An *in vitro* comparison of the frictional forces between archwires and self-ligating brackets of passive and active types

Tsui-Hsien Huang*,**, Hoi-Shing Luk**, Ying-Chi Hsu** and Chia-Tze Kao*,**

*School of Dentistry, College of Oral Medicine, Chung Shan Medical University, Taichung, Taiwan and
**Orthodontics Department, Chung Shan Medical University Hospital, Taichung, Taiwan

**Correspondence to:** Chia Tze Kao, School of Dentistry, Chung Shan Medical University, 110, Chien Kuo N Road, Taichung, Taiwan. E-mail: ctk@csmu.edu.tw

**SUMMARY** The aim of this study was to compare the static and kinetic frictional forces generated by various contemporary designs of self-ligating brackets (SLBs) and different wire alloys. In total, six different brackets (four passive type SLB, one active SLB, and one conventional bracket) were investigated using stainless steel, nickel–titanium, and titanium–molybdenum alloy archwires of several sizes. The friction forces were measured by sliding on a bracket–wire combination system in an EZ instron testing machine. A scanning electron microscope (SEM) was used to examine the wear effects of the wall surfaces of bracket slots. Energy-dispersive spectroscopy (EDS) was used to identify the elemental compositions of the bracket surfaces. The data were collected and statistically analysed using analysis of variance. The results of static and kinetic frictional forces were lower in passive type SLBs (*P*< 0.05), except in the Smart Clip bracket. The wire materials or wire dimensions in the present study showed similar friction forces with no statistical differences (*P* > 0.05). The wearing effects were not obviously found in bracket slots under SEM observation. Only conventional brackets and mini-Clippy SLB revealed nickel ions via EDS analysis. This study shows that passive SLBs are associated with lower static or kinetic friction forces than those of active SLBs or conventional brackets. Wear on the bracket slots was not observed in the present study.

**Introduction**

Friction is described as an opposing and parallel force when one surface moves against another (Bhushan, 1999). There are two types of friction: static and kinetic. The static frictional force is defined as the smallest force needed to start a motion between two solid surfaces. The kinetic friction force is defined as the force needed to resist the sliding motion of one solid object over another at constant speed (Dowlig *et al.*, 1998; Redlich *et al.*, 2003).

In orthodontic tooth movement, friction (static or kinetic) results from the interaction between an archwire and the sides of an orthodontic bracket or a ligature. Friction is a small part of the resistance to overall movement that results when a bracket slides along an archwire. The force of resistance to the sliding movement is by 1. friction, which comes from the contact of a wire with the bracket surface; 2. binding, which involves the tipping of the tooth tips when the flexing of the wire contact between the wire and the corners of the bracket; and 3. notching, which involves the permanent deformation of the wire at the wire–bracket corner interface (Kusy and Whiteley, 1999). The outcome of the frictional/sliding resistance is accompanied by damages to the contacting surfaces, which is mostly manifested by the wearing off of the surfaces.

For many years, the problem of friction has been studied by researchers, identified by orthodontists, and recognized by suppliers of orthodontic products who modified bracket designs accordingly in some cases. Conventional ligated edgewise brackets increased levels of frictional resistance via the elastomeric attachment between the bracket and the archwire (Pizzoni *et al.*, 1998; Schumacher *et al.*, 1999; Michelberger *et al.*, 2000). To reduce unwanted friction, various self-ligating bracket (SLB) systems have been developed. The new bracket shapes currently on the market must be subjected to scientific investigation as the clinical practitioner expects to be informed of their friction characteristics (Schumacher *et al.*, 1999).

Self-ligation eliminates the requirement for an elastomeric attachment and is associated with considerably reduced friction when used with different archwires (Read-Ward *et al.*, 1997; Thorstenson and Kusy, 2001; Henao and Kusy, 2004; Khambay *et al.*, 2004). According to bracket structures, SLBs are classified as an active type, interactive type, or passive type. The benefits of SLBs are that they may offer more archwire engagement, which requires less chair-side assistance and enables faster archwire removal and ligation (Harradine, 2001; Turnbull and Birnie, 2007). There is some debate, however, as some studies report that an overall reduction in treatment time is associated with these appliances (Chen *et al.*, 2010), while others do not support such findings. Current evidence suggests that SLBs only...
clinical benefits are in the reduction of chair time and the enhanced control of mandibular incisor angulation (Pandis et al., 2007; Chen et al., 2010; Fleming and Johal, 2010).

Only a few reports have comparatively evaluated the frictional forces of SLB designs combined with different archwire alloys. The purpose of the present study was to compare the static and kinetic frictional forces generated by various contemporary designs of SLBs and different wire alloys.

Materials and methods

The following maxillary right and left first bicuspids SLBs were used in the study: Tenbrook SLB T1 (Axis; OrthoClassic, McMinnville, Oregon, USA), Damon SL III MX (Sybron Dental Specialties Ormco, Orange, California, USA), mini-Clippy (TOMY International, Toyko, Japan), Smart Clip (2nd generation; 3 M Unitek, Monrovia, California, USA), Carriere LX (OrthoOrganizer, Carlsbad, California, USA), and OPA-K (TOMY International). All the brackets used had 0.022 inch slots (Table 1).

The passive type SLB used in this study were Tenbrook SLB T1, Damon SL III MX, Carriere LX, and Smart Clip. The active type SLB used in this study was Clippy. OPA-K was a conventional stainless steel pre-adjusted bracket, which was used as the control.

The following three types of straight orthodontic archwire alloys were evaluated: stainless steel (SS), nickel–titanium (NiTi), and titanium–molybdenum alloy (TMA; Sybron Dental Specialties Ormco Co.). The sizes of the SS wires were 0.016 × 0.022, 0.017 × 0.025, and 0.018 × 0.025 inches (3M Unitek). The sizes of NiTi wires were 0.018 × 0.025 inches low hysteresis (LH; TOMY International) and 0.019 × 0.025 inches heat activated (HA; 3M Unitek). The size of the TMA wire

<table>
<thead>
<tr>
<th>Bracket design</th>
<th>Name of bracket</th>
<th>Manufacturer</th>
<th>Archwire size</th>
<th>Archwire materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-ligating Passive type</td>
<td>Axis (Tenbrook self-ligating bracket)</td>
<td>Orthoclassic, McMinnville, Oregon, USA</td>
<td>0.016 × 0.022 0.017 × 0.025 0.018 × 0.025 0.019 × 0.025 0.017 × 0.025</td>
<td>Stainless steel (SS) Stainless steel (SS) Stainless steel (SS) HA (heat active NiTi) Titanium–molybdenum alloy (TMA)</td>
</tr>
<tr>
<td></td>
<td>Damon SL III MX</td>
<td>Sybron Dental Specialties Ormco, Orange, USA</td>
<td>0.016 × 0.022 0.017 × 0.025 0.018 × 0.025 0.019 × 0.025 0.017 × 0.025</td>
<td>Stainless steel (SS) Stainless steel (SS) HA (heat active NiTi) Titanium–molybdenum alloy (TMA)</td>
</tr>
<tr>
<td></td>
<td>Carriere LX</td>
<td>OrthoOrganizer, Carlsbad, California, USA</td>
<td>0.016 × 0.022 0.017 × 0.025 0.018 × 0.025 0.019 × 0.025 0.017 × 0.025</td>
<td>Stainless steel (SS) Stainless steel (SS) HA (heat active NiTi) Titanium–molybdenum alloy (TMA)</td>
</tr>
<tr>
<td></td>
<td>Smart Clip</td>
<td>3M Unitek, Monrovia, California, USA</td>
<td>0.016 × 0.022 0.017 × 0.025 0.018 × 0.025 0.019 × 0.025 0.017 × 0.025</td>
<td>Stainless steel (SS) Stainless steel (SS) HA (heat active NiTi) Titanium–molybdenum alloy (TMA)</td>
</tr>
<tr>
<td>Active type Mini-Clippy</td>
<td>Tomy International, Toyko, Japan</td>
<td>0.016 × 0.022 0.017 × 0.025 0.018 × 0.025 0.019 × 0.025 0.017 × 0.025</td>
<td>Stainless steel (SS) Stainless steel (SS) HA (heat active NiTi) Titanium–molybdenum alloy (TMA)</td>
<td></td>
</tr>
<tr>
<td>Conventional ligature OPA-K</td>
<td>Tomy International</td>
<td>0.016 × 0.022 0.017 × 0.025 0.018 × 0.025 0.019 × 0.025 0.017 × 0.025</td>
<td>Stainless steel (SS) Stainless steel (SS) HA (heat active NiTi) Titanium–molybdenum alloy (TMA)</td>
<td></td>
</tr>
</tbody>
</table>

Table 1  The bracket and archwire applied in study.
was 0.017 × 0.025 inches (Sybron Dental Specialties Ormco).

For each bracket–archwire combination, 10 observations were made. Each archwire sample was drawn only once through a bracket. In total, 720 bracket–archwire readings were made in this study. The frictional evaluation was performed according to the test protocol described by our previous study (Kao et al., 2006). Testing was performed on an EZ test machine (Shimadzu, Tokyo, Japan) with a crosshead speed of 10 mm/minute over a 5 mm stretch of archwire. A plumb line was hung to ensure that the bracket mount was parallel to the vertical line scribed on the steel bar base of the bracket mount assembly. A 5 N load cell was calibrated to be between 0 and 5 N, and the archwire was drawn through the bracket as the crosshead moved inferiorly at 10 mm/minute (Figure 1). This crosshead speed was selected because a previous study found no significant differences between crosshead speeds ranging from 0.5 to 50 mm/minute. The experimental conditions were performed in room temperature 22–25°C, and the humidity condition was 50–60 per cent (Cengiz and Ucar, 2006).

Emphasis was placed on aligning the archwires so that the samples were parallel to the vertical framework of the machine. The brackets were pulled vertically by a loop of 0.018 inch stainless steel wire. The forces required to initiate and maintain the movement of the brackets over the 5 mm test distance were measured. The programme was set to highlight the maximum frictional force at initial movement, which was taken to represent the peak static frictional resistance. For each bracket–wire combination, a new wire and bracket were used.

**Morphology observation and energy-dispersive spectroscopy analysis**

The morphologies of the tested brackets were observed by scanning electron microscopy (SEM). SEM evaluation focused on the wearing effects and the base material. Brackets were embedded in an epoxy resin in a horizontal direction. After the setting of the resin, the embedded brackets were ground with silicon carbide (SiC) papers (600, 800, 1000, 1200, and 2000 grid) under continuous water cooling until the floors of the bracket slots were exposed. Energy-dispersive spectroscopy (EDS) was used to identify the elemental compositions of the bracket surfaces.

**Statistical analysis**

The load cell registered the force levels needed to move the wires through the brackets, and these values were stored on a computer hard disk. The data were then analysed using a statistical package (Primer; McGraw-Hill, New York, USA). A completely randomized one-way analysis of variance was used to test for significant differences among the bracket wire types. This was followed by a Student–Newman–Keuls multiple comparison of means at $P < 0.05$ to determine differences among the groups.

**Results**

**Static friction force**

The result illustrated in Figure 2 represents the active and passive types of SLB and the associated static and kinetic friction forces. In measuring static friction force, the right
and left first bicuspids showed no statistical differences ($P > 0.05$). The passive type SLB (Axis, Damon SL III MX, and Carriere LX) showed a lower static friction force than the active SLB (mini-Clippy) and the control bracket ($P < 0.05$), except for the Smart Clip SLB.

The bracket–SS archwire combination groups showed higher static friction forces in the Smart Clip, mini-Clippy, and control (OPA-K) groups ($P < 0.05$). There was a tendency for SLB static friction to increase as the size of the SS archwire increased. A similar static friction force was seen in the same SLB bracket combined with SS, TMA, LH, and HA archwires ($P > 0.05$).

**Kinetic friction force**

In measuring kinetic friction forces (Figure 3), the right and left first bicuspids showed no statistical differences ($P > 0.05$). The active type SLB or control bracket showed higher kinetic friction than passive type SLB, except for the Smart Clip SLB ($P < 0.05$). The Smart Clip SLB showed the highest kinetic friction forces among the passive type
SLB ($P < 0.05$). A similar kinetic friction force was seen in the same SLB bracket combined with SS, TMA, LH, and HA archwires ($P > 0.05$).

**SEM morphology observation**

A post-frictional test of bracket morphologies is displayed in Figure 4. The Axis SLB surface showed an intact structure under low magnification ($\times 120$; Figure 4A and 4B) but displayed increased roughness under $\times 500$ magnification (Figure 4C). A similar result was seen with Carriere (Figure 4A and 4B), Damon III MX (Figure 4A and 4B), mini-Clippy (Figure 4A and 4B), Smart Clip (Figure 4A and 4B), and OPA-K (Figure 4A and 4B). Figure 4D shows the morphology of metal crystal under $\times 2000$ magnification.

**EDS analysis**

EDS analysis showed that the main components of Axis, Damon III MX, Carriere, and Smart Clip SLB were...
ferric and chromium ions in Figure 5. The EDS analysis of mini-Clippy and OPA-K SLB showed nickel ions (Figure 5).

**Discussion**

This study shows that passive SLB exhibits low static and kinetic friction forces. It is suggested that binding effect of
active SLB might be higher than that of passive SLB. In Frank and Nikolai (1980) and Tidy (1989), studies showed friction or binding may appear in orthodontics when maligned bracket are engaged onto an archwire, during bodily tooth movement along archwire or when active torque is applied (Frank and Nikolai, 1980; Tidy, 1989). Cash described that binding may occur at point contacts are formed between bracket, archwires, and/or ligatures producing a force couple that resists sliding. This binding force may block tooth movement and may result in damage to the surface of the orthodontic appliance resulting notching (Cash et al., 2004). In Fidalgo et al. study, the orthodontic brackets and wire submitted to mechanical traction tests were evaluated by using a profilometer to check the changes on the surface. The results of their study showed a decreased in the roughness of wire and brackets tested (Fidalgo et al., 2010). To clinician, the binding effect of SLB is lower and reducing quickly may provide better orthodontic effects.

The Smart Clip SLB, although classified as a passive type SLB, showed high levels of friction. The reason may be its structure because Smart Clip designs are different than other passive SLB designs. The Smart Clip SLB structure design consists of two clips at mesial and distal wings to hole the archwire. When the wire was in the SLB slot, the wire–bracket contact interface located at the bracket wings was increased. As the sliding occurred, the wire was seen to bind to the bracket at the wings. This increases the friction associated with the Smart Clip brackets. When binding occurred between the wire and the bracket, a wearing effect was seen on the surface. In this study, the surface of the bracket did not show any wear under SEM observation. But some bracket slots showed irregular levels of roughness.

Higher frictional forces for active and passive SLBs with NiTi wire were observed in comparison to SS (Thomas et al., 1998). Damon SL II and Smart Clip (passive SLB) and In-ovation and Time (active SLB) displayed distinct differences in frictional parameters in comparison to NiTi (Krishnan et al., 2009). This agreed with our present findings. A study that evaluated Damon SL II and Smart Clip with NiTi archwires in various cross sections, with first-order rotation, second-order intrusion, and third-order labial crown inclinations, showed that there were no significant bracket differences in terms of friction once binding occurred in the second-order distances (Yeh et al., 2007).

In orthodontic tooth movement, sliding along an archwire is not continuous but occurs as a series of intermittent movements. Thus, the bracket–archwire relationship is needed to overcome the static friction and binding, enabling sliding movements. At present, inevitable wear occurs on brackets or archwires, which increases friction and binding in subsequent movements. In our study, the observed bracket–wire systems after EZ testing were associated with fewer wearing effects on bracket or wire surfaces under microscopic examination. This may be due to the wire sizes being smaller than bracket slot sizes or due to the test system consisting of only one bracket and one straight wire. Such parameters are different than an oral environment in vivo, which consists of many brackets with a curved archwire.

The friction between the bracket and the archwire can result in loss of force of up to a 50 per cent (Keith et al., 1993). Although the normal periodontal blood pressure is 25 g, in an optimal bracket–wire combination system, approximately 40 g of frictional force must be applied to the tooth to initiate movement (Taylor and Ison, 1995; Wadhwa et al., 2004). It is understood that close to 15 g of force is needed to overcome the frictional resistance or binding forces. In the present study design consisting of a single bracket–wire test, the frictional resistance may have been lower. It is different than a multiple bracket–wire system. After overcoming the frictional resistance and binding forces, a multiple bracket–wire system’s residual force is also difficult to accurately calculate. As a result, optimal levels of force for tooth movement are difficult to achieve in clinical settings.

The OPA-K bracket was the conventional control bracket used in this study. The static or kinetic friction forces associated with OPK were higher than for other SLB, except for the Smart Clip bracket and Clippy bracket. An elastomeric modular ligation was used to tie the OPK bracket to the wire. The elastomeric modules lose approximately 50 per cent of their initial force within 24 hours of load application, with the force decreasing from 30 to 40 per cent after 4 weeks (De Genova et al., 1985). Because the frictional force observed in conventional brackets is directly related to the force of the elastomeric modules, there can be a concomitant reduction in friction after 4 weeks of intraoral use clinically (Krishnan et al., 2009).

Because there are many factors which affect the friction force. One of them is the different material surface characteristic. In present study, the SEM applications were to shown and understanding the surface topography of SLB. To discover if there were any connections within surface topography and friction force. EDS technique is used to identify the elemental composition of a sample or small area of interest on the sample. The EDS analysis was to demonstrate the composition of SLB. It is to know if different metal compositions may affect the friction or not in present study.

Nickel ions may be released from the metal brackets (Huang et al., 2001), which can cause an allergic reaction, cell toxicity, or mutagenicity (Burgardner and Lucas, 1995). Approximately 10 per cent of the general population exhibits a hypersensitive reaction to nickel. To prevent such adverse reactions, the nickel ions were gradually added onto the metal bracket materials. The present EDS test showed that Clippy SLB and OPA-K conventional brackets were associated with nickel ions. The rest of the SLB did not display nickel ions. It is recommended that nickel-hypersensitive patients not be exposed to brackets that may increase the risk of reactions. To reduce the corrosion and to increase the hardness of metal bracket surfaces, a diamond-like coating (DLC) was studied on.
the bracket surfaces (Huang and Kao, 2010). A wearing effect on the bracket surfaces was noticed. Future studies may consider applying DLC on bracket slots in order to observe their physical characteristics.

The present study does not replicate the clinical orthodontic situation. The limitations of present study include a frictional testing system that did not include wet condition and the fact that the testing archwire was a straight not a curved wire. The clinical application of this in vitro study is that if the sliding technique is applied on orthodontic tooth movement, the orthodontist may consider the passive type of SLB.

Conclusions

This study showed that passive SLBs are associated with a lower static or kinetic friction force than active SLBs or conventional brackets. Wear on the bracket slots was not observed.

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