European Journal of Orthodontics 34 (2012) 119–125
doi:10.1093/ejo/cjq180
Advance Access Publication 13 January 2011

A comparative *in vitro* study of frictional resistance between lingual brackets and stainless steel archwires

Yıldız Ozturk Ortan*, Tugce Yurdakuloglu Arslan* and Bulent Aydemir**
*Department of Orthodontics, Faculty of Dentistry, Istanbul University, Capa, Istanbul and **TUBITAK, National Metrology Institute, Gebze, Kocaeli, Turkey

Correspondence to: Yıldız Ozturk Ortan, Department of Orthodontics, Faculty of Dentistry, Istanbul University, 34093 Capa, Istanbul, Turkey. E-mail: yildizozturk@yahoo.com

SUMMARY Friction between archwires and labial brackets has received considerable attention; however, information on the frictional behaviour of commercially available lingual brackets is limited. The aim of this study was to investigate the frictional resistance resulting from a combination of lingual orthodontic brackets (7th Generation, STb, Magic, and In-Ovation L) and stainless steel archwires at 0, 5, and 10 degrees of second-order angulation. Each bracket type (n = 30) was tested with three different sizes of archwires. Static and kinetic frictional forces were evaluated with a universal testing machine. Statistical analysis of the data was performed with non-parametric Kruskal–Wallis and Dunn's multiple comparison tests.

All tested brackets showed higher frictional forces as the wire size and second-order angulation increased. The lowest friction was found with In-Ovation L brackets and 0.016 inch archwires at 0 degrees angulation, and the greatest friction with a combination of STb brackets and 0.017 × 0.025 inch archwires at 10 degrees angulation. For all combinations, Magic and In-Ovation L brackets showed lower frictional resistance when compared with 7th Generation and STb brackets. The slot width (occluso-gingival dimension) of the brackets, measured using the optics of a microhardness machine, showed that all brackets were oversized and that Magic brackets had the largest slot width. Surface roughness of the brackets investigated using atomic force microscopy and scanning electron microscopy, demonstrated that the 7th Generation brackets had the greatest surface roughness.

Introduction

Lingual orthodontics is a frequently used approach in the treatment of adult patients (Hohoff *et al.*, 2003). Many problems that existed when introduced have been resolved by improvements in bracket design and production. Lingual brackets are quite different in their configurations and clinical aspects (Wiechmann, 2002, 2003; Scuzzo and Takemato, 2003). The goal of recently developed brackets with reduced dimensions was to increase patient comfort and improve oral hygiene. On the other hand, self-ligating lingual brackets were designed for the convenience of practitioners and improvement of frictional resistance generated by archwire/bracket combinations (Sattler and Hahn, 2002; Geron, 2008).

The dimensions of orthodontic brackets are one of the essential parameters determining the critical contact angle (Θ_c) value during sliding mechanotherapy (Kusy and Whitley, 1997, 1999; Kusy, 2000, 2005). The frictional force between the archwire and bracket slot tends to increase rapidly above this angle (Articolo and Kusy, 1999; Articolo *et al.*, 2000).

Various reports (Gandini *et al.*, 2008; Kim *et al.*, 2008; Matarese *et al.*, 2008; Bach, 2009; Burrow, 2009; Franchi *et al.*, 2009; Katz, 2009) have described the levels of friction between archwires and labial brackets, but information on the frictional behaviour of commercially available lingual brackets is still limited (Park *et al.*, 2004).

The aim of this study was to evaluate the frictional forces between various lingual orthodontic brackets and stainless steel archwires and to relate this to their respective actual slot size and surface morphology and roughness.

Materials and methods

Materials

Detail of the brackets and archwires used in this study are shown in Table 1. Four types of upper premolar lingual brackets (STb: Ormco Corporation, Glendora, California, USA; 7th Generation: Ormco Corporation; In-Ovation L: GAC International, Bohemia, New York, USA; Magic: Dentaurum, Ispringen, Germany) were tested with stainless steel archwires of three different dimensions (0.016, 0.016 × 0.022, and 0.017 × 0.025 inch: Ormco Corporation; 0.018, 0.018 × 0.018, and 0.019 × 0.019 inch: G&H® Wire Company, Greenwood, Indianapolis, USA).

Methods

Measurement of frictional resistance. All brackets were tested at 0, 5, and 10 degrees of second-order angulation. The friction tests were undertaken at room temperature (21 ± 2°C) and under dry conditions. Bracket and archwire surfaces were cleaned with 95 per cent ethanol and each bracket was bonded on an aluminium plate with a light curing resin (Eagle Bond; American Orthodontics, Sheboygan, Wisconsin, USA) in a standardized occluso-gingival position. Prescription characteristics were eliminated by supporting the bracket with a full dimension stainless steel wire jig (0.018 × 0.025 inch for STb, 7th Generation, and In-Ovation L brackets, and 0.020 × 0.020 inch for Magic brackets). Once the light curing resin had hardened, the jig was removed. The aluminium plate was fixed with two screws into the notches of a device (Figure 1A) that was mounted to the base of a universal testing machine (Zwick/Roell, Ulm, Germany). The brackets were positioned at 0, 5, and 10 degrees of second-order angulation by rotating the aluminium plate with the help of these two screws. The upper end of the stainless steel wire was inserted into the tension load cell of the universal testing machine, and a 200 g weight was attached to the lower end of the wire. The 25 cm wire segment was then seated into the slots of the STb, 7th Generation, and Magic brackets with a 0.010 inch stainless steel ligature wire

Table 1 Summary of the investigated materials.

Bracket type $n = 30$		Archwires		
		Group A, $n = 10$	Group B, $n = 10$	Group C, $n = 10$
7th Generation	0.018 × 0.025	0.016	0.016 × 0.022	0.017 × 0.025
STb	0.018 × 0.025	0.016	0.016 × 0.022	0.017 × 0.025
In-Ovation L	0.018 × 0.025	0.016	0.016 × 0.022	0.017 × 0.025
Magic	0.020 × 0.020	0.018	0.018 × 0.018	0.019 × 0.019

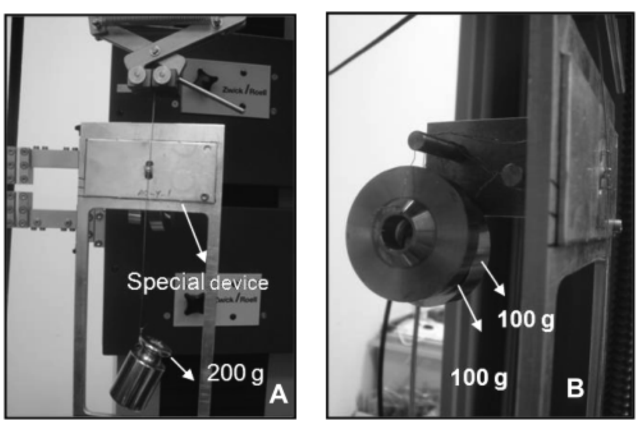

Figure 1 (A) Tension of the archwire (200 g). (B) Standardization of the ligation force (100 + 100 = 200 g).

and the ligation force was standardized at 200 g (Figure 1B), except for the self-ligating In-Ovation L brackets which were tested in a closed position. Static and kinetic frictional forces were measured throughout 2 mm translation of the bracket along the archwire at a crosshead speed of 1 mm/minute.

Each group contained 30 brackets tested with three different wire sizes (groups A, B, and C) (Table 1). The sample size for each archwire/bracket combination was 10. For each sample, 0, 5, and 10 degrees of second-order angulation were established and measurements were repeated three times, resulting in 1080 measurements (270 measurements per bracket type). During friction testing, the static friction (the peak force required to initiate movement) and kinetic friction (the mean force required to maintain movement) were digitally recorded using a software program (Testxpert V9.01 Zwick/Roell). The Zwick testing machine was set to zero and calibrated before each archwire/bracket type/angulation series was run.

Measurement of slot dimensions. The actual slot widths (occluso-gingival dimension) of 40 brackets (10 of each type) were measured across the base using the optics of a microhardness tester (Galavision, Galileo, Italy). Each measurement was repeated twice, resulting in 80 measurements. Corresponding mean values and standard deviations (SD) were determined. The total uncertainty of measurements was calculated as ±0.0005 inch (k = 2, 95%).

Surface morphology and roughness. Before scanning electron microscopy (SEM) and atomic force microscopy (AFM) observations, all samples were cleaned with 95 per cent ethanol. Scanning electron micrographs of the received brackets were recorded using a SEM (FEI/Philips XL30 FEG ESEM with electron backscatter diffraction analysis and energy-dispersive X-ray capability).

One sample was chosen from each bracket type and mounted on studs, which were later placed in the vacuum chamber of the microscope. The accelerating voltage, angle of fit, and the aperture were adjusted to optimize the quality of the micrograph. The slot surface was scanned and viewed on the monitor at different magnifications.

The three-dimensional surface roughness (R_a) of the slot base was evaluated using an AFM (Veeco Instruments Inc., Plainview, New York, USA, NanoScope IV MultiMode AFM, Contact Mode with Si3N4 tip, Analysis software: V5.12 RB by Digital Instrument, Arizona, USA). Scanning was carried out in air and at a scanning rate of 10 Hz. Ten brackets with an area of 10 × 10 μm of each type were inspected.

Statistical analysis. Descriptive statistics, including the means, SD, minimum and maximum values were calculated for each archwire/bracket combination.

A non-parametric Kruskal–Wallis test was carried out to determine if significant differences were present between the groups. Dunn's multiple comparison test was used to determine which of the means were significantly different from each other. Values of P equal to or less than 0.05 were considered statistically significant.

Results

Frictional forces

Examples of frictional resistance levels in newtons at 0, 5, and 10 degrees of second-order angulation for each archwire/ bracket combination are shown in Table 2 and Figure 2.

At 0 degrees angulation, the frictional resistance of the In-Ovation L brackets was significantly lower than that of the 7th Generation brackets for the group A archwire/ bracket combination. The frictional resistance of the 7th Generation and Magic brackets was found to be statistically lower than that of the STb brackets for group C archwire/ bracket combination. No statistically significant difference was found between the generated frictional forces when all brackets were coupled with group B archwires.

At 5 degrees angulation, when the brackets were coupled with groups B and C archwires, the frictional resistance of the Magic brackets was found to be statistically lower than that of the 7th Generation and STb brackets.

At 10 degrees angulation for groups A and B archwire/ bracket combinations, the frictional resistance of the Magic brackets was significantly lower than that of the 7th Generation and STb brackets. For the same combinations, the frictional resistance of the In-Ovation L brackets was significantly lower than that of the STb brackets. For group C archwire/bracket combination, frictional resistance of the Magic brackets was significantly lower than for the 7th Generation and STb brackets (Table 2).

Effect of angulation on friction

For all archwire/bracket combinations, an increased second-order angulation between the archwire and the bracket increased the frictional resistance to sliding (Table 2).

Bracket slot size measurements

The mean values and SD of the bracket slot size and their deviations from the manufacturers' values are presented in Table 3.

All bracket slots examined were found to be oversized. Magic brackets demonstrated the largest bracket slot with a mean slot width of 0.02129 ± 0.0096 inches. In-Ovation L brackets had a slot width closet to the labelled nominal value.

Surface morphology and roughness examinations of the bracket slots

AFM observations of the lingual brackets are shown in Figure 3 and the statistical comparisons of the R_a values are presented in Table 4.

A rougher surface was visible on the 7th Generation bracket (R_a: 108.47 ± 17.92), whereas In-Ovation L (R_a: 53.48 ± 14.03), Magic (R_a: 33.21 ± 15.57), and STb (R_a: 34.19 ± 17.92) brackets had lower surface roughness. Statistical analysis revealed that the surface roughness of the 7th Generation bracket was statistically higher (P < 0.01) than that of STb and Magic brackets (Table 4).

Figure 4 shows the SEM observations of the slot bases. It can be observed that the slot surface of 7th Generation brackets was more porous and rougher than the other

Table 2 Descriptive statistics of static frictional resistance evaluated for bracket type, wire size, and angulations.

Angulation (°)	Wire size	7th Generation (1)	STb (2)	In-Ovation L (3)	Magic (4)	Dunn's test					
						1–2	1–3	1–4	2–3	2–4	3–4
0	Group A	2.41 ± 0.1	2.26 ± 0.07	2.09 ± 0.04	2.26 ± 0.19	NS	***	NS	NS	NS	NS
	Group B	2.78 ± 0.36	2.75 ± 0.37	2.56 ± 0.58	2.53 ± 0.12	NS	NS	NS	NS	NS	NS
	Group C	2.9 ± 0.49	3.55 ± 0.48	2.94 ± 0.36	2.71 ± 0.22	**	NS	NS	NS	**	NS
	P	0.002	0.0001	0.0001	0.001						
5	Group A	2.64 ± 0.13	2.66 ± 0.16	2.46 ± 0.02	2.51 ± 0.18	NS	NS	NS	NS	NS	NS
	Group B	3.49 ± 0.34	3.44 ± 0.3	2.96 ± 0.52	2.67 ± 0.09	NS	NS	**	NS	**	NS
	Group C	3.71 ± 0.43	4.37 ± 0.39	3.66 ± 0.57	2.86 ± 0.32	NS	NS	*	NS	***	NS
	P	0.0001	0.0001	0.0001	0.004						
10	Group A	3.17 ± 0.13	3.39 ± 0.24	2.78 ± 0.09	2.67 ± 0.17	NS	NS	*	**	***	NS
	Group B	4.52 ± 0.47	5.02 ± 0.6	3.63 ± 0.47	2.86 ± 0.12	NS	NS	***	*	***	NS
	Group C	5.05 ± 0.65	5.96 ± 0.47	4.84 ± 0.73	3.02 ± 0.36	NS	NS	*	NS	***	NS
	P	0.0001	0.0001	0.0001	0.014						

NS, not significant. *P < 0.05; **P < 0.01; ***P < 0.001.

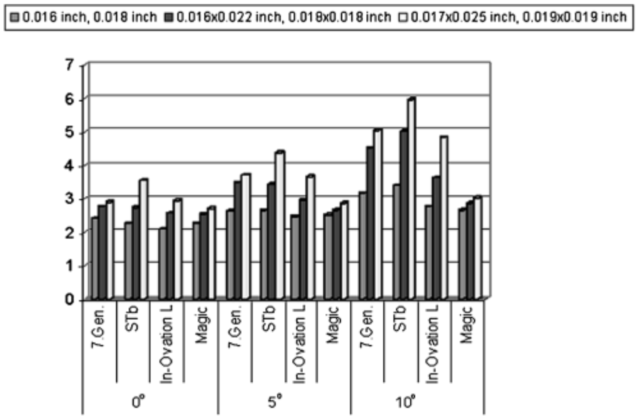

Figure 2 Summary of static frictional resistance values for all archwire/bracket combinations investigated.

Table 3 Slot width data in inches.

Bracket type $n = 10$	Minimum	Maximum	Mean ± SD	Deviation from manufacturers' value
7th Generation	0.01829	0.01918	0.0188 ± 0.00028	0.0008 ± 0.0028
STb	0.01777	0.01873	0.01829 ± 0.00035	0.00029 ± 0.0035
In-Ovation L	0.01779	0.01857	0.01817 ± 0.00026	0.00017 ± 0.0026
Magic	0.02016	0.02321	0.02129 ± 0.00096	0.00129 ± 0.0096

investigated brackets. Smoother slot surfaces were seen for the STb, In-Ovation L, and Magic brackets.

Discussion

The correct magnitude of force during orthodontic treatment will result in optimal tissue response and rapid tooth movement. Therefore, control of friction at the archwire/bracket interface is an important factor. To explain the friction between archwire and bracket, several variables such as wire material and section, bracket material and design, type and force of ligation, and surface topography of the materials should be studied.

As adult patients have high aesthetic requirements, in an extraction case, full canine retraction that produces space distal to the lateral incisor is not a preferred method in lingual orthodontic treatment. Partial canine retraction followed by *en masse* retraction where the six anterior teeth are retracted as a unit is more acceptable in terms of aesthetics (Scuzzo and Takemato, 2003).

Takemato (1995) reported that anchorage control using loop mechanics was superior compared with sliding mechanics in lingual orthodontics. However, as loop bending is difficult because of the small interbracket distance and adult patients have generally greater soft tissue sensitivity to appliance irritation (Brown *et al.*, 1990, 1991), sliding mechanics are used by most clinicians (Romano, 1998).

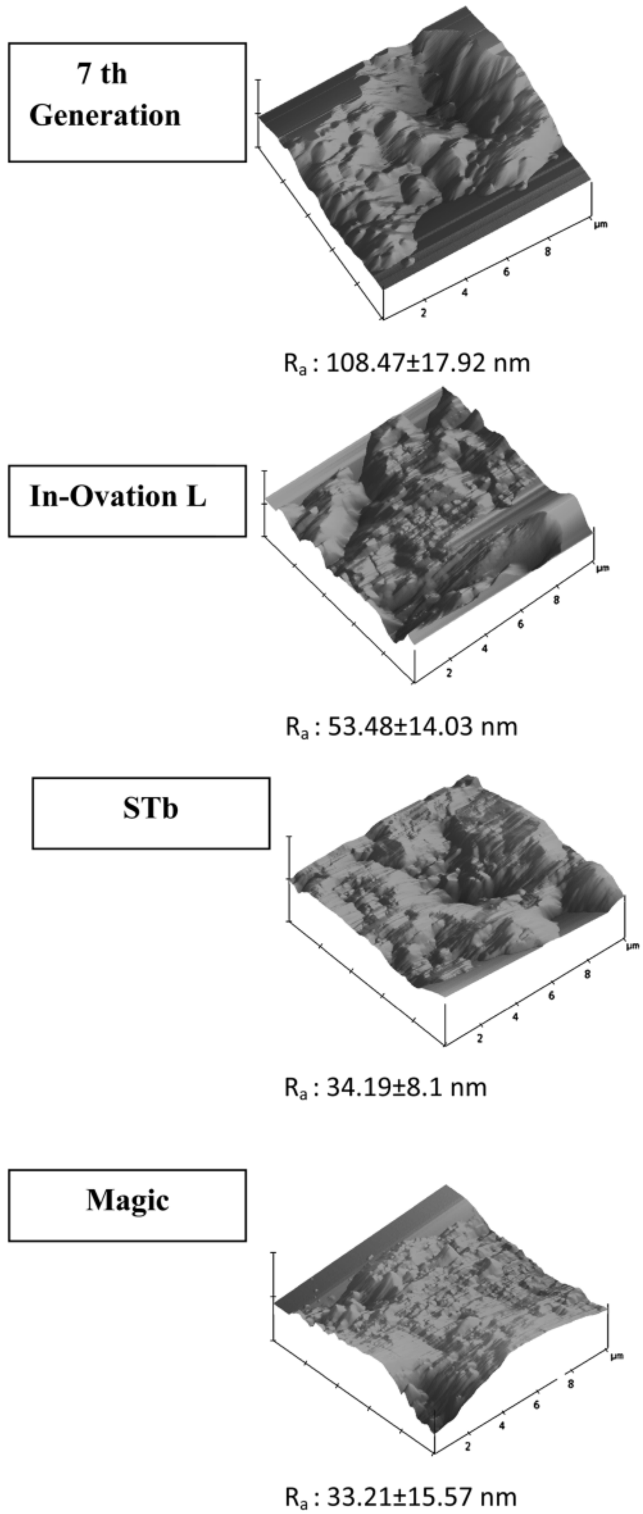

Figure 3 Atomic force microscopic observations and corresponding surface roughnesses [R_a nanometre (nm)] of the four tested lingual brackets.

Table 4 Comparison of mean surface roughness [R_a: nanometre (nm)] of the four lingual brackets.

Bracket type	7th Generation (1)	STb (2)	In-Ovation L (3)	Magic (4)	Dunn's test					
					1–2	1–3	1–4	2–3	2–4	3–4
R_a X ± SD	108.47 ± 17.92	34.19 ± 8.1	53.48 ± 14.03	33.21 ± 15.57	**	NS	**	NS	NS	NS

NS, not significant. $**P < 0.01$.

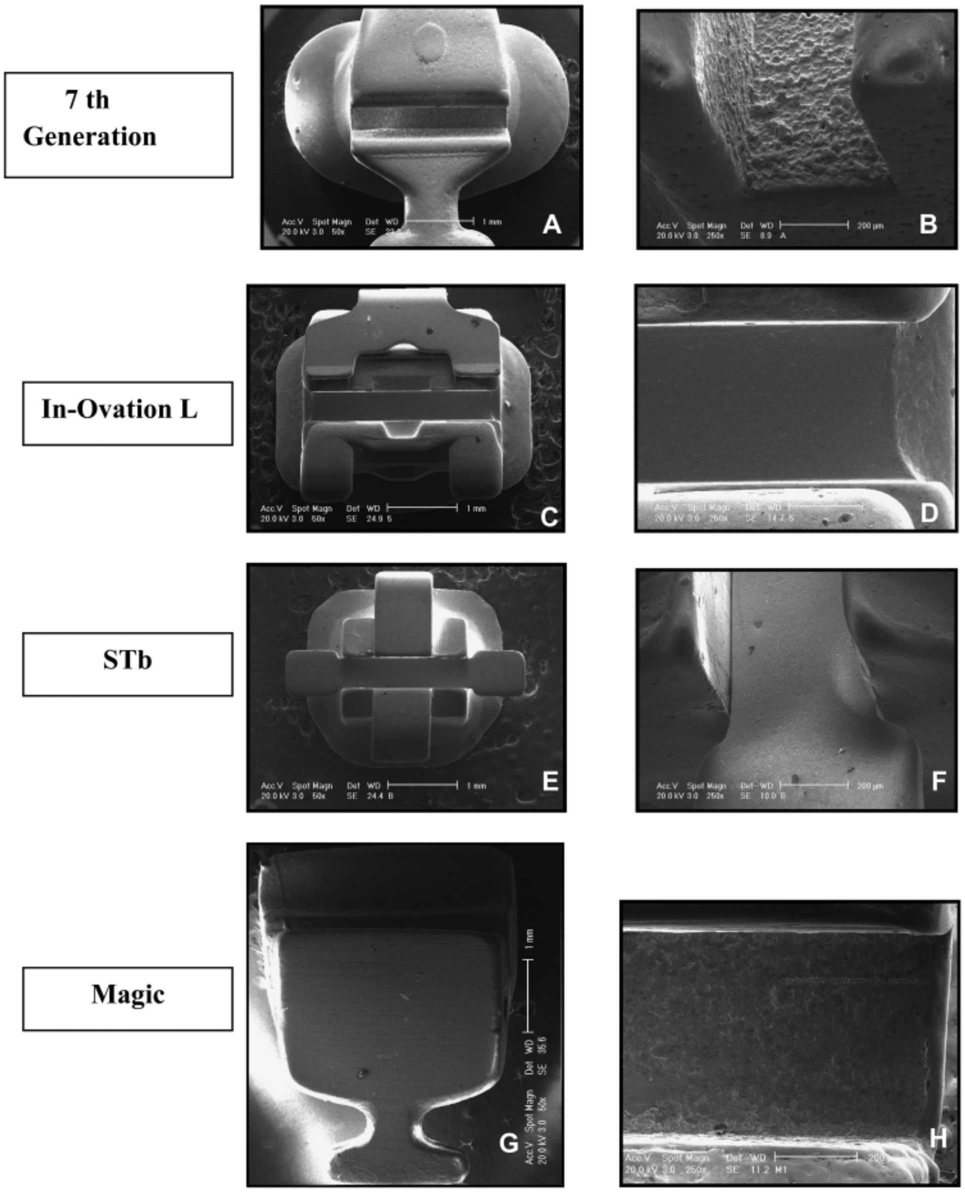

Figure 4 Scanning electron micrographs of the four lingual brackets. A, C, E, G: Magnification ×50 and B, D, F, H: Magnification ×250.

Wire sizes recommended for partial canine retraction and *en masse* retraction of the anterior teeth are 0.016 and 0.016 × 0.022 inch stainless steel archwires, respectively (Fillion, 2001).

In a maximum anchorage case, when sliding mechanics are used, better anchorage control in the posterior segment can be achieved with appliances exhibiting low friction. However, with lingual archwires, low friction brackets can increase the risk of mesio-buccal molar and disto-buccal canine rotation and arch expansion (transverse bowing effect; Scuzzo and Takemato, 2003). Accordingly, torque control and ideal tooth positioning should be accomplished with archwire/bracket couples that produce greater frictional resistance at the finishing stage of treatment. For this purpose, 0.017 × 0.025 inch stainless steel or 0.0175 × 0.0175 Beta titanium (TMA) archwires are used (Fillion, 2001; Mori, 2001). Accordingly, frictional resistance of the lingual brackets for 0.016, 0.016 × 0.022, and 0.017 × 0.025 inch stainless steel archwires were measured in this study. Because of the slot size difference, Magic brackets were coupled with 0.018 inch round and 0.018 × 0.018 and 0.019 × 0.019 inch stainless steel archwires as recommended by the manufacturer.

The results of the present research show that frictional forces were proportional to the archwire sizes, similar to the results of previous studies relating archwire dimension to friction (Andreasen and Quevedo, 1970; Kapila *et al.*, 1990; Redlich *et al.*, 2003). In relation to archwire/bracket angulation, the results indicated that the frictional resistance values increased for all combinations, suggesting that this factor influences the magnitude of friction between bracket and archwire (Kusy and Whitley, 1999; Thorstenson and Kusy, 2001; Redlich *et al.*, 2003; Nishio *et al.*, 2004; Cha *et al.*, 2007). Finally, kinetic frictional forces were generally lower than static forces for all combinations, confirming a previous report (Jones *et al.*, 2002).

For all archwire/bracket combinations, the lowest frictional forces were generated by the In-Ovation L and Magic brackets. The findings regarding the In-Ovation L brackets are in agreement with those of previous studies that found that stainless steel self-ligating labial brackets generated lower frictional resistance than conventional brackets (Berger, 1990; Thorstenson and Kusy, 2001; Cacciafesta *et al.*, 2003; Tecco *et al.*, 2005; Kim *et al.*, 2008; Ehsani *et al.*, 2009). A reduction in treatment time was also recorded (Harradine, 2001; Eberting *et al.*, 2001).

On the other hand, the decreased frictional forces of the Magic brackets may be due to bracket design and to its oversized slot dimensions. Thus, with rectangular wires at increased second-order angulations frictional force values of the Magic brackets were found to be significantly lower than those of the 7th Generation and STb brackets.

Comparison of STb and 7th Generation brackets showed less friction for the 7th Generation than the STb brackets but only at 0 degrees angulation with a 0.017× 0.025 inch archwire. A contributing cause for this difference may be the variation in slot dimensions. The slot dimensions of the 7th Generation brackets were found to be greater than those of the STb brackets.

Finally, at 10 degrees of angulation, In-Ovation L brackets produced significantly lower frictional resistance than STb brackets with 0.016 and 0.016 × 0.022 inch archwires. However, no significant difference was found when these brackets were tested with 0.017 × 0.025 inch archwires. This can be explained by the difference in the method of ligation (the clip of the inter-active self-ligating bracket presses against the archwire as the wire size and second-order angulation increase).

The findings of this study show that slot surface roughness did not have a direct influence on frictional resistance as reported in previous studies (Kusy and Whitley, 1990; Kusy, 1991). Despite the 7th Generation brackets showing higher surface roughness than the STb brackets, frictional force values were not significantly higher. The results also indicate that the slot widths of the investigated brackets were larger than the dimensions stated by their manufacturers.

Conclusions

Frictional resistance increases in direct proportion to archwire size and second-order angulation of the bracket.

Generated frictional resistance to sliding can be advantageous as well as disadvantageous depending on the stage of treatment, such as levelling, space closure, or torque control.

Self-ligating In-Ovation L lingual brackets showed generally lower friction when coupled with round and rectangular stainless steel wires. This can be beneficial for anchorage control if sliding mechanics is the method of choice. In addition, secure and full archwire engagement will contribute to the efficiency of treatment.

Funding

Research Support Unit of Istanbul University [T-911, 02062006].

References

Andreasen G F, Quevedo F R 1970 Evaluation of friction forces in the 0.022 × 0.028 edgewise bracket *in vitro*. Journal of Biomechanics 3: 151–160

Articolo L C, Kusy R P 1999 Influence of angulation on the resistance to sliding in fixed appliances. American Journal of Orthodontics and Dentofacial Orthopedics 115: 39–51

Articolo L C, Kusy K, Saunders C R, Kusy R P 2000 Influence of ceramic and stainless steel brackets on the notching of archwires during clinical treatment. European Journal of Orthodontics 22: 409–425

Bach R M 2009 Understanding friction and sliding. American Journal of Orthodontics and Dentofacial Orthopedics 136: 4–5

Berger J L 1990 The influence of the Speed bracket's self-ligating design on force levels in tooth movement: a comparative *in vitro* study. American Journal of Orthodontics and Dentofacial Orthopedics 97: 219–228

Brown L J, Oliver R C, Loe H 1990 Evaluating periodontal status of US employed adults. Journal of the American Dental Association 121: 226–232

Brown L J, Oliver R C, Loe H 1991 Variations in the prevalence and extent of periodontitis. Journal of the American Dental Association 122: 43–48

Burrow S J 2009 Friction and resistance to sliding in orthodontics: a critical review. American Journal of Orthodontics and Dentofacial Orthopedics 135: 442–447

Cacciafesta V, Sfondrini M F, Ricciardi A, Scribante A, Klersy C, Auricchio F 2003 Evaluation of friction of stainless steel and esthetic self-ligating brackets in various bracket-archwire combinations. American Journal of Orthodontics and Dentofacial Orthopedics 124: 395–402

Cha J Y, Kim K S, Hwang C J 2007 Friction of conventional and silica-insert ceramic brackets in various bracket-wire combinations. Angle Orthodontist 77: 100–107

Eberting J J, Straja S R, Tuncay O C 2001 Treatment time, outcome, and patient satisfaction comparisons of Damon and conventional brackets. Clinical Orthodontics and Research 4: 228–234

Ehsani S, Mandich M A, El-Bialy T H, Flores-Mir C 2009 Frictional resistance in self-ligating orthodontic brackets and conventionally ligated brackets. A systematic review. Angle Orthodontist 79: 592–601

Fillion D 2001 Anterior cross-bite and midline discrepancy treatment. Journal of Lingual Orthodontics 1: 19–29

Franchi L, Baccetti L, Camporesi M, Giuntini V 2009 Forces released by nonconventional bracket or ligature systems during alignment of buccally displaced teeth. American Journal of Orthodontics and Dentofacial Orthopedics 136: 316.e 1–e6

Gandini P, Orsi L, Bertoncini C, Massironi S, Franchi L 2008 *In vitro* frictional forces generated by three different ligation methods. Angle Orthodontist 78: 917–921

Geron S 2008 Self-ligating brackets in lingual orthodontics. Seminars in Orthodontics 14: 64–72

Harradine N W T 2001 Self-ligating brackets and treatment efficiency. Clinical Orthodontics and Research 4: 220–227

Hohoff A, Wiechmann D, Fillion D, Stamm T, Carsten L, Ehmer U 2003 Evaluation of the parameters underlying the decision by adult patients to opt for lingual therapy: an international comparison. Journal of Orofacial Orthopedics 64: 135–144

Jones S P, Tan C C, Davies E H 2002 The effects of reconditioning on the slot dimensions and static frictional resistance of stainless steel brackets. European Journal of Orthodontics 24: 183–190

Kapila S, Angolkar P V, Duncanson M G, Nanda R S 1990 Evaluation of friction between edgewise stainless steel brackets and orthodontic wires of four alloys. American Journal of Orthodontics and Dentofacial Orthopedics 98: 117–126

Katz M I 2009 Timely observations on friction and sliding. American Journal of Orthodontics and Dentofacial Orthopedics 136: 3–4

Kim T K, Kim K D, Baek S H 2008 Comparison of frictional forces during the initial leveling stage in various combinations of self-ligating brackets and archwires with a custom-designed typodont system. American Journal of Orthodontics and Dentofacial Orthopedics 133: 187.e15–e24

Kusy R P 1991 Materials and appliances in orthodontics: brackets, archwires and friction. Current Opinions in Dentistry 1: 634–644

Kusy R P 2000 Orthodontic biomechanics: vistas from the top of a new century. American Journal of Orthodontics and Dentofacial Orthopedics 117: 589–591

Kusy R P 2005 Influence of force systems on archwire-bracket combinations. American Journal of Orthodontics and Dentofacial Orthopedics 127: 333–342

Kusy R P, Whitley J Q 1990 Effects of surface roughness on the coefficients of friction in model orthodontic system. Journal of Biomechanics 23: 913–925

Kusy R P, Whitley J Q 1997 Friction between different wire-bracket configurations and materials. Seminars in Orthodontics 3: 166–177

Kusy R P, Whitley J Q 1999 Influence of archwire and bracket dimensions on sliding mechanics: derivations and determinations of the critical contact angles for binding. European Journal of Orthodontics 21: 199–208

Matarese G *et al.* 2008 Evaluation of frictional forces during dental alignment: an experimental model with 3 nonleveled brackets. American Journal of Orthodontics and Dentofacial Orthopedics 133: 708–715

Mori Y 2001 Case report 1: Skeletal Class II bi-maxillary protrusion. Journal of Lingual Orthodontics 1: 9–14

Nishio C, da Motta A F J, Elias C N, Mucha J N 2004 *In vitro* evaluation of frictional forces between archwires and ceramic brackets. American Journal of Orthodontics and Dentofacial Orthopedics 125: 56–64

Park J H, Lee Y K, Lim B S, Kim C W 2004 Frictional forces between lingual brackets and archwires measured by a friction tester. Angle Orthodontist 74: 816–824

Redlich M, Mayer Y, Harari D, Lewinstein I 2003 *In vitro* study of frictional forces during sliding mechanics of 'reduced-friction' brackets. American Journal of Orthodontics and Dentofacial Orthopedics 124: 69–73

Romano R 1998 Lingual orthodontics. B C Becher, Hamilton, London

Sattler N, Hahn W 2002 Self-ligating brackets versus conventional brackets. Journal of Lingual Orthodontics 2: 67–70

Scuzzo G, Takemato K 2003 Invisible orthodontics. Quintessenz Verlag GmbH, Berlin

Takemato K 1995 Lingual orthodontic extraction therapy. Clinical Impressions 3: 2–7

Tecco S, Festa F, Caputi S, Traini T, Di Iorio D, D'Attilio M 2005 Friction of conventional and self-ligating brackets using a 10 bracket model. Angle Orthodontist 75: 1041–1045

Thorstenson G A, Kusy R P 2001 Resistance to sliding of self-ligating brackets versus conventional stainless steel twin brackets with second-order angulation in the dry and wet (saliva) states. American Journal of Orthodontics and Dentofacial Orthopedics 120: 361–370

Wiechmann D 2002 A new bracket system for lingual orthodontic treatment. Part 1: theoretical background and development. Journal of Orofacial Orthopedics 63: 234–245

Wiechmann D 2003 A new bracket system for lingual orthodontic treatment. Part 2: first clinical experiences and further development. Journal of Orofacial Orthopedics 64: 372–388