Friction Produced by Types of Elastomeric Ligatures in Treatment Mechanics with the Preadjusted Appliance

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ABSTRACT

The objective was to compare the frictional forces generated by new nonconventional passive elastomeric ligatures (NCL) and conventional elastomeric ligatures (CL) under dry conditions. An experimental model reproducing the right buccal segment of the upper arch and consisting of five stainless steel 0.022-inch preadjusted brackets (from the second premolar through the central incisor) was used to assess both static and kinetic frictional forces produced by NCL and CL. The frictional forces generated by the 0.019 × 0.025–inch stainless steel wire with the two types of elastomeric ligatures were recorded by sliding the wire into the aligned brackets. The friction produced by the 0.014-inch superelastic nickel titanium wire was evaluated both in the presence of aligned brackets and of three-mm misaligned canine bracket. The amount of both static and kinetic frictions were minimal ($<$10 g) in the NCL group in the presence of aligned brackets with both types of wires, whereas it ranged from a minimum of 95.6 g for the 0.014-inch superelastic nickel titanium wire to a maximum of 590.7 g for the 0.019 × 0.025–inch stainless steel wire when using CL. The amount of both static and kinetic frictions in the presence of a misaligned canine bracket in the NCL group were less than half of that shown by the CL group. A recently developed passive ligature system is able to produce significantly lower levels of frictional forces in vitro when compared with conventional elastomeric modules. (*Angle Orthod* 2006;76:211–216.)

KEY WORDS: Orthodontic appliances; Orthodontic brackets; Orthodontic wires; Polyurethanes; Friction

INTRODUCTION

Treatment mechanics with the preadjusted appliance represent an effective method for controlled orthodontic tooth movement. During this type of mechanics, a frictional force is produced at the bracket/archwire/ligature (BAL) unit that tends to contrast the desired tooth movement. Because the efficiency of fixed appliance therapy depends on the fraction of force delivered with respect to the force applied,[1] high frictional forces due to the interaction between the bracket and the guiding archwire affect treatment outcomes and duration in a negative manner.[2–6] By controlling frictional resistance at the BAL interfaces, lower levels of force can be applied during orthodontic treatment to obtain an optimal biological response for effective tooth movement.[7,8]

The clinician must be cognizant of the main factors that influence frictional resistance at the BAL unit. Among these factors, features of both archwire and bracket (in terms of size and material) have been investigated extensively in relation to friction production.[9–17] On the other hand, it appears that methods and properties of archwire ligation, which entail an important role in the generation of friction, have received limited attention in literature with respect to frictional resistance at the BAL unit.

The importance of the ligature in creating friction at the BAL unit is emphasized indirectly by therapeutical approaches that avoid the use of any form of ligature (self-ligating bracket systems). These systems present

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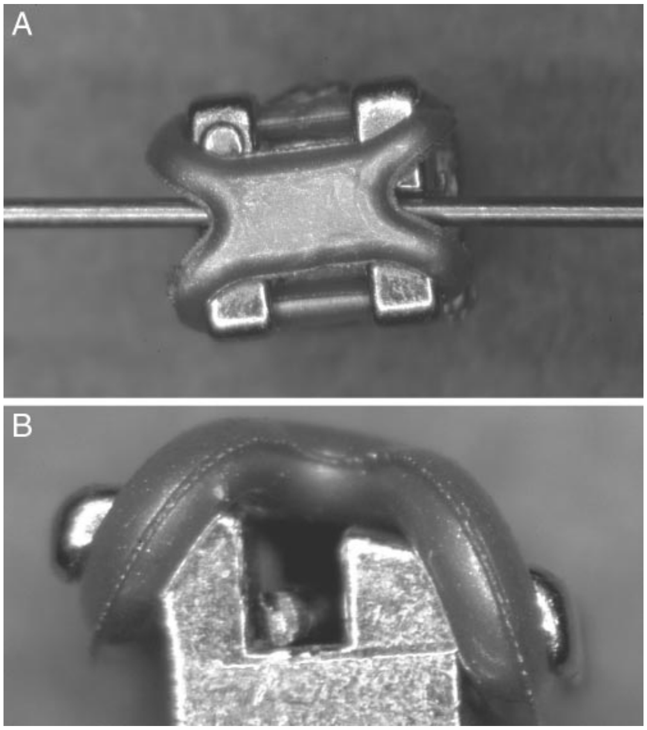

FIGURE 1. (A and B) The nonconventional elastomeric ligature. When the ligature is applied on the bracket, the interaction between the ligature and the slot forms a tubelike structure, which allows the archwire to slide freely.

with significantly lower levels of frictional resistance when compared with conventional bracket systems with conventional ligatures.[18–22] Furthermore, reduced levels of friction during treatment can be obtained also by differential placement of conventional elastomeric ligatures (CLs) on special versatile brackets (Synergy, Rocky Mountain Orthodontics, Denver, Colo)[23] or by using lubricated elastomeric modules[24,25] or loosely tied stainless steel ligatures.[23,24,26,27]

Recently, an innovative ligature manufactured with a special polyurethane mix by injection molding (Slide®, Leone Orthodontic Products, Sesto Fiorentino, Firenze, Italy) was introduced (Figure 1). The ‘‘nonconventional’’ elastomeric ligature (NCL) is used on conventional brackets to produce low levels of frictional resistance in treatment mechanics with the preadjusted appliance. Once the ligature is applied on the bracket, the interaction between the ligature and the slot forms a ‘‘tubelike’’ structure, which allows the archwire to slide freely and to produce its effects more readily on the dentoalveolar component. These ligatures can be applied on specific groups of teeth where lower levels of friction at the BAL units are desired.

The aim of this investigation was to compare the frictional forces generated by the NCLs with respect to CLs using an in vitro study in the dry state.

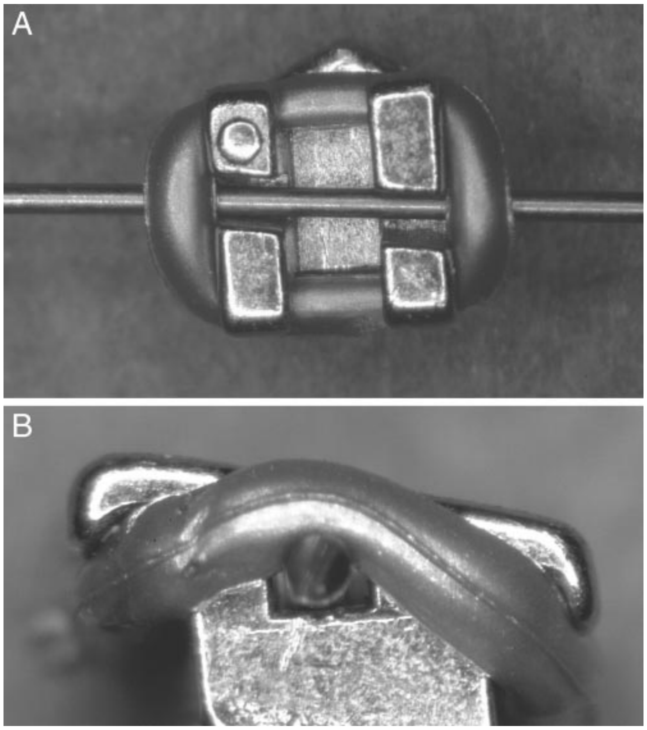

FIGURE 2. (A and B) The conventional elastomeric ligature. This ligature presses actively the archwire into the bracket slot.

MATERIALS AND METHODS

An experimental model reproducing the right buccal segment of the upper arch was used to assess the frictional forces produced by the NCLs (Figure 1) and by CLs (Figure 2). All materials used in this study were supplied by Leone Orthodontic Products. The buccal segment model consisted of five stainless steel 0.022-inch preadjusted brackets for the second premolar, first premolar, canine, lateral incisor, and central incisor (STEP® brackets). A section of the 0.0215 × 0.028–inch stainless steel wire was used to align the brackets before blocking them inside a vicelike device[25] (Figure 3). The distance between the brackets was set at 19 mm.

Two different types of 18-cm-long wires were tested: 0.019 × 0.025–inch stainless steel wire and 0.014-inch superelastic nickel titanium wire (Memoria® wire). The two types of wires were secured into the preadjusted brackets by using two types of elastomeric ligatures produced by injection molding: nonconventional ligatures (Slide®) and CLs (silver mini modules, with an inside diameter of 1.3 mm and a thickness of 0.9 mm). The frictional forces generated by the 0.019 × 0.025–inch stainless steel wire with the two types of elastomeric ligatures were recorded by sliding the wire into the aligned brackets. Friction produced by the 0.014-inch superelastic nickel titanium wire with the two types of elastomeric ligatures was evaluated both

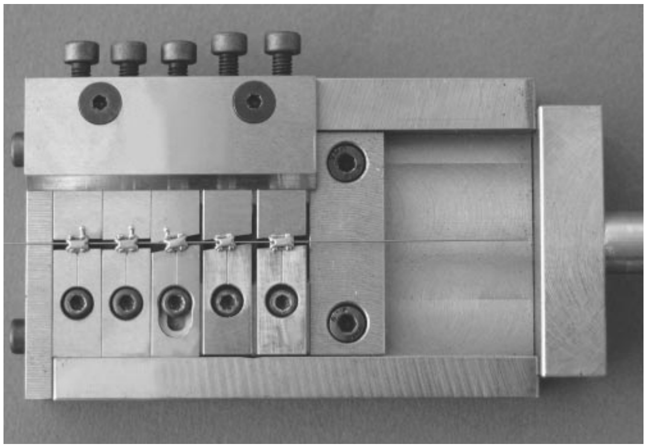

FIGURE 3. Experimental in vitro model reproducing the right buccal segment of the upper arch that was used to assess the frictional forces produced by nonconventional elastomeric ligature and by conventional elastomeric ligature (Figure 2). The buccal segment model consisted of five stainless steel 0.022-inch preadjusted brackets for the second premolar, first premolar, canine, lateral incisor, and central incisor. The brackets were aligned and blocked inside a vicelike device.

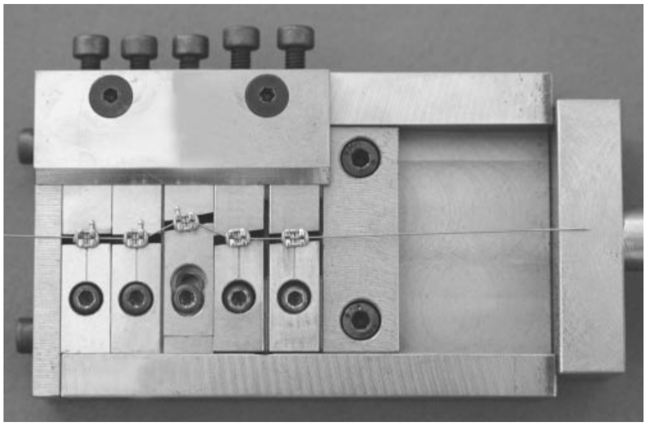

FIGURE 4. Experimental in vitro model with three-mm misaligned canine bracket and 0.014-inch wire.

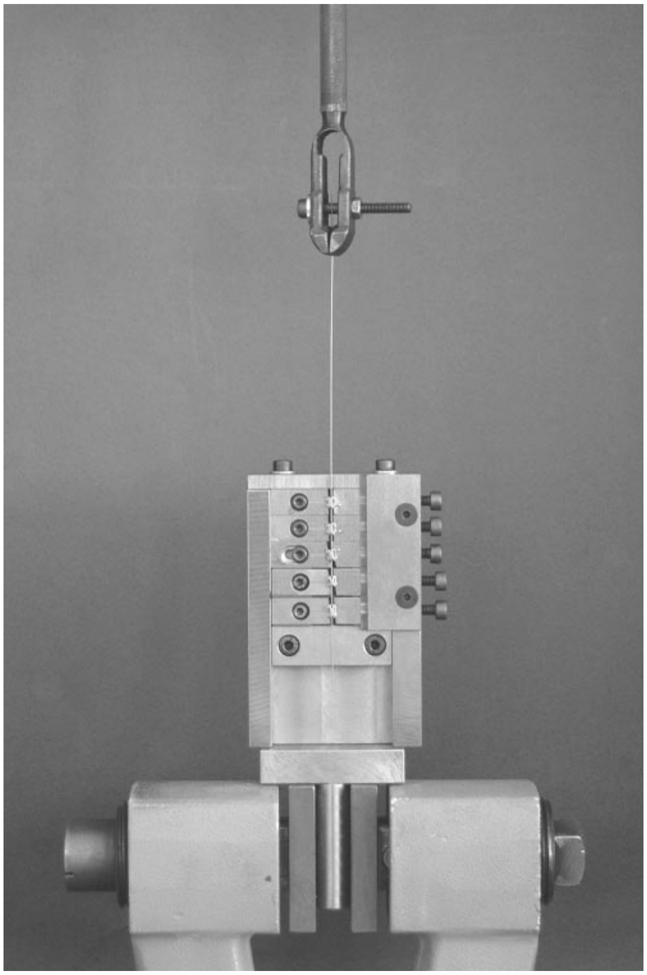

FIGURE 5. Friction testing apparatus. The test wire is ligated into the experimental model, and its bottom end is clamped by a vice mounted on the Instron crosshead.

in the presence of aligned brackets and of misaligned canine bracket (Figure 4). The vicelike device was allowed to create a three-mm misalignment of the canine bracket in an upward direction.

The friction generated by the testing unit consisting of wire, brackets, and elastomeric ligatures were measured under dry conditions and at room temperature (20 ± 2°C) using an Instron 4301 testing machine (Instron Corp, Canton, Mass) with a load cell of 10 N. The testing machine had been calibrated by the Instron Calibration Laboratory in terms of crosshead displacement/speed and load cell. The test wire was inserted into the testing unit, and its bottom end was clamped by a vice and mounted on the Instron crosshead (Figure 5). The elastomeric ligatures were placed immediately before each test run, to avoid ligature force decay. Frictional forces produced by each wire/ligature combination with aligned brackets for the 0.019 × 0.025–inch stainless steel wire and with both aligned and misaligned brackets for the 0.014-inch superelastic nickel titanium wire were tested 10 times with new wires and ligatures on each occasion.

A total of 60 tests (30 tests for each type of elastomeric ligatures) were carried out. Static and kinetic friction forces were recorded while 15 mm of wire was drawn through the brackets at a speed of 15 mm/min. Static friction 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 (Figure 6). Recommendations for usage with the Instron machine strongly suggest that in tests measuring kinetic friction this must be evaluated as an average of the frictional forces appraised at subsequent time periods during displacement. For the purpose of this study, measurements of kinetic friction were performed at two, five, and 10 mm of dis-

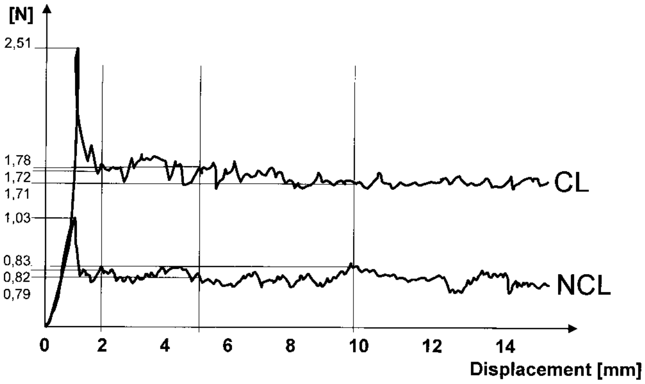

FIGURE 6. Diagram of the static and kinetic frictional forces produced conventional ligatures and nonconventional ligatures. Kinetic friction was measured at two, five, and 10 mm of displacement.

placement during experiment and then averaged (Figure 6).

Statistical analysis

Descriptive statistics including mean, median, standard deviation, minimum, and maximum values were calculated for the static and kinetic frictional forces produced by wire/ligature combination with both aligned brackets and misaligned brackets. Because normal distribution of the data was not found (Shapiro-Wilk test), the comparisons between the results for the two types of ligatures were carried out using a nonparametric test for independent samples (Mann-Whitney *U*-test).

All statistical computations were performed using statistical software (SigmaStat 3.0, SPSS Inc, Chicago, Ill).

RESULTS

The descriptive statistics and the analysis of the comparisons on static and kinetic frictional forces for the two ligature systems are shown in Tables 1 and 2. The Mann-Whitney test revealed significant differences between CL and NCL for both types of frictional forces for all tested variables ($P < .001$): use of 0.019 × 0.025–inch stainless steel wire with aligned brackets and use of 0.014-inch superelastic nickel titanium wire both in the presence of aligned brackets and of three-mm misaligned canine bracket.

The amount of both static and kinetic frictions were minimal (<10 g) in the NCL group in the presence of aligned brackets with both 0.019 × 0.025–inch stainless steel and 0.014-inch superelastic nickel titanium wires, whereas it ranged from a minimum of 95.6 g for the 0.014-inch superelastic nickel titanium wire to a maximum of 590.7 g for the 0.019 × 0.025–inch stainless steel wire when using CL. The amount of both static and kinetic frictions in the presence of misaligned canine bracket in the NCL group were less than half of that shown by the CL group.

DISCUSSION

Contemporary fixed appliance therapy with preadjusted brackets clearly benefits from the enhancement of the fraction of force delivered with respect to the force applied.[1] To attain this favorable condition, a reduction in frictional forces between the bracket and the guiding archwire must be achieved. Clinical evidence of the beneficial effects of low-friction archwire ligatures on the biomechanical characteristics of orthodontic treatment can be derived from the use of pas-

TABLE 1. Descriptive Statistics and Statistical Comparisons of Static Frictional Forces (g)[a]

	Conventional Elastomeric Ligatures					Non-conventional Elastomeric Ligatures					
	Mean	Median	SD	Min	Max	Mean	Median	SD	Min	Max	Significance
0.019 × 0.025–inch SS aligned br.	590.7	587.3	38.1	529.1	656.2	8.3	3.0	10.5	1.3	31.7	*
0.014-inch SE aligned br.	156.4	155.0	10.8	133.6	173.6	0.7	0.5	0.5	0.2	1.6	*
0.014-inch SE misaligned br.	255.9	253.4	68.5	155.0	347.7	105.1	109.6	18.8	78.5	135.6	*

[a] SS indicates stainless steel; SE, superelastic; and br., bracket.
* $P < .001$.

TABLE 2. Descriptive Statistics and Statistical Comparisons of Kinetic Frictional Forces (g)[a]

	Conventional Elastomeric Ligatures					Non-conventional Elastomeric Ligatures					
	Mean	Median	SD	Min	Max	Mean	Median	SD	Min	Max	Significance
0.019 × 0.025–inch SS aligned br.	541.6	538.6	41.7	491.4	631.6	0.9	1.0	0.4	0.4	1.6	*
0.014-inch SE aligned br.	95.6	92.3	20.6	66.3	137.7	0.1	0.1	0.1	0.0	0.4	*
0.014-inch SE misaligned br.	176.9	178.5	20.4	147.9	203.9	82.7	82.6	12.9	65.3	103.0	*

[a] SS indicates stainless steel; SE, superelastic; and br., bracket.
* $P < .001$.

sive self-ligating brackets,[21,22] a family of orthodontic attachments where the archwire is not compressed into the slot by any ligating system.

The aim of this study was to compare the friction generated by an innovative type of NCL (that transforms the orthodontic bracket into a tubelike structure virtually without any pressure on the archwire) with the friction produced by CLs. This in vitro study attempted to recreate frequent clinical conditions for straight-wire technique. The research was tailored to test the friction during two fundamental therapeutical phases: (1) sliding mechanics on aligned brackets with a rectangular archwire and (2) leveling and aligning with a superelastic archwire in the presence of misaligned canine bracket. The method of investigation used a device specifically designed and manufactured to simulate the clinical conditions of a dental arch section for the study of both static and kinetic attritions.[25]

The NCL showed levels of friction that were significantly lower than those produced by CL during sliding mechanics with a 0.019 × 0.025–inch rectangular wire. The amount of both static and kinetic frictional forces exerted by the NCL were minimal (approximately eight and one g, respectively) when compared with CL, which exhibited more than 500 g of force on an average for both frictional force types. The findings regarding the NCL are very similar to those concerning the Activa self-ligating brackets as reported by Sims et al[19] in 1993 and to the data related to the Damon self-ligating bracket.[21]

The use of a superelastic 0.014-inch archwire with aligned brackets showed that frictional forces were virtually absent for the NCL, whereas static and kinetic frictional forces were, respectively, approximately 150 and 100 g for the CL. Once again, the data for the NCL are in agreement with previous results for passive self-ligating Damon brackets.[21]

The amount of frictional forces produced by the NCL with three-mm misalignment of the canine bracket were less than half of the forces generated by CL (approximately 100 vs 250 g for the static forces, and approximately 80 vs 180 g for the kinetic forces). A specially designed device was used to simulate the clinical condition of a misaligned bracket in the presence of other aligned brackets. This provided researchers, for the first time, with the ability to analyze the amount of frictional forces generated by ‘‘passive’’ ligature systems in the presence of misaligned teeth, ie, the three-mm misaligned canine bracket of this study.

It can be speculated that the modification in the shape of the archwire because of the curvature in an apical direction imposed by the tooth misalignment may play a role in the increase of frictional forces regardless of the type of ligature. Because of the geometry of the interactions between the wire and the slot, a force due to binding is generated at the mesial aspect of the first premolar bracket, at the distal aspect of the lateral incisor bracket, and at both mesial and distal aspects of the canine bracket. The force due to the binding results in an additional frictional effect. This concept is corroborated by previous research by Kusy and Whitley[28] in 1999, who emphasized the importance of the ‘‘critical contact angle’’ in the production of binding over friction.

On the basis of the results of this study, the innovative elastomeric ligatures produce significantly lower levels of frictional forces than conventional elastomeric modules, so that the new ligatures may represent a valid alternative to passive self-ligating brackets when minimal amount of friction is desired. One of the most favorable features of the new ligatures is the possibility of turning any type of existing conventional bracket system into a ‘‘low-friction’’ bracket system. Furthermore, the innovative ligatures can be applied on specific groups of teeth where lower levels of friction at the BAL units are desired.

CONCLUSIONS

- A recently developed passive ligature system is able to produce significantly lower levels of frictional forces when compared with conventional elastomeric modules.
- This favorable outcome occurs in the presence of both aligned and misaligned brackets.

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REFERENCES

1. Kusy RP, Whitley JQ. Friction between different wire-bracket configurations and materials. *Semin Orthod.* 1997;3:166–177.
2. Rossouw PE. Friction: an overview. *Semin Orthod.* 2003;9:218–222.
3. Drescher D, Bourauel C, Schumacher HA. Frictional forces between bracket and arch wire. *Am J Orthod Dentofacial Orthop.* 1989;96:397–404.
4. Kapila S, Angolkar PD, Duncanson MG Jr, Nanda RS. Evaluation of friction between edgewise stainless steel brackets and orthodontic wires of four alloys. *Am J Orthod Dentofacial Orthop.* 1990;98:100–109.
5. Downing A, McCabe J, Gordon P. A study of frictional forces between orthodontic brackets and archwires. *Br J Orthod.* 1994;21:349–357.
6. Edwards GD, Davies EH, Jones SP. The ex vivo effect of ligation technique on the static frictional resistance of stainless steel brackets and archwires. *Br J Orthod.* 1995;22:145–153.
7. Angolkar PD, Kapila S, Duncanson MG Jr, Nanda RS. Eval-

uation of friction between ceramic brackets and orthodontic wires of four alloys. *Am J Orthod Dentofacial Orthop.* 1990; 98:499–506.

8. Ogata RH, Nanda RS, Duncanson MG Jr, Sinha PK, Currier GF. Frictional resistances in stainless steel bracket-wire combinations with effects of vertical deflections. *Am J Orthod Dentofacial Orthop.* 1996;109:535–542.
9. Andreasen GF, Quevedo FR. Evaluation of frictional forces in the 0.022 × 0.028 edgewise bracket in vitro. *J Biomech.* 1970;3:151–160.
10. Frank CA, Nikolai RJ. A comparative study of frictional resistance between orthodontic bracket and arch wire. *Am J Orthod.* 1980;78:593–609.
11. Peterson L, Spencer R, Andreasen G. A comparison of friction resistance for Nitinol and stainless steel wire in edgewise brackets. *Quintessence Int.* 1982;5:563–571.
12. Huffman D, Way DC. A clinical evaluation of tooth movement along archwires of two different sizes. *Am J Orthod.* 1983;83:453–459.
13. Kusy RP, Whitley JQ, Mayhew MJ, Buckthal JE. Surface roughness of orthodontic arch wire via laser spectroscopy. *Angle Orthod.* 1988;58:33–45.
14. Bednar JR, Gruendeman GW, Sandrik JL. A comparative study of frictional forces between orthodontic brackets and arch wires. *Am J Orthod Dentofacial Orthop.* 1991;100:513–522.
15. Ireland AJ, Sheriff M, McDonald F. Effect of bracket and wire composition on frictional forces. *Eur J Orthod.* 1991; 13:322–328.
16. Kusy RP, Whitley JQ. Frictional resistance of metal-lined ceramic brackets versus conventional stainless steel brackets and development of 3-D friction maps. *Angle Orthod.* 2001;71:364–374.
17. Cacciafesta V, Sfondrini MF, Scribante A, Klersy C, Auricchio F. Evaluation of friction of conventional and metal-insert ceramic brackets in various bracket-archwire combinations. *Am J Orthod Dentofacial Orthop.* 2003;124:403–409.
18. Shivapuja PK, Berger J. A comparative study of conventional ligation and self-ligation bracket systems. *Am J Orthod Dentofacial Orthop.* 1994;106:472–480.
19. Sims APT, Waters NE, Birnie DJ, Pethybridge RJ. A comparison of the forces required to produce tooth movement *in vitro* using two self-ligating brackets and a pre-adjusted bracket employing two types of ligation. *Eur J Orthod.* 1993; 15:377–385.
20. Berger JL. The influence of the SPEED bracket's self-ligating design on force levels in tooth movement: a comparative in vitro study. *Am J Orthod Dentofacial Orthop.* 1990;97: 219–228.
21. Thomas S, Sherriff M, Birnie D. A comparative in vitro study of the frictional characteristics of two types of self-ligating brackets and two types of pre-adjusted edgewise brackets tied with elastomeric ligatures. *Eur J Orthod.* 1998;20:589–596.
22. Pizzoni L, Ravnholt G, Melsen B. Frictional forces related to self-ligating brackets. *Eur J Orthod.* 1998;20:283–291.
23. Thorstenson GA, Kusy RP. Effects of ligation type and method on the resistance to sliding of novel orthodontic brackets with second-order angulation in the dry and wet states. *Angle Orthod.* 2003;73:418–430.
24. Hain M, Dhopatkar A, Rock P. The effect of ligation method on friction in sliding mechanics. *Am J Orthod Dentofacial Orthop.* 2003;123:416–422.
25. Chimenti C, Franchi L, Di Giuseppe MG, Lucci M. Friction of elastomeric orthodontic ligatures with different dimensions. *Angle Orthod.* 2005;75:421–425.
26. Bednar JR, Gruendeman GW, Sandrik JL. A comparative study of frictional forces between orthodontic brackets and arch wires. *Am J Orthod Dentofacial Orthop.* 1991;100:513–522.
27. Taylor NG, Ison K. Frictional resistance between orthodontic brackets and archwires in the buccal segments. *Angle Orthod.* 1996;66:215–222.
28. Kusy RP, Whitley JQ. Influence of archwire and bracket dimensions on sliding mechanics: derivations and determinations of the critical contact angles for binding. *Eur J Orthod.* 1999;21:199–208.