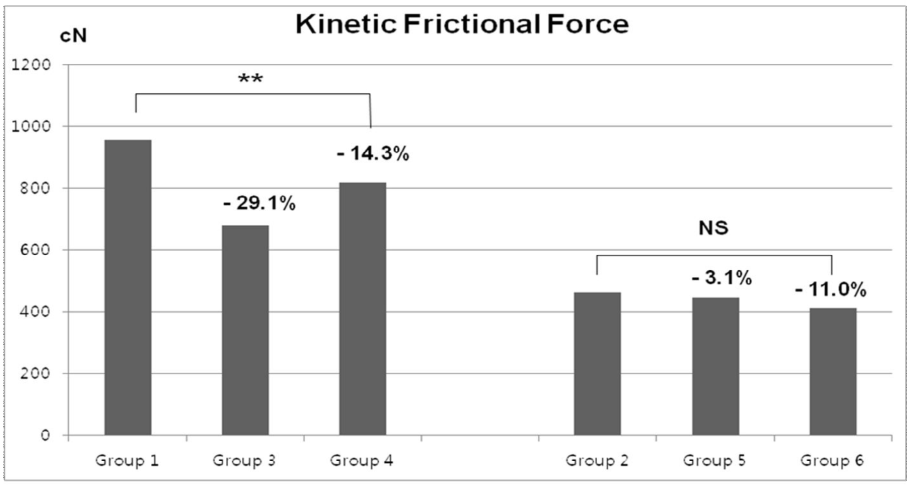
Figure 1. A. The stereolithographically-made typodont system. The maxillary teeth were aligned to their ideal positions according to a Broad Arch Form (SDS Ormco). For the evaluation of frictional force in sliding mechanics during extraction space closure, the maxillary first premolar was removed from the typodont. B. The stereolithographically-made typodont system and testing apparatus.

A



(Group 6, Group 5, Group 2) < Group 3 < Group 4 < Group 1 ***

B



(Group 6, Group 5, Group 2) < Group 3 < Group 4 < Group 1 ***

Figure 2. Comparisons of frictional force (cN) between Groups 1, 3, and 4 and between Groups 2, 5, and 6. A. static frictional force; B. kinetic frictional force. A one-way ANOVA was performed and the results were verified with Duncan's multiple comparison test. ** represents $P < 0.01$; ***, $P < 0.001$.

Table 1. Combinations of conventional-ligating brackets, active self-ligating brackets, and passive self-ligating brackets

Type		Group	MXAT	MXPT		
			Central incisor to Canine	Second Premolar	First Molar	Second Molar
Thoroughbred	CB	1	CB (ceramic bracket / metal slot; Clarity, 3M-Unitek)	CB (ceramic bracket / metal slot; Clarity, 3M-Unitek)	Conventional convertible single tube (metal tube, 3M-Unitek)	Conventional single tube (metal tube, 3M-Unitek)
	ASLB	2	ASLB (ceramic bracket / ceramic slot; In-Ovation C, GAC)	ASLB (ceramic bracket / ceramic slot; In-Ovation C, GAC)	Conventional convertible single tube (metal tube, GAC)	Conventional single tube (metal tube, GAC)
Hybrid 1 (Ant + Post)	CB + PSLB type 1	3	CB (ceramic bracket / metal slot; Clarity, 3M-Unitek)	PSLB type 1 (metal bracket / metal slot; Damon Q, Ormco)	PSLB type 1 (metal bracket / metal slot; Damon Q, Ormco)	Conventional single tube (metal tube; Ormco)
	CB + PSLB type 2	4	CB (ceramic bracket / metal slot; Clarity, 3M-Unitek)	PSLB type 2 (ceramic bracket / metal slot; Clarity SL, 3M-Unitek)	PSLB type 2 (metal bracket / metal slot; SmartClip, 3M-Unitek)	Conventional single tube (metal tube, 3M-Unitek)
Hybrid 2 (Ant + Post)	ASLB + PSLB type 1	5	ASLB (ceramic bracket / ceramic slot; In-Ovation C, GAC)	PSLB type 1 (metal bracket / metal slot; Damon Q, Ormco)	PSLB type 1 (metal bracket / metal slot; Damon Q, Ormco)	Conventional single tube (metal tube; Ormco)
	ASLB + PSLB type 2	6	ASLB (ceramic bracket / ceramic slot; In-Ovation C, GAC)	PSLB type 2 (ceramic bracket / metal slot; Clarity SL, 3M-Unitek)	PSLB type 2 (metal bracket / metal slot; SmartClip, 3M-Unitek)	Conventional single tube (metal tube; 3M-Unitek)

CB, conventional-ligating bracket; ASLB, active self-ligating bracket; PSLB, passive self-ligating bracket; MXAT, the maxillary anterior teeth (central incisor, lateral incisor, and canine), MXPT, the maxillary posterior teeth (second premolar, first molar, and second molar).

Table 2. Comparisons of static and kinetic frictional forces (cN) in each group

Type		Group	Static frictional force (N=13/group)		Kinetic frictional force (N=13/group)		P-value
			Mean	SD	Mean	SD	
Thoroughbred	CB	1	1018.77	280.06	955.45	209.64	0.0172*
	ASLB	2	466.08	155.31	461.46	150.27	0.3657
Hybrid 1 (Ant + Post)	CB + PSLB type 1	3	691.38	129.78	677.79	125.61	0.0408*
	CB + PSLB type 2	4	860.62	265.29	818.53	225.96	0.0056**
Hybrid 2 (Ant + Post)	ASLB + PSLB type 1	5	453.85	79.44	447.38	73.92	0.0185*
	ASLB + PSLB type 2	6	414.54	168.47	410.81	147.45	0.6239

A paired *t* test was performed.

Group 1, Anterior-CB + Posterior-CB; Group 2, Anterior-ASLB + Posterior-ASLB; Group 3, Anterior-CB + Posterior-PSLB-type 1; Group 4, Anterior-CB + Posterior-PSLB-type 2; Group 5, Anterior-ASLB + Posterior-PSLB-type 1; Group 6, Anterior-ASLB + Posterior-PSLB-type 2; *, $P < 0.05$; **, $P < 0.01$.

Table 3. Comparisons of static and kinetic frictional forces (cN) between the thoroughbred bracket and hybrid bracket groups

Combinations	Groups	Static frictional force (N=13/group)		Kinetic frictional force (N=13/group)	
		P-value	Difference within tested groups	P-value	Difference within tested groups
Thoroughbred group	1, 2	<0.001***	1>2 +	<0.001***	1>2 +
Anterior CB group	1ʃ, 3, 4	0.0045**	(3,4)<(4,1) ++	0.0032**	(3,4)<(4,1) ++
Anterior ASLB group	2ʃ, 5, 6	0.6222	NS ++	0.5900	NS ++
Overall group	1 to 6	<0.001***	(6,5,2)<3<4<1 ++	<0.001***	(6,5,2)<3<4<1 ++

+ An independent *t* test was performed.

++ A one-way ANOVA was performed and the results were verified with Duncan's multiple comparison test. ** represents P < 0.01; ***, P < 0.001; NS, not significant.

∫ represents the control groups for the Anterior-CB and Anterior-ASLB groups.

Group 1, Anterior-CB + Posterior-CB; Group 2, Anterior-ASLB + Posterior-ASLB; Group 3, Anterior-CB + Posterior-PSLB-type 1; Group 4, Anterior-CB + Posterior-PSLB-type 2; Group 5, Anterior-ASLB + Posterior-PSLB-type 1; Group 6, Anterior-ASLB + Posterior-PSLB-type 2.

국문초록

활주 역학에서 구치부에 수동 자가결찰 브라켓 사용 시 마찰력 감소의 효과에 관한 연구

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(지도교수 백 승 학)

김 규 리

본 연구의 목적은 상악 전치부에 기존 결찰 브라켓 (CB) 또는 능동형 자가결찰 브라켓 (ASLB) 을 배치하고, 상악 구치부에 수동형 자가결찰 브라켓 (PSLB) 을 배치한 후, 발치공간 폐쇄를 위한 활주 역학 (sliding mechanics) 적용 시 정지마찰력 (static frictional force, SFF) 과 운동마찰력 (kinetic frictional force, KFF) 을 조사하는 것이었다. 두 가지 종류의 동일형 브라켓 시스템 (Group 1, Anterior-CB + Posterior-CB; Group 2, Anterior-ASLB + Posterior-ASLB) 과 네 가지 종류의 하이브리드 브라켓 시스템 (Group 3, Anterior-CB + Posterior-PSLB-type 1; Group 4, Anterior-CB + Posterior-PSLB-type 2; Group 5, Anterior-ASLB + Posterior-PSLB-type 1; Group 6, Anterior-ASLB + Posterior-PSLB-type 2) 으로 실험을 진행하였다. 각 그룹당 표본수는 13개였다. 치아의 치관, 치근,

치주인대의 형태를 SLA공법 (StereoLithography Apparatus) 으로 재현한 타이포돈트를 사용하여 상악치열을 배열하고 제1소구치를 제거하였다. 상악 전치의 군집 후방이동 (En mass retraction)을 재현하기 위해, 상악 우측 사분악만 사용하기로 하였고 0.019 x 0.025 inch stainless steel (SS) 호선을 삽입하였다. 인스트론 4466 (Instron Corp., Canton, MA, USA)을 사용해 0.5mm/min의 속도로 5분간 정지마찰력과 운동마찰력을 측정하였다. 통계분석을 위해 paired t-test, independent t-test, one-way ANOVA를 사용하여 비교하였고 Duncan's multiple comparison test로 사후검증하였다.

1. 전체 그룹 중에서, 그룹1이 가장 높은 마찰력을 보였으며, 그룹 4와 3이 각각 두번째와 세번째로 높은 마찰력을 보였다. 마지막으로 그룹 2, 5, 6이 가장 낮은 마찰력을 보였다.
2. 상악 전치부에 기존 결찰 브라켓 (CB) 을 사용한 경우, 상악 구치부를 동일 브라켓 대신에 수동형 자가결찰 브라켓 (PSLB) 으로 바꾸면 유의한 마찰력의 감소 효과를 얻을 수 있었다. 그러나 상악 전치부에 능동형 자가결찰 브라켓 (ASLB) 을 사용한 경우에는, 상악 구치부 브라켓을 동일 브라켓 대신에 수동형 자가결찰 브라켓 (PSLB) 으로 바꾸는 것으로는 이러한 마찰력 감소 효과를 얻을 수 없었다.

이런 결과는 기존 결찰 브라켓 (CB) 의 경우는 마찰력이 매우 크기 때문에, 구치부 브라켓만 수동형 자가결찰 브라켓 (PSLB) 으로 바꾸어도 마찰력의 감소가 유의하게 나타나는 것으로 보인다. 그러나 능동형 자가결찰 브라켓 (ASLB) 은 이미 마찰력을 줄인 브라켓 타입으로 구치부 브라켓 변화에 따른 마찰력의 감소가 유의성이 없는

것으로 보인다. 그러므로 향후 활주 역학에서 상악 구치부에 마찰력을 감소시키기 위한 하이브리드 브라켓 시스템 설계에 있어 이러한 결과가 도움이 될 것으로 보인다.

… …

주요어 : 마찰력, 하이브리드 브라켓 시스템, 활주 역학, 기존 결찰 브라켓, 자가결찰 브라켓
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