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Orthodontic forces released by low-friction versus conventional systems during alignment of apically or buccally malposed teeth

Tiziano Baccetti, Lorenzo Franchi, Matteo Camporesi and Efisio Defraia
Department of Orthodontics, University of Florence, Italy

Correspondence to: Dr Lorenzo Franchi, Via G. F. Mariti 10, 50127 Firenze, Italy. E-mail: lorenzo.franchi@unifi.it

SUMMARY The aim of the present study was to analyse the forces released by passive stainless steel self-ligating brackets (SLBs) and by a non-conventional elastomeric ligature–bracket system on conventional brackets ([slide ligatures on conventional brackets (SLCB)]) when compared with conventional elastomeric ligatures on conventional brackets (CLCB) during the alignment of apically or buccally malposed teeth in the maxillary arch.

An experimental model consisting of five brackets was used to assess the forces released by the three different bracket–ligature systems with 0.012-inch super-elastic (SE) nickel–titanium (NiTi) wires in the presence of different amounts of apical or buccal canine misalignment of the canine (ranging from 1.5 to 6 mm). The forces released by each wire/bracket/ligature combination with the three different amounts of apical or buccal canine misalignment were tested 20 times. Comparisons between the different types of wire/bracket/ligature systems were carried out by means of analysis of variance on ranks with Dunnett's *post hoc* test ($P < 0.05$).

No difference in the amount of force released in presence of a misalignment of 1.5 mm was recorded among the three systems. At 3 mm of apical misalignment a significantly greater amount of orthodontic force was released by SLB or SLCB when compared with CLCB, while no significant differences were found among the three systems at 3 mm of buccal canine displacement. When correction of a large amount of misalignment (6 mm) was attempted, a noticeable amount of force for alignment was still generated by the passive SLB and SLCB systems while no force was released in presence of CLCB.

Introduction

In recent years, a series of methods have been proposed with the aim of limiting the frictional restraints that contrast tooth movement at the bracket archwire–ligature interface, such as self-ligating brackets (SLBs; Pizzoni *et al.*, 1998; Thomas *et al.*, 1998; Henao and Kusy, 2005; Franchi *et al.*, 2008; Kim *et al.*, 2008) and unconventional ligature systems (Thorstenson and Kusy, 2003; Baccetti and Franchi, 2006; Yeh *et al.*, 2007). Among SLBs those in which the self-ligating clip does not press against the archwire (passive SLBs) have consistently shown a smaller amount of friction than conventional systems (Pizzoni *et al.*, 1998; Thomas *et al.*, 1998). A significant reduction in friction has also been reported for non-conventional elastomeric ligatures on conventional brackets (Baccetti and Franchi, 2006; Franchi and Baccetti, 2006; Franchi *et al.*, 2008).

The forces produced in the presence of SLBs have generally been tested on typodont systems with different amounts of tooth displacement. In these studies, however, friction affecting sliding mechanics was evaluated by 'pulling' the orthodontic archwire through a series of aligned/misaligned SLBs. A specific testing device has been proposed to re-create clinical conditions for the levelling and aligning phase of the straight-wire technique, i.e. to study the forces released during alignment of a malposed tooth. The tests were conducted with unconventional ligatures on conventional brackets in presence of different amounts of misalignment of one bracket (canine bracket) with regard to four remaining aligned brackets (Franchi and Baccetti, 2006).

The aim of the present study was to analyse the forces released by passive stainless steel SLBs and by non-conventional ligature systems when compared with conventional elastomeric ligatures on conventional brackets during the alignment of apically or buccally malposed teeth in the maxillary arch at three different levels of tooth misalignment.

Materials and methods

The study used an experimental model reproducing the right buccal segment of an upper arch to assess the forces released during the alignment of apically or buccally malposed canines. The following brackets were tested: passive SLB (Carriere, Ortho Organizers, Carlsbad, California, USA) and stainless steel brackets (Logic Line brackets, Leone Orthodontic Products, Sesto Fiorentino, Firenze, Italy). The buccal segment model consisted of five brackets of the same type for the second premolar, first premolar, canine, lateral incisor, and central incisor. All brackets tested had a 0.022-inch slot. The inter-bracket distance was set at 8.5 mm. The brackets

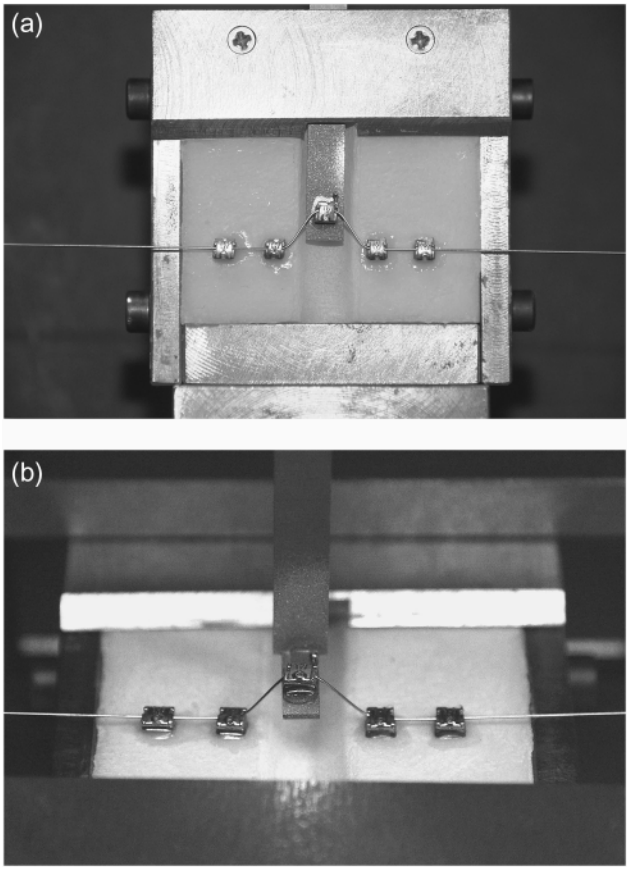

Figure 1 Experimental *in vitro* model with (a) an apically malposed canine bracket and (b) a buccally malposed canine bracket.

were bonded onto an acrylic block with light-cure orthodontic adhesive (Leone Orthodontic Products), with the exception of the canine bracket that was laser welded to a moveable bar (Figure 1). A section of 0.0215 × 0.028 inch stainless steel wire was used to align the brackets before they were fixed onto the acrylic block. For the ligation systems on the conventional brackets, either non-conventional elastomeric ligatures (Slide, Leone Orthodontic Products) or conventional elastomeric ligatures (silver mini modules, Leone Orthodontic Products) were applied on conventional stainless steel brackets. To summarize, three bracket/ligature combinations were tested: passive SLBs (SLB group), conventional stainless steel brackets with low-friction Slide ligatures (Slide ligatures and conventional brackets, SLCB group), and conventional stainless steel brackets with conventional elastomeric ligatures (conventional ligatures and conventional brackets, CLCB group).

Round 0.012-inch super-elastic (SE) nickel–titanium (NiTi) wires (Memoria wire, Leone Orthodontic Products) were tested. The wires were made of austenitic NiTi alloy with a temperature transitional range below room temperature (Santoro *et al.*, 2001). 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 an Instron 4301 (Instron Corp, Canton, Massachusetts, USA). The force recorded by the Instron machine when pulling the sliding bar with the canine bracket in a misaligned position in the absence of any orthodontic wire was 0 g. The Instron machine with a load cell of 10 Newton recorded the forces released by the wire/bracket/ligature combination following three different amounts of apical or buccal displacement of the canine bracket (canine misalignment): 1.5, 3, and 6 mm. The moveable bar with the canine bracket was then released and this allowed recording of the peak forces produced during 60 seconds of the test run for the different bracket/wire/ligature combinations. These forces could be considered as the forces available for bracket alignment.

The forces released by each wire/bracket/ligature combination at the three different amounts of apical or buccal canine misalignment were tested 20 times with new wires and ligatures (when elastomeric ligatures were used) on each occasion. A total of 360 tests (120 tests for each type of wire/bracket/ligature combination) were carried out. All tests were performed under dry conditions and at room temperature (20 ± 2°C).

Statistical analysis

Descriptive statistics were calculated for the amount of force released by the various wire/bracket/ligature combinations in presence of the three different amounts of canine misalignment in the two directions. Normal distribution of the data and equality of variance were not found (Shapiro–Wilk and Levene's tests). A non-parametric test (analysis of variance on ranks with Dunnett's *post hoc* test, $P < 0.05$) was therefore used (SigmaStat 3.5, Systat Software Inc., Point Richmond, California, USA) to compare the two low-friction systems (SLB and SLCB groups) versus the CLCB group that was considered as the control.

Results

Descriptive statistics and the statistical comparisons between the forces released by the different wire/bracket/ligature combinations in the presence of different amount of canine misalignment are reported in Table 1 and depicted in Figure 2.

No significant differences among the three groups were found with 1.5 mm of canine displacement in either direction. Both the SLB and SLCB groups produced significantly greater orthodontic forces than the CLCB group at both 3 and 6 mm of apical canine displacement. With 6 mm of apical canine misalignment, the force released dropped to zero in the CLCB group.

Table 1 Descriptive statistics and comparisons between the different bracket/archwire/ligature systems (measurement unit = grams). Test groups are indicated as (1), (2), and (3).

	Self-ligating brackets, Carriere (1)		Low-friction ligatures (Slide) on conventional bracket (2)		Conventional elastomeric ligatures on conventional brackets (3)		Significant comparisons
	Mean	SD	Mean	SD	Mean	SD	
Apical canine misalignment							
0.012″ SE—1.5 mm	74.2	3.9	71.4	5.5	63.3	3.6	NS
0.012″ SE—3.0 mm	96.9	6.5	89.5	4.2	51.4	3.6	(1) versus (3), (2) versus (3)*
0.012″ SE—6.0 mm	62.9	7.0	64.2	6.2	0.0	0.0	(1) versus (3), (2) versus (3)*
Buccal canine misalignment							
0.012″ SE—1.5 mm	57.7	5.0	47.3	6.8	61.3	3.8	NS
0.012″ SE—3.0 mm	89.0	6.5	79.6	4.2	79.9	4.2	NS
0.012″ SE—6.0 mm	80.2	7.0	75.9	6.2	0.0	0.0	(1) versus (3), (2) versus (3)*

SD = standard deviation; SE = super-elastic nickel–titanium archwire; NS = not significant; $*P < 0.05$.

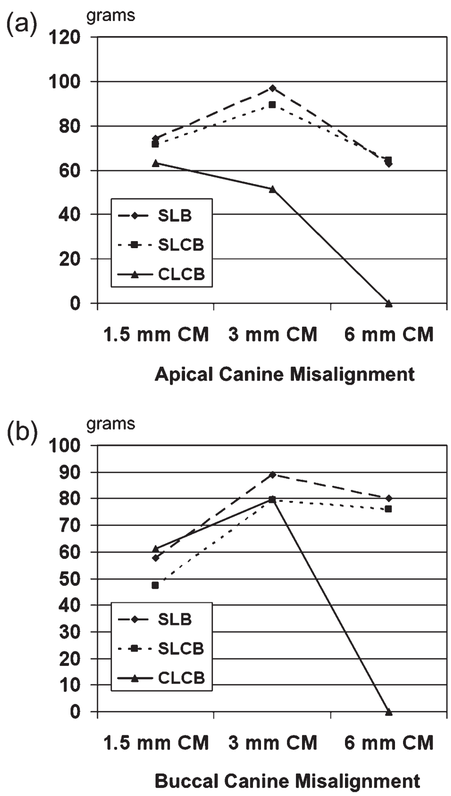

Figure 2 Graphical representation of the forces released by the low-friction and conventional systems in presence of a malposed canine positioned 1.5, 3, and 6 mm (a) apically and (b) buccally.

For buccal displacement of the canine, no significant difference in the amount of force released for tooth movement was found among the three groups either at 1.5 or 3 mm of canine misalignment, while the force generated was significantly greater in the SLB and SLCB groups when compared with the CLCB group at 6 mm of buccal canine misalignment. Once again, at this amount of canine misalignment, the force generated in the presence of the CLCB dropped to zero. In the presence of the 0.012 inch SE wire, both the SLB and SLCB groups showed a tendency for an increase in the amount of force released from 1.5 mm to 3 mm of apical or buccal canine misalignment.

Discussion

The present investigation compared the forces released by SE NiTi wires during alignment of an apically or buccally malposed tooth in the presence of two low-friction systems (passive SLBs, and conventional stainless steel brackets with Slide ligatures) versus a conventional system (conventional elastomeric ligatures on conventional stainless steel brackets).

Forces released during alignment of an apically malposed tooth

The forces released by the low-friction and conventional systems in the presence of a 1.5 mm apically malposed canine were similar and ranged from 63.3 to 74.2 g. At 3.0 mm of apical canine misalignment, both the SLB and SLCB groups produced a significantly greater amount of force released for orthodontic alignment with respect to the CLCB group. The average amount of force released by the SLB and SLCB groups was 96.9 and 89.5 g, respectively. These forces were significantly greater when compared with the CLCB group (51.4 g). At 6 mm of apical misalignment of the canine the amount of force released by the CLCB group was 0 g, while those produced by the SLB and SLCB groups still averaged over 60 g.

Forces released during alignment of a buccally malposed tooth

The amount of force released for tooth alignment of buccal tooth displacement was similar for the three systems investigated at 1.5 mm of canine misalignment (ranging from 47.3 to 61.3 g), and also at 3 mm of canine misalignment (about 80–90 g). At 6 mm of buccal canine displacement, the forces available for tooth movement were still about 75–80 g for the SLB and SLCB systems, while they dropped to zero for the CLCB system.

General considerations based on experimental data

The results of the present study revealed that in the presence of both 'minimal' or 'moderate' tooth displacement, either in buccal or apical positions (1.5 or 3 mm of misalignment with respect to adjacent teeth), the amount of force released for tooth movement ranged from 55 to 90 g for both low-friction and conventional bracket–ligature systems. Noteworthy was that the amount of force released by the conventional system at 3 mm of apical canine misalignment was approximately half that of the SLB or SLCB systems (about 50 versus 90 g respectively).

The greatest differences in performance between the low-friction and conventional systems became apparent at 6 mm of canine misalignment in either an apical or buccal position. At 6 mm of canine misalignment, while no force was released in the presence of CLCB, the SLB and SLCB systems were able to produce an amount of force for orthodontic movement averaging about 60 g in the case of apical tooth misalignment and about 70–80 g in case of buccal tooth misalignment.

In general, it can be concluded that a certain amount of orthodontic force can be released by any of the investigated systems (either low-friction or conventional) when apical or buccal misalignment to be corrected is minimal to moderate. On the other hand, in the presence of severe apical or buccal misalignment (6 mm), the conventional ligatures on conventional brackets did not allow forces to be produced for orthodontic movement, while a significant amount of force was still released in the presence of either the passive self-ligating system or the combination of low-friction ligatures on conventional brackets.

Previous *in vitro* studies (Franchi and Baccetti, 2006; Baccetti *et al.*, 2009) indicated that no amount of force was released with the conventional system when the apical misalignment equalled 6 mm. The different low-friction systems also showed the greatest amount of force released at 3.0 mm of apical misalignment, while the force tended to decrease at 6.0 mm of apical displacement (Baccetti *et al.*, 2009). In agreement with previous studies (Franchi and Baccetti, 2006; Baccetti *et al.*, 2009), the present investigation demonstrated that a non-conventional elastomeric ligature–bracket system (conventional stainless steel brackets with slide ligatures) is able to produce a significant amount of force for tooth movement, so that this system may represent a valid alternative to passive SLBs during levelling and aligning of malposed teeth.

Considerations on the clinical relevance of the experimental findings

The findings of the current *in vitro* experimental study are in line with the results of a recent randomized clinical trial (Scott et *al*., 2008) in patients with mandibular incisor crowding, where the authors failed to find a significant difference between low-friction and conventional systems in the alignment of dental arches showing a total irregularity index of the lower incisors between 3.0 and 12.0 mm (that means, on average, from less than 1 mm to less than 3 mm of bucco-lingual misalignment per single tooth in relation to neighbouring teeth in the crowded area).

When analysing the clinical relevance of the data in the present investigation, it should be emphasized that this *in vitro* study did not evaluate the behaviour of bracket/ligature systems with time. It can be argued that decay of conventional elastomeric ligatures due to their permanence in the oral environment along with changes in temperature, presence of saliva, tooth brushing, etc, may considerably affect the amount of force released by the conventional systems along with time, before new ligatures are placed at a subsequent appointment .

Conclusions

1. For apical or buccal misalignments of 1.5 and 3.0 mm both low-friction and conventional systems appeared to be potentially effective in releasing an adequate amount of force for tooth movement (ranging from ~50 to 100 g); with the low-friction combinations being significantly more effective at 3.0 mm of apical misalignment. For a large amount of apical or buccal tooth misalignment (6.0 mm), the low-friction systems presented a significant amount of force released for tooth movement, whereas no orthodontic force was recorded for the conventional bracket/ligature combination.
2. The non-conventional elastomeric ligature–bracket system produced levels of force available for tooth movement that were very similar to those generated in presence of passive SLBs.

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