

Forces Produced by Different Nonconventional Bracket or Ligature Systems during Alignment of Apically Displaced Teeth

Tiziano Baccetti^a; Lorenzo Franchi^b; Matteo Camporesi^c; Efisio Defraia^d; Ersilia Barbato^e

ABSTRACT

Objective: To analyze the forces released by four types of passive stainless steel self-ligating brackets (SLBs), and by two nonconventional elastomeric ligature-bracket systems when compared with conventional elastomeric ligatures on conventional stainless steel brackets during the alignment of apically displaced teeth at the maxillary arch.

Materials and Methods: An experimental model consisting of five brackets was used to assess the forces released by the seven different ligature-bracket systems with 0.012" or 0.014" super-elastic nickel titanium wire in the presence of different amounts of apical displacement of the canine (ranging from 1.5 mm to 6 mm). Comparisons between the different types of bracket/wire/ligature systems were carried out by means of ANOVA on ranks with Dunnett's post hoc test ($P < .05$).

Results: When correction of a misalignment greater than 3 mm is attempted, a noticeable amount of force for alignment is generated by passive SLBs and nonconventional elastomeric ligature-bracket systems, and a null amount of force is released in the presence of conventional elastomeric ligatures on conventional brackets.

Conclusions: When minimal apical displacement is needed (1.5 mm), the differences in performance between low-friction and conventional systems are minimal. These differences become significant when correction of a misalignment of greater than 3.0 mm is attempted. (*Angle Orthod.* 2009;79:533–539.)

KEY WORDS: Friction; Orthodontic materials; Self-ligating brackets

INTRODUCTION

During fixed appliance therapy, the main force that contrasts tooth movement is the frictional force devel-

oped between the interface of the bracket slot and the archwire.¹ 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 ligatures,² self-ligating brackets (SLBs),^{3–7} and unconventional ligature systems.^{6,8–11} Over past years, a variety of SLBs have been developed, including those that have a spring clip that presses against the archwire ("active" or "interactive" SLBs) and those in which the self-ligating clip does not press against the archwire ("passive" SLBs). Passive SLBs have consistently shown a smaller amount of friction than active SLBs, with the exception of the use of undersized round archwires.^{3,4} Significant reduction in friction has been reported also for nonconventional elastomeric ligatures on conventional brackets^{6,9,10} and low-friction combinations of conventional elastomeric ligatures on specially designed brackets.^{8,11}

The frictional forces produced by SLBs have been tested on typodont systems with different amounts of tooth displacement. In these studies, however, the friction affecting sliding mechanics was evaluated by

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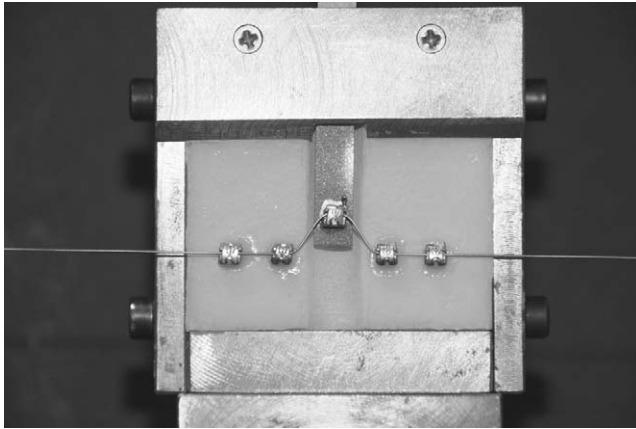


Figure 1. Experimental in vitro model with misaligned canine bracket.

“pulling” the orthodontic archwire through a series of aligned/misaligned self-ligating brackets. Recently, a specific testing device has been proposed to re-create clinical conditions for the leveling and aligning phase of straight-wire technique, that is, to study the forces released during alignment of a displaced tooth. These tests were conducted with unconventional ligatures on conventional brackets in the presence of different amounts of misalignment of one bracket (canine bracket) in an apical direction with regard to four remaining aligned brackets.¹⁰

The aim of the present study was to analyze the forces released by four types of passive stainless steel SLBs and by two nonconventional elastomeric ligature-bracket systems when compared with conventional elastomeric ligatures on conventional brackets during alignment of apically displaced teeth at the maxillary arch.

MATERIALS AND METHODS

An experimental model consisting of five brackets reproducing the right buccal segment of the upper arch (although they were not aligned along a curvature) was used to assess forces released during the alignment of apically displaced canine. The following different types of brackets were tested: four types of passive SLBs (Carriere, Ortho Organizers, Carlsbad, Calif; Damon 3 MX, SDS Ormco, Orange, Calif; SmartClip, 3M Unitek, Monrovia, Calif; and Opal-M, Ultradent Products, South Jordan, Utah), conventional stainless steel brackets (Logic Line brackets, Leone Orthodontic Products, Florence, Italy), and Synergy brackets (Synergy, Rocky Mountain Orthodontics, Denver, Colo). The experimental model consisted of five brackets of the same type for the second premolar, first premolar, canine, lateral incisor, and central incisor. The interbracket distance was set at 8.5 mm.

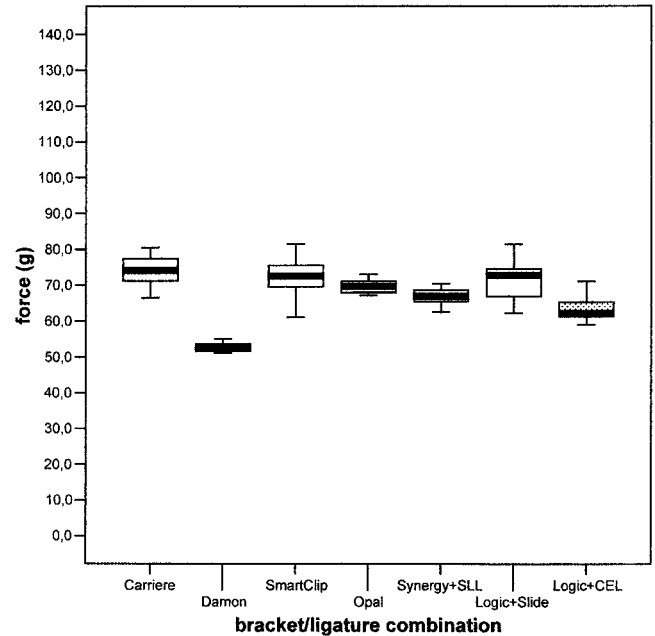


Figure 2. Boxplot of forces (g) released by the seven types of ligature-bracket combinations in the presence of 0.012" superelastic nickel titanium wire and 1.5 mm of canine misalignment. The box with dots corresponds to the Logic + CEL combination that was considered as the control group in statistical comparisons versus the other six ligature-bracket combinations (Table 1). The boxplot indicates the first quartile (bottom of the box), third quartile (top of the box), median (bold line in the box), smallest non-outlier (lower whisker), largest non-outlier (upper whisker), and outliers (circles) defined as data far from more than 1.5-fold of a box size. SLL indicates Synergy low-friction ligatures; CEL, conventional elastomeric ligatures.

The canine bracket was welded to a sliding bar that allowed for different vertical positions, and the other brackets were bonded onto an acrylic block with light-cure orthodontic adhesive (Leone Orthodontic Products) (Figure 1). A section of 0.0215" × 0.028" stainless steel wire was used to align the brackets before they were fixed onto the acrylic block. As for the ligation systems on brackets other than the four passive SLBs, either nonconventional elastomeric ligatures (Slide, Leone Orthodontic Products) or conventional elastomeric ligatures (CELs; silver mini-modules, Leone Orthodontic Products) were applied on conventional stainless steel brackets. Specific elastomeric ligatures (Synergy low-friction white opaque ligatures [Rocky Mountain Orthodontics] with the zero friction ligating option) were used for the Synergy brackets. To summarize, seven bracket/ligature combinations were tested: four passive SLBs, Synergy brackets with Synergy low-friction ligatures, conventional stainless steel brackets with Slide ligatures, and conventional stainless steel brackets with CEL.

Two different sizes of round superelastic nickel titanium wire (Memoria wire, Leone Orthodontic Prod-

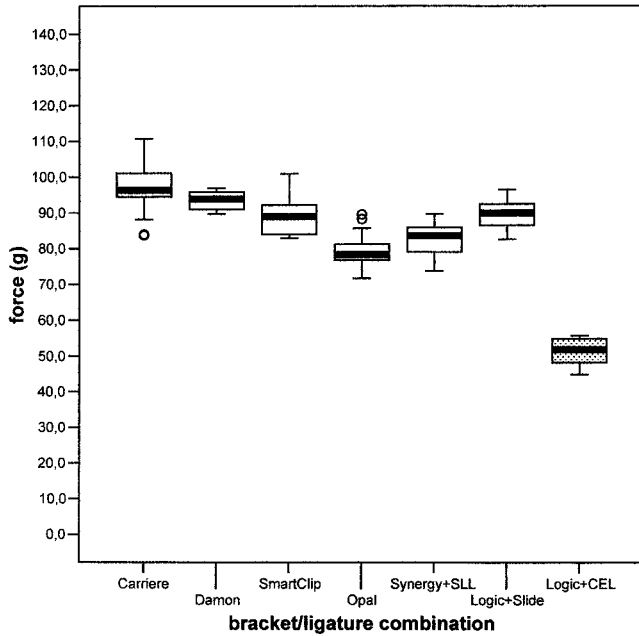


Figure 3. Boxplot of forces (g) released by the seven types of ligature-bracket combinations in the presence of 0.012" superelastic nickel titanium wire and 3.0 mm of canine misalignment. SLL indicates Synergy low-friction ligatures; CEL, conventional elastomeric ligatures.

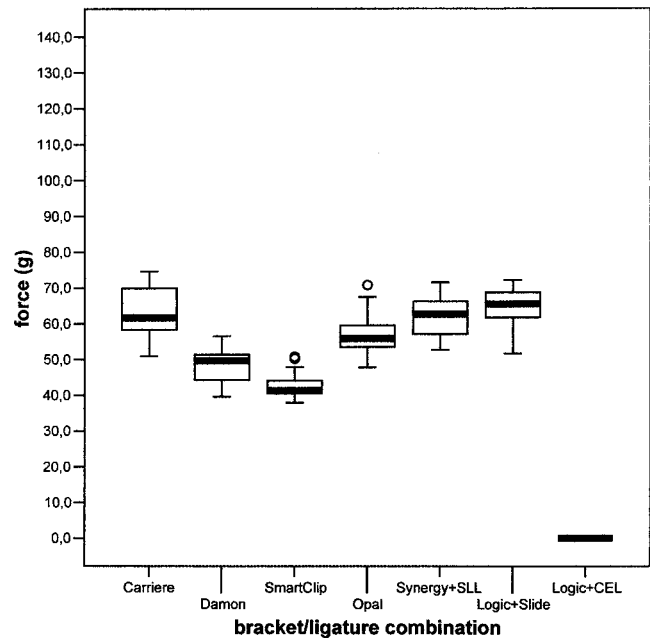


Figure 5. Boxplot of forces (g) released by the seven types of ligature-bracket combinations in the presence of 0.012" superelastic nickel titanium wire and 6.0 mm of canine misalignment. SLL indicates Synergy low-friction ligatures; CEL, conventional elastomeric ligatures.

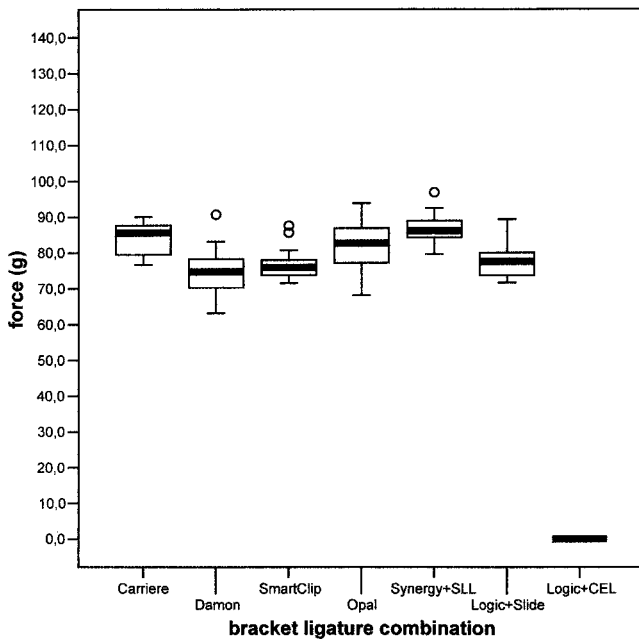


Figure 4. Boxplot of forces (g) released by the seven types of ligature-bracket combinations in the presence of 0.012" superelastic nickel titanium wire and 4.5 mm of canine misalignment. SLL indicates Synergy low-friction ligatures; CEL, conventional elastomeric ligatures.

ucts) were tested: 0.012" and 0.014". When used, new elastomeric ligatures were placed in a conventional manner (figure-O pattern) immediately before each test run, to avoid ligature force decay. The upper end of the sliding bar bearing the canine bracket was connected to the Instron 4301 testing machine (Instron Corp, Canton, Mass) crosshead (Figure 1). The force recorded by the Instron machine when the sliding bar was pulled with the canine bracket in an upward direction in the absence of any orthodontic wire was 0 grams (g). The Instron machine with a load cell of 10 Newton recorded the forces released by the bracket/wire/ligature combination following four different amounts of upward displacement of the canine bracket (canine misalignment): 1.5 mm, 3 mm, 4.5 mm, and 6 mm of misalignment. When the sliding bar is released, the canine bracket tends to return to the aligned position, and the force released by the system (force available for bracket alignment) is recorded.

Forces released by each bracket/wire/ligature combination at four different amounts of vertical canine misalignment were tested 20 times with new wires and ligatures (when elastomeric ligatures were used) on each occasion. A total of 1120 tests (160 tests for each type of bracket/wire/ligature combination) were carried out. All tests were performed under dry conditions and at room temperature ($20 \pm 2^\circ\text{C}$).

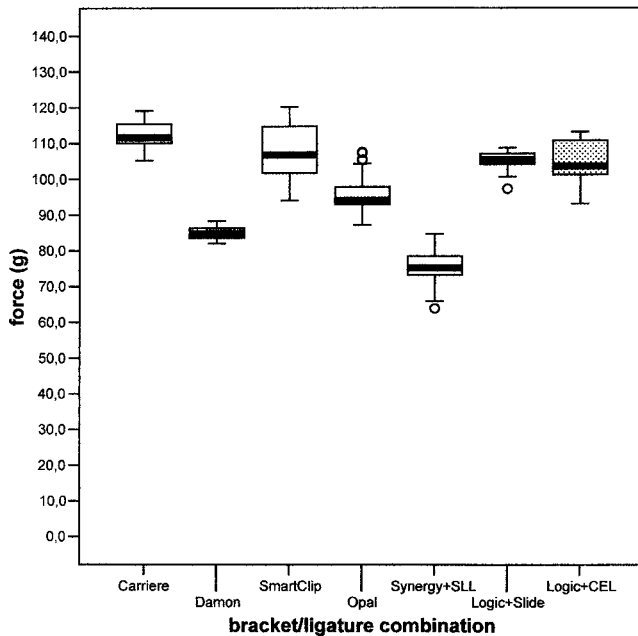


Figure 6. Boxplot of forces (g) released by the seven types of ligature-bracket combinations in the presence of 0.014" superelastic nickel titanium wire and 1.5 mm of canine misalignment. SLL indicates Synergy low-friction ligatures; CEL, conventional elastomeric ligatures.

Statistical Analysis

Descriptive statistics were calculated for the amount of force released by the various bracket/wire/ligature combinations at four different amounts of canine misalignment. Normal distribution of the data and equality of variance were not found (Shapiro-Wilk test and Levene's test). A nonparametric test (analysis of variance [ANOVA] on ranks with Dunnett's post hoc test; $P < .05$), therefore, was used (SigmaStat 3.5, Systat Software Inc, Point Richmond, Calif) to compare six "low-friction systems" (four passive SLBs, Synergy brackets with Synergy low-friction ligatures, and conventional stainless steel brackets with Slide ligatures) versus the conventional system (conventional stainless steel brackets with CEL) that was regarded as the control group.

RESULTS

Descriptive statistics and statistical comparisons of forces released by the different bracket/wire/ligature combinations in the presence of different amounts of canine misalignment are shown in Figures 2 through 9 and in Table 1.

In the presence of 0.012" or 0.014" superelastic nickel titanium wire, all low-friction systems produced a significantly greater amount of force available for tooth movement with respect to the conventional system at all different amounts of canine misalignment.

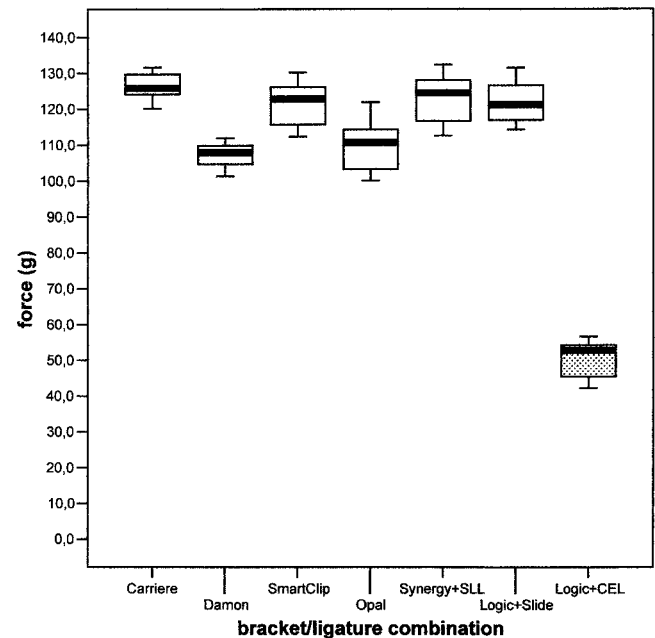


Figure 7. Boxplot of forces (g) released by the seven types of ligature-bracket combinations in the presence of 0.014" superelastic nickel titanium wire and 3.0 mm of canine misalignment. SLL indicates Synergy low-friction ligatures; CEL, conventional elastomeric ligatures.

The only exceptions were found at 1.5 mm of canine misalignment: with the 0.012" wire, the amount of force generated by one passive SLB (Damon) and by elastomeric ligatures on specific brackets (Synergy) were not significantly different from the conventional system, but with the 0.014" wire, two passive SLBs (Damon and Opal) and elastomeric ligatures on specific brackets (Synergy) showed release of a significantly smaller amount of force.

All systems showed a tendency to decrease the amount of force released from 3.0 mm through 6.0 mm of canine misalignment in the presence of 0.012" or 0.014" wire. In particular, with the 0.012" wire, the low-friction systems showed force decay from 3.0 mm of canine misalignment (range, 78.2 to 96.3 g) through 6.0 mm of canine misalignment (range, 41.2 to 65.3 g). The low-friction system that showed the greatest amount of force decay with the 0.012" wire from 3.0 mm through 6.0 mm of canine misalignment was the SmartClip bracket (47.7 g), and the low-friction system that showed the smallest amount of force decay was the Synergy bracket (21.0 g).

In the presence of the 0.014" wire, low-friction systems showed a force decay from 3.0 mm of canine misalignment (range, 107.9 to 125.8 g) through 6.0 mm of canine misalignment (range, 96.1 to 122.4 g). The low-friction system that showed the greatest amount of force decay with the 0.014" wire from 3.0

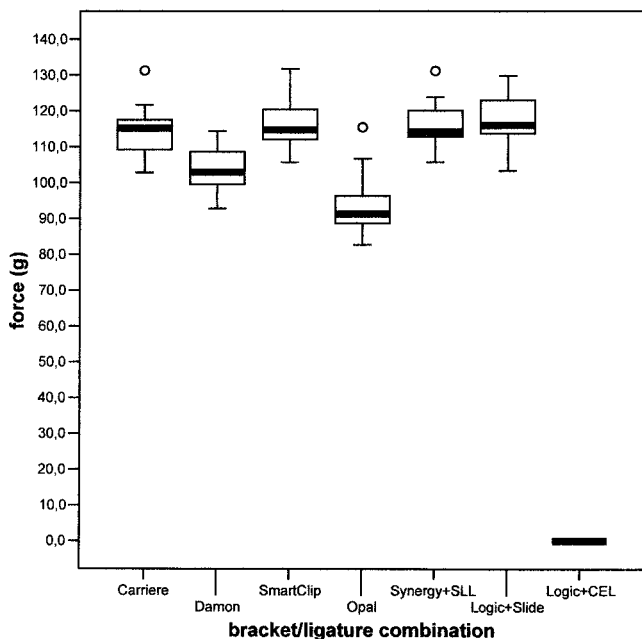


Figure 8. Boxplot of forces (g) released by the seven types of ligature-bracket combinations in the presence of 0.014" superelastic nickel titanium wire and 4.5 mm of canine misalignment. SLL indicates Synergy low-friction ligatures; CEL, conventional elastomeric ligatures.

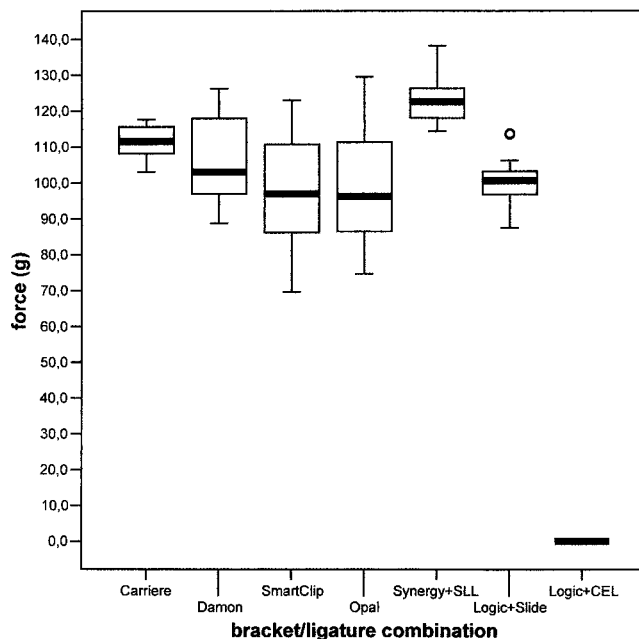


Figure 9. Boxplot of forces (g) released by the seven types of ligature-bracket combinations in the presence of 0.014" superelastic nickel titanium wire and 6.0 mm of canine misalignment. SLL indicates Synergy low-friction ligatures; CEL, conventional elastomeric ligatures.

mm through 6.0 mm of canine misalignment was the SmartClip bracket (25.9 g), and the low-friction system that showed the smallest amount of force decay was the Synergy bracket (2.0 g).

As for the conventional system (control group), the amount of force released at 1.5 mm of canine misalignment was similar to amounts shown by low-friction systems in the presence of 0.012" or 0.014" wire. From 3.0 through 6.0 mm of canine misalignment, the amount of force released by the system decreased dramatically from 51.6 g and 52.5 g at 3.0 mm of canine misalignment (with the 0.012" and 0.014" wires, respectively) to 0 g at 4.5 mm and 6.0 mm of canine misalignment with both types of superelastic nickel titanium wire.

DISCUSSION

The aim of the present study was to compare the forces released by superelastic nickel titanium wire during alignment of an apically displaced tooth in the presence of six low-friction systems (four passive SLBs, Synergy brackets with Synergy low-friction ligatures, and conventional stainless steel brackets with Slide ligatures) versus a conventional system (CEL on conventional stainless steel brackets). An in vitro testing device described in a previous study¹⁰ was used to evaluate the forces available for orthodontic tooth movement.

The amount of force released by the low-friction and conventional systems in the presence of the 0.012" wire was less than with the 0.014" wire. In the presence of a 1.5 mm apically displaced canine, forces produced by the low-friction systems and by the conventional system were rather similar and ranged from 52.5 to 74.0 g for the 0.012" wire to 103.4 to 111.6 g for the 0.014" wire. Although statistically significant, the average difference between the amount of force released by the low-friction systems versus that released by the conventional system with the two superelastic nickel titanium wires ranged only from -28.3 g to 12.2 g. All systems showed a tendency to decrease the amount of force released from 3.0 mm through 6.0 mm of canine misalignment in the presence of 0.012" or 0.014" wire. At 3.0 mm of canine misalignment, all low-friction systems produced a significantly greater amount of force released for orthodontic alignment with respect to the conventional system with either 0.012" or 0.014" wire. At 4.5 mm and 6.0 mm of apical misalignment of the canine, the amount of force released by the conventional system with any of the two superelastic nickel titanium round wires was zero grams, and forces produced by the low-friction systems ranged from 41.2 to 85.6 g for the 0.012" wire to 96.1 to 122.4 g for the 0.014" wire.

Results of the present study confirm those of a previous investigation¹⁰ that showed that when a slight amount of tooth alignment in the vertical plane is need-

Table 1. Descriptive Statistics and Comparisons Between Forces (g) Released by Different Bracket/Archwire/Ligature Systems^a

	Carriere (1)			Damon (2)			SmartClip (3)			Opal (4)		
	Med.	25%	75%	Med.	25%	75%	Med.	25%	75%	Med.	25%	75%
0.012' SENT 1.5 mm of CM	74.0	71.2	77.3	52.5	51.6	53.6	72.5	69.4	75.4	69.5	67.9	71.0
0.012' SENT 3.0 mm of CM	96.3	94.5	101.1	93.9	90.9	95.8	88.9	83.9	92.1	78.2	76.7	81.1
0.012' SENT 4.5 mm of CM	85.6	79.4	87.6	74.6	70.2	78.3	75.8	73.7	77.9	82.5	77.1	86.7
0.012' SENT 6.0 mm of CM	61.6	58.3	69.8	49.6	44.3	51.3	41.2	40.3	44.0	55.8	53.4	59.4
0.014' SENT 1.5 mm of CM	111.6	110.1	115.4	84.8	83.5	86.3	106.7	101.6	114.6	94.0	92.9	97.7
0.014' SENT 3.0 mm of CM	125.8	124.1	129.7	107.9	104.6	109.8	122.7	115.6	126.0	110.6	103.1	114.2
0.014' SENT 4.5 mm of CM	115.1	109.2	117.5	102.9	99.5	108.5	114.7	112.0	120.3	91.2	88.6	96.3
0.014' SENT 6.0 mm of CM	111.5	108.1	115.6	102.9	96.9	117.9	96.8	86.1	110.6	96.1	86.4	111.2

^a SENT indicates superelastic nickel titanium; CM, canine misalignment; SLL, Synergy low-friction ligatures; CEL, conventional elastomeric ligatures; Med., median; 25%, 25th percentile; and 75%, 75th percentile.

* Statistical significance was set at $P < .05$.

ed (1.5 mm), the differences in performance by a conventional system (consisting of conventional brackets with elastomeric ligatures) versus low-friction systems are minimal, and these differences become extremely significant when correction of a misalignment greater than 3 mm is attempted. A null amount of force for alignment is actually released in the presence of the conventional system when the misalignment either equals or is greater than 4.5 mm. Moreover, the current study demonstrated that nonconventional elastomeric ligature-bracket systems (Synergy brackets with Synergy low-friction ligatures and conventional stainless steel brackets with Slide ligatures) are able to produce a significant amount of force that is available for tooth movement, so these systems may represent a valid alternative to passive self-ligating brackets during leveling and aligning of apically displaced teeth.

The amount of released force measured in the present testing unit was influenced by friction at the bracket/wire/ligature interface that tends to contrast the alignment of the canine bracket. The higher the friction at the bracket/wire/ligature interface, the lower is the force released by the system to produce bracket alignment. Resistance to sliding at the bracket/wire/ligature unit represents a combination of friction produced by the ligation method, by the wire-bracket binding, and by wire notching.¹²

In this experiment, the friction produced by the ligation method was expected to be present only when conventional elastomeric ligatures were applied on conventional stainless steel brackets. This type of friction, however, did not change because of the vertical displacement of the canine bracket. In fact, the frictional force would have changed only if the canine bracket were moved horizontally in or out relative to the aligned brackets. The component of resistance to sliding that actually changed during this experiment was the force that was acting between the edge of the bracket and the wire; this occurs independent of ligation

method (wire-bracket binding, contact angle θ equal or greater than the critical contact angle θ_c).¹³ In the experimental model used here, binding can be expected 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.¹³ For the two types of superelastic nickel titanium wire used in this study, the contact angle θ exceeded the critical contact angle θ_c at all four amounts of canine displacement (contact angle θ ranged from 10 to 35.2 degrees; critical contact angle θ_c ranged from 4.3 to 6.0 degrees for the 0.012" wire and from 3.4 to 4.7 degrees for the 0.014" wire). Therefore, binding could be assessed for all the conditions reproduced here. As vertical interbracket displacement increased, binding dramatically increased. In fact, all analyzed systems showed a decrease in the amount of force released from 3.0 mm through 6.0 mm of canine misalignment in the presence of either 0.012" or 0.014" wire. In those systems in which friction produced by the ligation method was maximal (conventional elastomeric ligatures on conventional stainless steel brackets), the amount of released force dropped down to zero in the presence of greater vertical canine displacement (4.5 mm and 6.0 mm) because of the additional effect of binding. However, in low-friction systems, forces available for orthodontic alignment were released at all canine bracket displacement levels, with the amount of force decreasing when displacement was increased (because of binding). This enabled the low-friction systems to generate orthodontic forces of about 50 to 100 g even at maximal canine bracket displacement (6.0 mm). The role of notching on friction at the bracket/wire/ligature interface was not evaluated in the current study. Articulo et al¹⁴ found that nickel titanium wires are more resistant to notching than are stainless steel wires when used with stainless steel brackets.

Clinical interpretation of the results of the present

Table 1. Extended

Synergy + SLL (5)			Logic + Slide (6)			Logic + CEL (7) (Control Group [CG])			Statistically Significant Comparisons vs CG (7)*
Med.	25%	75%	Med.	25%	75%	Med.	25%	75%	
66.7	65.3	68.5	72.6	66.7	74.4	61.8	61.0	65.1	1, 3, 4, 6
83.5	78.9	85.8	89.8	86.4	92.3	51.6	48.0	54.7	1, 2, 3, 4, 5, 6
86.0	84.1	88.8	77.4	73.5	79.8	0.0	0.0	0.0	1, 2, 3, 4, 5, 6
62.5	56.9	66.1	65.3	61.5	68.58	0.0	0.0	0.0	1, 2, 3, 4, 5, 6
75.1	73.1	78.4	105.3	104.1	107.0	103.4	101.1	110.7	1, 2, 4, 5
124.4	116.6	128.0	121.1	116.8	126.5	52.5	45.2	54.0	1, 2, 3, 4, 5, 6
114.1	112.7	120.1	115.9	113.6	123.0	0.0	0.0	0.0	1, 2, 3, 4, 5, 6
122.4	117.9	126.1	100.4	96.6	103	0.0	0.0	0.0	1, 2, 3, 4, 5, 6

investigation, however, requires further consideration. First, the testing instrument did not allow the brackets contiguous to the misaligned bracket to move (thus reproducing a condition of “absolute anchorage”). Second, no attempt was made in the present study to evaluate the effects of time and the oral environment on the amount of force released in the presence of different types of elastomeric ligatures.¹⁵

CONCLUSIONS

- When the alignment of a tooth with minimal apical displacement is needed (1.5 mm), the differences in performance between low-friction and conventional systems are minimal.
- These differences become significant when correction of a misalignment greater than 3.0 mm is attempted. With 4.5 mm of tooth misalignment or more, the average amount of force released in the presence of a conventional system could be approximated to zero, but in the presence of low-friction systems, forces ranged from 40 to 120 g.

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