In Vitro Frictional Forces Generated by Three Different Ligation Methods

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ABSTRACT

Objective: To test the hypothesis that there is no difference between the frictional forces produced by a passive self-ligating bracket (SLB) in vitro and a conventional bracket (CB) used with two types of elastomeric ligatures.

Materials and Method: The brackets, wires and ligation methods used in vitro were a passive SLB and a CB used with two types of elastomeric ligatures (conventional elastomeric ligature [CEL] and unconventional elastomeric ligatures [UEL]). The bracket ligation systems were tested with two types of wires (0.014″ super elastic 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 g were recorded in all tests with SLB and in all tests with UEL on CB with both wire types. Resistance to sliding increased significantly (87–177 g) ($P <$ .05) when CEL on CB was used with both wires.

Conclusion: UELs may represent a valid alternative to passive SLBs for low-friction biomechanics.

KEY WORDS: Friction; Self-ligating bracket; Low-friction biomechanics; Elastomeric ligatures

INTRODUCTION

When sliding biomechanics are used with fixed appliances, the main force that contrasts tooth movement is the frictional force developed by the interaction of the bracket slot and the orthodontic wire. As the efficiency of fixed appliance therapy depends on the fraction of force delivered with respect to the force applied,[1] high frictional forces resulting from the interaction between the bracket and the guiding archwire affect treatment outcomes and duration in a negative way.[2–6] 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.[7,8]

Several factors can influence frictional resistance directly or indirectly. Among these factors, features of archwire and bracket (in terms of size and material) have been investigated extensively in relation to friction production,[9–17] Methods and properties of archwire ligation, which have an important role in generating friction, have received limited attention in literature.[6,18–24] Most investigations[6,18–21] 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, self-ligating brackets (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. Several studies[25–30] have demonstrated a significant decrease in friction by using these

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types of brackets with a reduction in the time necessary for single tooth movements.

Recently, an innovative unconventional elastomeric ligature (Slide, Leone Orthodontic Products, Sesto Fiorentino, Firenze, Italy) has been introduced into the market. Once applied on conventional brackets (CBs) this ligature is completely passive, like the labial cover of passive SLBs; thus, it guarantees the same freedom of sliding to the wire.[31] Previous in vitro studies[32,33] have shown that this unconventional elastomeric ligature (UEL) is able to reduce frictional forces with respect to conventional elastomeric ligatures (CEL) both during leveling and aligning and during sliding mechanics.

The aim of the present in vitro study was to compare the frictional forces produced by a passive SLB and two types of elastomeric ligatures (UEL and CEL) on a CB used with two types of wires (0.014″ super elastic nickel titanium [SE NiTi] wire 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 brackets were used, each incorporating +17° torque and +4° angulation: a SS CB with 0.022″ × 0.030″ nominal slot dimensions (STEP, Leone Orthodontic Products) and a passive SLB with 0.022″ × 0.0275″ nominal slot dimension (SmartClip, 3M Unitek, Monrovia, Calif). Two types of orthodontic wires were tested: SE NiTi and SS wires with a nominal cross-section of 0.014″ and 0.019″ × 0.025″, respectively (Leone Orthodontic Products). These wire dimensions were chosen because round wires of small size are recommended during the aligning and leveling phase of orthodontic treatment while rectangular wires of larger size are required during the final phase of treatment when a remarkable torque control is necessary.

The wires were ligated into the slots of CBs using either CELs (silver medium mini modules with inside diameter of 1.3 mm, outside diameter of 3.1 mm, and thickness of 0.9 mm, Leone Orthodontic Products) or UELs (silver medium Slide ligatures, Leone Orthodontic Products) (Figures 1 through 3).

Resistance to sliding produced by the different bracket/wire/ligature combinations were measured using a frictional testing device that was set on the crosshead of a testing machine (Instrom 4301, Canton, MA) with a load cell of 10 N. The experimental model consisted of

- the bracket welded to a little steel bar;
- the orthodontic wire, along which the bracket could slide, clamped to a custom-made steel support;
- the ligation method, consisting of CEL or UEL for the CB and two lateral clips for the SLB.

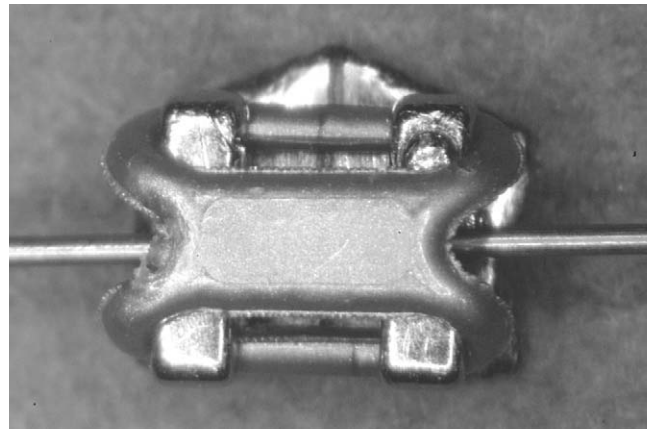

Figure 1. Unconventional elastomeric ligature.

This apparatus was secured to a steel support especially designed for this study, and the lower part of the support was locked to the lower fixed clamp of the testing machine (Figure 4).

Two little holes were present in the upper and lower part of the steel support. These holes allowed the wire to cross through and, once entered, it was held in place by a simple system of screws. The base of the bracket was welded to a steel bar that was secured to the upper movable clamp attached to the load cell. Care was taken to weld 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 steel support.

This device allowed the bracket to move along the wire 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. Each of the six bracket/wire/ligation combinations was tested 10 times, with new elastomeric ligatures on each trial, to minimize the influence of elastic deformation. For every traction test over a distance of

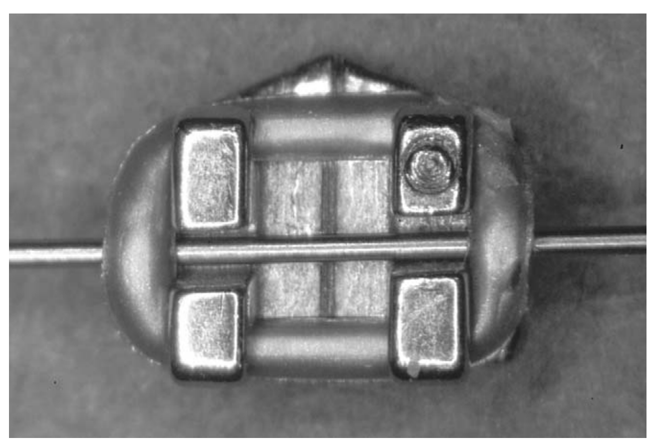

Figure 2. Conventional elastomeric ligature.

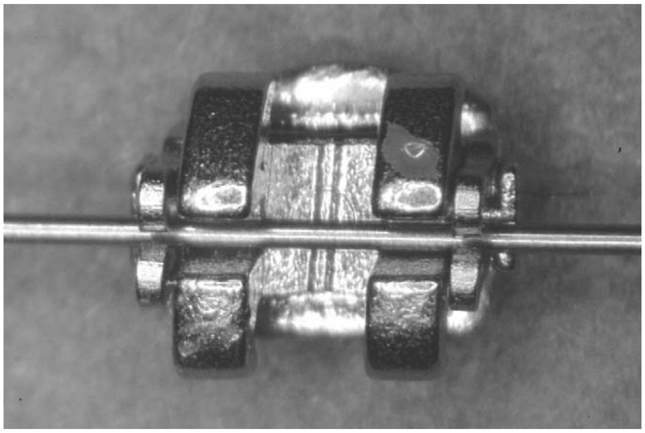

Figure 3. Passive self-ligating bracket.

12 mm at a speed of 6 mm/min the following frictional forces were recorded: the maximum force needed to move the bracket along the wire (static friction) and the mean frictional force registered at 5 mm, at 7 mm, and at 9 mm of movement (kinetic friction). All measurements were performed under dry conditions at room temperature of 20° ± 2°C.

Statistical analysis

Data were tested for normal distribution (Shapiro-Wilks test). As normal distribution could not be assessed for all frictional forces recorded in the different bracket/wire/ligation combinations, descriptive statistics for nonparametric tests were calculated. Differences between frictional forces produced by the different bracket/wire/ligation combinations were compared using Kruskal-Wallis one-way analysis of variance on ranks followed by Tukey's post hoc test ($P < .05$) (SigmaStat 3.1, Systat Software, Point Richmond, Calif).

RESULTS

Descriptive statistics and statistical comparisons of the frictional forces recorded in the different bracket/wire/ligation combinations are reported in Table 1. No statistically significant difference was found between the frictional forces produced by SLB and by UEL on CB when used with 0.014″ SE NiTi wire and with 0.019″ × 0.025″ SS wire. All of these values were close to 0 g (mean values ranging from 0.1 g to 1.2 g). CEL on CB coupled with both types of wires generated significantly greater static and kinetic frictional forces with respect both to SLB and to UEL on CB (mean values ranging from 86.7 g to 177.4 g).

DISCUSSION

The present study compared the friction generated by a passive SLB with the frictional forces produced

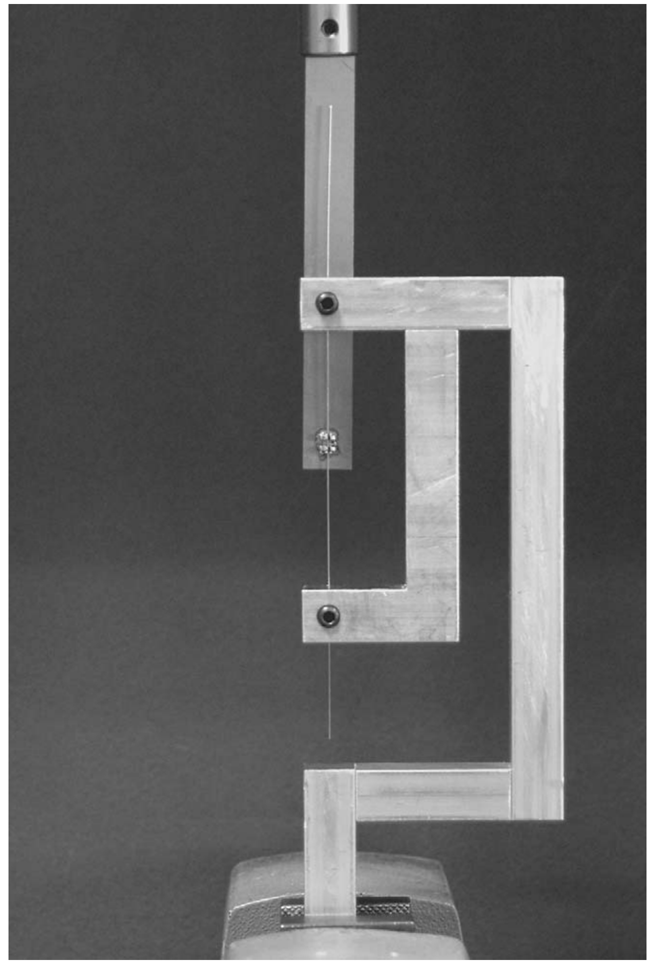

Figure 4. Friction testing apparatus.

by an innovative type of UEL on CB and by CEL on CB. The results of the present investigation indicated that both SLB and UEL on CB produced significantly lower frictional forces compared with CEL on CB when coupled both with .014″ SE NiTi wire and with 0.019″ × 0.025″ SS wire. These results fully agree with those of previous studies[22,24–28,30] that found that passive SLBs generated smaller frictional forces than conventional ligatures on CBs. The significant differences between SLB and CEL on CB in the current study are very similar to those reported by Thomas et al[26] and Hain et al[24] who used a single-bracket experimental model.

Recently, an innovative UEL, manufactured with a special polyurethane mix by injection molding (Slide), was introduced. Once the ligature is applied on the bracket it simulates the labial cover of a passive self-ligating bracket, thus transforming the slot into a tube that allows the archwire to slide freely. The results of the present study confirm previous findings by Baccetti and Franchi[33] who reported significantly lower levels of friction for CB with UEL compared with CB with CEL

Table 1. Descriptive Statistics and Comparisons (ANOVA on ranks with Tukey's post hoc test) of Frictional Forces (g)

	SLB (1)					
	Mean	Median	SD	Range	Min	Max
SF 0.014″ NiTi	0.4	0.4	0.1	0.3	0.2	0.5
KF 0.014″ NiTi	0.1	0.1	0.1	0.2	0.0	0.2
SF 0.019″ × 0.025″ SS	1.0	0.9	0.4	1.2	0.6	1.8
KF 0.019″ × 0.025″ SS	0.7	0.6	0.2	0.6	0.4	1.0
	LFEL on CB (2)					
	Mean	Median	SD	Range	Min	Max
SF 0.014″ NiTi	0.5	0.5	0.1	0.4	0.3	0.7
KF 0.014″ NiTi	0.1	0.1	0.1	0.1	0.0	0.1
SF 0.019″ × 0.025″ SS	1.2	0.9	0.9	3.0	0.6	3.6
KF 0.019″ × 0.025″ SS	0.5	0.5	0.1	0.5	0.2	0.7
	CEL on CB (3)					
	Mean	Median	SD	Range	Min	Max
SF 0.014″ NiTi	119.2	92.8	81.6	280.7	63.5	344.3
KF 0.014″ NiTi	86.7	85.3	24.1	75.6	57.6	133.2
SF 0.019″ × 0.025″ SS	177.4	171.9	17.4	55.4	161.1	216.5
KF 0.019″ × 0.025″ SS	155.6	153.3	18.6	57.1	135.5	192.6
	Statistical Comparisons					
	1 vs 2		1 vs 3		2 vs 3	
	q	Sig	q	Sig	q	Sig
SF 0.014″ NiTi	1.132	NS	7.035	*	5.903	*
KF 0.014″ NiTi	0.462	NS	6.102	*	6.564	*
SF 0.019″ × 0.025″ SS	0.063	NS	4.427	*	4.364	*
KF 0.019″ × 0.025″ SS	0.733	NS	4.165	*	4.898	*

SLB indicates self-ligating bracket; UEL, unconventional elastomeric ligature; CB, conventional bracket CEL, conventional elastomeric ligature; SF, static friction; KF, kinetic friction; q, studentized range statistic; Sig, significance; NS, not significant.

* $P < .05$.

during sliding mechanics with 0.014″ SE NiTi wire and 0.019″ × 0.025″ SS wire.

Based on the results of the present study, UELs are able to produce significantly lower levels of frictional forces than CEL when applied on CB; thus, UELs may represent a valid alternative to passive self-ligating brackets for low-friction biomechanics. One of the clinical advantages that arises from the use of UELs is that they can be placed on every type of CBs with considerable cost reduction compared with SLBs. Another advantage is that the clinician can apply friction and low-friction mechanics simultaneously on the same archwire by using CEL and UEL only in particular segments. For example, during en masse space closure on a rectangular stainless steel archwire, UELs can be used in the posterior segments to reduce friction, while CELs are used in the anterior segment to maximize torque expression and control.

The clinical interpretation of these experimental data, however, requires further considerations that modulate the findings. It should be stressed that in vitro studies cannot reproduce exactly what occurs in vivo in the oral cavity during orthodontic tooth movement. Minimal adjustments at the bracket/wire/ligature system may significantly change frictional resistance because of physiologic oral functions as well as the oral tissues or food contacting the orthodontic appliance. UELs may represent a valid alternative to passive SLBs for low-friction biomechanics.

CONCLUSIONS

- SLB and UEL on CB are able to produce significantly lower frictional forces compared with CEL on CB when coupled with .014″ SE NiTi wire and with 0.019″ × 0.025″ SS wire.

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