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In vitro evaluation of the frictional forces between brackets and archwire with three passive self-ligating brackets

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SUMMARY The aim of this *in vitro* study was to evaluate the frictional forces between bracket and archwire that included three passive self-ligating brackets (Damon SL2 SDS). The brackets were individually bonded to a brass mount using a preformed 0.021 × 0.025 inch stainless steel wire jig in order to exclude adverse tipping or torsion. The central bracket was positioned 1 mm higher than the others, in order that the three brackets were vertically unaligned. Thirty-six similar set-ups including in total 108 brackets were investigated using the same wire: copper (nickel–titanium) 0.014 inches. A testing machine was designed and constructed to measure the frictional forces between the wire and the three-bracket set-up. Twelve set-ups were tested to measure kinetic frictional forces between the wire and unaligned passive self-ligating brackets used in the closed position. The frictional properties of two sets of 12 three-bracket set-ups (control) were tested and measured with an open slide and conventional ligation. A stainless steel ligature wire was used in the former, while elastomeric modules were employed in the latter.

One-way analysis of variance showed a significant effect of ligation mode on the frictional properties of the three-bracket set-ups ($P < 0.001$). *Post hoc* pairwise comparison showed that the frictional forces arising from passive self-ligation were significantly lower ($P < 0.01$) than those resulting from elastic ligation. The same result was achieved when comparing self-ligation and metallic ligation ($P < 0.01$). No significant difference was found when comparing elastic and metallic ligation.

Introduction

When sliding mechanics are used during orthodontic treatment, friction arising from the bracket and the archwire affects the amount of force delivered to the teeth (Frank and Nikolai, 1980).

Friction is defined as the force resisting motion when an object moves tangentially against another (Besançon, 1985). Friction is proportional to the normal force acting perpendicular (Giancoli, 1980) to the direction of motion on the contacting surface (Besançon, 1985). Frictional force is the product of the friction coefficient and normal force. The resistance to friction comes not only from static force but also from kinetic force. Static friction results when movement is started from a stationary position (its modulus equals that of the force required to start movement), while kinetic friction is that needed to keep the object in linear uniform motion. The force resulting from kinetic friction is thus less intense than that resulting from static friction (Besançon, 1985).

Several variables influence frictional force between a bracket and archwire, such as bracket and wire material (Angolkar *et al*., 1990; Kusy *et al.*, 1991, 1992; Prososki *et al.*, 1991; Kusy and Whitley, 1997; Cacciafesta *et al.*, 2003; Thorstenson and Kusy, 2003), the dimension and shape of the slot and wire (Kusy and Whitley, 1997, 1999; Cacciafesta *et al.*, 2003), second order angulation between the slot and the wire (Frank and Nikolai, 1980; Sims *et al.*, 1993; De Franco *et al.*, 1995; Pizzoni *et al.*, 1998; Thorstenson and Kusy, 2001, 2002a,b; Redlich *et al.*, 2003), and dry and wet conditions (Kusy *et al.*, 1991; Downing *et al.*, 1995; Thorstenson and Kusy, 2001, 2002a,b).

The ligation method of the bracket can significantly influence friction between the bracket and archwire. Several studies have shown that self-ligating brackets result in a significant reduction in friction compared with conventional tied Siamese brackets (Berger, 1990; Bednar *et al.*, 1991; Sims *et al.*, 1993; Voudouris, 1997; Thomas *et al.*, 1998).

Conventional ligation methods (stainless steel ligature wires or polymeric O-rings) apply a force to the archwire pushing it against the depth of the slot, thus increasing friction.

Not all self-ligating brackets behave in the same way. Active self-ligating brackets (e.g. Speed and Time) showed higher frictional forces compared with passive self-ligating brackets (Damon SL2 SDS), when the archwire was greater than 0.017 inches (Sims *et al.*, 1993; Thomas *et al.*, 1998). This difference in friction is due to the presence of the spring clip closing the slot and contacting the archwire when this is greater than 0.017 inches. On the contrary, passive self-ligating brackets have a slide to close the slot, thus transforming it into a 0.022 × 0.028 inch tube.

According to some authors (Berger, 1994; Harradine and Birnie, 1996; Damon, 1998), treatment time is shorter when self-ligating brackets are used. This reduction is probably due to the absence of a ligating force. These findings were confirmed clinically by Eberting *et al.* (2001) who demonstrated that treatment with passive self-ligating brackets resulted in a significantly shorter treatment time. The aim of this *in vitro* study was to evaluate the frictional forces arising from the archwire and three identical passive self-ligating brackets, which were not vertically aligned.

Material and methods

Three passive self-ligating brackets (Damon SL2 SDS, Ormco, Amersfoort, Netherlands) were assembled in the same set-up (Figure 1) to measure the frictional forces between the set-up and archwire. The central bracket was positioned 1 mm higher than the others along a horizontal line in order to have three unaligned vertical brackets. The interbracket distance was 11 mm. The experiment was performed using three brackets since they can simulate an unaligned segment of the dental arch. Thirty-six such set-ups, in total 108 Damon SL2 brackets, were studied (Table 1). The same wire (copper nickel–titanium 0.014 inch 'A' Company SDS, Ormco) was employed in all experiments.

Twelve three-bracket set-ups were tested in order to measure the kinetic frictional forces between the wire and unaligned self-ligating brackets. Twenty-four three-bracket configurations were used as the control; the frictional properties of which were measured with the open slide of the self-ligating brackets and with the wire kept in the slot by conventional ligation (Thorstenson and Kusy, 2001).

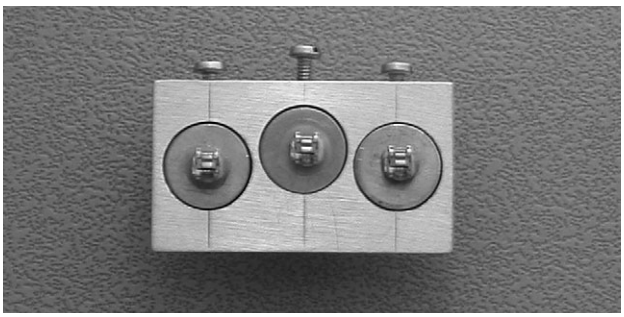

Figure 1 Set-up including three passive self-ligating brackets. The tested brackets were individually bonded to a brass mount using a preformed 0.021 × 0.025 inch stainless steel wire jig in order to exclude adverse tipping or torsion moments.

Table 1 Descriptive statistics of the kinetic frictional forces (*n*).

Ligation mode	Number of observations	Mean	Standard deviation	Minimum	Median	Maximum
Self-ligation	12	1.639	0.379	1.16	1.61	2.42
Elastic ligation	12	4.718	0.665	3.57	5.01	5.5
Metallic ligation	12	5.664	1.469	3.92	5.36	9.43

Twelve three-bracket set-ups were tested with stainless steel ligature wire (preformed 0.010 inch SDS, Ormco) and the other 12 with elastomeric modules (Preformed power 'O' 110 SDS, Ormco). All the stainless steel ligature wires were tightened by the same operator (RN).

Each bracket and wire were tested only once to exclude the influence of wear. The tested Damon SL2 brackets were stainless steel and had a 0.022 × 0.028 inch slot with a prescribed torque of −7 degrees and +2 degrees angulation. Only one type of bracket was used in this research in order to avoid lack of homogeneity in the data due to different torque and angulation prescription, and different bracket and interbracket widths. Before testing, the bracket, archwire, and ligature wires were cleaned with ethanol to remove surface debris.

The test brackets were bonded individually with a composite resin (Enlight LV SDS, Ormco) to a brass mount, which was cylindrical in shape (diameter 10 mm, height 4 mm) in which a hole was preformed to retain the resin. The bracket and bonding resin were placed on the brass mount using a specially designed stainless steel jig in order to align the slot with the 0.021 × 0.025 stainless steel wire (Figure 2). After each bracket was correctly positioned, the resin was polymerized to avoid any adverse tipping or torsion moments that could influence frictional force (Sims *et al.*, 1993). The brackets were then correctly positioned in the three-bracket set-up, ensuring that an appropriate assembly was obtained with the testing machine to measure the frictional forces without tipping and torque.

The testing machine consisted of a carriage, with the test set-up running along two vertical, parallel rods by four smooth linear ball bearings (Figure 3). The carriage weight acts on a force sensor through a vertical rod to which it is firmly tied. The output from the sensor is read, through an opposite interface, by a personal computer. The wire, passing through the brackets assembled on the carriage, is fixed to a moving platform, driven by a computer-controlled stepper motor. Each wire was assembled on the mobile set-up maintaining a tension of 150 g. The stepper motor moved (upward and downward alternately) the moving platform at a fixed speed of 4 mm/minute. Due to the frictional coupling between the moving wire and the

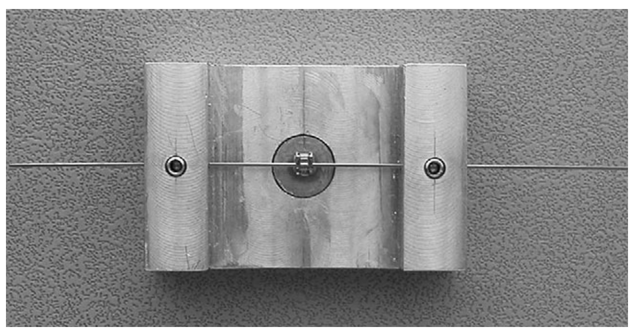

Figure 2 Stainless steel jig.

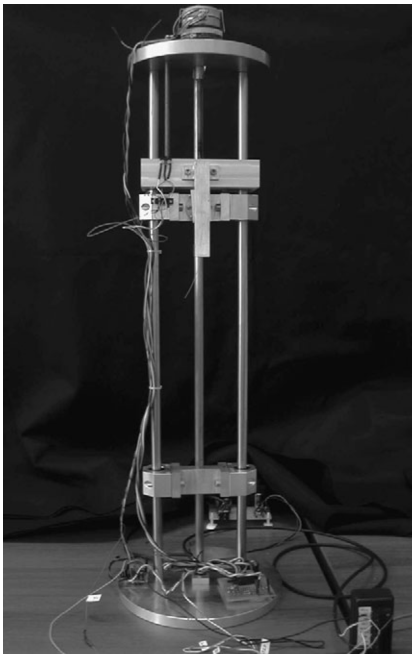

Figure 3 Testing apparatus.

brackets, the force measured by the sensor will change during motion. Fifty per cent of the difference between the force acting on the sensor during upward and downward motion is equal to the friction. The testing machine was housed in a special box so that the experiment was carried out at a constant temperature of 37°C and in the dry state. All the data were processed and recorded on software specially designed for this study.

Statistical analysis, including the mean and standard deviation (SD), was carried out. One-way analysis of variance (ANOVA) was used to evaluate the effects of the three different ligation types on frictional forces. *Post hoc* comparison between pairs of means was made with Scheffe's test, to determine different kinds of ligation mode. Statistical significance was set at $P < 0.01$.

Results

The descriptive statistics of kinetic frictional forces on the different ligation modes are given in Table 1. One-way ANOVA showed a significant ligation mode effect (Table 2) on the frictional properties of the tested three-bracket set-up ($P < 0.001$). *Post hoc* pairwise comparison showed that frictional forces arising from passive self-ligation were significantly lower than those resulting from elastic and metallic ligation ($P < 0.01$). No significant difference was found when comparing elastic with metallic ligation (Table 3).

Table 2 One-way analysis of variance (ANOVA, single factor).

Summary						
Groups	Count	Sum	Average	Variance		
Self-ligation	12	19.67	1.639	0.144		
Elastic ligation	12	56.61	4.718	0.442		
Metallic ligation	12	67.97	5.664	2.157		
ANOVA						
Source of variation	Sum of square	df	Mean of square	*F*	*P* value	Critical *F* value
Between groups	106.292	2	53.146	58.122	<0.001	3.285
Within groups	30.175	33	0.914			
Total	136.466	35				

Table 3 *Post hoc* pairwise comparison (Scheffe's test).

Comparisons	*F* value	Critical $F_{0.01}$ value
Self-ligation versus elastic ligation	33.13	5.312**
Self-ligation versus metallic ligation	55.17	5.312**
Elastic ligation versus metallic ligation	2.79	5.312 (NS)

NS, not significant. $^{**}P < 0.01$.

Discussion

Previous *in vitro* investigations demonstrated lower frictional forces when one self-ligating bracket slides against a wire (Frank and Nikolai, 1980; Sims *et al.*, 1993; Pizzoni *et al.*, 1998; Thomas *et al.*, 1998). These studies are clinically relevant because they prove how passive self-ligating brackets can improve orthodontic sliding mechanotherapy during space closure (in extraction or distalization treatment). It is important to know the magnitude of frictional forces when sliding mechanics are used as a certain force is required to overcome frictional force to allow tooth movement.

The basis of this laboratory study consisted of employing three unaligned brackets, which would seem to be the most suitable representation of an unaligned segment of the dental arch. The finding of significantly lower frictional forces during passive self-ligation, compared with elastic and metallic ligation, has clinical relevance.

In all straightwire techniques, the alignment of one part of the dental arch depends on the amount of frictional force in the adjacent segment of the arch, since the alignment phase implies the slide of the wire in the nearby segment of the arch. The easier the wire slides, the faster the teeth are aligned. When the wire slides through passive self-ligating brackets, the presence of lighter frictional forces in one part of the arch (e.g. canine and the two premolars) increases the alignment of the adjacent arch (e.g. anterior teeth). This could partly explain the clinical findings of Eberting *et al.* (2001), who demonstrated that orthodontic treatment is significantly faster with passive self-ligating brackets.

Descriptive statistics on the kinetic frictional forces revealed high SDs when metallic ligation was used despite standardization of the fixation of the metallic ligature. This result shows that it is not easy to standardize the magnitude of the grasping force of a metallic ligature and consequently of friction.

Conclusion

1. The *in vitro* set-up of three vertically unaligned brackets shows significantly lower frictional forces for passive self-ligation compared with elastic or metallic ligation.
2. When the wire slides through passive self-ligating brackets, the presence of lighter frictional forces in one part of the arch increases alignment and levelling.
3. No significant differences, in terms of frictional forces, were found when comparing metallic and elastic ligation.

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