Original Article

Friction of Orthodontic Elastomeric Ligatures with Different Dimensions

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Abstract: The aim of this study was to evaluate in vitro the effect of variations in the size of elastomeric ligatures on the static frictional resistance generated by orthodontic sliding mechanics under dry condition. Frictional forces generated by elastomeric ligatures treated with a lubricating material (silicone) were analyzed as well. An Instron testing machine was used to assess the static frictional forces of a 0.019 × 0.025-inch stainless steel rectangular wire that was ligated to a molar convertible tube and to three stainless steel 0.022-inch pre-adjusted brackets with elastomeric ligatures with different dimensions: small, medium, and large. The static friction produced by two prototypes of silicone-lubricated elastomeric ligatures was also measured. The small and medium elastomeric ligatures produced significantly less friction than the large ligatures. No statistically significant difference was found between small and medium ligatures. The decrease in frictional forces of small and medium modules had to be ascribed mainly to the smaller thickness of both ligatures with respect to large ligatures. The lubricated elastomeric ligatures generated significantly smaller frictional forces than nonlubricated elastomeric ligatures with different dimensions. The variation in the dimensions of the elastomeric ligatures is able to influence the static frictional resistance generated by orthodontic sliding mechanics in the buccal segments. The use of small and medium elastomeric ligatures determines a 13–17% decrease in static friction compared with large ligatures. Silicone-lubricated modules can reduce static friction by 23–34% with respect to the small and medium nonlubricated elastomeric ligatures and by 36–43% compared with nonlubricated large ligatures. (*Angle Orthod* 2005;75:421–425.)

Key Words: Friction; Orthodontic appliances; Orthodontic brackets; Orthodontic wires; Polyurethanes

INTRODUCTION

Orthodontic sliding mechanics using pre-adjusted brackets is a common method of translating a tooth or a group of teeth. In particular, overjet reduction or space closure with the so-called ''straight-wire techniques'' is achieved by applying a distal force that makes the archwire slide through the slot of the brackets or the tubes of the posterior teeth.

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The major disadvantage with the use of sliding mechanics is the friction that is generated between the bracket and the archwire during orthodontic movement. Friction is defined as ''the force tangential to the common boundary of two bodies in contact that resists the motion of one relative to the other. The amount of friction is proportional to the force with which the two surfaces are pressed together and dependent on the nature of the surfaces in contact'' (composition of the material, surface roughness, etc.)[1] The force applied, therefore, has to overcome friction to achieve the desired orthodontic movement. The dissipation of the orthodontic force as resistance to sliding may vary between 12% and 60%[2] or it may lead to a stop in tooth movement. On the other hand, an excessive increase in orthodontic forces to overcome frictional resistance during retraction of the anterior teeth may produce increased posterior anchorage loss.[3]

The friction encountered during tooth movement can be divided into static friction and kinetic friction.[4] Static friction is defined as the force required to initiate tooth movement, whereas kinetic friction is the force that resists motion. Because tooth movement along an archwire is not continuous, but occurs in a series of very short steps or jumps, static friction is considered to have a greater importance because it needs to be overcome each time the tooth moves a little.[4]

Frictional resistance must be kept to a minimum during sliding mechanics so that orthodontic tooth movement can be generated through light optimal forces. A number of studies have identified the principal factors that may influence orthodontic frictional resistance: relative bracket-wire clearances,[5] archwire size,[4,6] archwire section (round vs rectangular wires),[3,7] torque at the bracket-wire interface,[7] surface conditions of the archwires and bracket slot,[8] bracket and archwire materials,[2,9–12] bracket slot width,[7] bracket type (conventional vs self-ligating brackets),[9,13–15] type and force of archwire ligation.[1,9,13,16–21]

The method of archwire ligation has been investigated in relatively few studies.[1] The majority of the authors agree that loosely tied stainless steel ligatures produce less friction than standard elastomeric ligatures.[9,15,17,20] According to other studies, frictional forces produced by elastomeric ligatures and stainless steel ligatures are similar,[4,16] whereas others found that friction caused by elastomeric ligatures was less than that generated by steel ligatures.[19,22] These differences in results may be ascribed to the different forces used to tie the stainless steel ligatures. Although loose stainless steel ligatures produce less friction compared with elastomeric modules, the convenience and speed of application of elastomeric rings are likely to ensure their continued popularity among clinicians. In addition, the low force exerted by loose steel ligatures may be inadequate to ensure torque expression because of incomplete adaptation of the archwire inside the bracket slot.

Frictional forces produced by elastomeric modules may vary from 50 to 150 g.[23] Elastomeric ligatures consists of polyurethane polymers that are subject to permanent deformation with time and they also deteriorate in moist environment as a result of slow hydrolysis.[24] In vitro studies under dry[15] and wet conditions (water at 37°C)[1] have demonstrated that frictional forces generated by elastomeric modules decrease during a 3–4 week period with a concurrent decrease in failure load strength.[1] A reduction in frictional force can be obtained by stretching an elastomeric ligature to double its initial diameter.[15] The elastomeric ligatures can be performed either in a conventional manner (figure-O pattern) or in a figure-8 pattern. The figure-8 pattern, although useful to ensure full archwire engagement inside the bracket slot, produces significantly greater friction when compared with figure-O pattern.[16,17,21,23]

Elastomeric ligatures can be manufactured either by injection molding or by cutting from elastomeric tubing (generally with a rectangular section). Different types of modules are available on the market including grey and clear modules, modules with different colors, fluoride-impregnated modules, and recently, lubricated modules.[17] Clear round modules produced by injection molding generate the lowest frictional forces compared with colored, fluoride-impregnated modules, and gray rectangular modules produced by cutting.[1] The use of lubricated modules also is associated with a reduction of frictional resistance.[17]

Surprisingly, there is lack of information concerning the frictional forces developed by elastomeric ligatures with different dimensions in sliding mechanics. Thus, it is the purpose of this study to evaluate in vitro the effect of the variation in the dimensions of elastomeric ligatures on the static frictional resistance generated by orthodontic sliding mechanics in the buccal segments under dry condition. Frictional forces produced by elastomeric ligatures treated with a lubricating material (silicone) were analyzed as well.

MATERIALS AND METHODS

An experimental model reproducing the right buccal segment of the upper arch was used to assess the static friction produced by elastomeric ligatures with different dimensions and also by elastomeric ligatures lubricated with silicone. This model allowed simulating the frictional resistance in the buccal segments during incisor retraction with sliding mechanics. All materials used in this study were supplied by Leone SpA (Sesto Fiorentino, Firenze, Italy).

The buccal segment model consisted of a 0.022-inch second molar buccal tube, a 0.022-inch convertible first molar buccal tube in the converted state, three stainless steel 0.022-inch pre-adjusted brackets for the right second premolar, first premolar, and canine (STEP brackets, Leone SpA, Sesto Fiorentino, Firenze, Italy). A section of 0.0215 $\times$ 0.028-inch stainless steel wire was used to align the brackets and the tubes prior to blocking them inside a vice-like device (Figure 1). The distance between the first premolar bracket and the second premolar bracket and the distance between the first premolar bracket and the canine was set at 9 mm, whereas the distance between the second molar tube and the first molar tube and the distance between the first molar tube and the second premolar bracket was set at 10 mm.

A 0.019 $\times$ 0.025-inch stainless steel wire was secured into the preadjusted brackets and the convertible molar tube using elastomeric modules produced by injection molding with three different dimensions (silver mini modules, Leone SpA) (Figure 1)—small: inside diameter 1.0 mm, outside diameter 2.6 mm, thickness 0.85 mm; medium: inside diameter 1.3 mm, outside diameter 3.1 mm, thickness 0.9 mm; and large: inside diameter 1.6 mm, outside diameter 3.6 mm, thickness 1.0 mm.

Two prototypes of elastomeric ligatures produced by injection molding and lubricated with silicone (Leone SpA) were also used to tie the wire to the brackets: clear lubricated modules, inside diameter 1.5 mm, outside diameter 3.0 mm, thickness 0.65 mm; gray lubricated modules, inside diameter 1.5 mm, outside diameter 3.0 mm, thickness 0.65 mm.

Friction generated by the testing unit consisting of wire,

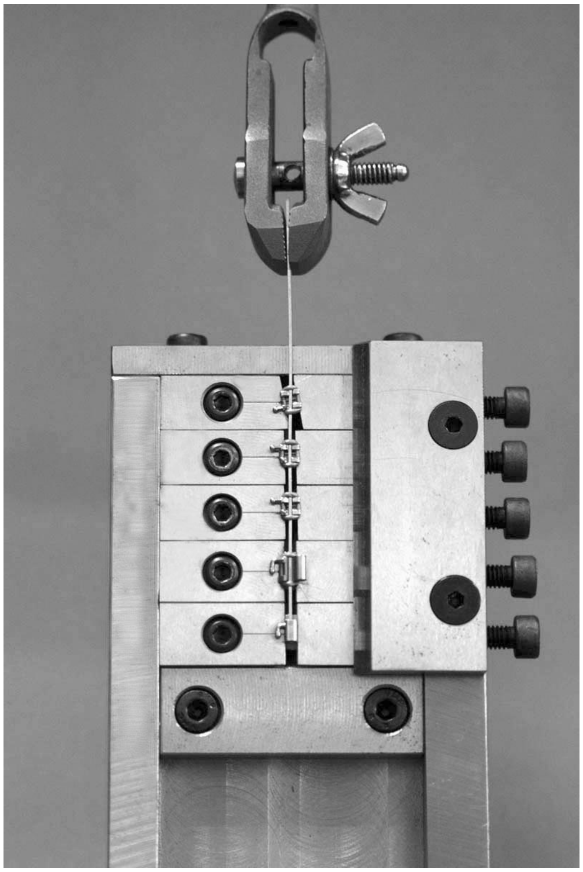

FIGURE 1. Friction testing apparatus. The buccal segment model consists of a 0.022-inch second molar buccal tube, a 0.022-inch convertible first molar buccal tube in the converted state, three stainless steel 0.022-inch preadjusted brackets for the right second premolar, first premolar, and canine. The brackets and the tubes are aligned and blocked inside a vicelike device. The test wire is ligated into the testing unit and its bottom end clamped by a vice mounted on the Instron crosshead.

brackets, and elastomeric ligatures was measured on an Instron 4301 testing machine (Instron Corp, Canton, Mass) with a load cell of 100 N. The test wire was inserted into the testing unit and its bottom end clamped by a vice mounted on the Instron crosshead. Care was taken to avoid introducing torsion into the test wire during clamping. Static friction was recorded while 5 mm of wire was drawn through the brackets at a speed of 20 mm/min and it was defined as the force needed to start the wire moving through the bracket assembly. This force was measured as the maximal initial rise on the Instron chart trace. After each test, the testing machine was stopped, the wire-bracket-ligature unit was removed and a new assembly was placed. For each type of elastomeric ligature, a series of 10 friction recordings were taken. The friction tests were started immediately after ligation with new elastomeric ligatures placed in a conventional manner (figure-O pattern). All measurements were made in the dry state at room temperature (20 ± 2°C).

Statistical analysis

Descriptive statistics including mean, standard deviation, median, range, minimum, and maximum values were calculated for the static frictional forces produced by each type of elastomeric ligatures. The normal distribution of the data for each type of ligatures (Shapiro-Wilk test) allowed statistical comparisons among the five groups (small, medium, large, clear lubricated, and gray lubricated modules) using one-way analysis of variance (ANOVA) followed by Holm-Sidak post hoc test for multiple comparisons (level of significance, $P < .05$). To evaluate the influence of the dimensional features of the five types of modules and of lubrication on the static frictional forces, linear regressions between the static frictional force (dependent variable) and the inner diameter, the outside diameter, the thickness, and the presence or absence of lubrication (independent variables) were also performed. All statistical computations were performed by statistical software (SigmaStat 3.0, SPSS Inc, Chicago, Ill).

RESULTS

Descriptive statistics for the static friction for the five groups of elastomeric ligatures are reported in Table 1. Comparisons among the different types of elastomeric ligatures with ANOVA followed by Holm-Sidak post hoc test are described in Table 2. The small and medium elastomeric ligatures produced significantly smaller static frictional forces than the large ligatures. No statistically significant difference was found between small and medium ligatures.

The silicone-lubricated elastomeric ligatures generated significantly smaller static frictional forces than small, medium, and large nonlubricated ligatures. The gray lubricated modules showed the smallest value in static friction (even though not significantly different from the clear lubricated modules). Linear regression analysis showed significant positive correlations between the thickness of the modules and the frictional forces ($r^2 = 0.587$; $P < .001$) and be-

TABLE 1. Descriptive Statistics of the Static Frictional Forces (g)

	Mean	SD	Median	Range	Minimum	Maximum
Small modules	533.16	79.38	507.11	240.34	436.34	676.68
Medium modules	508.80	74.71	507.82	229.94	400.75	630.69
Large modules	611.14	95.83	627.18	273.18	446.74	719.92
Clear lubricated modules	392.44	76.93	386.43	284.70	284.40	569.10
Gray lubricated modules	350.38	59.28	354.92	413.39	256.46	469.85

TABLE 2. Statistical Comparisons Among the Different Types of Elastomeric Modules (ANOVA Followed by Holm-Sidak post hoc Test. t Values are Reported)

	Small modules	Medium modules	Large modules	Clear lubricated modules	Gray lubricated modules
Small modules		0.697	2.233*	4.029*	5.233*
Medium modules	0.697		2.930*	3.331*	4.535*
Large modules	2.233*	2.930*		6.261*	7.465*
Clear lubricated modules	4.029*	3.331*	6.261*		1.204
Gray lubricated modules	5.233*	4.535*	7.465*	1.204	

* $P < .05$.

tween the outside diameter and the frictional forces ($r^2 = 0.098$; $P < .05$). The inside diameter was not correlated significantly with the frictional forces ($r^2 = 0.023$; $P = .289$). The presence of lubrication was correlated significantly with decreases in frictional forces ($r^2 = 0.532$; $P < .001$).

DISCUSSION

The present in vitro study evaluated the static friction produced by elastomeric ligatures with different dimensions and also by elastomeric ligatures lubricated with silicone within an experimental model that reproduced the right buccal segment of the upper arch. This model allowed assessment of the frictional resistance in the buccal segments during incisor retraction. The results of the present study revealed that, all other factors being equal (stainless steel 0.022-inch pre-adjusted brackets and 0.019 $\times$ 0.025-inch stainless steel wire), small and medium elastomeric ligatures produced significantly smaller static frictional forces than large ligatures.

This outcome appears to be quite counterintuitive because one would expect that larger and consequently looser elastomeric ligatures would create smaller frictional forces when compared with smaller and consequently tighter ligatures. Taloumis et al[25] found a positive correlation between the wall thickness and the force developed by elastomeric ligatures when stretched 5.5 mm, whereas a negative correlation existed between the inside diameter and the force. In the present study, the regression analysis revealed a significant positive correlation between the thickness of the modules and the frictional forces ($r^2 = 0.587$; $P < .001$). The outside diameter also showed a weak positive correlation with the frictional forces ($r^2 = 0.098$; $P < .05$). The inside diameter did not show significant correlation with the static frictional forces. Therefore, the decrease in frictional forces of small and medium modules had to be ascribed mainly to the smaller thickness of both ligatures compared with large ligatures.

The present study also demonstrated that prototypes of elastomeric ligatures lubricated with silicone produced significantly smaller frictional forces than nonlubricated ligatures. Regression analysis confirmed that the presence of lubrication was significantly associated with a decrease in the static frictional forces. In particular, silicone-lubricated modules allowed a reduction in the static frictional force by 23–34% with respect to nonlubricated small and medium elastomeric ligatures and by 36–43% compared with nonlubricated large ligatures. The smaller thickness of the lubricated ligatures with respect to the nonlubricated ligatures also could have contributed to the decrease in static frictional resistance, as revealed by the results of regression analysis.

Hain et al[17] also found a significant decrease (up to 60%) in static friction with lubricated modules with respect to regular modules. According to these authors,[17] the use of lubricated modules determined a reduction of the friction compared with self-ligating SPEED brackets. However, loosely tied stainless steel ligatures offered the lowest frictional resistance of all the ligation methods tested. The new prototype of silicone-lubricated module used in the present study needs to be further tested in vitro to evaluate the stability of the favorable features along with time, especially under wet condition.

It should also be stressed that caution must be exercised when evaluating the clinical applicability of the results of the present study. It has been emphasized already that, from a clinical point of view, static friction is considered to have a greater importance than kinetic friction. The mean values for the static friction reported in Table 1 can be regarded as the maximum expected because they were derived from an experimental model that consisted of four wire-bracket-ligature units. Moreover, previous investigations[16] showed that the values for static friction tend to increase in presence of human saliva when compared with dry conditions. Finally, 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.[26]

CONCLUSIONS

The results of the present study showed that the variation in the dimensions of the elastomeric ligatures can influence significantly the static frictional resistance generated by orthodontic sliding mechanics in the buccal segments. Small and medium elastomeric ligatures produced a significant decrease (13–17%) in the static frictional force when compared with large ligatures. The decrease in frictional forces of small and medium modules has to be ascribed mainly to the smaller thickness of both ligatures with respect to large ligatures. Prototypes of the elastomeric ligatures treated with a lubricating substance (silicone) determined a significant decrease of the static frictional force when compared with nonlubricated ligatures with different dimensions. The smaller thickness of the lubricated ligatures with respect to the nonlubricated ligatures also could have contributed to the decrease in static frictional resistance. In particular, silicone-lubricated elastomeric modules can reduce the static frictional force by 23–34% with respect to nonlubricated small and medium elastomeric ligatures and by 36–43% compared with nonlubricated large ligatures.

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