FRICTION IN A HYBRID SYSTEM. AN *IN VITRO* STUDY

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SUMMARY

Friction in a hybrid system. An* in vitro *study

Aim. The aim of this study was to compare the frictional force generated by self-ligating and conventional brackets coupled with stainless steel wires when conventional elastomeric or stainless steel ligatures were applied.
Method. Four types of brackets were selected for the study: one passive self-ligating bracket, two active self-ligating brackets, and one conventional bracket. For each type of bracket one molar tube and two upper premolars were used in combination with three different wires (0.016x0.022, 0.017x0.025 and 0.019x0.025 inch). Testing was performed with an Instron machine. Each bracket/wire combination was tested with conventional elastomeric and stainless steel ligatures. Tests performed with self-ligating brackets were carried out also without conventional ligatures. ANOVA with Tukey's post hoc tests were used to compare the results for the different bracket/wire/ligature assemblies.
Results. Active self-ligating bracket/0.017x0.025 inch or 0.019x0.025 inch/stainless steel ligature assemblies showed significantly higher values of frictional forces than conventional bracket for the same combinations. Passive self-ligating brackets showed significantly lower values of friction than conventional brackets for each wire/ligature assembly.
Conclusions. The use of stainless steel ligatures applied on active self-ligating brackets produced significantly higher level of frictional force than in combination with conventional brackets for 0.017x0.025 inch and 0.019x0.025 inch wires.

Key words: friction, self-ligating brackets, orthodontic ligatures.

RIASSUNTO

***Attrito in un sistema ibrido: uno studio* in vitro.**

Obiettivi. Scopo di questo lavoro è stato comparare la forza di attrito generata da brackets autoleganti e convenzionali utilizzati in combinazione con l'apposizione di legature convenzionali elastiche e metalliche.
Metodi. Per l'esecuzione dei test sono stati selezionati quattro modelli di brackets: un autolegante passivo, due brackets autoleganti interattivi ed un attacco convenzionale. Per ogni tipologia di bracket sono stati utilizzati un tubo molare e due attacchi premolari. Le prove sono state condotte con una Instron machine, tutti gli attacchi sono stati testati in combinazione con tre sezioni di archi ortodontici (0.016x0.022, 0.017x0.025 e 0.019x0.025 inch). Ogni combinazione arco-bracket è stata testata con legature elastiche e metalliche. Per l'analisi statistica dei dati è stato utilizzato il test ANOVA a tripla via e come Post-hoc test il test di Tukey.
Risultati. I brackets autoleganti attivi hanno evidenziato valori di resistenza allo scorrimento maggiori rispetto a quelli degli attacchi convenzionali se analizzati in combinazione con legature metalliche ed archi di sezione 0.017x0.025 e 0.019x0.025 inch. I brackets autoleganti passivi hanno prodotto valori di attrito inferiori rispetto agli attacchi standard.
Conclusioni. L'utilizzo di legature metalliche in combinazione con brackets autoleganti interattivi su archi 0.017x0.025 e 0.019x0.025 produce valori di attrito superiori rispetto agli attacchi convenzionali.

Parole chiave: attrito, brackets self-ligating, legature ortodontiche.

Introduction

The overall resistance to sliding in orthodontic appliances is a combination of classical friction, bracket/wire binding and wire notching (1). At the minimal bracket/wire angulation and torque, friction is mainly due to classical friction, whereas binding and notching become more important at large bracket/wire angulations. As the friction at the bracket/wire interface increases, the proportion of the applied force that is actually transmitted into tooth movement decrease. This turns out into a less efficient orthodontic appliance (1) so that more force is required to achieve the desired result (2).
Numerous *in vitro* studies have demonstrated a dramatic decrease in friction for self-ligating brackets, compared to conventional bracket designs (3, 4, 5, 6, 7). The self-ligating systematic, however, should allow the modulation of the friction in the various stages of therapy: low friction in the early stages for leveling and aligning, controlled friction during the translation movement, high friction in the last stage for the finishing and stabilization of the teeth position. An ideal bracket system should permit not only the low and controlled friction but also the high friction for an ideal finishing and stabilization of the teeth position (8, 9). Moreover, this system should allow the modulation of friction not only between different treatment phases but also within the same arch. Rinchuse and Miles (10) suggested the possibility to use an hybrid system in which various combinations of conventional brackets and ligation, spring self-ligating clip, and self-ligating passive slide brackets could be integrated into the patient's treatment by using the same slot size for all teeth.
The friction generated by various self-ligating bracket/wire combinations previously has been studied using various *in vitro* testing models that analyzed the effects self-ligating systems on friction. However, no studies have investigated the effect of conventional ligatures used in combination with self-ligating brackets.
The aim of this *in vitro* study was to compare the frictional force generated by self-ligating and conventional brackets coupled with stainless steel wires when conventional elastomeric ligatures or stainless steel ligatures were applied.

Methods

In this study, the test apparatus was constructed to record the frictional forces at the orthodontic bracket/wire interface by sliding the wire through the bracket slots.
Four types of brackets were selected for the study: one passive self-ligating bracket (Damon 3MX, Ormco, Orange, CA, USA), two active self-ligating brackets (InOvation R, Dentsply GAC International, Bohemia, NY, USA; Time 3, American Orthodontics, Sheboygan, WI, USA) and one conventional bracket (Standard Boston, Leone Orthodontic Products, Sesto Fiorentino, Firenze, Italy). All the brackets had a 0.022 inch slot. For each type of bracket one molar tube and two upper premolars were used in combination with three rectangular stainless steel wires of different size (0.016x0.022 inch, 0.017x0.025 inch, and 0.019x0.025 inch). The study was carried out in dry conditions at an ambient temperature of 34 °C. Brackets were bonded with an epoxy adhesive (Araldite, Ciba-Geigy plc, Stafford, UK) to Perspex block, built with a specific design to simplify the assembling and alignment with the test apparatus. Straight lengths of wire to be tested were fitted to the brackets slot and ligated to the tie wings with elastomeric or stainless steel ligatures for conventional brackets and in combination with the slide or spring clips for the self-ligating brackets. Each bracket was supported on a 0.021x0.025 inch stainless steel wire jig while the adhesive hardened. The wire jig was bent to enable the bracket slot to be aligned along the length of the Perspex block and parallel to it (Fig. 1).
Testing was performed on an Instron 3344 machine (Instron Ltd, High Wycombe, Buckinghamshire, United Kingdom) with the cross-head speed was set at 1.0 mm per minute and the wire pulled through the brackets for 2 minutes.
The Instron load cell (tension) was calibrated between 0 and 10 Newton for every test run of each bracket/wire combination. The load cell registered the force levels needed to move the wire along the 3 aligned brackets (at the static peak), and the levels were transmitted to a computer. The block/bracket/wire assembly was mounted to the lower jaws

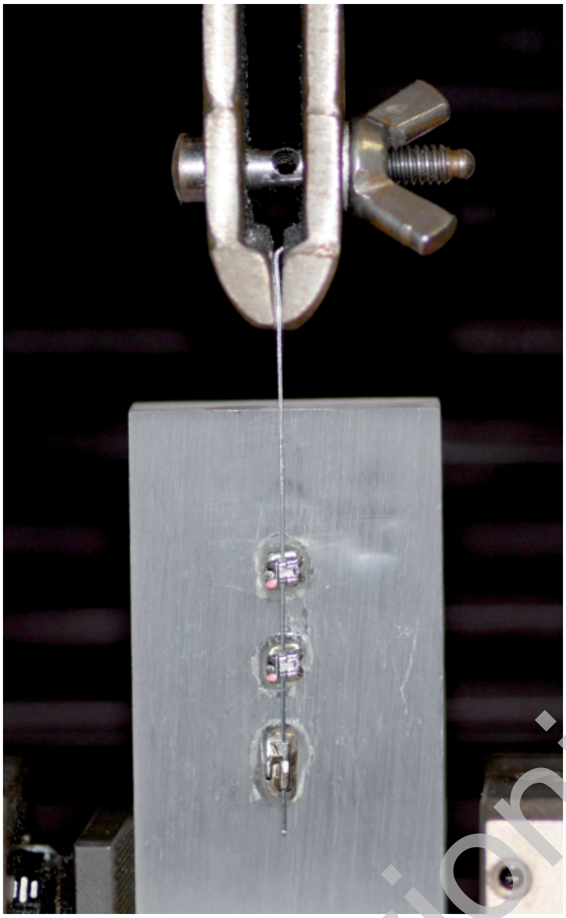

Figura 1
Experimental *in vitro* model.

of the Instron testing machine. The bottom end of the test wire already inserted into the test brackets assembled on the Perspex block was clamped by a vice mounted on the Instron cross-head. Care was taken to avoid introducing torsion into the test wire during clamping. Each bracket/wire combination was tested with elastomeric ligatures and stainless steel ligatures. Tests performed with self-ligating brackets were also carried out without conventional ligatures. A total of 330 testing procedures were performed in this investigation. Stainless steel ligatures were turned with a Mathieu ligature tying plier until the ligature wire turned on itself (11). In order to compensate the differences in size a standard number of turns was established for each bracket type. Elastic modules were placed over the tie wings of the brackets with a ligature gun (Straight-shooter, TP Orthodontics Inc., La Porte, IN, USA). This method limited possible differences in stretching between the elastomeric ligatures. Each bracket/wire combination was run 10 times with a new wire and conventional ligatures on each occasion. All wires were washed in 95 per cent ethanol and air-dried prior to testing.

Descriptive statistics, including the mean, standard deviation, minimum and maximum values for static friction were calculated for each bracket/wire/ligature combination. For statistical analysis a three-way analysis of variance (ANOVA) was used to study the effects of the three main variables (wire size, bracket type and ligature method). For the *post hoc* test, a Tukey's HSD test was used and the Bonferroni adjustment was applied. The level of significance for all the tests was set at $P<0.05$. The assessment of the method error for the tests was performed with the Dahlberg's formula, on measures repeated. In total 66 tests were performed again. No systematic error was detected. The errors for frictional measurement ranged from 0.03% to 1.8%.

Results

The technique of bracket ligation significantly affected frictional forces, the lowest values of friction was registered for both active and passive self-ligating brackets for all wire size. All brackets showed higher frictional forces as the wire size increased ($P<0.001$). Stainless steel ligatures produced significantly more friction than elastomeric ligatures ($P<0.001$). The mean values of resistance to sliding are given in Table 1. The results of Tukey's *post hoc* test for the different bracket/wire/ligature combinations are shown in Table 2.

0.016 x 0.022 inch wire

The lowest values of friction were registered for self-ligating brackets. Tests for self-ligating brackets registered the lowest frictional values using passive design ($P<0.001$) while no statistically significant differences were found among the two active designs ($P=0.983$). The *post hoc* pairwise comparison revealed that stainless steel ligatures produced significantly higher frictional forces with all bracket ty-

Table 1 - Recorded frictional force values expressed in Newton for each bracket-wire-ligature combination.

		0.016 X 0.022-in wire				0.017 X 0.025-in wire				0.019 X 0.025-in wire			
		MEAN	SD	MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD	MIN	MAX
Passive SLB (Damon 3MX)	EL	0.32	0.07	0.23	0.40	1.05	0.19	0.90	1.17	1.41	0.15	1.06	1.56
	SSL	1.15	0.16	1.02	1.27	1.49	0.18	1.38	1.64	2.26	0.20	1.85	2.65
	SLB	0.01	0.01	0.01	0.01	0.02	0.08	0.01	0.03	0.03	0.04	0.03	0.04
Active SLB (InOvation R)	EL	0.61	0.08	0.51	0.71	1.66	0.18	1.47	1.84	2.26	0.21	1.96	2.50
	SSL	1.62	0.16	1.46	1.77	2.52	0.14	2.19	2.83	3.34	0.22	2.91	3.70
	SLB	0.06	0.02	0.03	0.10	0.50	0.08	0.46	0.54	1.32	0.07	1.15	1.52
Active SLB (Time 3)	EL	0.78	0.07	0.66	0.85	1.76	0.19	1.65	1.87	2.51	0.15	2.18	2.63
	SSL	0.77	0.18	0.66	0.91	2.47	0.18	2.32	2.63	3.23	0.20	2.81	3.53
	SLB	0.06	0.01	0.05	0.07	0.61	0.08	0.55	0.67	1.17	0.04	0.81	1.22
CB	EL	0.80	0.10	0.74	0.86	1.41	0.14	1.29	1.50	2.06	0.15	1.76	2.26
	SSL	1.49	0.12	1.38	1.59	1.76	0.05	1.58	2.01	2.19	0.14	2.05	2.31

SLB = Self-ligating bracket; CB = Conventional bracket; EL = Elastomeric ligature; SSL = Stainless steel ligature.

pes than did the elastomeric ligatures (P<0.001), except for the Time 3 (P=0.931). When the different bracket/elastomeric ligature combination were compared, the *post hoc* test showed the highest frictional values for Time 3 and conventional brackets. There were no statistically significant differences among the two assembly (P=0.564). When the brackets were tested in combination with stainless steel ligatures descriptive statistics of frictional force showed that the Time 3 produced the lowest values. The couple Damon 3MX/stainless steel ligature exhibited a significantly higher frictional force than the Time 3/stainless steel ligature assembly (P<0.01). The highest values of friction were found with the InOvation R and conventional brackets used with stainless steel ligatures. No significant differences were found between the pairings Time 3/stainless steel ligature and conventional bracket/elastomeric ligature (P=0.680). No significant differences were found among Time 3/stainless steel ligature, conventional bracket/elastomeric ligature and InOvation R/elastomeric ligature (P=0.265).

0.017 x 0.025 inch wire

The lowest values of friction were registered for self-ligating brackets (P<0.001). Damon 3MX registered the lowest friction values (P<0.001), no significant differences were found between InOvation R and Time 3 (P=0.620). Stainless steel ligatures produced more friction than elastomeric ligatures for all bracket types (P<0.001). The tests performed with elastomeric ligatures and stainless steel ligatures showed the lowest frictional forces for the Damon 3MX. There were no significant differences in the frictional properties of InOvation R and Time 3 used with elastomeric or stainless steel ligatures (P=0.216; P=0.469). Conventional brackets produced significantly less friction than active self-ligating brackets tested with elastomeric or stainless steel ligatures with exception for the pairing InOvation R/elastomeric ligature (P=0.362).

0.019 x 0.025 inch wire

Statistical analysis showed that the lowest mean values of friction were for self-ligating brackets. Friction increased with elastomeric ligatures and even more with stainless steel ligatures. The tests performed with self-ligating brackets showed the lowest frictional force values for Damon 3MX (P<0.001). Time 3 had a significantly higher mean frictional force than the Damon and lower than the InOvation R (P<0.001). The maximum values of frictional forces produced by the elastomeric ligatures were found with Time 3, while the minimum values were recorded with Damon 3MX. The results indicated that there were no statistically significant differences between conventional and InOvation R (P=0.261) and between Time 3 and InOvation R (P=0.101). Time 3 and InOvation R tested with stainless steel ligatures showed significantly higher frictional forces than the Damon 3MX and conventional brackets.
No significant differences were found between InOvation R and Time 3 (P=0.254) and between Damon 3MX and CBs (P=0.219) with SSLs.

Table 2 - Comparisons between the different bracket-wire-ligature combinations (Tukey's post hoc tests).

		0.0.16 x 0.022 wire	0.0.17 x 0.025 wire	0.019 x 0.025 wire
DAM EL	INO EL	***	***	***
	TIME EL	***	***	***
	DAM SSL	***	***	***
	INO SSL	***	***	***
	TIME SSL	***	***	***
	DAM SLB	***	***	***
	INO SLB	***	***	NS
	TIME SLB	***	***	NS
INO EL	TIME EL	**	NS	NS
	CB EL	**	NS	NS
	DAM SSL	***	NS	NS
	INO SSL	***	***	***
	TIME SSL	NS	***	***
	CB SSL	***	NS	NS
	DAM SLB	***	***	***
	INO SLB	***	***	***
	TIME SLB	***	***	***
TIME EL	CB EL	NS	**	***
	DAM SSL	***	NS	*
	INO SSL	***	***	***
	TIME SSL	NS	***	***
	CB SSL	***	NS	**
	DAM SLB	***	***	***
	INO SLB	***	***	***
	TIME SLB	***	***	***
CB EL	DAM SSL	**	NS	NS
	INO SSL	***	***	***
	TIME SSL	NS	***	***
	CB SSL	***	***	NS
DAM SSL	INO SSL	***	***	***
	TIME SSL	**	***	***
	CB SSL	**	***	NS
	DAM SLB	***	***	***
	INO SLB	***	***	***
	TIME SLB	***	***	***
INO SSL	TIME SSL	***	NS	NS
	CB SSL	NS	***	***
	DAM SLB	***	***	***
	INO SLB	***	***	***
	TIME SLB	***	***	***
TIME SSL	CB SSL	***	***	***
	DAM SLB	***	***	***
	INO SLB	***	***	***
	TIME SLB	***	***	***
DAM SLB	INO SLB	***	***	***
	TIME SLB	***	***	***
INO SLB	TIME SLB	NS	NS	***

DAM = Damon 3MX; TIME = Time 3; INO = InOvation R; CB = Conventional bracket; EL = Elastic ligature; SSL = Stainless steel ligature; SLB, Self-ligating bracket. NS= not significant; * = P<.05; ** = P<.01; *** = P<.001.

Discussion

The variety of experimental methods used in the literature makes it difficult to compare the results of different studies of this type (12, 13, 6). Differences in the results among such studies may therefore reflect differences in the method error due to inaccurate mounting of the models in the testing machine, rather than differences in normal force through differences in ligation tightness.
The current study was carried out under ideal conditions in a passive frictional configuration, as shown in previous reports (2, 14, 11, 4), not taking into account the influence of binding, notching and oral functions. It is essential to point out that this *in vitro* study cannot reflect completely the mode of frictional resistance that may actually occur *in vivo* (15).
Regarding the effect of the wire section, we found that each of the four brackets type had higher frictional force values as the wire size increased. Most current literature suggests that wires of larger diameter produce greater friction (2, 11, 5). On the contrary, a few studies found that the smaller the wire, the larger the resistance to sliding (16, 17), which is probably explained by the ability of teeth to tip more on smaller wires.
In the present study each bracket/wire combination was tested with elastomeric ligatures and stainless steel ligatures. Tests performed with self-ligating brackets were also carried out without conventional ligatures. Generally self-ligating brackets consistently produced low levels of friction as shown by previous studies (2, 14, 4, 12, 18, 6). This study also supports the previous literature (3, 4, 5) that has shown that higher frictional resistance occurs with active self-ligating brackets when compared with passive self-ligating brackets (P<0.001). This is probably due to the design of the Time 3 and InOvation R which incorporates a spring clip which in the closed position impinges on wires greater than 0.017 inch in depth.
Statistical analysis showed that the stainless steel ligatures produced significantly more friction than elastomeric ligatures (P<0.001), in agreement with previous studies (19, 20) and in disagreement with others which found that stainless steel ligatures were associated with lower or similar frictional forces than elastomeric ligatures (11, 18).
Conventional ligatures used with active self-ligating brackets coupled with 0.017x0.025 inch and 0.019x.0.025 inch wire produced higher level of frictional force than conventional brackets. The reason for this could be that, the effect of spring clip action adds to the seating force of the conventional ligature with 0.017x0.025 inch and 0.019x0.025 inch wires. Probably with a 0.016x0.022 inch wire the spring-clip of the active SLB did not press strongly against the wire. Consequently, friction values for Time 3 and InOvation R were similar or lower with respect to those produced by conventional brackets. Budd et al. (21) reported that the wire dimension in the bucco-lingual direction appears to be an important factor in the friction generated by interactive self-ligating brackets.
The effects of conventional ligatures in combination with self-ligating brackets could be used by the orthodontist to modulate the amount of friction in different parts of the dental arch. Keeping with this idea, the orthodontist could determine the particular clinical needs and vary the type of control for each tooth accordingly.

Conclusions

- The effect of wire dimension on frictional forces appeared to be significant. All tested brackets showed higher frictional forces as the wire size increased.
- The ligation technique significantly influenced friction: the lowest values of resistance to sliding was registered for self-ligating brackets; stainless steel ligatures produced significantly more friction than elastomeric ligatures for all tested brackets.
- Passive self-ligating brackets showed significantly lower values of friction than conventional brackets for each wire/ligature assembly.
- Conventional ligatures applied on active self-ligating brackets produced significant higher level of frictional force than the conventional bracktes for 0.017x0.025 inch and 0.019x0.025 inch wires with the exception of the combination InOvation R/0.019x0.025 inch/elastomeric ligature which showed values of friction equal to the conventional brackets.

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