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A comparative *in vitro* study of the frictional characteristics of two types of self-ligating brackets and two types of pre-adjusted edgewise brackets tied with elastomeric ligatures

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SUMMARY The aim of this *in vitro* study was to investigate the frictional characteristics of two types of self-ligating brackets ('A' Company Damon SL and Adenta Time brackets) and two types of pre-adjusted edgewise brackets (TP Tip-Edge and 'A' Company Standard Twin brackets). The test brackets were glued to steel bars and aligned using a preformed jig. Five combinations of archwire size and material were used (0.014-inch nickel titanium, 0.0175-inch multistrand stainless steel, 0.016 × 0.022-inch nickel titanium, 0.016 × 0.022-inch stainless steel and 0.019 × 0.025-inch stainless steel wires). The wires were drawn through the brackets and the frictional resistance was measured using an Instron 1193 testing machine. The data were analysed using a one-way analysis of variance and Scheffe's multiple comparison of means test.

The results revealed that the Damon brackets demonstrated the lowest friction for all dimensions of test wires followed by the Time bracket. The 'A' Company Standard Twin brackets produced the highest friction with all wire dimensions tested, followed by the Tip-Edge bracket. With all brackets the 0.016 × 0.022-inch nickel titanium wires produced a higher frictional resistance than the 0.016 × 0.022-inch stainless steel wires.

The results indicate that these self-ligating brackets produce less frictional resistance than elastomerically-tied pre-adjusted edgewise brackets.

Introduction

A wide range of metal, polymeric and ceramic edgewise brackets are now available. Archwires are conventionally ligated into edgewise brackets with steel or elastomeric ligatures. Although the first self-ligating bracket was the Russell lock (Stolzenberg, 1935), there has been renewed interest in the development of self-ligating brackets by manufacturers and orthodontists since the mid 1970s. Self-ligating brackets are ligatureless bracket systems that have a mechanical device built into the bracket to close off the edgewise slot. Originally, these brackets may have been developed to reduce the dependence on learning the use of ligature lockers. However, an unforeseen benefit of self-ligating bracket systems has been their low frictional resistance. Two types of self-ligating brackets have been developed; those that have a spring clip which presses against the archwire such as the Hanson SPEED bracket and the Adenta Time bracket (Adenta, GmbH, Germany), and those whose self-ligating clip does not press against the wire such as the Activa bracket ('A' Company, San Diego, USA) and the more recently developed Damon SL bracket ('A' Company). Not surprisingly, less friction is generated by those brackets whose clip does not

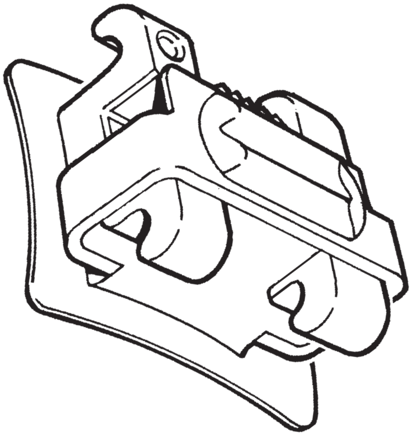

Figure 1 ‘A’ Company Damon SL bracket.

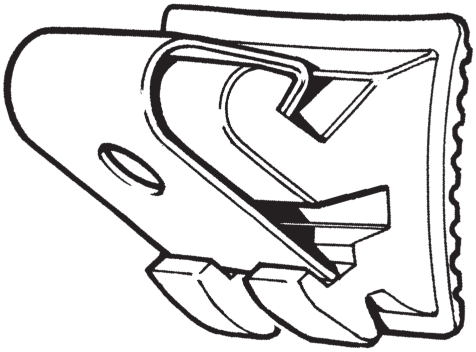

Figure 2 Adenta Time bracket.

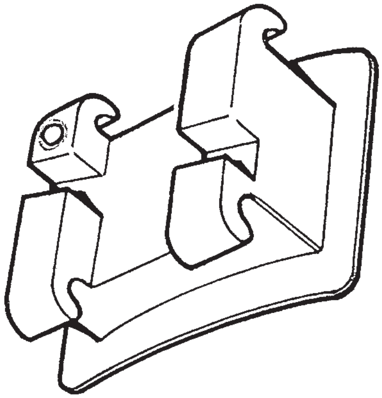

Figure 3 ‘A’ Company Standard Twin bracket.

exert spring pressure on the archwire (Sims *et al.*, 1993, 1994).

The Damon SL bracket is a second generation self-ligating bracket which does not exert spring pressure on the archwire. This bracket uses a self-ligating archwire cover which slides vertically in an occlusal direction in the upper arch and in a gingival direction in the lower arch (Figure 1). When the cover is closed, the slot is converted into a rectangular edgewise tube through which the archwire passes. This bracket will supersede the Activa bracket which have a hinged self-ligating cover rotating around the body of the bracket. Sims *et al.* (1993) have shown that Activa brackets produce substantially less friction than edgewise brackets with archwires ligated with elastomeric ligatures.

The Adenta Time bracket employs a self-ligating mechanism which has a resilient spring clip designed to lock the archwire into place (Figure 2). The manufacturers claim that the spring clip provides simplified ligation and optimal rotational control. Time brackets were designed to provide near friction-free movement in the initial stages of orthodontic treatment. However, as the archwire sizes increase over and above 0.017-inch depth, the clip engages with the archwire to provide early levels of torque control. As the archwire size increases, the level of force of the clip increases.

Since both the ‘A’ Company Damon SL and Adenta Time brackets use a self-ligating mechanism, the resistance to sliding would be less when compared with conventional pre-adjusted Siamese edgewise brackets. At present no published data exists to evaluate the friction produced by these new brackets.

The aim of this study was to evaluate the resistance to movement of various archwires through two types of self-ligating brackets and two conventional elastomerically tied brackets. The conventional brackets were ‘A’ Company Standard Twin bracket (Figure 3) representing a pre-adjusted edgewise appliance and TP’s Tip-Edge bracket (TP Industries Inc., Laporte, Indiana, USA; Figure 4), because its slot design is claimed to produce low friction.

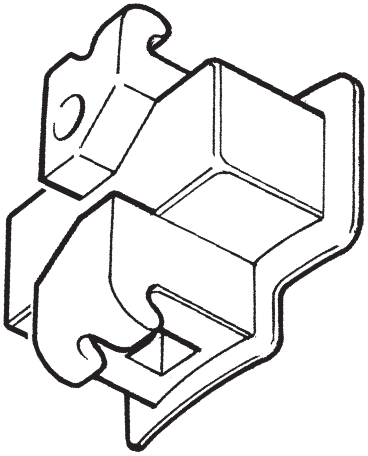

Figure 4 TP Tip-Edge bracket.

Materials and methods

The method used in this study was similar to Sims *et al.* (1993). Fifty right maxillary canine ‘A’ Company Standard Twin, TP Tip-Edge, ‘A’ Company Damon SL, and Adenta Time brackets were bonded with an epoxy adhesive (Araldite, Ciba-Geigy plc, Stafford, UK) to steel bars of dimensions 200 × 15 × 2 mm. Each steel bar had a line scribed parallel to its long axis. This was to aid in aligning the pull of the wire through the bracket so that friction was not induced by adverse tipping or torsion moments. The bracket specifications are given in Table 1. Each bracket was supported on a 0.021 × 0.025-inch stainless steel wire jig (Figure 5) while the adhesive hardened. The wire jig was bent to enable the bracket slot to be aligned along the length of the steel bar and parallel to it. This allowed the slot axis of the bracket to be perpendicular to the surface of the steel bar.

The five different archwire dimensions used were:

1. 0.014-inch nickel titanium wire (Rematitan ‘Lite’ nickel titanium, Dentaurum, Germany).
2. 0.0175-inch multistrand stainless steel wire (Dentaflex 3 strand stainless steel, Dentaurum, Germany).
3. 0.016 × 0.022-inch nickel titanium wire (Rematitan ‘Lite’ nickel titanium, Dentaurum, Germany).

Table 1 Bracket characteristics.

Bracket	STD ‘A’	Tip-Edge	Time	Damon
Company	‘A’ Company	TP Ortho	Adenta	‘A’ Company
Slot size (inches)	0.022 × 0.028	0.022 × 0.030	0.022 × 0.028	0.022 × 0.028
Material	Steel	Steel	Steel	Steel
Manufacture	Milled	Cast	Machined and milled with heat treated spring clip	Metal injection moulded with pressed clip

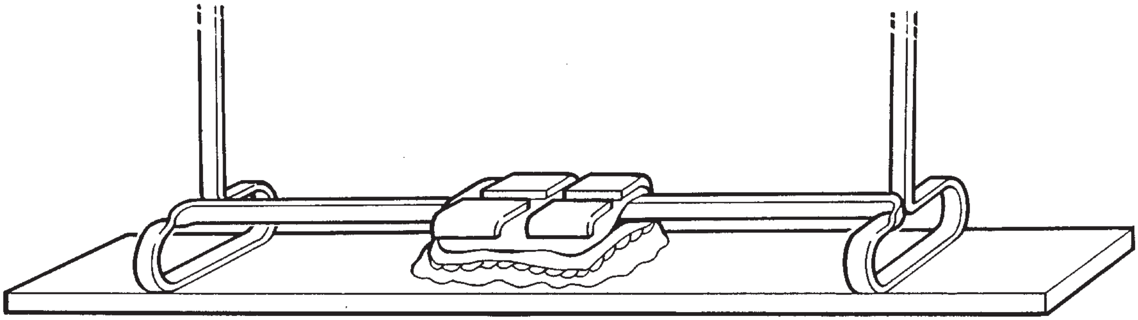

Figure 5 Diagram of the 0.021 × 0.025-inch stainless steel wire jig used to support the brackets whilst the adhesive hardened to the steel.

4. 0.016 × 0.022-inch stainless steel (Remanium stainless steel, Dentaurum, Germany).
5. 0.019 × 0.025-inch stainless steel (Remanium stainless steel, Dentaurum, Germany).

A new bracket and a 10-cm length of archwire was used for each test run to prevent any distortion of the bracket slot or archwire surface. Each archwire/bracket slot was cleaned with methylated spirit and then dried with compressed air 5 minutes before each test run.

'A' Company Standard Twin and TP Tip-Edge brackets were ligated with polyurethane rings (Quicksticks Al, Unitek Corporation, California, USA) over each tie wing in the conventional manner. The elastomeric rings were placed immediately before each test run. A flat plastic instrument was used to close the cover of the bracket vertically for the Damon SL bracket, and a modified dental probe (Adenta, GmbH, Germany) was used to open the spring clip of the Time bracket.

The bracket/archwire assembly was vertically mounted and clamped to the upper jaws of an Instron floor mounted testing machine (Instron 1193, Instron Corporation, Massachusetts, USA). A plumbline was used to ensure the test apparatus was vertical. The archwire protruding from the bracket was carefully clamped to the lower jaws of the moveable crosshead, so that the wire was parallel to the line scribed on the steel bar and also to the long axis of the Instron. Care was taken not to twist the test wire. The load cell was calibrated between 0 and 10 N with every 10 test runs. The archwire was pulled through the bracket for 10 minutes at a constant crosshead speed of 0.5 mm per minute and the resultant force recorded.

Each bracket/archwire combination was tested 10 times with a new bracket and archwire on each occasion. Test runs using both Damon and Time brackets consistently yielded low loads. As a consequence the load range was changed from 0 to 1 N. In total, 250 test runs were carried out. The mean load on each run was determined from the pen graph flow chart from five readings taken at 2 minute intervals.

Results

The data were analysed using SAS/PC version 6.10 and Stata version 4.0. Table 2 provides a statistical summary of friction data for all bracket/archwire combinations. A one-way analysis of

Table 2 Statistical summary of friction data for all bracket/archwire combinations (N).

Bracket	Archwire size (inches)	Archwire type	*n*	Mean	SD	Minimum	Maximum
Standard twin	0.014	Nickel titanium	10	1.17	0.15	1.00	1.50
Standard twin	0.0175	Multistrand s/steel	10	1.33	0.20	0.92	1.60
Standard twin	0.016 × 0.022	Nickel titanium	10	1.74	0.20	1.43	2.04
Standard twin	0.016 × 0.022	Stainless steel	10	1.56	0.21	1.29	2.01
Standard twin	0.019 × 0.025	Stainless steel	10	2.25	0.36	1.88	3.22
Tip-Edge	0.014	Nickel titanium	10	0.95	0.43	0.14	1.27
Tip-Edge	0.0175	Multistrand s/steel	10	1.18	0.20	0.80	1.44
Tip-Edge	0.016 × 0.022	Nickel titanium	10	1.66	0.25	1.24	2.01
Tip-Edge	0.016 × 0.022	Stainless steel	10	1.30	0.18	0.95	1.50
Tip-Edge	0.019 × 0.025	Stainless steel	10	1.78	0.24	1.43	2.17
Time	0.014	Nickel titanium	10	0.01	0.01	0.01	0.02
Time	0.0175	Multistrand s/steel	10	0.01	0.01	0.01	0.01
Time	0.016 × 0.022	Nickel titanium	10	0.31	0.16	0.14	0.54
Time	0.016 × 0.022	Stainless steel	10	0.24	0.13	0.05	0.40
Time	0.019 × 0.025	Stainless steel	10	0.75	0.25	0.50	1.23
Damon	0.014	Nickel titanium	10	0.01	0.01	0.01	0.02
Damon	0.0175	Multistrand s/steel	10	0.01	0.01	0.08	0.02
Damon	0.016 × 0.022	Nickel titanium	10	0.01	0.04	0.02	0.02
Damon	0.016 × 0.022	Stainless steel	10	0.01	0.01	0.02	0.04
Damon	0.019 × 0.025	Stainless steel	10	0.07	0.03	0.03	0.13

Table 3 Summary of Scheffe's multiple comparison of means test.

Wire	Bracket	Bracket
0.014-inch nickel titanium	Std. A Tip-Edge	Time Damon
0.0175-inch multistrand stainless steel	Std. A Tip-Edge	Time Damon
0.016 × 0.022-inch nickel titanium	Std. A Tip-Edge	Time Damon
0.016 × 0.022-inch stainless steel	Std. A Tip-Edge	Time Damon
0.019 × 0.025-inch stainless steel	Std. A Tip-Edge	Time Damon

Brackets that are joined by an underline are not significantly different $\alpha = 0.05$.

variance was carried out to determine the effect of the bracket type on each wire type. Where appropriate, Scheffe's multiple comparison of means test was applied. The results are summarized in Table 3 and Figure 6. Sims *et al.* (1993) showed a fourth root transformation was necessary to stabilize the variance. In the present work this was also found to be appropriate; however, the analysis between transformed and untransformed data provided identical conclusions, and so the data analysis is presented in terms of the untransformed data.

It can be seen from Figure 6, that the 'A' Company Damon SL system demonstrated the lowest friction for all dimensions of the test wires. The frictional forces for Damon brackets could only just be detected by the load measuring system. 'A' Company Standard Twin brackets produced the highest friction with all wire dimensions tested.

With all the brackets, the 0.019 × 0.025-inch stainless steel wires produced the highest friction and 0.016 × 0.022-inch nickel titanium wires produced a higher frictional resistance than 0.016 × 0.022-inch stainless steel wires.

The results in Table 3 reveal no significant differences in the mean force between 'A' Company Standard Twin and TP Tip-Edge brackets with

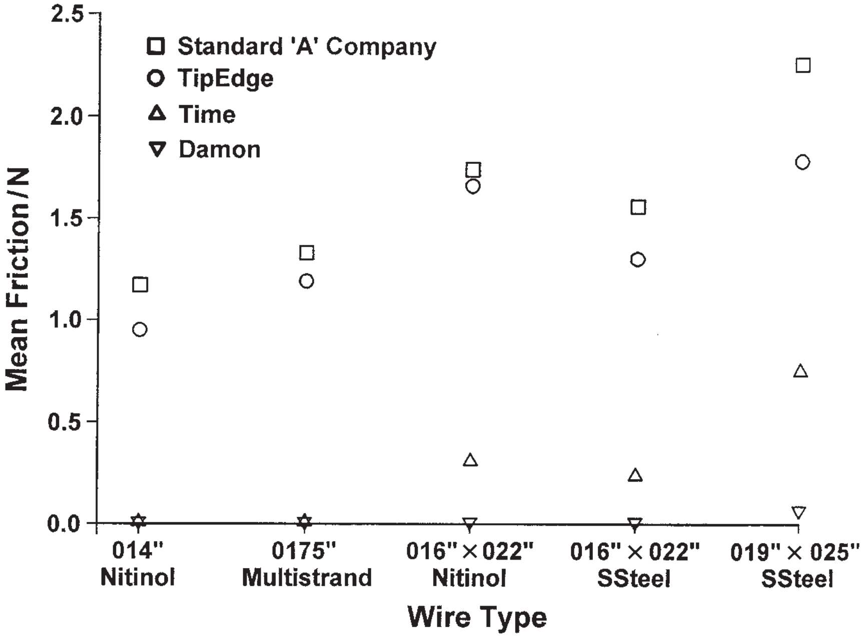

Figure 6 Graph showing variation of mean friction with wire type and bracket.

0.014-inch nickel titanium, 0.0175-inch multistrand stainless steel wire and 0.016 × 0.022-inch nickel titanium wires. There were no significant differences between Time and Damon SL brackets with 0.014-inch nickel titanium and 0.0175-inch multistrand stainless steel wires. The mean forces of both these self-ligating brackets at these wire sizes were significantly different from the 'A' Company Standard Twin and TP Tip-Edge brackets. With increasing wire dimensions including 0.016 × 0.022-inch stainless steel and 0.019 × 0.025-inch stainless steel, all bracket types were significantly different from each other. With all the four different bracket systems the lowest level of mean applied force was produced by the 0.014-inch nickel titanium wire.

Discussion

This laboratory study was designed to compare friction produced by various bracket and archwire combinations. Tipping and torquing forces can also affect the frictional resistance during space closure, however these factors were not studied in this investigation. It must be remembered, as with any *in vitro* study, this investigation cannot reproduce what occurs clinically during orthodontic tooth movement but great care was taken to ensure the methodology was comparable with previously published work (Sims *et al.*, 1993).

The cause of frictional resistance between archwire and brackets is multifactorial and varies with archwire size and material (Tidy, 1989; Angolakar *et al.*, 1990; Kapila *et al.*, 1990; Ireland *et al.*, 1991), mode of ligation (Berger, 1990; Bednar *et al.*, 1991; Sims *et al.*, 1993), bracket width (Frank and Nikolai, 1980; Drescher *et al.*, 1989), and angulation of the wire to the bracket (Andreasen and Quevado, 1970; Dickson *et al.*, 1994; Sims *et al.*, 1994).

In this study 'A' Company Standard Twin and TP Tip-Edge brackets were ligated with elastomeric modules, whereas Time and Damon SL brackets used a self-ligating mechanism. The results show that 'A' Company Standard Twin brackets produce the highest friction followed by the TP Tip-Edge bracket for all bracket archwire combinations.

In general the Damon SL bracket produced the lowest friction (Figure 6). Both self-ligating systems consistently produced low levels of friction. Although the design of the TP Tip-Edge bracket might lead to low friction, ligation with an elastomeric module significantly increases the friction produced. This study supports previous investigations (Berger, 1990; Sims *et al.*, 1993; Shivapuja and Berger, 1994) which have shown that higher frictional resistance occurs with elastomeric ties when compared with self-ligating mechanisms. Sims *et al.* (1993) investigated friction produced in two forms of self-ligating brackets and in two methods of ligating 'A' Company MiniTwin brackets with polyurethane elastomeric ligatures. The results indicated that self-ligating brackets required less force to produce tooth movement than conventionally tied Siamese brackets.

Generally, friction appears to increase as archwire diameter increases (Angolkar *et al.*, 1990; Kapila *et al.*, 1990) and the results from this investigation support this view. With all four bracket types, the 0.019 × 0.025-inch stainless steel wire produced the highest friction. The frictional resistance was greater for the Time brackets with 0.016 × 0.022-inch stainless steel wires than for Damon SL brackets for the same wire dimension. This is probably due to the design of the Time bracket which incorporates a spring clip which in the closed position impinges on wires greater than 0.017 inch in depth. The self-ligating mechanism of the Damon SL bracket is different to that of the Time bracket in which the archwire cover slides vertically, forms the fourth outer wall of the archwire slot, and converts the bracket into a rectangular tube.

There was a statistically significant difference in the mean friction values with the 0.016 × 0.022-inch stainless steel wire in the Activa bracket (Sims *et al.*, 1993) compared with the Damon SL bracket using wires of the same dimension. The mean difference was –0.017 N and the 95 per cent confidence intervals range between –0.03 and –0.01 N. This indicates that the Damon SL bracket has a lower friction than the Activa bracket. However, due to the small sample size this conclusion should be treated with caution. Comparing the 0.019 × 0.025-inch stainless steel archwires with these two brackets the mean difference was 0.008 N, and the 95 per cent confidence intervals range from –0.032 to 0.045 N. This indicates that no significant differences were found between these two brackets with these wire dimensions.

The material of the wire affects the frictional resistance produced (Peterson *et al.*, 1982; Tidy, 1989; Kapila *et al.*, 1990; Ireland *et al.*, 1991). Examination of the flow charts for each bracket archwire combination revealed more irregular trace patterns with 0.0175-inch multistrand stainless steel wires than with 0.014-inch nickel titanium wires. This may be due to the surface roughness of the multistrand wire.

The 0.016 × 0.022-inch nickel titanium produced a greater mean force value compared with the 0.016 × 0.022-inch stainless steel. This would support the findings of Tidy (1989) and Kapila *et al.* (1990) who found stainless steel wires generated less friction than nickel titanium wires. However, other investigators (Peterson *et al.*, 1982; Downing *et al.*, 1994) found no significant differences. Downing *et al.* (1994) suggested such contradictory findings could be attributed to the force of ligation employed in each such study and the archwires used being supplied by different manufacturers.

The mode of ligation has been shown to affect the friction produced (Berger, 1990). Elastomeric ligatures used to ligate archwires are polyurethane-based polymers, and studies have verified that these materials undergo stress relaxation (Chang and Sherriff, 1991) and slow hydrolytic decomposition over time (Ash and Nikolai, 1978). In this study 'A' Company Standard Twin brackets and TP Tip-Edge brackets were ligated with elastomeric ligatures. It is important to remember that as these elastomeric ligatures were placed immediately before each test run, the forces recorded would be expected to be at a maximum as the tightness of the elastomeric ligatures would not have reduced significantly. Bednar *et al.* (1991) found the mean frictional values for self-ligating SPEED brackets were similar or greater than elastomerically ligated stainless steel brackets. However, this was contradictory to results of an earlier study by Berger (1990) who found consistently lower friction values with the self-ligating SPEED bracket. The differences in the results can be explained by analysing the different experimental methods employed. In the former study the brackets were made to tip relative to the archwire; however, in this investigation, as in the study by Berger (1990) and Sims *et al.* (1993), the bracket was locked in place so that the slot was parallel to the archwire. In this way, the bracket width as a factor contributing to friction was eliminated. The Tip-Edge bracket has two 20-degree wedges removed from each side of the bracket which allows the slot size to change from 0.022 to 0.028 inch as the bracket tips. The manufacturers of this bracket claim the design decreases frictional resistance of the wire during tooth retraction. However, brackets were not allowed to tip in this study.

Conclusions

This laboratory study measured the mean forces required to overcome friction with various bracket and archwire combinations. The results demonstrate a difference in the friction produced in self-ligating brackets and elastomerically tied brackets.

1. 'A' Company Standard Twin brackets produced the highest levels of friction for all bracket/archwire combinations. The Damon SL bracket produced the lowest friction for all bracket/archwire combinations. Both Time and Damon self-ligating brackets produced significantly lower levels of friction when compared with the elastomerically tied 'A' Company Standard Twin and TP Tip-Edge brackets.
2. The mean friction in Damon brackets was lower by a factor of 11 compared with Time brackets for 0.019 × 0.025-inch stainless steel wires and by a factor of 32 when compared with 'A' Company Standard Twin brackets for the same wire dimension.
3. With 'A' Company Standard Twin brackets the friction increased with increasing archwire dimensions. Theoretically, the design of the Tip-Edge bracket should allow low levels of friction. However, the use of elastomeric

modules for ligation significantly increased the friction.

4. Friction increased with Time brackets when the archwire depth was greater than 0.017 inch because of the contact of the spring clip with the archwire in the slot. With Damon SL brackets the friction was negligible at the lower archwire dimensions and very low, even with 0.019 × 0.025-inch rectangular archwires.

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