Evaluation and comparison of frictional forces generated by three different ligation methods (An in vitro study)

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ORTHODONTICS

Evaluation and Comparison of Frictional Forces Generated by Three Different Ligation Methods: An In Vitro Study

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ABSTRACT

Background: **This study aims to evaluate and compare the static and kinetic frictional forces produced by a passive self-ligating bracket (SLB) and a conventional stainless steel bracket (CB) ligated with two different ligation methods when used with two types of wires.**

Materials and Method: **The brackets, wires and ligation methods used in vitro were a passive SLB and a CB ligated with two different ligation methods (stainless steel ligature wire [SSLW] and conventional figure "O" elastomeric ligature [CEL]). The bracket ligation systems were tested with two types of wires (0.014" nickel titanium wire and 0.019" × 0.025" stainless steel wire). Resistance to sliding of the bracket/wire/ligature systems was measured with an experimental model mounted on the crosshead of an Instron testing machine with a 10 N load cell. Each sample was tested 10 consecutive times under a dry state.**

Results: **Frictional forces close to 0 gm were recorded in all tests with SLB with both wire types. Resistance to sliding increased significantly (18-38 gm) (*P* < .05) when SSLW on CB was used with both wires and (84-104 gm) (*P* < .05) when CEL on CB was used with both wires.**

Conclusion: **SLB is able to produce statistically high significant lower frictional forces compared with SSLW and CEL, while SSLW is able to produce statistically high significant lower frictional forces compared with CEL.**

KEY WORDS

friction, Self-ligating bracket, Lower frictional forces, Stainless steel ligature wires, Elastomeric ligatures

INTRODUCTION

During fixed appliance therapy, the main force that contrasts tooth movement is the frictional force developed between the interface of the bracket slot and the archwire[1)]. As the efficiency of fixed appliance therapy depends on the fraction of force delivered with respect to the force applied, high frictional forces resulting from the interaction between the bracket and the guiding archwire affect treatment outcomes and duration in a negative way[2)]. During orthodontic treatment with fixed appliances, frictional forces should be kept to a minimum so that lower levels of force can be applied to obtain an optimal biological response for effective tooth movement[2)].

Several factors can influence frictional resistance directly or indirectly. Among these factors, features of archwire and bracket (in terms of size and material) which have been investigated extensively in relation to friction production[2)]. Methods and properties of archwire ligation, which have an important role in generating friction, have received limited attention in literatures[2-5)].

A series of methods have been proposed with the aim of limiting the friction at the bracket/wire/ ligature interface, such as loosely tied stainless steel ligature wires (SSLW)[3)], self-ligating brackets (SLBs) and unconventional ligature systems[6)].

Most investigations[3,4)] have concluded that elastomeric modules significantly increase resistance to sliding compared with stainless steel ligatures, especially when the latter are tied loosely.

Since the 1980s, SLBs have become increasingly popular. These types of brackets are characterized by the presence of a fourth mobile wall that converts the slot into a tube. SLBs are claimed to reduce friction levels in a considerable way because they simply allow the wire to move freely into the bracket slot[2)]. Previous in vitro studies[2,7)] have demonstrated a significant decrease in friction by using these types of brackets with a reduction in the time necessary for single tooth movements.

The aim of the present in vitro study was to evaluate and compare the static and kinetic frictional forces produced by a passive SLB and a conventional stainless steel bracket (CB) ligated with two different ligation methods (SSLW and conventional figure "O" elastomeric ligature [CEL]) used with two types of wires (0.014" nickel-titanium wire [NiTi] and 0.019" × 0.025" stainless steel [SS] wire) in the dry state.

MATERIALS AND METHODS

In this in vitro study, two types of upper central incisor SS brackets, Roth type, were used, each incorporating +12° torque and +5° angulation: 10 passive SLBs with 0.022" × 0.0275" nominal slot dimension (Lotus, Ortho Technology, USA) and 20 SS CBs with 0.022" × 0.030" nominal slot dimensions (Marquis, Ortho Technology, USA). Two types of orthodontic wires were tested: SS and NiTi wires with a nominal cross section of 0.019" × 0.025" and 0.014", respectively (Ortho Technology, USA). These arch wire dimensions were chosen because round wires of small size are recommended during the aligning and leveling phase of orthodontic treatment[2,8,9)] while rectangular wires of larger size are necessary in space closure with sliding mechanics with 0.022"

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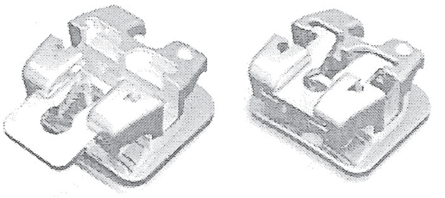
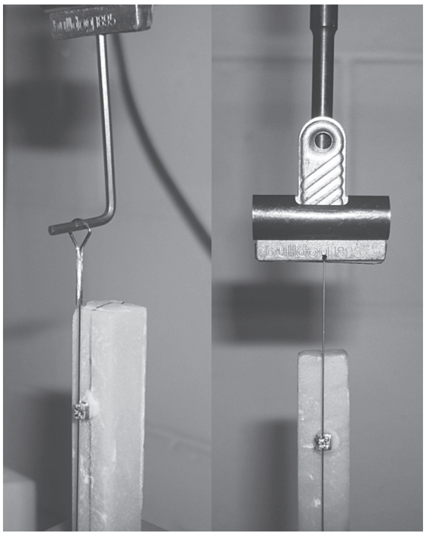


Figure 1. The self-ligating bracket in open and closed positions.



(A) (B)

Figure 3. (A) The test unit with the 0.019" × 0.025" SS archwire attached to the hook of Instron testing machine. (B) The test unit with the 0.014" NiTi archwire attached to the hook of Instron testing machine.

slot brackets[8] and are required during the final phase of treatment when a remarkable torque control is necessary[2], in addition the manufactures were able to supply straight lengths of wire (a preliminary study had indicated that any residual curve in the wire influenced friction)[10].

Each testing archwire was seated in the slot of the brackets after it was degreased with ethanol to remove oil, dirt and debris as factors affecting frictional resistance[10,11] and ligated either with SSLWs (0.010", Ortho Technology, USA), cut to 17 mm length and twisted 8 turns (to have a full twist ligation) then untwisted 90-to become slackened and to allow the archwire to slide freely, and then cut the access leaving a small part of it[3], or with CELs (clear medium size, with inner diameter of 1.3 mm, outer diameter of 3.1 mm, and thickness of 0.9 mm, Ortho Technology, USA) in the conventional figure "O" manner for the CBs, and with the solid labial slider by moving the slider downward into the slot-open position with a dental probe, which then slided upward with finger pressure to entrap the archwire in a passive configuration[12] for the SLBs (figure 1). The different ligation methods divided into 6 groups each group consisted of 5 models.

An experimental model was especially designed for this study to assess the friction produced by different ligation methods precisely by a testing machine (Instron H50KT Tinius Olsen testing machine with a load cell of 10 N[2,9], and speed of 6 mm/minute[2], this speed was chosen as the standard because other researchers have found no significant difference in friction measurements using speeds from 0.5 to 50 mm/min[10]. The experimental model consisted of:

- the bracket bonded to an acrylic block (cold-cured) of 1.2 × 1.2 × 15 cm in dimensions;
- the orthodontic wire, along which the bracket could slide, fixed to the load cell of the testing machine;

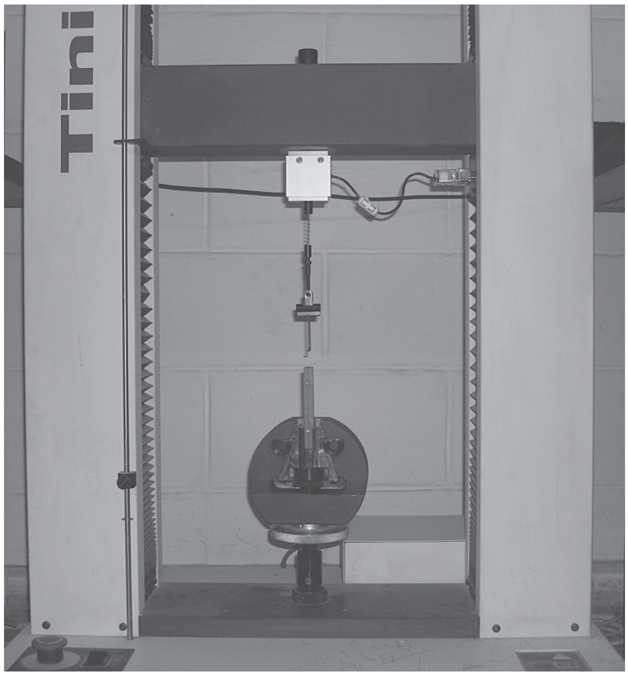


Figure 2. Instron H50KT Tinius Olsen testing machine with a testing model in place.

- the ligation method, consisting of the solid labial slider for the SLBs and SSLW or CEL for the CBs.

The lower part of this model was locked to the lower fixed clamp of the testing machine (figure 2).

The base of the bracket was fixed to the acrylic block that was clamped by the lower fixed crosshead of the Instron machine by light-cured composite of 2.5 mm thickness. Care was taken to bond each bracket in a position so that the slot was perfectly passive with respect to a straight section of 0.0215" × 0.025" SS wire mounted on the acrylic block.

The 0.019" × 0.025" SS testing archwires were bent at one end in to a key-hole loop bend and soldered[13], this loop made as a mean of attachment of the archwire to a hook that attached to the load cell of Instron machine to avoid any torque or deviation in the archwire in comparison with the direct attachment to the load cell of Instron machine[5,10,13], (figure 3A). The same preparation was not done to the 0.014" NiTi wires since such torque never happens, so they were clamped directly to the load cell of Instron testing machine, (figure 3B).

This arrangement allowed the wire to move along the bracket as an axial tensile force was applied by the Instron's load cell with a crosshead speed of 6 mm/min. In the meantime, a computer connected to the testing machine displayed a graph showing peak force variation and recording the frictional resistance force generated on every 0.01 mm distance of the tested wire in addition to the maximum frictional resistance force generated. Each of the six bracket/wire/ligation combinations was tested 10 times, with new tested archwire and ligation method on each trial. New elastomeric ligatures were used on each trial, to minimize the influence of elastic deformation[2]; the elastomeric ligatures were placed immediately (without pre-stretching) before each test run to avoid ligature force decay[9]. Also a new ligature wires and tested archwires were used on each trial to obtain more accurate measurements[9,10]. For every traction test over a distance of 12 mm at a speed of 6 mm/min the following frictional forces were recorded: the maximum force needed to move the wire along the bracket (static friction) and the mean frictional force registered at every one millimeter of movement from 1mm to 9 mm distance (kinetic friction). All measurements were performed under dry conditions at room temperature of 25 ± 2 degrees centigrade[2]. A total of 300 tests were carried out (50 tests for each group).

Statistical analysis

SPSS 15 under windows 7 was used for statistical analysis and Excel 2007 was used for statistical tables and bar charts. Statistics

Table 1. Descriptive statistics of Static Frictional Force of all the ligation groups:

Groups	No.	N	Mean (gm)	SD	Min (gm)	Max (gm)
SLB+SS wire	1	50	0.04	0.006	0.03	0.05
SLB+NiTi wire	2	50	0.064	0.007	0.05	0.07
CEL+SS wire	3	50	103.93	10.264	88.98	121.43
CEL+NiTi wire	4	50	104.3	8.71	88.67	116.79
SSLW+SS wire	5	50	18.487	1.1	16.45	19.96
SSLW+NiTi wire	6	50	37.614	3.662	31.59	42.02

Table 2. Descriptive statistics of Kinetic Frictional Force of all the ligation groups:

Groups	No.	N	Mean (gm)	SD	Min (gm)	Max (gm)
SLB+SS wire	1	50	0.034	0.005	0.03	0.04
SLB+NiTi wire	2	50	0.0455	0.008	0.03	0.06
CEL+SS wire	3	50	84.289	7.372	70.83	97.99
CEL+NiTi wire	4	50	98.709	9.629	85.86	116.91
SSLW+SS wire	5	50	17.798	0.886	16.60	19.37
SSLW+NiTi wire	6	50	36.197	2.361	33.02	40.00

Table 3. Least significant difference (LSD) of Static Frictional Forces for Groups 1, 3 and 5:

(I) Groups	(J) Groups	Mean Difference (I-J)	Std. Error	Sig
Group 1	**Group 3**	-103.89**	1.216	**0.000***
Group 1	**Group 5**	-18.447**	1.216	**0.000***
Group 3	**Group 5**	85.443**	1.216	**0.000***

** The mean difference is significant at the .05 level.

Table 4. Least significant difference (LSD) of Kinetic Frictional Forces for Groups 1, 3 and 5:

(I) Groups	(J) Groups	Mean Difference (I-J)	Std. Error	Sig.
Group 1	**Group 3**	-84.255**	0.875	**0.000***
Group 1	**Group 5**	-17.764**	0.875	**0.000***
Group 3	**Group 5**	66.491**	0.875	**0.000***

** The mean difference is significant at the .05 level.

Table 5. Least significant difference (LSD) of Static Frictional Forces for Groups 2, 4 and 6:

(I) Groups	(J) Groups	Mean Difference (I-J)	Std. Error	Sig.
Group 2	**Group 4**	-104.235**	1.114	**0.000***
Group 2	**Group 6**	-37.55**	1.114	**0.000***
Group 4	**Group 6**	66.686**	1.114	**0.000***

** The mean difference is significant at the .05 level.

Table 6. Least significant difference (LSD) of Kinetic Frictional Forces for Groups 2, 4 and 6:

(I) Groups	(J) Groups	Mean Difference (I-J)	Std. Error	Sig.
Group 2	**Group 4**	-98.664**	1.168	**0.000***
Group 2	**Group 6**	-36.152**	1.168	**0.000***
Group 4	**Group 6**	62.512**	1.168	**0.000***

** The mean difference is significant at the .05 level.

include:

Descriptive statistics, including: mean, standard deviation, standard error, minimum values and maximum values.

Inferential statistics, including:

i. One way analysis of variance (ANOVA) test was used to examine any significant difference among more than two groups.
ii. Least significant difference (LSD) test was used to find any statistical significant difference between any two groups.

RESULTS

Descriptive statistics and statistical comparisons of the frictional forces recorded in the different bracket/ wire/ligation combinations are reported in tables 1-6. Statistically, a highly significant difference (* $P < 0.01$ on ANOVA test) was found between the frictional forces produced by the three ligation methods when used with 0.019" × 0.025" SS wire and with 0.014" NiTi wire, with the lowest static and kinetic frictional forces recorded for the SLB (mean values ranging from 0.034 gm to 0.064 gm), followed by SSLW on CB (mean values ranging from 17.798 gm to 37.614 gm). CEL on CB coupled with both types of wires generated significantly the greatest static and kinetic frictional forces with respect both to SLB and to SSLW on CB (mean values ranging from 84.289 gm to 104.3 gm).

DISCUSSION

The present in vitro study compared the frictional forces generated by a passive SLB with the frictional forces produced by a CEL on CB and by SSLW on CB, on two different arch wires (0.019" × 0.025" SS and 0.014" NiTi). The readings obtained from the Instron testing machine for each combination represented the outcome of the interaction of the bracket, arch wire and ligation method, which makes it difficult to identify the effect of ligation method separately, therefore in the present study we tried to evaluate the effect of ligation method separately by making other variables constants by fixing the bracket material to SS and the arch wire material once to 0.019" × 0.025" SS then to 0.014" NiTi while varying the ligation method. In addition, since we used pre-adjusted brackets incorporating tip and torque, which considered as factors affecting friction, so we eliminated them by aligning the brackets with a section of 0.0215" × 0.025" straight SS archwire[11].

The results of the present investigation indicated that SLB produced highly significant lower frictional forces compared with both SSLW and CEL on CB when coupled with both types of arch wires, this could be contributed to the fact that SLB is characterized by the presence of a fourth mobile wall that converts the slot into a tube and creates a passive labial surface to the slot with no intention or ability to encroach on the slot and thus reduces friction levels by simply allowing the archwire to slide freely within the bracket slot[2,11,14], while for the SSLW and the CEL they exert force that compresses the archwire into the bracket slot and thus produce more friction levels. These results fully agree with those of most previous studies[2,18,15] who compared SLB with CEL or SSLW on SS CBs, and partially agree with other studies[10,16] who indicated that SLBs exhibited superior performance when coupled with smaller wires (0.014" NiTi wire) but with larger wires (0.019" × 0.025" NiTi and 0.016" × 0.022" NiTi wires) the differences between the CBs and SLBs were not as evident (non-significant difference between values of frictional forces), the cause of this partial agreement maybe because in those studies they used only NiTi arch wires which create higher frictional resistance in comparison to SS archwires[7,17] especially in high gauges[18,19], or maybe because they made their tests on typodonts in the presence of rotation, angulation, and torque in the pretreatment typodont models which also increase frictional resistance; attributing to binding rather than classic friction[20,21)].

The present study also indicated that SSLW produced highly significant lower frictional forces compared with CEL on CB when coupled with both types of arch wires. The method of arch wire ligation with SSLW has been investigated in relatively few studies. The majority of the authors agreed with the present study that SSLW produces less friction than standard CEL[3,4,10,11,22,23)]. According to other studies, frictional forces produced by CEL and SSLW are similar[18,24)], whereas others found that friction caused by CEL was less than that generated by SSLW[25-27)]. These differences in results may be attributed to the different forces used to ligature the stainless steel ligatures[28)]. The reason behind this controversy is further clarified by[22)] who stated that whether the SSLW is tightly or loosely ligated, it will greatly affecting frictional resistance, for loosely ligatured SSLW (as in the present study), there are a plenty of reasons that make elastic ligatures more friction generator, some of those are:

First is the continuous force exerted on the arch wire by the CEL when stretched over the bracket wings which is very much less for the loosely ligatured SSLW, whereas for tightly ligated SSLW the force of ligation will exceed that of the CEL and might reach to complete locking of the arch wire to the bracket.

Second is the coefficient of friction between elastic material and stainless steel sliding surfaces is much greater than that between two stainless steel surfaces in contact.

It should be stressed that caution must be exercised when evaluating the clinical applicability of the results of the present study, this is because:

First, it has been emphasized already that, from a clinical point of view, static friction is considered to have a greater importance than kinetic friction and previous investigations[24)] showed that the values for static friction tend to increase in the presence of human saliva when compared with dry conditions.

Second, it is essential to point out that an in vitro study cannot reflect completely the mode of frictional resistance that may actually occur in vivo. As a matter of fact, in the oral cavity, physiological functions such as chewing, swallowing, and speaking may produce random, intermittent, repeated minimal adjustments or perturbations at the bracket-archwire interface that may significantly decrease, if not completely eliminate, frictional resistance[5,29)].

CONCLUSIONS

- SLB is able to produce a statistically high significant lower static and kinetic frictional forces compared with SSLW and CEL on CB when coupled with 0.014" NiTi arch wire and with 0.019" × 0.025" SS arch wire.
- SSLW on CB can produce a statistically high significant lower static and kinetic frictional forces compared with CEL on CB when coupled with 0.014" NiTi arch wire and with 0.019" × 0.025" SS arch wire.

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