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An *in vitro* investigation of the influence of self-ligating brackets, low friction ligatures, and archwire on frictional resistance

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SUMMARY This study, performed using a specially designed apparatus that included 10 aligned brackets, evaluated the frictional resistance generated by conventional stainless steel (SS) brackets (Victory Series), self-ligating Damon SL II brackets, Time Plus brackets, and low-friction ligatures (Slide) coupled with various SS, nickel-titanium (NiTi), and beta-titanium (TMA) archwires. All brackets had a 0.022-inch slot and the orthodontic wire alloys were 0.016, 0.016 × 0.022, and 0.019 × 0.025 inch NiTi, 0.017 × 0.025 inch TMA, and 0.019 × 0.025 inch SS. Each bracket–archwire combination was tested 10 times.

Coupled with 0.016 inch NiTi, Victory brackets generated the most friction and Damon SL II the least ($P < 0.001$); with 0.016 × 0.022 inch NiTi, the self-ligating brackets (Time and Damon SL II) generated significantly lower friction ($P < 0.001$) than Victory Series and Slide ligatures; with 0.019 × 0.025 inch SS or 0.019 × 0.025 inch NiTi, Slide ligatures generated significantly lower friction than all other groups. No difference was observed among the four groups when used with a 0.017 × 0.025-inch TMA archwire.

These findings suggest that the use of an *in vitro* testing model that includes 10 brackets provides information about the frictional force of the various bracket–archwire combinations.

Introduction

Friction is the resistance to motion when an object moves tangentially against another (Besancon, 1985; Cacciafesta *et al.*, 2003). In orthodontics, many studies have evaluated factors that influence frictional resistance between the bracket and archwire using experimental testing models that included one and three brackets (Andreasen and Quevedo, 1970; Kapila *et al.*, 1990; Rose and Zernik, 1996; Braun *et al.*, 1999; Cacciafesta *et al.*, 2003; Khambay *et al.*, 2004, 2005) or a typodont (Henao and Kusy, 2005). These studies have shown that the most important factors involved in the determination of the level of friction are the bracket and wire materials, the surface conditions of the archwires and bracket slot, the wire section, the torque at the wire–bracket interface, the type and force of ligation, use of self-ligating brackets, interbracket distance, saliva, and oral functions (Andreasen and Quevedo, 1970; Kapila *et al.*, 1990; Rose and Zernik, 1996; Braun *et al.*, 1999; Cacciafesta *et al.*, 2003). Consequently, the above factors are important when considering the clinical application of sliding mechanics, as they could influence friction. Such a reduction in friction can help shorten overall treatment time, especially in patients undergoing extractions where tooth translation is achieved by sliding mechanics (Cacciafesta *et al.*, 2003).

However, low friction may be desired during the early alignment phase, when all the teeth move at the same time and the wire slides through 10 brackets and two tubes. For this, a new experimental method to investigate the friction generated during the sliding of an archwire along a group of 10 aligned brackets was introduced (Tecco *et al.*, 2005).

Self-ligating brackets (Stolzenberg, 1935, 1946) are ligature-less bracket systems that have a mechanical device built into the bracket to close off the edgewise slot (Cacciafesta *et al.*, 2003); they are generally more comfortable for the patients, because of the absence of a wire ligature (Shivapuja and Berger, 1994) and because they also do not require significant chair side time (Maijer and Smith, 1990; Damon, 1998). Several studies have demonstrated a significant decrease in friction using self-ligating brackets compared with a conventional bracket design (Berger, 1990; Sims *et al.*, 1993, 1994; Read-Ward *et al.*, 1997; Thomas *et al.*, 1998; Thorstenson and Kusy, 2001; Khambay *et al.*, 2004; Henao and Kusy, 2005).

Recently, as it has been stated that friction is determined mostly by the nature of the ligation (Cacciafesta *et al.*, 2003), new low-friction ligatures (Slide©, Leone, Firenze, Italy) have been introduced, similar to elastic ligatures, but with an anterior part that is more rigid and similar to the mechanical device of self-ligating brackets. This is useful when low friction is desired, while common ligatures (not low friction) can be used when more friction is required (Figure 1). According to the manufacturer, Slide© is constructed from a special polyurethane mix for medical use. It can be applied in the same way as classical elastic ligatures and, once on the bracket, it self ligates on the slot leaving the wire free to slide and to act on the dentoalveolar structures. According to the manufacturer, its particular form noticeably improves patient comfort during the first phases of treatment.

The purpose of this study was to compare the frictional forces generated by two types of self-ligating brackets and conventional stainless steel (SS) brackets, and elastic or

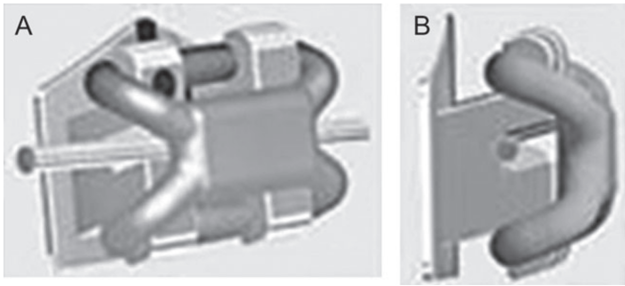

Figure 1 Slide© ligatures. (A) Frontal and (B) lateral view.

low-friction ligatures, using a specially custom-designed apparatus that included 10 brackets.

Material and methods

Mechanical testing

The brackets tested were: (1) Damon SL II brackets (SDS, Ormco, Glendora, California, USA), (2) Time Plus brackets (American Orthodontics, Sheboygan, Wisconsin, USA), (3) Victory brackets (Victory Series, 3M Unitek, Monrovia, California, USA) ligated with elastic modules (Ligature Ringlet, RMO, Denver, Colorado, USA), and (4) Victory brackets (3M Unitek) ligated with Slide© low-friction ligatures.

The testing model (Figure 2; Myrmex Laboratory, Foggia, Italy) has been described previously (Tecco *et al.*, 2005).

On the test model, 10 brackets of the same group were mounted in alignment using a cyanoacrylate adhesive (Loctite 416, Loctite Corp., Rocky Hill, Connecticut, USA). The alignment of the brackets was obtained through preliminary insertion of a 0.021 × 0.028-inch SS archwire in the slots of the brackets, without ligation, before bonding. After bonding of the brackets on the metal bar, the SS archwire was removed. However, as minor malalignments of the brackets or non-linearity of the wire could not be controlled, to estimate the extent to which the friction could be attributed to malalignment rather than ligation, a confirmatory check was performed by measuring the friction for each bracket–archwire combination with only the terminal brackets ligated.

In total, 20 test models were constructed, i.e. five models for each group of brackets (Victory Series, Time, Damon SL II and Slide ligatures). For each group, a single model was used 10 times to test the same bracket–archwire combination with all the brackets ligated, and 10 times to test the same bracket–archwire combination with only the terminal brackets ligated. In this way, each model was used for a total of 20 tests.

The archwires (Table 1) were selected for testing as a representation of those used in various stages of orthodontic treatment: 0.016, 0.016 × 0.022, and 0.019 × 0.025 inch nickel-titanium (NiTi), 0.017 × 0.025 inch beta-titanium (TMA), and 0.019 × 0.025 inch SS. For each testing

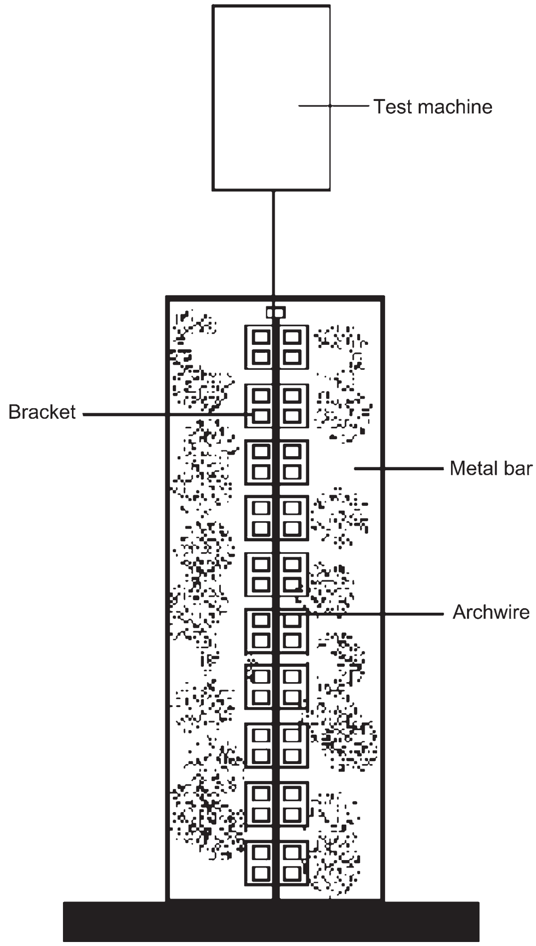

Figure 2 Diagrammatic representation of the testing model and mechanical testing machine.

procedure, a new archwire was employed. The sliding force values (*F*) were evaluated for each archwire 10 times. Thus, a total of 400 testing procedures were performed. The tests were run in the dry state at an ambient temperature of 34°C.

For friction evaluation, a mechanical testing machine (Model 30K, Lloyd Instruments Ltd, East Fareham, Harts, UK) with a 10-lb tension load cell, set on a range of 1 lb and calibrated from 0 to 1000 g, was employed (Figure 2). The archwires were gripped by crimping brass fittings on the distal ends, which allowed sliding of the wire along the 10 brackets and recording of the frictional forces.

The archwires moved through all 10 brackets at a crosshead speed of 0.5 mm/minute. Once archwire movement began, each run lasted approximately 5 minutes. *F* value were calculated in centi-Newtons (cN). After each test, the machine was stopped, the bracket and wire assembly was removed, and a new assembly was placed. This was undertaken for 20 non-repeated evaluations (10 evaluations with all the brackets ligated and 10 evaluations with only the terminal brackets ligated) for each bracket–archwire

Table 1 The self-ligating, conventional bracket and archwires used in the study.

Self-ligating and conventional brackets*	Archwire† nominal dimension (inch) and alloy
Damon SL II, SDS Ormco	0.016 NiTi-A‡,§
Time, American Orthodontics	0.016 × 0.022 NiTi-A‡,§
Victory, 3M Unitek with elastic ligatures	0.017 × 0.025 TMA¶
Victory, 3M Unitek with slide ligatures (Leone)	0.019 × 0.025 NiTi-A‡,§
	0.019 × 0.025 stainless steel¶

NiTi, nickel-titanium; TMA, beta-titanium.
*Bracket had nominal slot dimension of 0.022 inch.
†Archwires obtained directly from the manufacturers.
‡Nickel-titanium in the austenitic phase.
§RMO, Denver, Colorado, USA.
¶Dentaurum, Pforzheim, Germany.

combination. A randomized sequence for each type of archwire was performed.

The load cell registered the force levels needed to move the wire along the 10 aligned brackets, and the levels were transmitted to a computer.

Statistical analysis

Descriptive statistics, including the mean and standard deviation (SD), were calculated for each bracket–archwire combination.

In order to estimate the extent to which friction could be attributed to the malalignment of the brackets rather than the type of ligation, for each bracket–archwire combination, a statistical comparison, undertaken using a Student's *t*-test, was performed between the data for all ligated brackets and the data with only the terminal brackets ligated. In addition, in order to evaluate whether the differences in the friction could be attributed to the malalignment of the brackets, rather than ligation, a one-way analysis of variance (ANOVA) test was carried out to determine the existence of statistically significant differences among the four groups of brackets for each archwire tested, when only the terminal brackets were ligated.

The data were then analysed as the differences in frictional force observed in the five groups of archwires among the four groups of brackets. If the one-way ANOVA test was significant, a *t*-test for independent groups was calculated to evaluate the significance of the differences among the groups.

To better understand the influence associated with the type of archwire alloy, the data of each type of archwires were then considered (as a mean of the values from the four groups of brackets) and statistically compared using the one-way ANOVA and, if significant, the *t*-test for between-group comparisons. Values that were not significant were defined as $P > 0.05$.

Results

For each bracket–archwire combination, the *F* values obtained when all 10 brackets had been ligated were statistically significantly higher than when only the terminal brackets had been ligated ($P < 0.001$; Table 2). Only for one combination, was no significant difference observed, i.e. when the Damon SL II brackets were engaged with the 0.016-inch NiTi archwire (Table 2).

In addition, when the difference among the four types of ligation for each archwire, wase evaluated, no statistically significant difference was observed among the four groups for each archwire (Table 2).

The frictional forces (*F*), observed when all the brackets had been ligated, for each bracket–archwire combination are reported in Table 2 as the mean and SD, and their significant differences are shown in Figure 3.

When engaged with 0.016-inch NiTi wire, the Damon SL II brackets showed significantly lower friction compared with all other groups, while Victory Series brackets showed significantly higher friction. No significant difference was observed between Time brackets and Slide ligatures (Table 2, Figure 3). When engaged with 0.016 × 0.022-inch NiTi wire, the self-ligating brackets (Time and Damon SL II) generated significantly lower friction than Victory Series brackets and Slide ligatures (Table 2, Figure 3). For 0.017 × 0.025 inch TMA, no significant difference was observed among the four groups (Table 2, Figure 3). With 0.019 × 0.025 inch NiTi and SS, the trend was the same, as Slide ligatures generated significantly lower friction, compared with the other groups, with no significant differences between groups (Table 2, Figure 3).

When comparisons among the different types of archwires were performed, the thicker rectangular archwires (0.017 × 0.025 inch TMA, 0.019 × 0.025 inch SS, and 0.019 × 0.025 inch NiTi) showed a significantly higher level of friction when compared with 0.016 and 0.016 × 0.022 inch NiTi. No other significant difference was observed (Figure 4).

Discussion

Force magnitude during orthodontic treatment will result in optimal tissue response and rapid tooth movement (Cacciafesta *et al.*, 2003). During mechanotherapy involving movement of the wire along the brackets, friction at the bracket–archwire interface might prevent optimal force levels in the supporting tissues (Cacciafesta *et al.*, 2003). Therefore, an understanding of the forces required to overcome friction is important so that the appropriate magnitude of force can be used to produce optimal biological tooth movement (Cacciafesta *et al.*, 2003). To elucidate the nature of friction between archwire and bracket, several variables such as bracket material, wire alloy, and wire section should be studied (Cacciafesta *et al.*, 2003).

Table 2 Friction recorded for each bracket–archwire combination, with 10 brackets ligated and with only terminal brackets ligated. Statistically significant differences were evaluated as intra-group differences (Student's *t*-test) and among the four types of brackets for each archwire, when only terminal brackets were ligated.

	Victory Series				Time				Damon SL II				Slide ligatures			
	10 brackets ligated		Only terminal brackets ligated		10 brackets ligated		Only terminal brackets ligated		10 brackets ligated		Only terminal brackets ligated		10 brackets ligated		Only terminal brackets ligated	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
0.016 NiTi	800***	150	50	20	550***	250	50	20	50	15	50	15	580***	230	50	20
0.016 × 0.022 NiTi	1700***	200	50	30	850***	150	60	20	900***	150	45	20	1550***	180	50	30
0.017 × 0.025 TMA	2100***	350	150	50	1950***	190	160	60	2000***	200	160	50	1950***	300	150	55
0.019 × 0.025 stainless steel	1900***	200	300	110	2100***	150	310	115	2200***	200	320	120	1850***	150	310	130
0.019 × 0.025 NiTi	2000***	200	340	120	2200***	200	330	115	2300***	250	320	120	1900***	150	330	120

NiTi, nickel-titanium; SD, standard deviation; TMA, beta-titanium. Significant intra-group differences (the differences between the two tested conditions for each group).
***$P < 0.001$.

The model employed in this investigation

In this investigation, the use of a model that includes 10 aligned brackets provides more data than previous studies (Andreasen and Quevedo, 1970; Kapila *et al.*, 1990; Rose and Zernik, 1996; Braun *et al.*, 1999; Cacciafesta *et al.*, 2003; Khambay *et al.*, 2004, 2005) or a typodont (Henao and Kusy, 2005) and provides interesting observations. Some recent studies have used different methods to test the frictional force between bracket and archwires; these other methods are briefly described, since the differences in methodology should be acknowledged before analysis and comparison of the results.

Henao and Kusy (2005), for example, used typodont models either mounted with a self-ligating or a conventional design. The authors observed that, at the third-stage archwires, no archwire was engaged, probably because of the minor malalignments of the brackets on the typodont. Thus, for the present investigation, a linear design of the brackets was chosen.

In another recent study, a model which employed only one Damon SL II bracket and one conventional straightwire bracket was used (Khambay *et al.*, 2004). In that investigation, 0.017 × 0.025- and 0.019 × 0.025-inch SS and TMA wires were tested with four types of elastomeric modules and preformed 0.09-inch SS ligatures. Each bracket/wire combination with each method of ligation was tested 10 times in the presence of human saliva. The authors found that the Damon II self-ligating and unligated conventional SS brackets produced negligible mean frictional forces with any of the wires tested, but for the 0.017 × 0.025- and 0.019 × 0.025-inch SS or 0.019 × 0.025-inch TMA wires, SS ligatures produced the lowest mean frictional forces.

Khambay *et al.* (2005) used a maxillary premolar bracket (3M Unitek) that was welded to a sheet of SS and glued to a Perspex block. The bracket base was removed and the cut continued into the Perspex below. A length of test wire was taken and bent to form a 'U' shape, with the middle portion 20 mm in length. The free ends of the wire were secured to the load cell of the Nene testing machine. Two wire sizes were tested, 0.017 × 0.025 and 0.019 × 0.025 inch SS. The load cell was activated and the force with which the wire was displaced into the slot by the ligation method was measured. However, while the complex assembly of brackets used in that investigation seems to offer much greater potential, the results could be affected by minor malalignments of the brackets or non-linearity of the wire, thereby invalidating any conclusions on the effects of ligation.

For these reasons, in the present study, the brackets were accurately aligned during assembly using the 0.022 × 0.028-inch SS wire. In addition, in order to provide an estimate of the extent to which the friction could be attributed to malalignment rather than ligation, frictional forces were

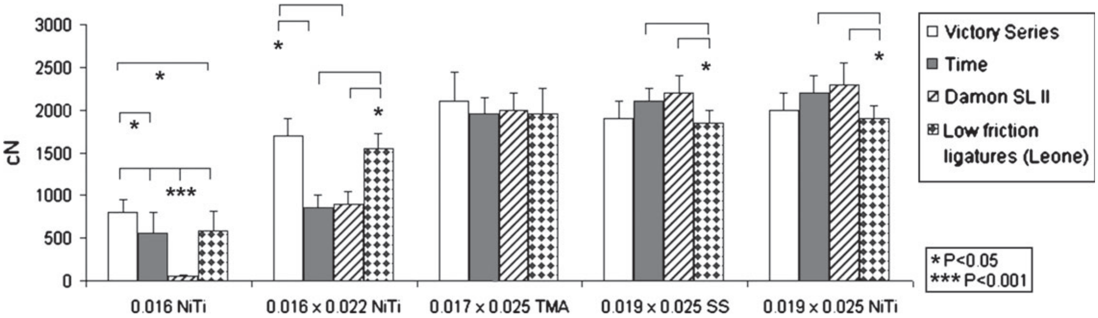

Figure 3 Descriptive statistics of force (*F*) measured in centi-Newtons, generated when archwires moved through all 10 brackets at a crosshead speed of 0.5 mm/minute for approximately 5 minutes. * indicates a statistically significant difference among the four groups.

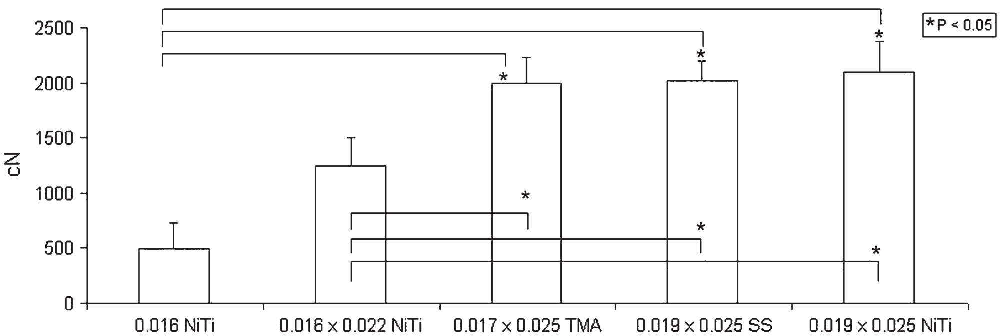

Figure 4 Descriptive statistics of force (measured in centi-Newtons), generated when archwires moved through all 10 brackets at a crosshead speed of 0.5 mm/minute for approximately 5 minutes. The levels of force are grouped according to the archwires employed. * indicates a statistically significant difference among the groups.

also recorded when only the terminal brackets had been ligated and the data were compared with frictional forces observed when all 10 brackets had been ligated, for each bracket–archwire combination.

Finally, another confirmatory check was performed as the existence of differences among the four groups of ligations was evaluated for each archwire employed, when only the terminal brackets had been ligated.

As noted, for each bracket–archwire combination, the friction values obtained when all 10 brackets had been ligated resulted in statistically significantly higher friction than when only the terminal brackets had been ligated ($P < 0.001$; Table 2). Only for the Damon SL II brackets engaged with 0.016-inch NiTi archwire was no significant difference observed (Table 2). These observations seem to suggest that ligation plays an important role in the generation of friction between bracket and slot. The result for Damon SL II, when engaged with 0.016-inch NiTi archwire is in agreement with the findings of Khambay *et al.* (2004), with a model that included only one bracket.

When the differences among the four groups, with only the terminal brackets ligated, were evaluated, no statistically significant difference was found among the groups for each archwire (Table 2), suggesting that all the differences observed when all the 10 brackets had been ligated (Figures 3 and 4) could be attributed to the type of ligation.

With regard to the testing model employed in this study, it must be noted that the archwires moved through all 10 brackets at a crosshead speed of 0.5 mm/minute and once archwire movement began, each run lasted approximately 5 minutes. This crosshead speed is generally lower than that used in other investigations. In the study by Khambay *et al.* (2004), which included one bracket, the specimens were tested on a Nene M3000 testing machine, with a crosshead speed of 5 mm/minute and each test run lasted 4 minutes. The speed used in the present investigation was generally lower than that in other studies, since the 10-bracket model needed very small movements of the archwires in order to avoid failure of the brackets from the metal bar.

Findings

One of the main findings of the present study was that self-ligating and Victory Series brackets showed a different trend depending on the section (round or rectangular) of the archwire (Figure 3). While Victory brackets generated significantly higher friction when coupled with 0.016 inch NiTi compared with the two self-ligating brackets (Damon SL II and Time), no significant differences among Victory Series, Damon SL II, and Time brackets were observed when engaged with the rectangular archwires (Figure 3). This seems to indicate that the design of the self-ligating brackets results in low friction only when engaged with round wires, and not with rectangular archwires.

However, it should be noted that Damon SL II showed the lowest level of friction with round wires, compared with all the other combinations, suggesting that, among the considered archwire–bracket combinations it remains the bracket of choice when lower frictional force is required during the alignment phase.

Another interesting observation concerns the results observed with Slide ligatures (Figure 3). They showed similar friction compared with self-ligating brackets when coupled with 0.016 inch NiTi, 0.016 × 0.022 inch NiTi, and 0.017 × 0.025 inch TMA, that is low friction with round wires and high friction with rectangular wires. In addition, when coupled with 0.016 × 0.022 inch NiTi, they also generated significantly higher friction compared with the two self-ligating brackets. However, when engaged with 0.019 × 0.025-inch NiTi and SS archwires, their trend changed as they generated significantly lower friction compared with all other groups. It was hypothesized that this could be associated with their elastic design; probably, when coupled with the larger archwires, their elastic properties decrease and they may loose the capability to create high friction between the archwire and slot. The difference observed could probably be explained by the design of self-ligating brackets. Self-ligating bracket systems have a mechanical device built into the bracket to close off the edgewise slot; this device generally has a small metal sliding door that is rigid and rather stiff, compared with the soft and elastic surface of the low-friction ligatures.

Clinically, the lower friction observed with the Slide ligatures when coupled with rectangular wires could be considered either as an advantage or as a disadvantage in different situations; for example, during anterior tooth retraction, lower friction is required in the lateral segment of the dental arches, while in the final phase of stabilization, higher friction is desired in all slots. The primary advantage of Slide ligatures seems to be that they can be used when low friction is necessary. These findings seem to confirm one of the manufacture's statements, i.e. that Slide ligatures must be used only when low friction is needed.

Another important finding of the present study was that there was no significant difference in frictional force between the two groups of self-ligating brackets; only a significant difference was observed when coupled with 0.016 inch NiTi. This seems to suggest that, despite their differences in structural design and material composition of the bracket slot and cap (Shivapuja and Berger, 1994), the level of the generated frictional force is approximately the same, except for the significantly lower friction generated by Damon SL II when coupled with 0.016 inch NiTi.

The findings of the present investigation are not in complete agreement with the general statement that SS self-ligating brackets generate lower frictional resistance than conventional SS brackets (Sims *et al.*, 1993, 1994; Shivapuja and Berger, 1994; Pizzoni *et al.*, 1998; Thomas *et al.*, 1998; Thorstenson and Kusy, 2001; Cacciafesta *et al.*, 2003; Tecco *et al.*, 2005) as the friction level changed when different archwire sizes and shapes were employed, but no difference in friction was observed among the self-ligating and conventional SS brackets, when coupled with 0.017 × 0.025 inch TMA, 0.019 × 0.025 inch NiTi, and 0.019 × 0.025 inch SS. Thus, the self-ligating brackets did not appear to have any advantages when larger rectangular archwires were used. This observation seems to indirectly indicate that previous studies had often failed to show dramatic reductions in treatment time when self-ligating brackets were used (Harradine, 2001; Cacciafesta *et al.*, 2003).

The present study also demonstrated that the wire alloy and the size and shape of its section seem to have a significant influence on friction, as 0.017 × 0.025 inch TMA, 0.019 × 0.025 inch NiTi, and 0.019 × 0.025 inch SS showed a significantly higher frictional force when compared with 0.016 and 0.016 × 0.022-inch NiTi archwires, suggesting that, generally, larger rectangular archwires generate higher friction than round small archwires.

However, although this concept is generally clinically accepted, there were some differences between the present findings and those of other researchers; for example, in this study no significant difference was observed among TMA, SS, and NiTi archwires in terms of friction, although it has been reported that TMA generates higher friction than both SS and NiTi for all bracket–archwire combinations (Angolkar *et al.*, 1990; Pratten *et al.*, 1990; Ireland *et al.*, 1991; Keith *et al.*, 1993; Downing *et al.*, 1994; Dickson and Jones, 1996; Bazakidou *et al.*, 1997; Loftus *et al.*, 1999; Cacciafesta *et al.*, 2003) probably due to the adherence of the archwire material to the slot material during the experimental procedure (Kusy and Whitley, 1990; Cacciafesta *et al.*, 2003).

However, in agreement with the findings of Loftus *et al.* (1999) and Cacciafesta *et al.* (2003), but not with Angolkar *et al.* (1990) who found higher frictional forces with SS, no significant differences were observed between NiTi and SS archwires in terms of frictional force.

This general variability in the reported findings may be due to differences in the experimental set-up or the number of brackets or angulations between the bracket and wire, which in many studies was not zero (Ogata *et al.*, 1996). Therefore, direct comparison of the various published studies on this topic is complex.

One limitation of the present research, is that it was carried out under ideal conditions, in a passive, not an active configuration which included some malalignment of brackets, as shown in previous reports (Angolkar *et al.*, 1990; Bednar *et al.*, 1991; Keith *et al.*, 1993; Downing *et al.*, 1994; Shivapuja and Berger, 1994; Bazakidou *et al.*, 1997; Thomas *et al.*, 1998; Loftus *et al.*, 1999; Cacciafesta *et al.*, 2003; Tecco *et al.*, 2005). Frictional investigations in an active configuration (with different bracket angulations) are still in progress and it will be useful in the future to compare these findings with those in the passive state.

Another limitation of this *in vitro* testing model concerns the lack of reproducibility of tipping, that always occurs when orthodontic force is applied to a tooth, even when a fixed appliance is used.

In addition, the functional forces of the stomatognathic muscles, which could affect tooth orthodontic movement and the effect of the saliva were not considered. These limitations could have influenced the findings.

Conclusion

When coupled with 0.016-inch NiTi wire, the Damon SL II brackets showed significantly lower friction compared with all other groups, while Victory Series brackets showed significantly higher friction. With 0.016 × 0.022 inch NiTi, the self-ligating brackets (Time and Damon SL II) generated significantly lower friction than Victory Series brackets and Slide ligatures, while, with 0.019 × 0.025 inch NiTi and 0.019 × 0.025 inch SS, Slide ligatures generated significantly lower friction, compared with the other groups. There was, however, no significant difference among the other groups.

When comparisons among the different types of archwires were performed, the thicker rectangular archwires (0.017 × 0.025 inch TMA, 0.019 × 0.025 inch SS, 0.019 × 0.025 inch NiTi) showed a significantly higher level of frictional force when compared with 0.016 inch and 0.016 × 0.022 inch NiTi.

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