Original Article

Effect of bracket bevel design and oral environmental factors on frictional resistance

Chen-Jung Chang[a]; Tzer-Min Lee[b]; Jia-Kuang Liu[c]

ABSTRACT

Objective: To investigate the effects of bracket bevel design and oral environmental factors (saliva, temperature) on frictional resistance.

Materials and Methods: Five types of brackets, namely a conventional bracket (Omni-arch), an active self-ligating bracket (Clippy), and three passive self-ligating brackets (Carriere, Damon, and Tenbrook T1) coupled with a 0.014-inch austenitic nickel-titanium archwire were tested. In the experimental model, which used a group of five identical brackets, the center bracket was displaced 3 mm to mimic the binding effects. The friction experiments were performed at three temperatures (20°C, 37°C, 55°C) in a dry or a wet (artificial saliva) state. Finally, the surfaces of the bracket slots were observed using scanning electron microscopy (SEM) before and after the friction tests.

Results: The sliding frictional force was significantly influenced by the bracket slot bevel and saliva whether in the active or passive configuration ($P < .05$). The frictional force significantly increased as the temperature increased in the active configuration ($P < .01$). Based on the SEM observations, a correlation was found among the level of frictional force, the bevel angle, and the depth of scratches on bracket bevels.

Conclusion: Frictional force can be reduced by increasing the bevel angle and by lowering the oral temperature, whereas the presence of saliva increases frictional resistance. (*Angle Orthod.* 2013;83:956–965.)

KEY WORDS: Frictional resistance; Self-ligating bracket; Bracket bevel design; Temperature change

INTRODUCTION

Reducing frictional force is essential for optimal orthodontic force and effective tooth movement. During an orthodontic sliding movement, a bracket moves along an archwire with a tipping-uprighting pattern, rather than as a smooth continuous movement. Kusy and Whitley[1] investigated the binding and notching of archwires and found that seven parameters affect friction, namely material, roughness, hardness, wire stiffness, geometry, fluid media, and surface chemistry. They derived equations for the critical contact angle for binding (θc)[2] and stated that frictional resistance is related to the dimensions of the archwire, the bracket slot, and the bracket width.

The first self-ligating bracket was described by Stolzenberg in 1935.[3] Active, passive, and interactive self-ligating systems have since been developed.[4–7] Several studies have indicated that passive self-ligating brackets generate lower frictional forces than active self-ligating brackets, modified ligatures, and conventional bracket systems.[8–16] Most research has focused on comparing ligation methods, and very little studies have investigated the effect of slot bevel design on frictional resistance.

In an oral environment, brackets and archwires are bathed in saliva. Thus, three-body friction needs to be considered.[17] Kusy and Schafter[18] found that saliva

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Table 1. Brackets Evaluated[a]

Bracket	Ligation Method	Prescription Torque	Angulation	Material	Manufacturer
Omni-arch	Elastic modules	−7°	0°	SS	Tomy
Clippy	ASLB	−7°	0°	SS	Tomy
Damon 3MX	PSLB	−7°	+2°	SS	Ormco
Carrier	PSLB	−7°	0°	Nickel-free SS	Ortho Organizers
TenBrook T1	PSLB	−7°	−2°	SS	Ortho Classic

[a] SS indicates stainless steel; ASLB, active self-ligating bracket; PSLB, passive self-ligating bracket.

increases frictional coefficients. However, one study found that a significant difference between dry and wet states exists only for a specific combination of brackets and malocclusion.[13] Kusy and Whitley[19] found that human saliva lowered the frictional coefficient for TMA archwires against alumina brackets. Thus, the effects of saliva on frictional force remain unclear.

Airoldi et al.[20] investigated the effect of changes in temperature inside the oral cavity using cold water (5°C) and hot tea (60°C). The results showed that the oral temperature ranged from 7.1°C to 57.4°C and that it took 10 to 15 minutes for the initial oral temperature to be restored. Furthermore, it has been found that short-term temperature changes can affect the stiffness of an archwire,[21,22] which is correlated with friction and binding.[15,23,24] However, no studies have been conducted on the effect of oral temperature changes with respect to friction. The aims of the study were to investigate the influence of bracket bevel design and oral environment on frictional resistance.

MATERIALS AND METHODS

Five brands of brackets were tested. These were the conventional bracket Omni-arch Twin bracket (Tomy, Tokyo, Japan), which was ligated with elastic modules (Clear Versa-Ties Ligatures, G&H Wire Co, Franklin, Ind), the active self-ligating Clippy bracket (Tomy), the passive self-ligating Carriere (Ortho Organizers, Carlsbad, Calif), Damon 3 MX (Ormco, Orange, Calif), and TenBrook T1 (Ortho Classic, McMinnville, Ore) brackets. All brackets had a 0.022-inch slot (Table 1). The selected archwire, 0.014-inch austenitic nickel-titanium (NiTi) (Ormco), is commonly used during the initial alignment and leveling stages.

A customized experimental model that comprised the five metal bracket holders was constructed. Each bracket holder was designed to clamp a bracket base. The middle holder was connected to a linear guideway that allowed the bracket to slide up to 5 mm in the occluso-gingival direction (Figure 1). Two experimental conditions were used. In the passive configuration (center bracket set in the 0-mm position) (Figure 1A), the five brackets were well-aligned via the insertion of a 0.0215 × 0.028 inch stainless steel straight wire. In the active configuration, the center bracket was displaced 3 mm to simulate the binding effect on the brackets of apically displaced canines (Figure 1B).

A temperature-controlled chamber (Figure 2A) was constructed using heating tape and a temperature controller (HT-720; Newlab Co Ltd., Taipei, Taiwan) (Figure 2B). To study the effect of temperature, the specimens were tested at room temperature (20°C), body temperature (37°C), and a temperature simulating a hot drink (55°C). To allow testing in a wet state, artificial saliva[25] was prepared and dripped onto the brackets and

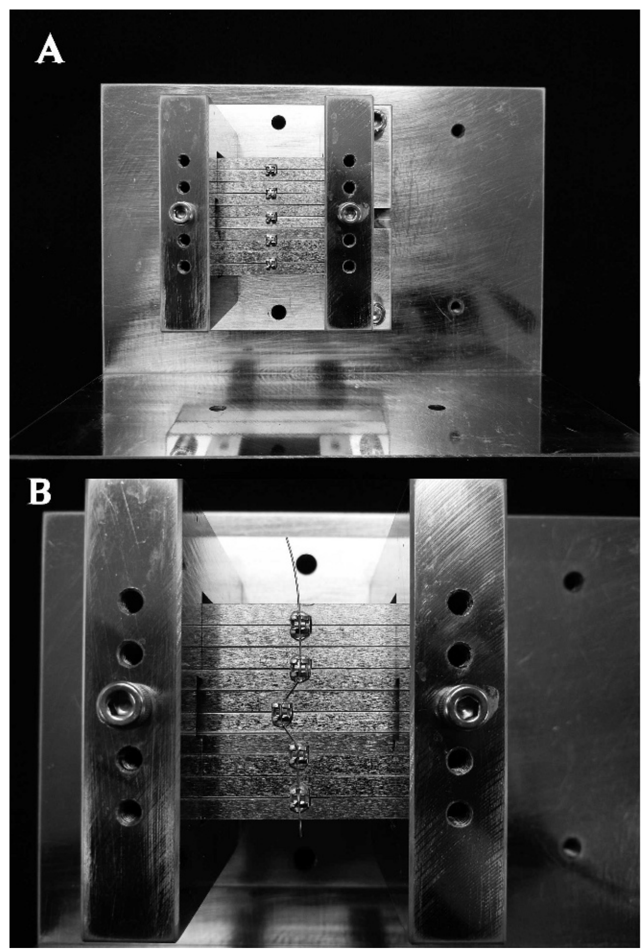

Figure 1. Customized experiment model. (A) 0-mm position of center bracket (passive configuration). (B) 3-mm displacement of center bracket (active configuration).

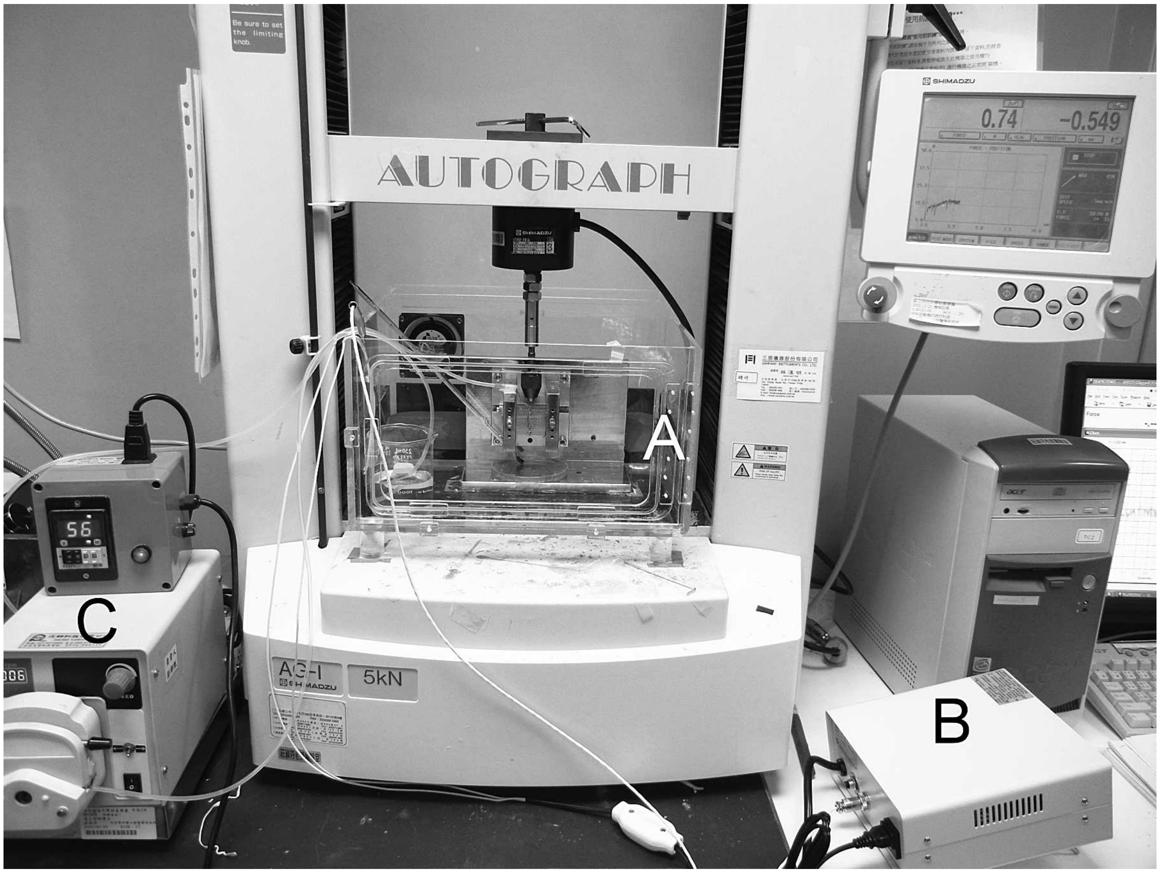

Figure 2. Experiment setup. (A) Temperature-controlled chamber. (B) Temperature controller. (C) Peristaltic pump.

archwires via a peristaltic pump (Figure 2C) at a rate of 3 mL/min.[26] A 50-mm section of wire was ligated to each five-bracket group. The upper end of the wire was then linked to a universal testing machine (AG-1, Shimadzu, Kyoto, Japan) with a customized gripper and a 50-N load cell. The wire was pulled at a crosshead speed of 0.5 mm/min. The raw data were imported into a software program (Trapezium2 version 2.32, Shimadzu) to obtain drawings of force-displacement plots. Each experimental combination was repeated five times. The kinetic frictional force was determined by averaging the readings on the Y-axis when the drawing force was constant (Figure 3). Descriptive statistics of the kinetic frictional force were calculated for each combination. Analysis of variance and *t*-test were used separately to identify the differences in the parameters. A post hoc test, Duncan's test, was also carried out to determine whether there was a significant difference between group means. The level of significance was set at $P < .05$.

Finally, to examine the effect of binding on bracket slot bevels, the bevel surfaces of the center brackets were observed using a low/variable-vacuum scanning electron microscope (Inca 350, Oxford, UK).

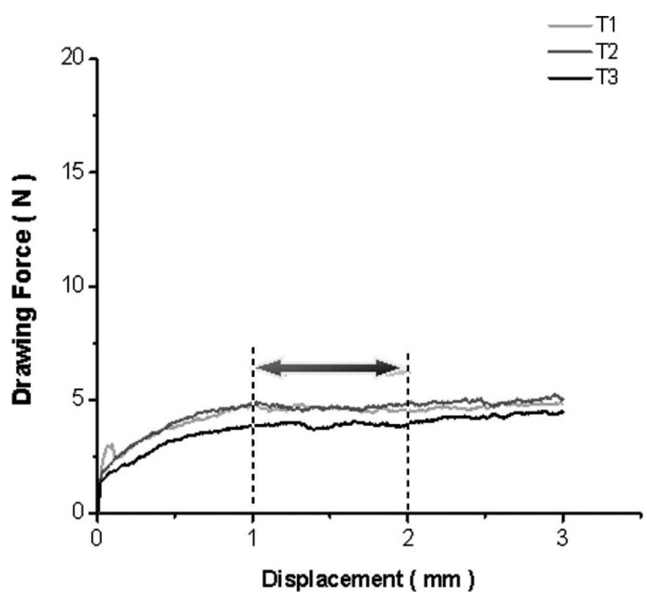

Figure 3. Force-displacement plots. Each combination was tested three times (T1, T2, T3). The kinetic frictional force was determined by averaging the readings on the Y-axis at intervals of constant drawing force.

Table 2. Means and Standard Deviations of Kinetic Frictional Force in Newtons (N) for the Passive Configuration of Austenitic Nickel-Titanium (A-NiTi) Archwires

	20°C		37°C		55°C	
	Dry	Wet	Dry	Wet	Dry	Wet
Bracket	A-NiTi	A-NiTi	A-NiTi	A-NiTi	A-NiTi	A-NiTi
Omni-arch						
Mean	6.54	16.32	12.16	18.32	12.15	15.49
SD	1.06	0.78	0.67	0.61	0.47	2.31
Clippy						
Mean	0.07	0.01	0.09	0.01	0.08	0.19
SD	0.02	0.00	0.02	0.01	0.02	0.02
Carriere						
Mean	0.01	0.03	0.01	0.01	0.08	0.04
SD	0.00	0.01	0.00	0.0	0.01	0.02
Damon						
Mean	0.06	0.01	0.00	0.01	0.01	0.08
SD	0.01	0.00	0.00	0.00	0.00	0.02
Tenbrook T1						
Mean	0.02	0.01	0.01	0.01	0.01	0.04
SD	0.00	0.01	0.01	0.00	0.01	0.01

Table 4. Means and Standard Deviations of Kinetic Frictional Force in Newtons (N) for the Active Configuration of Austenitic Nickel-Titanium (A-NiTi) Archwires

	20°C		37°C		55°C	
	Dry	Wet	Dry	Wet	Dry	Wet
Bracket	A-NiTi	A-NiTi	A-NiTi	A-NiTi	A-NiTi	A-NiTi
Omni-arch						
Mean	10.88	17.19	20.69	30.90	22.08	31.42
SD	1.36	0.73	0.74	1.13	0.72	0.64
Clippy						
Mean	7.64	8.11	8.90	12.52	12.44	16.14
SD	1.08	0.69	1.54	0.26	0.45	3.09
Carriere						
Mean	7.35	6.07	8.14	10.83	10.23	12.23
SD	0.51	0.48	1.30	1.32	1.53	0.61
Damon						
Mean	4.34	5.28	4.81	9.64	8.95	12.52
SD	0.52	0.45	0.55	0.72	1.56	2.02
Tenbrook T1						
Mean	2.94	4.97	5.06	8.22	7.50	8.09
SD	0.52	0.84	0.54	0.99	0.85	1.03

RESULTS

Friction Test

Table 2 shows the means and standard deviations of the frictional forces for various combinations of brackets and oral environmental conditions in the passive configuration. Table 3 shows the statistical analysis of the frictional forces for these combinations. The mean frictional values among the five types of brackets were significantly different ($P < .05$). The conventional bracket had a significantly higher frictional force than the self-ligating brackets. The four self-ligating brackets exhibited near-zero frictional forces. However, the frictional forces in the wet state were higher than in the dry state ($P < .01$). The mean frictional force values for the three different temperatures showed no significant differences ($P > .05$).

The descriptive data and comparisons of the frictional force for various combinations of brackets and oral conditions in the active configuration are shown in Tables 4 and 5. There were significant differences in the frictional force among the various types of brackets ($P < .01$). A post hoc comparison shows that the conventional bracket produced the highest frictional forces, followed by the Clippy and Carriere brackets, and then the Damon and Tenbrook T1 brackets. The friction in the wet state was higher than in the dry state, and the mean values of frictional force for the three different temperatures were significantly different ($P < .01$).

Table 3. Statistic Analysis for the Passive Configuration

Parameter	Variable	Significance	Multiple Comparison[a]
Brackets	Omni-arch	$P < .05$[b]	A
	Clippy		B
	Carriere		B
	Damon		B
	Tenbrook T1		B
Oral conditions	Dry	$P < .01$[c]	A
	Wet		B
	20°C	$P > .05$[b]	A
	37°C		A
	55°C		A

[a] A post hoc test was done with the Duncan test. Variables with the same letter did not differ from each other.
[b] ANOVA test.
[c] A *t*-test.

Table 5. Statistical Analysis for the Condition of 3-mm Displacement of the Center Bracket

Parameter	Variable	Significance	Multiple Comparison[a]
Brackets	Omni-arch	$P < .01$[b]	A
	Clippy		B
	Carriere		B C
	Damon		D C
	Tenbrook T1		D
Oral conditions	Dry	$P < .01$[c]	A
	Wet		B
	20°C	$P < .01$[b]	A
	37°C		B
	55°C		C

[a] A post hoc test was done with the Duncan test. Variables with the same letter did not differ from each other.
[b] ANOVA test.
[c] A *t*-test.

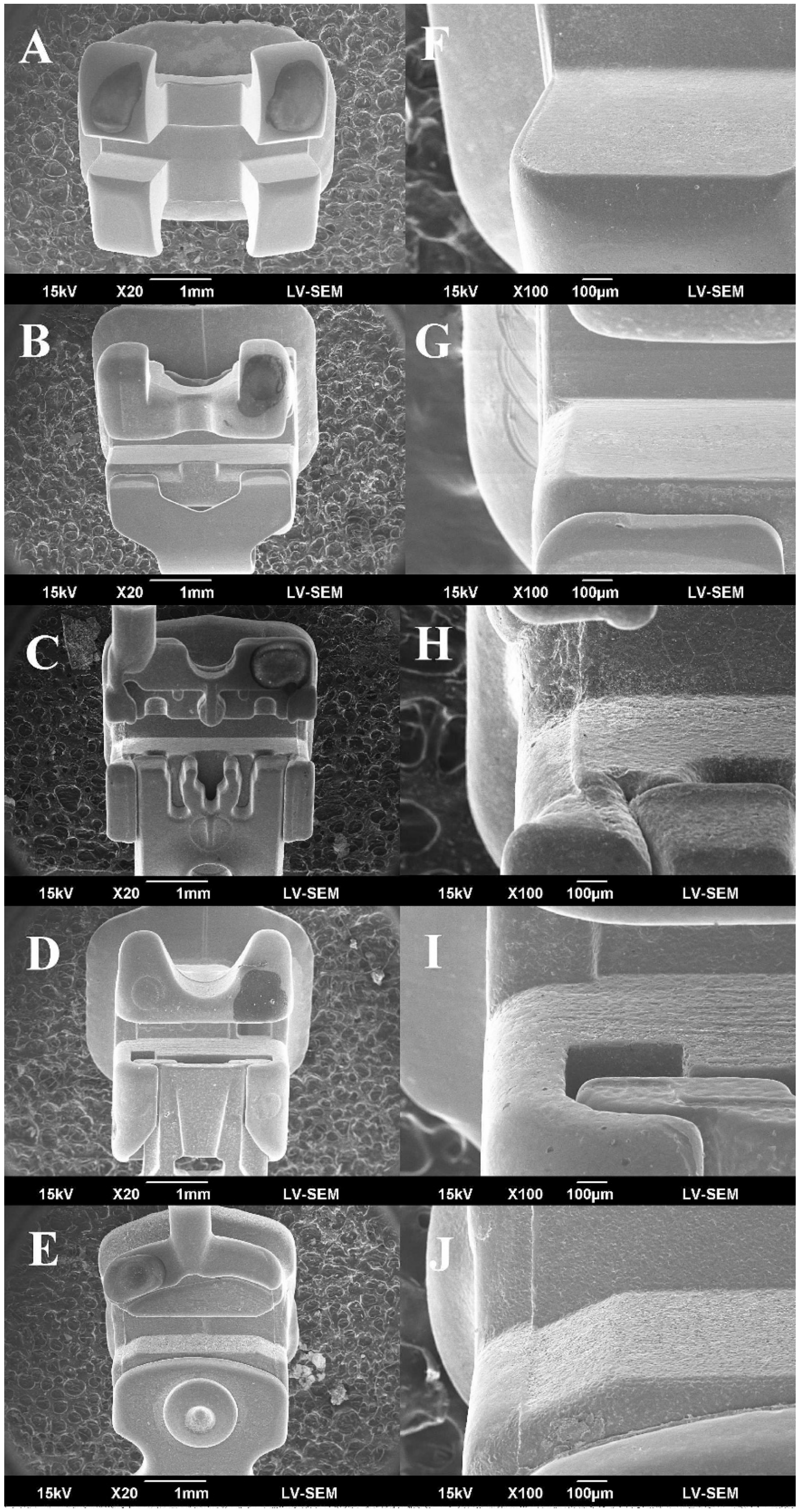

Figure 4. Top view, SEM images of five types of bracket, at 20× (left column) and 100× (right column). (A) (F), Omni-arch (conventional bracket). (B) (G), Clippy (ASLB). (C) (H), Carriere (PSLB). (D) (I), Damon (PSLB). (E) (J), Tenbrook T1 (PSLB).

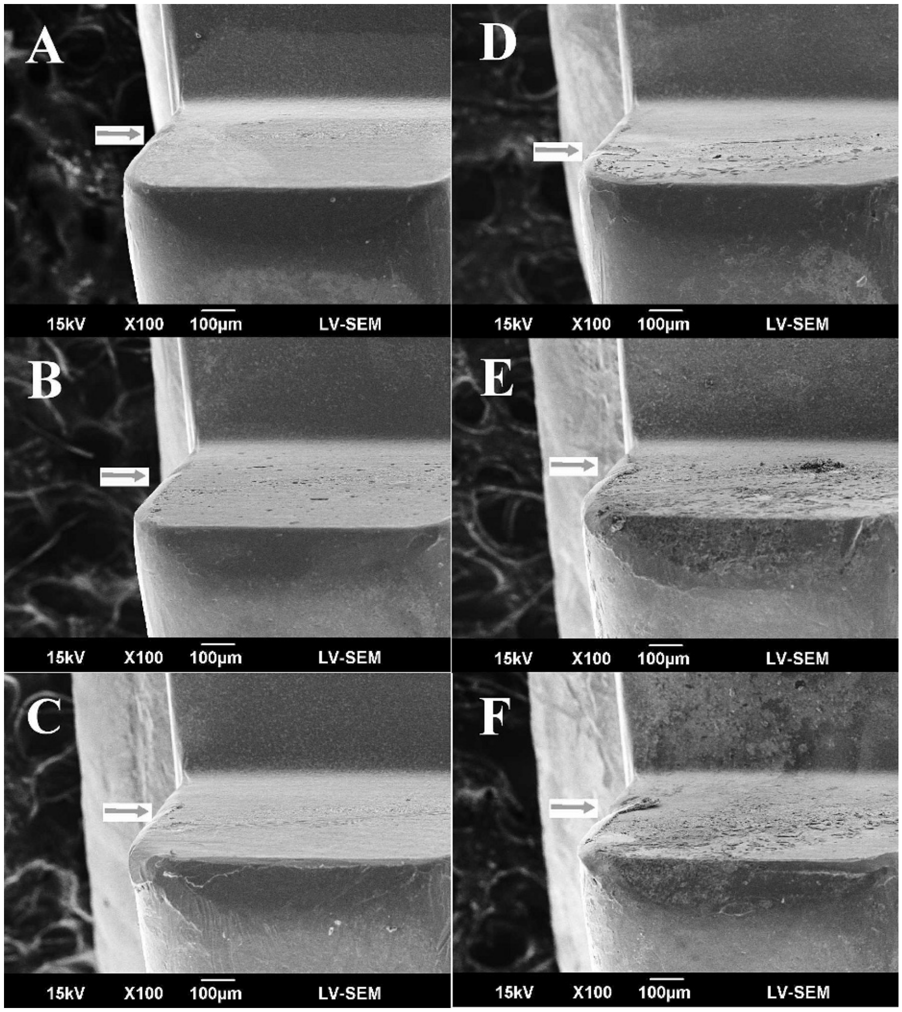

Figure 5. SEM images (100×) of Omni-arch (conventional) bracket slot under six oral conditions taken after friction test in the active configuration. Scratches are indicated by arrows. (A) 20°C dry state. (B) 37°C dry state. (C) 55°C dry state. (D) 20°C wet state. (E) 37°C wet state. (F) 55°C wet state.

Bevel Surface Observation by Scanning Electron Microscopy

Scanning electron microscopy (SEM) imaging showed that the five brands of brackets have five different types of bevel design (Figure 4). The conventional bracket has no bevel design (Figure 4A,F). Among the four brands of self-ligating bracket, the Clippy bracket has the smallest bevel angle (Figure 4B,G), and the Tenbrook T1 bracket has the largest bevel angle (Figure 4E,J). The Carriere and Damon brackets have almost the same bevel angles, and the Carriere and Tenbrook T1 brackets have a bump and an uneven bevel surface interface (Figure 4C,E,H,J).

After friction tests were carried out, no scratches were found affecting the slot surfaces of all five bracket types in the passive configuration. In the active configuration, scratched surfaces could be observed at the bevel angle of the conventional bracket under all oral environmental conditions after friction tests (Figure 5). The Clippy and the Carriere brackets only had scratched surfaces at 37°C and at 55°C in a dry and a wet state (Figure 6). The Damon and Tenbrook T1 brackets showed only small scratches at 37°C and 55°C in the wet state (Figure 7).

DISCUSSION

Study Design

A variety of experimental models have been used in in vitro frictional studies. Most model systems using fewer than three brackets have not provided sufficient data.[8–10,16,26,27] Thus, an experimental model using groups of five brackets was designed for the present study to simulate the buccal segment of the dental arch.

Experiments using models with straight aligned brackets may neglect the influence of the binding

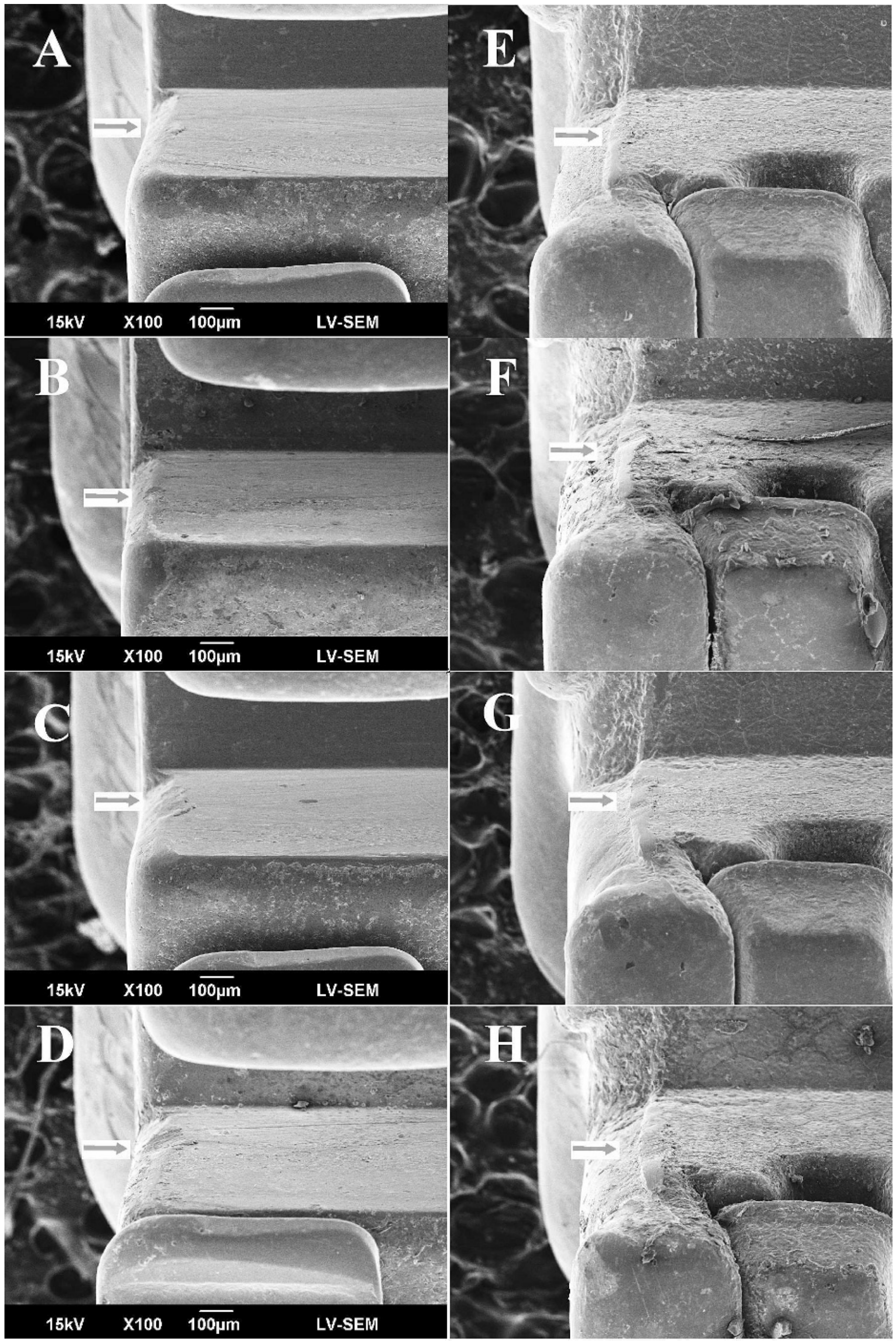

Figure 6. SEM images (100×) of Clippy (ASLB, left column) and Carriere (PSLB, right column) bracket slots under various oral conditions taken after friction test in the active configuration. Scratches are indicated by arrows. (A) (E), 37°C dry state. (B) (F), 37°C wet state. (C) (G), 55°C dry state. (D) (H), 55°C wet state.

effect.[12,28,29] With the model set in a straight aligned position, the conventional brackets had significantly higher frictional resistance because of the ligation force produced by elastomeric ligatures. The frictional forces of the self-ligating brackets were almost zero because no ligation force is generated by the active clip or the passive slide. These results are consistent with previous findings.[10,12,16,30,31] With the model set in a malaligned position, the ligation force from the elastomeric ligature is a contributing factor to the friction, and factors, such as bevel design and wire stiffness, both of which affect binding, are likely to increase the friction.

Effect of Bracket Bevel

In the high-canine simulation model, the presence of scratches, as shown by SEM imaging after the friction

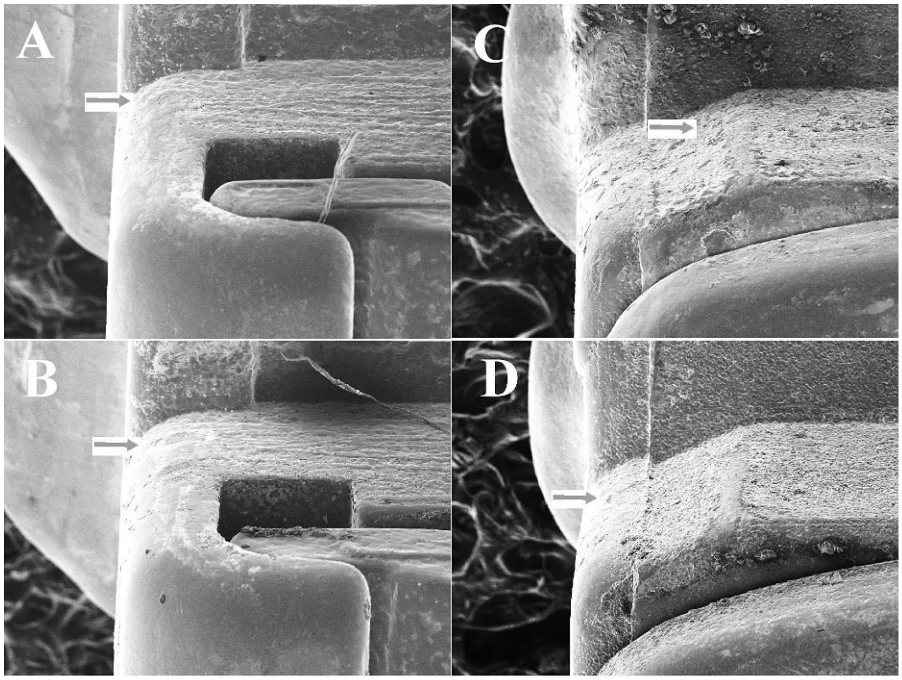

Figure 7. SEM images (100×) of Damon (left column) and Tenbrook T1 (right column) bracket slots under two different oral conditions taken after friction test in the active configuration. Scratches are indicated by arrow. (A) (C), 37°C wet state. (B) (D), 55°C wet state.

test, clearly demonstrates the effect of binding. Thorstenson and Kusy[11] found that rounded slot walls increase the critical contact angle. Based on the SEM observations, the conventional bracket without a bevel design had the smallest critical contact angle and thus had the highest frictional force, which resulted in the most scratches under each experimental condition. The bracket with the largest bevel, the Tenbrook T1, had the shallowest scratches and a significantly lower frictional force than the conventional Clippy and Carriere brackets.

Surface roughness also affects friction. Doshi and Bhad-Patil[27] evaluated the relationship between frictional resistance and surface roughness of four archwire alloys and three kinds of brackets. They found a positive correlation between bracket slot roughness and frictional resistance. The bump and the presence of an uneven interface on the bevel of the Carriere and Tenbrook T1 brackets increased the roughness of the bracket slot. This may explain why the Carriere bracket had a significantly higher frictional force than the Damon bracket, even though their bevels are approximately the same. This may also explain why the Tenbrook T1 bracket had a similar frictional force to the Damon bracket, even though the bevel of the former was larger than that of the latter.

Effect of Fluid Media

The role of saliva, lubricant, or adhesive, has been debated previously.[1] Pratten et al.[32] noted that friction increased in the presence of artificial saliva. They suggested that low saliva loads acts as a lubricant, while high saliva loads may increase friction if it is forced out from the contact surfaces between brackets and archwire.[32] In contrast, Tselepis et al.[33] found that the artificial saliva acted as a lubricant and reduced friction significantly. These inconsistent findings may be a result of the different artificial saliva solution formulations used and the technique used to apply the saliva to the experimental models.[33] In the present study, the thin saliva layer might explain the increased friction. When the archwires bind against the bevel surface under high load, artificial saliva might be forced out from the contact surfaces. Solids or suspensions of plaque also increase friction.[17]

Effect of Oral Temperature Changes

The load-deflection behavior of superelastic NiTi wires is significantly affected by temperature. The loads produced by NiTi wire were 60 cN/mm at 20°C, 102 cN/mm at 35°C, and 112 cN/mm at 50°C.[21] Meling and Odegaard[22] found that short-term heating has a prolonged effect during the recovery phase. It is believed that an increase in temperature increases the stiffness of the NiTi wire, which ought to result in a greater binding effect and higher frictional force. The SEM imaging showed that the detected scratches became deeper as the temperature increased from 20°C to 55°C, which supports the earlier suggestion.

CONCLUSIONS

- The conventional brackets showed the highest frictional force levels.
- The smaller and rougher bevel angle of the self-ligating brackets led to significantly higher frictional levels.
- Frictional force was higher in the wet state than in the dry state.
- Frictional force increased significantly as the temperature increased from 20°C to 55°C in the active configuration.
- SEM imaging showed that the presence of deeper binding scratches was correlated with a small bevel angle, with the system being in the wet state and with a higher temperature.
- The clinical conclusions based on our results are that the larger bevel angle of the self-ligating brackets results in lower friction and that a higher oral temperature increases friction in the active configuration.

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