Original Article

Third-Order Torque and Self-Ligating Orthodontic Bracket–Type Effects on Sliding Friction

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ABSTRACT

Objective: To examine the influence of third-order torque on kinetic friction in sliding mechanics involving active and passive self-ligating brackets.

Materials and Methods: Wire-slot frictional forces were quantified and compared across five sets of brackets and tubes within a simulated posterior dental segment with $-15°$, $-10°$, $-5°$, $0°$, $+5°$, $+10°$, and $+15°$ of torque placed in the second-premolar bracket; a working archwire was pulled through the slots.

Results: Increasing the torque from $0°$ to $\pm15°$ produced significant increases in frictional resistance with all five sets of brackets and tubes. At $0°$ and $\pm5°$ of torque, generally less friction was created within the passive than within the active self-ligating bracket sets, and the conventional bracket sets with elastomeric ligation generated the most friction. At $\pm10°$ of torque, apparently with wire-slot clearance eliminated, all bracket-and-tube sets displayed similar resistances, with one exception at $+10°$. At $\pm15°$ of torque, one passive set and one active set produced significantly larger frictional resistances than the other three sets.

Conclusions: Third-order torque in posterior dental segments can generate frictional resistance during anterior retraction with the archwire sliding through self-ligating bracket slots. With small torque angles, friction is less with passive than with active self-ligating brackets, but bracket design is a factor. Frictional forces are substantial, regardless of ligation if the wire-slot torque exceeds the third-order clearance. (*Angle Orthod.* 2009;79:551–557.)

KEY WORDS: Self-ligation; Torque; Friction

INTRODUCTION

The specific objective of minimizing friction within sliding mechanics has contributed to the recent reintroduction of self-ligating bracket systems to mainstream orthodontics. It is claimed that these newer brackets reduce wire-slot friction, improve oral hygiene, lessen anchorage loss, and shorten chair and treatment time.[1–5] Studies have reported that self-ligating brackets generate less sliding friction than elastomerically tied brackets.[1,6–12]

In general, self-ligating brackets fall into one of two design categories, based on the manner of slot closure. The typical active bracket features a resilient spring clip that snaps closed into the slot, reducing its faciolingual depth. Because this clip can store energy when it is activated by a lingual malalignment, a rotated tooth, or a twisted rectangular wire, it has the potential to exert lingual force on the wire and help bring the tooth into its proper position.[13] Critics of the clip design say, however, that an active component of the ligation unnecessarily increases frictional resistance.[14] Some investigators have found that any advantage from decreased friction with active self-ligating brackets is reduced when rectangular wires are placed.[3,6,9,15–18] Suggested also is that the asymmetric design of the cantilevered clip delivers a diagonally directed force to the archwire, in effect reducing torque efficiency and causing errors in torque expression.[4]

Passive ligating mechanisms do not compromise the depth of the slot. One passive design uses a door

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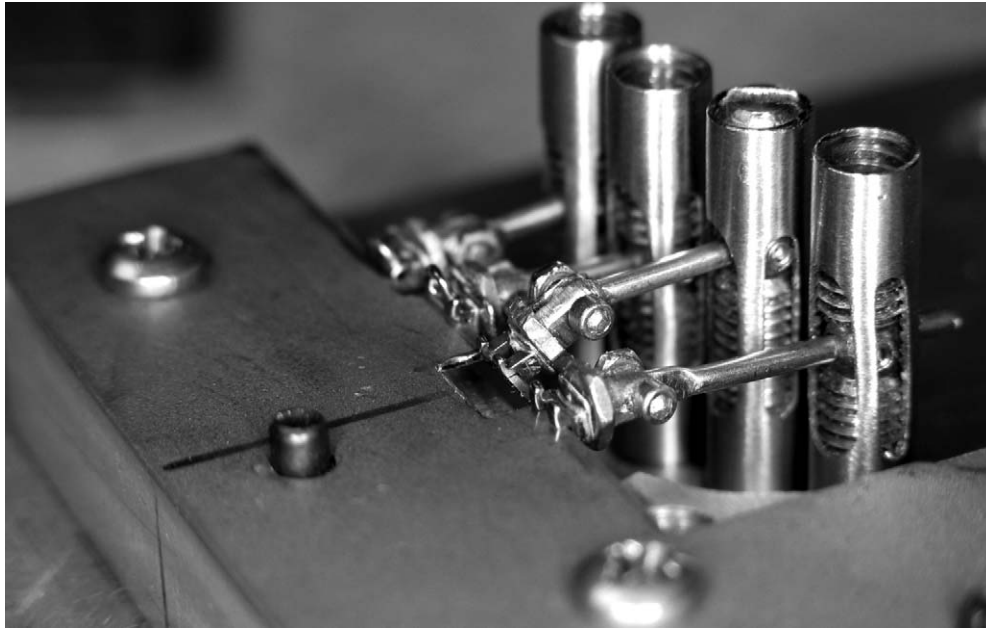(e-mail: oliverdr@slu.edu)

Figure 1. Modeled four-tooth buccal segment with template in place to establish slot orientations.

that slides across the slot, effectively transforming the bracket into a tube.[14] Another design features a C-clip lateral to each of the mesial and distal tie wings.[19] The claimed benefit of passive self-ligating systems is reduced friction with all archwire sizes, resulting in faster tooth movement.[20] With the absence of a lingually directed force against it, however, some critics argue that the inability to control torque could be a problem with less than full-sized (rectangular) wires.[21]

In active orthodontic therapy, if an engaged rectangular wire does not completely fill the slot, some unconstrained third-order rotation is allowed. Should the associated clearance within the slot be zero, occlusogingival forces are created through direct wire contact with the slot. Moore et al[22] measured friction in two different brackets with predetermined faciolingual tip and torque. They reported significant increases in friction with torque imposed. Sims et al[10] also quantified friction produced with wires sliding through bracket slots positioned to input specific torque values. They reported that, with torque present, a self-ligating bracket showed consistently less resistance to sliding than the two conventionally ligated brackets.

The purpose of the present study was to evaluate the effect of wire-slot torque on kinetic friction within retraction mechanics, comparing active and passive self-ligating and elastomerically ligated brackets.

MATERIALS AND METHODS

A posterior maxillary right quadrant with a first premolar extracted and canine retracted was simulated. Wire-slot kinetic friction generated in the buccal seg-

ment, as during incisal-segment retraction, was measured. Two independent variables were bracket (and ligation) and third-order torque in the bracket slot of the second premolar.

The modeled posterior segment consisted of four cylinders (teeth) mounted in a base plate. The design of the cylinder assembly enables the facial surface to be located and oriented in all three planes of space. Represented were the right canine, second premolar, first molar, and second molar.

Seven templates individually oriented the slots of three of the four crown attachments; the slots were engaged and filled by the working edge of the template. In each of six templates, at the site of the second-premolar bracket slot, a rectangular piece of the plate was cut away; the cutout left a 0.022- by 0.025-inch cross section that was inelastically rotated to one of six specific angles to enable torque placement in the slot. The seventh template was left uncut to place 0° of second-premolar torque. Each template was also shaped to place the canine and first-molar attachment slots in zeroed first- and second-order positions (see Figure 1). The second-molar tube was aligned with a full-size wire segment, cantilevered from the three adjacent attachment slots.

Each test specimen included two brackets, two molar tubes, and an archwire. Affixed at the first-molar site was a self-ligating first-molar tube (SLBUCCAL, Ormco Corporation, Glendora, Calif). The second-molar attachment was a single tube (#68-172-82; GAC International, Bohemia, NY). The arch blanks were 0.019- by 0.025-inch NuBryte Standard Arch stainless-steel wires (#03-925-51; GAC International).
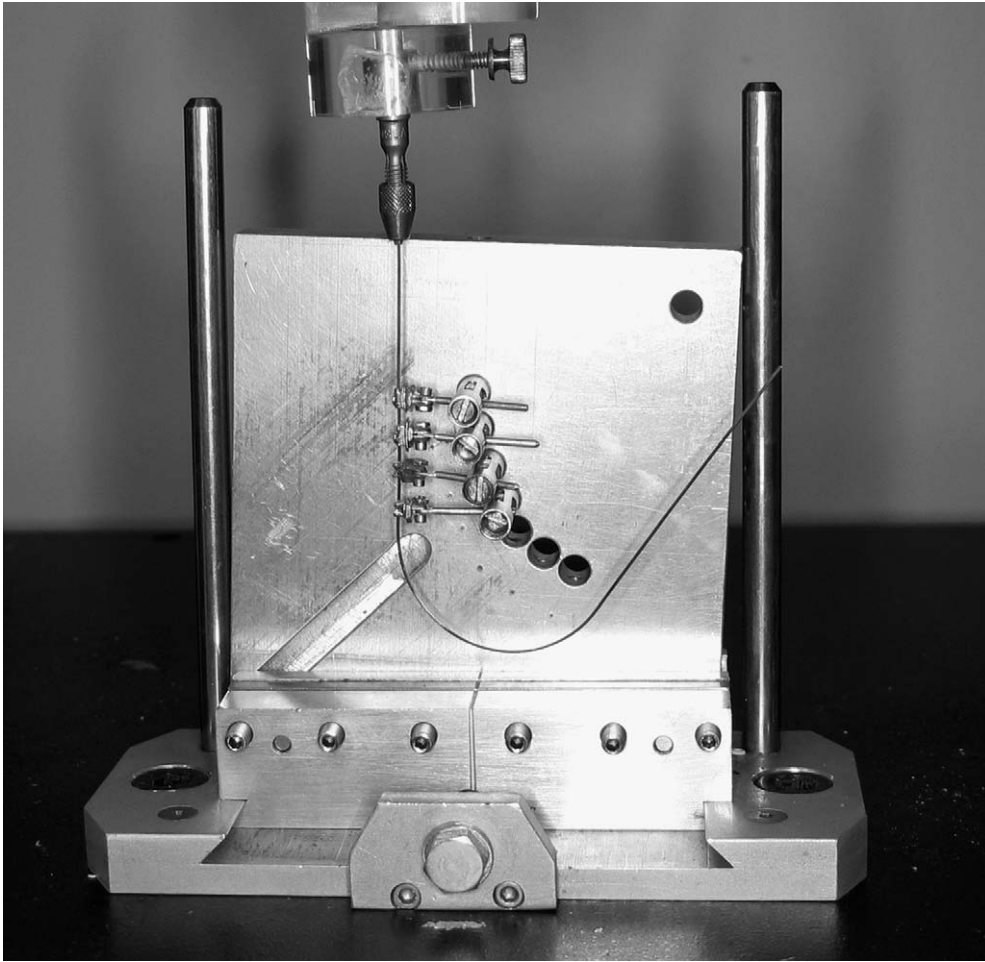
Figure 2. Modeled buccal segment with archwire engaged in bracket and tube slots; the assembly prepared for a test.

Five different pairs of canine and second-premolar brackets were selected. The active self-ligating attachments were In-Ovation R brackets (GAC International) and Time2 brackets (American Orthodontics, Sheboygan, Wis). The passive self-ligating attachments were Damon 3MX brackets (Ormco Corporation) and SmartClip brackets (3M/Unitek Corporation, Monrovia, Calif). The traditional brackets were from the Victory MBT series (3M/Unitek Corporation, Monrovia, Calif); wires were tied in the slots with silver Unistick elastomeric ligatures (#854-262; American Orthodontics).

The torque at the second-premolar bracket slot was $-15°$, $-10°$, $-5°$, $0°$, $+5°$, $+10°$, or $+15°$ for an individual test; slots in the other bracket and tubes were maintained at zero torque.

Brackets and molar tubes were affixed with a cyanoacrylate adhesive (Loctite Super Glue Gel, Henkel Consumer Adhesives, Gulph Mills, Penn). A new archwire was engaged in the attachment slots and ligated for each test. New elastomeric ligatures were placed prior to each test with Victory brackets using a Straight Shooter® (TP Orthodontics, LaPorte, Ind). The simulated dental segment was mounted to the fixed head of a universal testing machine (Model 1011, Instron Corporation, Canton, Mass) with one buccal section of the archwire oriented vertically and its end attached to the movable head of the Instron testing machine (Figure 2). The wire was pulled 1.5 mm posteriorly through the bracket and tube slots at a rate of 1 mm per minute, and a chart recorder (Model 2310-069, Instron Corporation) generated a force-versus-displacement plot.

Testing was performed in the dry state and at room temperature. From each test, a mean frictional force magnitude was determined from 10 points, equally spaced across the plot.

The research design consisted of all combinations of the five bracket/tube/ligation sets and seven torque values. One set of four brackets and tubes was in place for testing at all torque values. The order of torque values during the testing of each set was randomized. Based on a previous study,[10] six replications of each bracket-torque combination (210 total tests)

Table 1. Frictional Force Means and Standard Deviations in Grams at Seven Second-Premolar Torque Angles From Five Sets of Brackets and Tubes

	Torque, °						
	−15	−10	−5	0	+5	+10	+15
Victory	551 ± 36	329 ± 84	339 ± 52	303 ± 63	363 ± 84	471 ± 32	549 ± 59
In-Ovation R	752 ± 128	440 ± 34	205 ± 8	221 ± 14	236 ± 35	623 ± 32	757 ± 79
Time2	562 ± 103	407 ± 74	186 ± 50	196 ± 17	335 ± 22	517 ± 50	529 ± 79
Damon 3MX	498 ± 110	358 ± 113	120 ± 17	149 ± 31	165 ± 89	440 ± 81	496 ± 69
SmartClip	736 ± 26	433 ± 73	149 ± 44	55 ± 24	151 ± 47	427 ± 87	744 ± 38

were anticipated to be sufficient to give meaningful statistical results.

RESULTS

The data were analyzed using SPSS software, version 14.0 (SPSS, Inc, Chicago, Ill). The mean frictional resistances and their standard deviations, across the five crown-attachment sets and each of the seven torque values, are shown in Table 1. Figure 3 displays the mean force magnitudes from each of the crown-attachment sets; the seven means (associated with torque angles) for an individual set were connected in order by a series of line segments, showing symmetry or lack thereof in the means across the range of torque angles. Frictional resistances across pairs torque values from each set were examined for significant differences with the Mann-Whitney U test. Kruskal-Wallis one-way analyses of variance and post hoc Tukey comparisons sought significant differences ($P < .05$) between frictional forces across the five crown-attachment sets at each of the seven torque angles; these outcomes are presented in Table 2.

Neither +5° nor −5° of third-order slot rotation resulted in significant changes in frictional force from baseline values at 0° of torque with three of the five bracket/tube/ligation sets, but placing ±10° of torque produced significant increases in frictional resistance from all four self-ligating bracket sets (Table 2). Further increases to +15° and −15° of torque generally produced additional significant increases in frictional resistance. The elastomerically ligated Victory set showed the smallest force change from 0° when the largest torque angles were placed. The SmartClip set displayed the smallest mean frictional force at 0°, but at ±15°, it also generated the greatest resistance (Table 1).

At +5°, 0°, and −5° of torque, the Victory crown-attachment set generally produced significantly more friction than the four self-ligating sets (Table 2). The two passive (self-ligating) sets generated the smallest mean frictional forces at 0° of torque.

No significant differences in mean frictional forces were produced across the five attachment sets at −10° of torque. At +10°, however, the In-Ovation R

set displayed significantly greater frictional resistance than each of the other four attachment sets (Table 2).

At +15° and −15° of torque, the In-Ovation R and SmartClip sets generated significantly greater mean frictional forces than the other three sets (Table 2).

DISCUSSION

Effect of Torque

Increasing torque in the second-premolar slot from 0° to and beyond ±10° caused increases in frictional forces from all except the Victory set from 0° to −10°. Increases were not seen from most of the sets, with placement of only 5° of torque. These outcomes tend to support the suggestion[22] that torque will not have a dramatic effect on mesiodistal sliding friction until it exceeds the third-order clearance angle of the wire-slot combination. Reportedly, the third-order clearance for a fully drawn, 0.019- by 0.025-inch wire in a 0.022-inch open slot is close to 10°.[23] Presently, beyond 10° of torque, an increase in friction was due to the presence of occlusogingival normal forces between wire and slot, components of the torsional couple generated.[24] In addition, calculations indicate that this rectangular wire rotated 10° in a 0.022-inch slot would extend it buccolingually to 0.028 inches. The Damon 3MX and Smartclip brackets have slot depths of 0.028 and 0.0275 inches, respectively; hence, rotating the slot 10° of either of these two passive self-ligated brackets should create ligation wire–slot contacts that can contribute to the frictional resistance.

Of the two active self-ligated brackets, In-Ovation R has a slot depth of 0.018 inches, whereas the Time2 has a slot depth of 0.024 inches for the canine and 0.027 for the second premolar. The MBT Victory traditional bracket has a slot depth of 0.024 and 0.027 inches for the canine and second premolar, respectively.

Active self-ligating brackets may respond differently from passive brackets when wire-slot torque is present. The clip is cantilevered occlusogingivally such that it first contacts a rectangular wire along just one edge. An engaged 0.019- by 0.025-inch archwire with zero torque should deflect the free end of the clip of the
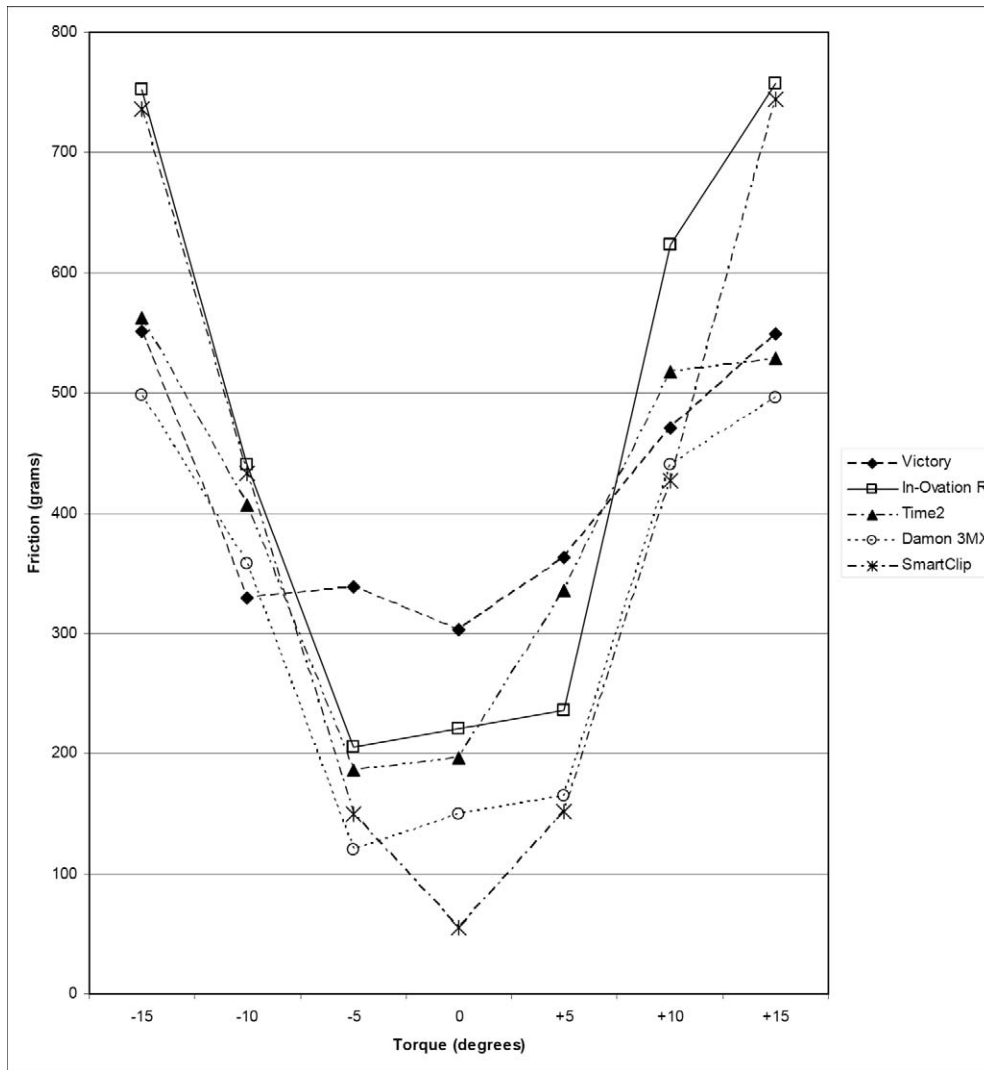
Figure 3. Plots of mean kinetic frictional force versus second-premolar torque angle from five sets of brackets and tubes.

bracket.[25] Imposing a third-order rotation of the slot relative to the archwire, depending on its direction, could potentially cause more or less deflection of the clip, thereby affecting the faciolingual normal forces exerted by the wire and the frictional resistance. The Time2 set generated larger frictional forces at +5° than at −5° of torque. When comparing frictional resistances at +10° and −10° of torque, both the Time2 and In-Ovation R brackets showed greater forces at the positive third-order angulation. Force asymmetries from these clip designs are seen in Figure 3.

The Victory set also produced a larger mean frictional force at +10° of torque than at −10°. The occlusal tie wing of the Victory bracket extends farther facially than the gingival tie wing, suggesting that the elastomeric module stretched across the rectangular wire may skew the direction of the net normal force from the tie.

Only the SmartClip set showed a significant in-

crease in friction with every 5° increase in torque (in either twist direction). Because placement of 5° of torque did not eliminate wire-slot clearance, the source could be contact of the nickel-titanium-alloy C-clips by the wire. An orthodontic materials study found a Ni-Ti-alloy/stainless-steel couple to have a relatively large kinetic frictional coefficient.[26]

Effect of Bracket Design

At 0° of torque, the results of this study were similar to those from a previous research effort[12] that evaluated friction in self-ligating and traditionally ligated brackets; in both studies, elastomerically tied brackets produced the greater resistance. Here, friction values obtained from both passive self-ligating sets at ±5° remained significantly smaller than the friction produced by the Victory set, likely because of the presence of third-order clearances in all slots. With the ex-

Table 2. Mean Differences in Frictional Forces in Grams and Significance Values (α = .05) Between Bracket-and-Tube Sets at Each of Seven Second-Premolar Torque Angles[a]

		Torque, °												
		−15		−10		−5		0		+5		+10		+15	
(a)	(b)	(a − b)[b]	Sig	(a − b)	Sig	(a− b)	Sig	(a − b)	Sig	(a − b)	Sig	(a − b)	Sig	(a − b)	Sig
Victory	In-Ovation R	−201	.006	−111	NS	134	.000	82	.003	127	.011	−152	.002	−208	.000
	Time2	−11	NS	−78	NS	153	.000	107	.000	28	NS	−46	NS	20	NS
	Damon 3MX	53	NS	−29	NS	219	.000	154	.000	198	.000	31	NS	53	NS
	SmartClip	−185	.013	−104	NS	190	.000	247	.000	213	.000	44	NS	−195	.000
In-Ovation R	Victory	201	.006	111	NS	−134	.000	−82	.003	−127	.011	152	.002	208	.000
	Time2	190	.010	33	NS	19	NS	25	NS	−99	NS	106	.043	228	.000
	Damon 3MX	254	.000	82	NS	85	.006	72	.010	71	NS	183	.000	261	.000
	SmartClip	16	NS	7	NS	56	NS	166	.000	86	NS	196	.000	13	NS
Time2	Victory	11	NS	78	NS	−153	.000	−107	.000	−28	NS	46	NS	−20	NS
	In-Ovation R	−190	.010	−33	NS	−19	NS	−25	NS	99	NS	−106	.043	−228	.000
	Damon 3MX	64	NS	49	NS	66	.045	47	NS	170	.001	77	NS	−33	NS
	SmartClip	−174	.022	−26	NS	37	NS	141*	.000	185	.000	90	NS	−215	.000
Damon 3MX	Victory	−53	NS	29	NS	−219	.000	−154	.000	−198	.000	−31	NS	−53	NS
	In-Ovation R	−254	.000	−82	NS	−85	.006	−72	.010	−71	NS	−183	.000	−261	.000
	Time2	−64	NS	−49	NS	−66	.045	−47	NS	−170	3001	−77	NS	33	NS
	SmartClip	−238	.001	−75	NS	−29	NS	94	.001	14	NS	13	NS	−248	.000
Smart Clip	Victory	182	.013	104	NS	−190	.000	−247	.000	−213	.000	−44	NS	195	.000
	In-Ovation R	−16	NS	−7	NS	−56	NS	−166	.000	−86	NS	−196	.000	−13	NS
	Time2	174	.022	26	NS	−37	NS	−141	.000	−185	.000	−90	NS	215	.000
	Damon 3MX	238	.001	75	NS	29	NS	−94	.001	−14	NS	−13	NS	248	.000

[a] NS indicates not significant; Sig, significance.

[b] Mean difference in frictional resistance between a and b in grams.

ception of the In-Ovation R set and positive angles, increasing the torque from ±5° to ±10° brought the frictional resistances from the self-ligating attachment sets to magnitudes similar to those from the Victory set. This finding contrasted outcomes from a previous study[10] that found self-ligating brackets to produce smaller frictional forces than traditionally ligated brackets with significant torque placed (but tie tension can be a factor). In the present research, the marked increase in friction found with the self-ligating (but not in the Victory) sets when increasing the torque from ±5° to ±10° suggests that faciolingual forces arose from substantial contacts with the ligating mechanisms. The In-Ovation R set, when the torque angle was increased from +5° to +10°, displayed the greatest increase in frictional resistance, possibly a result of magnified normal forces from its active self-ligation and asymmetrical clip.

When the torque was increased substantially beyond third-order clearance values to ±15°, the friction associated with the SmartClip and the In-Ovation R sets grew to significantly larger magnitudes than the values displayed by the other three sets. This finding may be related to the individual ligating mechanisms of these brackets. Faciolingual interactions of the wires with the ligations of both brackets were enlarged partially because of clip spring back. Flexure of the nickel-titanium-alloy clips contributing to normal forces

as well as the roughness of the clip surfaces could have affected the Smartclip set.[27] The clip integral to the In-Ovation R bracket is made of a relatively stiff, cobalt-chromium alloy that has greater frictional potential associated with surface roughness than stainless steel,[28] and it may also have contributed to the large resistance displayed.

The design of this study does not entirely represent what might occur in clinical situations. Because teeth tend to tip and rotate somewhat during mesiodistal displacements,[29] first- and second-order angulations may also contribute to slot-wire friction. Bracket width might well have a bearing on friction. The bracket widths in this study, expressed in inches, varied as follows: Damon 3MX 0.130, Smart Clip 0.134 (including the clips,) Time2, canine 0.092, second premolar 0.1030, InnovationR 0.12, and the traditional MBT Victory, 0.127 for the canine and 0.122 for the second premolar. The present effort did, however, help to clarify friction issues with several of the newer bracket designs. A clear recommendation from this study is to minimize torque in the buccal segments before beginning en masse retraction of anterior teeth.

CONCLUSIONS

- At small torque angles, friction will tend to be less with passive than with active self-ligating sets.

- A substantial increase in frictional resistance occurs if the torque in a bracket slot exceeds the third-order clearance angle of the wire-slot combination.
- As torque increases toward the third-order clearance angle, however, differences in frictional resistances across crown-attachment sets generally lessen. With this clearance eliminated, the differences in frictional resistance may not depend so much on the category of ligation but rather on the basic design of the ligating mechanism.

REFERENCES

1. Shivapuja PK, Berger J. A comparative study of conventional ligation and self-ligation bracket systems. *Am J Orthod Dentofacial Orthop.* 1994;106:472–480.
2. Berger J, Byloff FK. The clinical efficiency of self-ligated brackets. *J Clin Orthod.* 2001;35:304–308.
3. Damon DH. The Damon low-friction bracket: a biologically compatible straight-wire system. *J Clin Orthod.* 1998;32:670–680.
4. Harradine NW. Self-ligating brackets: where are we now? *J Orthod.* 2003;30:262–273.
5. Maijer R, Smith DC. Time savings with self-ligating brackets. *J Clin Orthod.* 1990;24:29–31.
6. Sims APT, Waters NE, Birnie DJ, Pethybridge RJ. A comparison of the forces required to produce tooth movement in vitro using two self-ligating brackets and a pre-adjusted bracket employing two types of ligations. *Eur J Orthod.* 1993;15:377–385.
7. Thorstenson GA. SmartClip self-ligating brackets frictional study. In: *Orthodontic Perspectives: The System Approach.* Monrovia, Calif: 3M-Unitek; 2005; 12:8–11.
8. Hain M, Dhopatkar A, Rock P. The effect of ligation method on friction in sliding mechanics. *Am J Orthod Dentofacial Orthop.* 2003;123:416–422.
9. Pizzoni L, Ravnholt G, Melsen B. Frictional forces related to self-ligating brackets. *Eur J Orthod.* 1998;20:283–291.
10. Sims APT, Waters NE, Birnie DJ. A comparison of the forces required to produce tooth movement ex vivo through three types of pre-adjusted brackets when subjected to determined tip or torque values. *Br J Orthod.* 1994;21:367–373.
11. Thomas S, Sherriff M, Birnie DJ. A comparative in vitro study of the frictional characteristics of two types of self-ligating brackets and two types of pre-adjusted edgewise brackets tied with elastomeric ligatures. *Eur J Orthod.* 1998;20:589–596.
12. Thorstenson GA, Kusy RP. Resistance to sliding of self-ligating brackets versus conventional stainless steel twin brackets with second-order angulation in the dry and wet (saliva) states. *Am J Orthod Dentofacial Orthop.* 2001;120:361–370.
13. Woodside DG, Berger JL, Hanson GH. Self-ligation orthodontics with the SPEED appliance. In: Graber TM, Vanarsdall RL, Vig KWL, eds. *Orthodontics: Current Principles and Techniques.* 4th ed. St Louis, Mo: Elsevier Mosby; 2005:717–752.
14. Damon DH. Treatment of the face with biocompatible orthodontics. In: Graber TM, Vanarsdall RL, Vig KWL, eds. *Orthodontics: Current Principles and Techniques.* 4th ed. St Louis, Mo: Elsevier; 2005:753–831.
15. Heiser W. Time: a new orthodontic philosophy. *J Clin Orthod.* 1998;32:44–53.
16. Henao SP, Kusy RP. Evaluation of the frictional resistance of conventional and self-ligating bracket designs using standardized archwires and dental typodonts. *Angle Orthod.* 2004;74:202–211.
17. Read-Ward GE, Jones SP, Davies EH. A comparison of self-ligating and conventional orthodontic bracket systems. *Br J Orthod.* 1997;24:309–317.
18. Taylor NG, Ison K. Frictional resistance between orthodontic brackets and archwires in the buccal segments. *Angle Orthod.* 1996;66:215–222.
19. Trevisi HJ. *The SmartClip Self-Ligating Appliance System Technique Guide.* Monrovia, Calif: 3M-Unitek; 2005.
20. Weinberger GL. Utilizing the SmartClip self-ligating appliance. In: *Orthodontic Perspectives: The System Approach.* Monrovia, Calif: 3M-Unitek Publication; 2005; 23:3–7.
21. Roth RH, Sapunar A, Frantz RC. The In-Ovation bracket for fully adjusted appliances. In: Graber TM, Vanarsdall RL, Vig KWL, eds. *Orthodontics: Current Principles and Techniques.* 4th ed. St Louis, Mo: Elsevier; 2005:833–853.
22. Moore MM, Harrington E, Rock WP. Factors affecting friction in the pre-adjusted appliance. *Eur J Orthod.* 2004;26:579–583.
23. Proffit WR. *Contemporary Orthodontics.* 3rd ed. St Louis, Mo: CV Mosby; 2000.
24. Meling TR, Odegaard J, Meling EO. On mechanical properties of square and rectangular stainless steel wires tested in torsion. *Am J Orthod Dentofacial Orthop.* 1997;111:310–320.
25. 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.
26. Kusy RP, Whitley JQ, Prewitt MJ. Comparison of the frictional coefficients for selected archwire-bracket slot combinations in the dry and wet states. *Angle Orthod.* 1991;61:293–302.
27. Bunkall DM. *The Effect of Extraneous Forces Upon the Frictional Characteristics of Self-ligating Orthodontic Brackets and Nickel-Titanium Archwires Utilizing a Novel In-Vitro Model* [master's thesis]. St Louis, Mo: Center for Advanced Dental Education, Saint Louis University; 2006.
28. Drescher D, Bourauel C, Schumacher HA. Frictional forces between bracket and arch wire. *Am J Orthod Dentofacial Orthop.* 1989;96:397–404.
29. Nanda RS. *Biomechanics and Esthetic Strategies in Clinical Orthodontics.* St Louis, Mo: Elsevier Saunders; 2005.