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Original Article

Analysis of resistance to sliding expressed during first order correction with conventional and self-ligating brackets: an *in-vitro* study

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Abstract: Purpose: To investigate the resistance to sliding (RS) related to self-ligating and conventional ligation bracket systems at several first order rotational angulations using typical aligning arch wires in a 3-bracket experimental model. Materials and methods: Resistance to sliding (RS) was measured in self-ligating (SL: Interactive self-ligating brackets with closed slide) and conventional ligation (CL: Interactive self-ligating brackets with open slide and elastomeric ligatures) groups in conjunction with 0.014-in heat-activated NiTi (Af temp: 36°). A custom-made machine was used to measure frictional resistance with tests repeated on 5 occasions at each simulated angulation. Results: The RS increased significantly as the angulation increased in both groups ($P < 0.0001$). However, RS measurements were significantly higher at each angulation ($P < 0.0001$) with the conventional ligation system than with self-ligation. Conclusion: During simulated tooth movement with low stiffness wires, RS is increased in conventional-ligating systems particularly at higher degrees of angulation.

Keywords: Sliding, self ligating, NiTi

Introduction

During fixed appliance-based treatment, the resistance to sliding (RS) impedes the tooth movement. Attenuation of applied forces as a consequence of friction has been estimated at 12% to 60% [1]. This degree of variability may also make the rate of tooth movement inconsistent; minimizing the causes of RS may both accelerate tooth movement and increase its predictability.

The RS between bracket and wire depends on two chief determinants: classical friction (FR), in which the ligation method is influential, and the force of binding (BI) [1, 2]. Controlling the phenomena contributing to RS may lead to more efficient and reproducible fixed appliance treatment. FR is proportional to the normal force (FN), acting perpendicular to the direction of movement on the contact surface and depends on the coefficient of friction (μ) of a specific material according to the formula: $FR = \mu FN$ [3]. BI represents the force produced when the wire first contacts both opposing edges of the slot and is governed by the angular relationship between bracket slot and wire [3]. BI is encountered throughout treatment, and indeed during arch alignment and leveling. Based on *in vitro* findings, the height and width of both bracket slot and arch wire [3], wire stiffness [4] and brackets design [5] are thought to contribute most significantly to binding forces during second order correction.

First order correction is also governed by these factors, although the depths of the bracket slot and wire thickness are likely to assume greater importance. Self-ligating brackets have been proposed as a mechanism of reducing resistance to sliding, expediting orthodontic treatment, although there remains little clinical proof of their effectiveness in this respect [6].

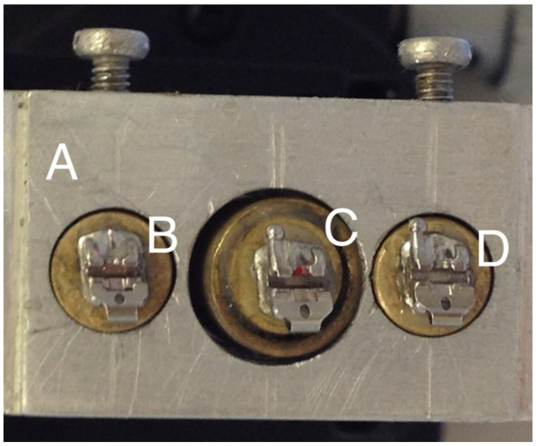

Figure 1. View of the experimental model. A. Stainless steel apparatus; B-D. Lateral incisor, canine, first premolar bracket-brass mount couples.

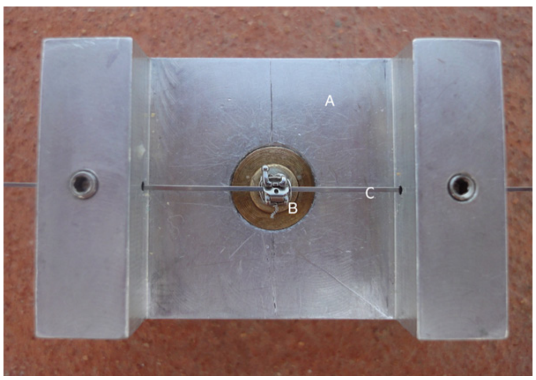

Figure 2. View of the mounting apparatus. A. Mounting apparatus; B. Single bracket-brass mount couple; C. Stainless steel jig (0.022 × 0.028-in).

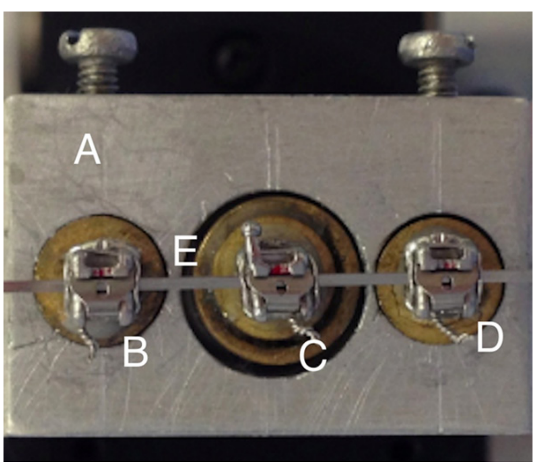

Figure 3. 0.022 × 0.028-in stainless steel jig engaged within all brackets. A. Mounting apparatus; B-D. Lateral incisor, canine, first premolar bracket-brass mount couples; E. 0.022 × 0.028-in stainless steel jig.

The RS expressed by self-ligating and conventional ligation systems at specific angular bracket slot to wire relationship has not been investigated in relation to first order correction. Second order correction, however, has been assessed with both high [2, 4, 7] and low stiffness archwires [8, 9]. These studies confirmed that binding increases with increasing angulation, while the main component of RS differed between studies, being attributed either to binding [2, 4, 7], or being primarily influenced by the ligation method [8, 9]. If binding were shown to be the primary contributor to RS, a dramatic reduction in RS would be unlikely with use of self-ligating brackets (SLBs) [4] as binding phenomena are independent of the method of ligation during second order correction. This *ex vivo* study aimed to compare the resistance to sliding (RS) between self-ligating and conventional ligation systems during derotation of teeth in an experimental model with simulated first order rotational angulations.

Material and methods

One hundred twenty self-ligating brackets (Empower; ®*American Orthodontics*, Sheboygan, WI), including 40 lateral incisor, 40 cuspid and 40 first premolar brackets were divided into self-ligating (SL) and conventional ligation (CL) groups. The bracket groups shared the following features: MBT prescription; nominal slot height dimension - .022-in; nominal slot depth dimension - .028-in; wire engaging system - interactive (lateral incisor/canine) and passive (premolar). For the CL group, self-ligating brackets with open slides were surrounded by elastomeric ligatures (1 mm internal diameter; ®*Leone S.p.A.,* Florence, Italy) placed with a needle holder. The tested wires were supplied in straight lengths: 0.014-in heat-activated NiTi wires with nominal Af temperature stabilization at 36°C (Therma-Lite; ®*American Orthodontics*, Sheboygan, WI).

Experimental apparatus

A stainless steel apparatus (**Figure 1**) was constructed to hold 3 vertically- and horizontally-aligned brackets with the set-up designed to simulate a dental segment involving a lateral incisor, canine and first premolar. The inter-bracket distance, measured from the center of the brackets, was 14.5 mm in accordance with Wilkinson *et al.* [10]. Composite resin (Transbond; ®*3M Unitek,* Monrovia, CA) was used to

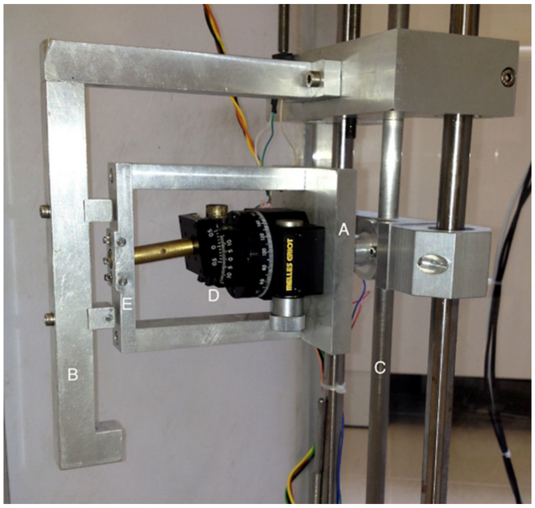

Figure 4. Testing machine. A. Static carriage. B. Moving carriage. C. Vertical road. D. Tipping protractor. E. 3-brackets apparatus.

Figure 5. Thermostatic appliance.

bond each test bracket on a dedicated brass mount in a mounting apparatus (**Figure 2**) before incorporating them into the 3-bracket system. The bonding procedure, described by Matarese et al. [11] and Cordasco et al. [12], was used for the outer brass mount-bracket (lateral incisor and first premolar) couples of the mounting apparatus.

The central pit of the 3-bracket apparatus had no base on either side, allowing the brass mount soldered to a protractor, which was fixed to the testing machine, to be set on the 3-bracket apparatus. A canine bracket was placed on this brass mount with the top end of the vertical line aligned with the dedicated line engraved on the 3-bracket apparatus to guarantee a correct mesio-distal positioning. Before bonding the canine bracket, a 0.022 × 0.028-in SS jig was used so that its largest cross-section (0.022-in) occupied the entire slot height of the lateral incisor, canine and first premolar brackets (**Figure 3**). During the bonding phase, a metal ligature was used to attach the canine bracket to the jig and bring it into contact with the floor of the slot. Consequently, the influence of the pre-adjusted bracket prescription on friction was eliminated (with all slots parallel); moreover, it also ensured that bracket position was reproducible in all 3 spatial planes.

Testing machine

A custom-made testing machine (**Figure 4**), based on the Universal testing machine (Istituto per i Processi Chimico Fisici, Consiglio Nazionale delle Ricerche, Messina, Italy), was used to measure the resistance to sliding. It consisted of a static carriage, bearing the 3-bracket apparatus firmly fixed to a vertical rod through acting on a force sensor. The output from the sensor was read by a computer via a special interface. The aligning wire, passing through the brackets on the static carriage, was fixed to the end of a moving carriage with 2 stop screws. The moving carriage was driven by a computer-controlled stepper motor at a set speed of 4 mm per minute.

A protractor (**Figure 4**) was mounted on the static carriage allowing the central bracket to be rotated along the horizontal plane. The protractor was set at the following rotational angulations: 0°, 3°, 7° and 10°. The testing machine calculated the average sum of the static friction resisting initial movement and the kinetic friction expressed in newton (N) and recorded during the test over approximately 100 data points for the first run of the wire through the set of brackets on a 5-mm section of arch-wire. An initial test was carried out for each set of brackets and each wire. All tests were repeated 5 times and the wire and brackets were replaced before each test. The testing machine was placed in a temperature-controlled room, with the tests carried out at a constant temperature of 35.5°C in a dry state (**Figure 5**) [13].

Statistical analysis

Statistical power analysis was performed on preliminary data obtained from 10 measurements at 7° angulation of the self-ligating and

Table 1. Descriptive statistics of RS (N) in the *self-ligating* and *conventional ligation* groups

Ligation	Degree of rotation	Observations	Mean	SD	Minimum	Maximum
SL group	0°	5	0.028	0.004	0.02	0.03
	3°	5	0.028	0.02	0.01	0.06
	7°	5	0.082	0.008	0.07	0.09
	10°	5	0.808	0.09	0.72	0.94
CL group	0°	5	2.734	0.037	2.7	2.79
	3°	5	3.008	0.049	2.95	3.06
	7°	5	3.054	0.061	2.95	3.11
	10°	5	3.064	0.027	3.02	3.09

RS, Resistance to sliding; N, newton; SL, self-ligation; CL, conventional ligation; SD, standard deviation.

conventional ligation set-ups with the following parameters: Variance 1, 2: 0.26, 3.29; alpha, 0.05; power, 0.8. A total of 5 repeated measurements was found to be sufficient to accomplish power of 0.8.

Data analysis was performed with statistical software (GraphPad Prism 5 for Windows; ®*GraphPad Software Inc.,* La Jolla, CA, USA). Before descriptive and inferential statistical analysis, each data set was analyzed using the Shapiro-Wilk normality test. Two-way Analysis of variance (ANOVA) and Bonferroni's multiple comparison tests were used to compare the RS at each angulation in the self-ligating (SL) and conventional ligation (CL) groups. Student t-tests were also carried out to compare the RS between the two groups at each angulation tested.

Results

Descriptive statistics for RS at all tested angulations are shown in **Table 1**. A student's t-tests (**Table 2**) showed higher RS values in the conventional ligation (CL) group than in self-ligating (SL) group for each first order rotational angulation ($P < 0.0001$). In the SL group (**Table 2**), RS increased significantly as the degree of first order displacement increased ($P < 0.0001$). Bonferroni's Multiple Comparison Test showed no statistically significant differences between RS recorded at 0°, 3° and 7° ($P > 0.05$), although a statistically significant difference was found between 7° and 10° ($P < 0.0001$).

In the conventional ligation (CL) test group (**Table 2**), RS increased significantly as the degree of rotation increased ($P < 0.0001$). A statistically significant difference between 0° and 3° ($P < 0.0001$) was identified; however, there were no differences in RS at 3°, 7° and 10° ($P > 0.05$). In general, the change in angulation and the ligation method affected the RS, respectively accounting for 2.19 % and 96.6 % of total variation in RS (**Table 2**).

Discussion

In the present study, RS increased in both conventional and self-ligating systems with increasing first order rotational angulations; it is difficult to pinpoint whether this could be attributed to either binding or frictional resistance to a greater or lesser degree [2, 4]. With increasing first order rotational angulation the interactive clip of self-ligating brackets (SL group) is likely to flex, while the elastic ligatures of the conventional brackets also stretch increasing the perpendicular force on the archwire (FR). In the present study the RS in the CL group was significantly higher than in the SL group for each first order rotational angulation simulated. The observed differences are almost certainly related to the addition of elastomerics in the conventional ligation system.

In the SL group, the first significant increment in RS was noted between 7 and 10 degrees suggesting that the wire was not in an active configuration until almost 10 degrees of displacement was reached. In the CL group, RS increased significantly between zero and 3 degrees, with no significant differences found for higher increments. This finding suggests that ligation forces exerted by elastomerics may introduce resistance to sliding during initial alignment with NiTi wires [8] even in the presence of relatively minor rotations. With conventional ligation the wire inevitably interacts with the ligature irrespective of how oblique its orientation relative to the slot. Pandis *et al*., in a well-designed *in vitro* study [14], found an increased rotational moment respectively for Damon 2 brackets (passive) compared with In-Ovation R (inter-active) and conventional brackets, with 0.14 × 0.025-in NiTi wires. From a clinical perspective, these contrasting results may be explained by self-ligating bracket slot walls allowing significant play when small diameter wires are engaged, while their rigidity results in higher loads and moments during engagement of rectangular

Table 2. St atistical data obtained by 2-way ANOVA, Bonferroni's post-hoc test and Student's t-test

Source of variation	% of total variation	Significance	Sum of square	Mean Square	F
Interaction	1.12	***	0.8658	0.2886	184.8
Angulations	2.19	***	1.686	0.562	359.9
Ligation method	96.6	***	74.45	74.45	19287

Post-hoc test	Post-hoc test	Student's T-test
SL group	CL group	
0° (n = 5) vs 3° (n = 5) ns	0° (n = 5) vs 3° (n = 5)***	0° SL (n = 5) vs 0° EL (n = 5)***
0° (n = 5) vs 7° (n = 5) ns	0° (n = 5) vs 7° (n = 5)***	3° SL (n = 5) vs 3° EL (n = 5)***
0° (n = 5) vs 10° (n = 5)***	0° (n = 5) vs 10° (n = 5)***	7° SL (n = 5) vs 7° EL (n = 5)***
		10° SL (n = 5) vs 10° EL (n = 5)***
3° (n = 5) vs 7° (n = 5) ns	3° (n = 5) vs 7° (n = 5) ns	
3° (n = 5) vs 10° (n = 5)***	3° (n = 5) vs 10° (n = 5) ns	
7° (n = 5) vs 10° (n = 5)***	7° (n = 5) vs 10° (n = 5) ns	

ANOVA, Analysis of variance; SL, self-ligation; CL, conventional ligation. ***P < 0.0001; *P < 0.05; ns = non significant.

wires [14]. The results of the present study therefore suggest that self-ligating brackets may delay complete rotational correction for which the engagement of a rectangular NiTi wire is required.

In this study, ligation forces were found to have a major bearing on RS recorded for each tested bracket displacement. This finding may relate to the low stiffness of the wires tested [15-17]. Henao and Kusy [18, 19] found that self-ligaingt brackets outperformed conventional brackets with a 0.14-in SE NiTi wire, while both systems showed comparable values of RS with stiffer NiTi wires. These results suggest that during initial alignment with flexible NiTi wires, SL may present less frictional resistance than conventional brackets with other variables being equal. The relative importance of binding as a factor in RS is related to the tooth movements required and may also be influenced by wire size and alloy characteristics during various stages of orthodontic treatment.

While these results suggest that, during the alignment phase of orthodontic treatment, the use of self-ligating brackets in conjunction with low stiffness wires may promote more consistent force delivery and the possibility of more efficient tooth movement, the *ex vivo* nature of this study leaves unanswered questions. It is impossible to reproduce the biological processes underpinning tooth movement [20]. Tooth movement does not occur as a smooth progression but rather as a series of intermittent steps [17] with static friction of greater relevance than dynamic [21]; the sum of static and kinetic friction were considered in the present investigation. Certainly, there is no convincing clinical proof that self-ligating brackets have a bearing either way on the rate of tooth movement or on the duration of orthodontic treatment [6, 22-26].

In conclusion, the RS increased significantly with the increasing first order rotational angulations in both self-ligating and conventional ligation systems. RS within the conventional ligation system group were significantly higher than those with SL at each degree of rotational displacement.

Disclosure of conflict of interest

None.

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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] Articolo LC, Kusy RP. Influence of angulation on the resistance to sliding in fixed appliances. Am J Orthod Dentofacial Orthop 1999; 115: 39-51.
[3] Kusy RP. Ongoing innovations in biomechanics and materials for the new millennium. Angle Orthod 2000; 70: 366-76.
[4] Thorstenson GA, Kusy RP. Effect of archwire size and material on the resistance to sliding of self-ligating brackets with second-order angulation in the dry state. Am J Orthod Dentofacial Orthop 2002; 122: 295-305.
[5] Nucera R, Lo Giudice A, Matarese G, Artemisia A, Bramanti E, Crupi P, Cordasco G. Analysis of the characteristics of slot design affecting resistance to sliding during active archwire configurations. Prog Orthod. 2013; 14: 35.
[6] Fleming PS, DiBiase AT, Sarri G, Lee RT. Efficiency of mandibular arch alignment with 2 preadjusted edgewise appliances. Am J Orthod Dentofacial Orthop 2009; 135: 597-602.
[7] Pliska BT, Beyer JP, Larson BE. A comparison of resistance to sliding of self-ligating brackets under an increasing applied moment. Angle Orthod 2011; 81: 794-799.
[8] Cordasco G, Lo Giudice A, Militi A, Nucera R, Triolo G, Matarese G. *In vitro* evaluation of resistance to sliding produced by self-ligating and conventional ligation methods during dental alignment. Korean J Orthod 2012; 42: 218-224.
[9] Haskova JE, Palmer G, Jones SP. An ex vivo laboratory study to determine the static frictional resistance of a variable ligation orthodontic bracket system. J Orthod 2008; 35: 112-8.
[10] Wilkinson PD, Dysart James PS, Hood AA, Herbison GP. Load-deflection characteristics of superelastic nickel-titanium orthodontic wires. Am J Orthod Dentofacial Orthop 2002; 121: 483-95.
[11] Cordasco G, Portelli M, Militi A, Nucera R, Lo Giudice A, Gatto E, Lucchese A. Low-dose protocol of the spiral CT in orthodontics: comparative evaluation of entrance skin dose with tra-

ditional X-ray techniques. Prog Orthod 2013; 14: 24
[12] Cordasco G, Farronato G, Festa F, Nucera R, Parazzoli E, Grossi GB. In vitro evaluation of the frictional forces between brackets and archwire with three passive self-ligating brackets. Eur J Orthod 2009; 31: 643-6.
[13] Moore RJ, Watts JTF, Hood JA, Burritt DJ. Intraoral temperature variation over 24 hours. Eur J Orthod 1999; 21: 1-13.
[14] Pandis N, Eliades T, Partowi S, Bourauel C. Moments generated during simulated rotational correction with self-ligating and conventional brackets. Angle Orthod 2008; 78: 1030-1034.
[15] Drescher D, Bourauel C, Schumacher HA. Frictional forces between bracket and arch wire. Am J Orthod Dentofacial Orthop 1989; 96: 397-404.
[16] Tidy DC. Frictional forces in fixed appliances. Am J Orthod Dentofacial Orthop 1989; 96: 249-254.
[17] Moore MM, Harrington E, Rock WP. Factors affecting friction in the pre-adjusted appliance. Eur J Orthod 2004; 26: 579-83.
[18] Henao SP, Kusy R. Evaluation of the frictional resistance of conventional and self- ligating bracketdesigns using standardized archwires and dental typodonts. Angle Orthod 2004; 74: 202-211.
[19] Henao SP, Kusy R. Frictional Evaluations of Dental Typodont Models Using Four Self-ligating Designs and a Conventional Design. Angle Orthod 2004; 75: 75-85.
[20] Meikle MC. The tissue, cellular and molecular regulation of orthodontic tooth movement: 100 years after Carl Sandstedt. Eur J Orthod 2006; 28: 221-240.
[21] Kim TK, Kim KD, Baek SH. Comparison of frictional forces during the initial leveling stage in various combinations of self-ligating brackets and archwires with a custom-designed typodont system. Am J Orthod Dentofacial Orthop 2008; 133: 187.e15-187.e24.
[22] Čelar A, Schedlberger M, Dörfler P, Bertl M. Systematic review on self-ligating vs. conventional brackets: initial pain, number of visits, treatment time. J Orofac Orthop 2013; 74: 40-51.
[23] Fleming PS, Johal A. Self-ligating brackets in orthodontics. A systematic review. Angle Orthod 2010; 80: 575-584.
[24] Lo Giudice G, Lo Giudice A, Isola G, Fabiano F, Artemisia A, Fabiano V, Nucera R, Matarese G. Evaluation of bond strength and detachment interface distribution of different bracket base designs . Acta Medica Mediterranea 2015; 31: 585-590.
[25] Cicciù M, Matacena G, Signorino F, Brugaletta A, Cicciù A, Bramanti E. Relationship between oral health and its impact on the quality life of Alzheimer's disease patients: a supportive care trial. Int J Clin Exp Med 2013; 6: 766-772.
[26] Cicciu M, Bramanti E, Matacena G, Guglielmino E, Risitano G. FEM evaluation of cemented-retained versus screw-retained dental implant single-tooth crown prosthesis. Int J Clin Exp Med 2014; 7: 817-825.