

Frictional Characteristics of Active and Passive Self-Ligation Bracket Systems: An *in vitro* Study

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ABSTRACT

Self-ligating brackets are ligatureless bracket systems which are gaining immense popularity in contemporary orthodontics. Compared with conventional appliances, self-ligating mechanisms attribute their increased efficiency and reduced treatment time to their improved frictional characteristics.

Aim: The present study was conducted to evaluate the kinetic frictional resistance of four self-ligating brackets: Two active types, (Speed™ and In-Ovation® R) two passive types (Damon 3 and SmartClip) and compare them with conventional brackets ligated with elastomeric module. The brackets were tested against five different dimensions of round and rectangular stainless steel wires (0.018, 0.020, 0.017 × 0.025, 0.019 × 0.025, 0.021 × 0.025).

Materials and methods: A universal testing machine (Auto Graph AGS-J Series) was used to determine the frictional resistance to sliding movements. The test readings were statistically analyzed with a one-way ANOVA, post-hoc Tukey's test for multiple comparisons and Student's t-tests using SPSS software.

Results: Damon 3 brackets exhibited least kinetic frictional resistance to sliding movement for all the archwires tested followed by SmartClip, In-Ovation and Speed respectively. Maximum resistance was recorded for conventional twin brackets ligated with elastomeric modules. There was also increase in the frictional force value with increase in wire dimensions.

Conclusion: Self-ligating brackets offered less frictional resistance than conventional brackets. Passive bracket systems offered less frictional resistance than active self-ligating bracket systems and Damon 3 brackets offered the least frictional resistance among all the brackets studied.

Keywords: Self-ligating brackets, Frictional resistance, Sliding mechanics, Archwires.

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INTRODUCTION

Friction is the resistance to motion encountered when one solid body slides or tends to slide over another. It may be described as a force acting parallel and opposite to the direction of this motion.¹ Friction is considered to be significant in decreasing the effective orthodontic force available to move teeth thus reducing the efficiency and rate of tooth movement.²

To reduce the incidence of friction during sliding mechanics, many improvements have been made to enhance the treatment outcome.³ One such modification is the introduction of self-ligating system. Self-ligating (SL) brackets introduced by Dr Stolzenberg⁴ are ligatureless bracket systems that have a mechanical device built into the bracket to close off the edgewise

slot. SL brackets are broadly classified as passive clip type in which the slot is transformed into a tube by means of a labial fourth wall to retain the archwire and active clip type in which the archwire is retained by means of a super elastic clip.

The primary motive for introducing SL brackets was to quicken the process of archwire placement and removal but the manufacturers claim that one of its main advantages is reduced friction thereby leading to low force values which accelerate tooth movement and reduce treatment time.⁵⁻⁷ However, considerable variation exists between commercially available bracket types in terms of their mechanical, geometrical, and material-related specifications and this would be expected to affect their frictional performance.^{8,9}

Therefore, the aim of the present study was to compare the kinetic frictional resistance of four commercially available SL brackets and a preadjusted twin bracket conventionally ligated with elastomeric modules with various stainless steel archwire combinations.

MATERIALS AND METHODS

Upper right first premolar brackets (0.022" slot) were used and the brackets selected for the study are divided into three groups as follows.

- Group I:* Active self-ligating bracket systems
- Speed™ (Strite Industries, Canada)
 - In-Ovation R (GAC-Dentsply, USA).

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Group II: Passive self-ligating bracket systems

- a. Damon 3 (Ormco Corporation, USA)
- b. SmartClip (3M Unitek, USA)

Group III: Conventional bracket system ligated with modules

- a. Mini Ovation (GAC-Dentsply, USA)

These brackets were tested against five different dimensions of round and rectangular stainless steel wires which are commonly used during sliding mechanics. They are as follows:

1. 0.018 inches—AJ Wilcock stainless steel wires of straight length.
2. 0.020 inches—AJ Wilcock stainless steel wires of straight length.
3. 0.017 × 0.025 inches straight length stainless steel wires (GAC, USA).
4. 0.019 × 0.025 inches straight length stainless steel wires (GAC, USA).
5. 0.021 × 0.025 inches straight length stainless steel wires (GAC, USA).

Two brackets of each type were bonded with epoxy resin adhesive (Araldite, Ciba-Geigy, India) to color-coded acrylic

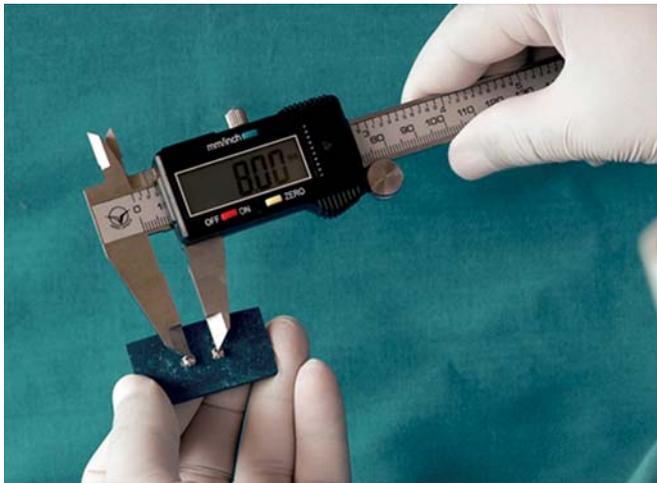


Fig. 1: Bracket positioning with digital caliper



Fig. 2: Jig with 21 × 25 SS wire for paralleling of bracket slot



Fig. 3: Bracket archwire assembly mounted on universal testing machine

rectangular blocks. Interbracket distance was set at 8 mm replicating clinical condition⁶ (Fig. 1). A special jig was designed with 0.021 × 0.025 inch straight length wire for accurate paralleling of the bracket slot, to the base of acrylic rectangular blocks⁵ (Fig. 2).

A universal testing machine (Autograph AGS-J Series Load cell capacity 50N, Shimadzu Corp, Japan) was used to determine the frictional force in a dry environment^{10,11} (Fig. 3).

Each archwire was pulled by a force of 2N to a distance of 10 mm at a constant crosshead speed of 1 mm/minute¹² and the readings were recorded in Newtons (1N = 101.97 gm). The procedure was carried out 10 times with each bracket type and archwire combination. Thus, a total of two hundred and fifty readings were recorded (5 types of brackets × 5 types of archwires = 25 samples × 10 times = 250 readings). Each time, a new archwire is used for testing to eliminate the influence of wear and notching.⁶ The relative kinetic frictional forces were recorded and the collected data were statistically analyzed.

RESULTS

The test readings were statistically analyzed using a one-way ANOVA followed by post-hoc Tukey's test for multiple comparisons and Student's t-tests through SPSS version 10 (Statistical Package for Social Sciences Software, New York, USA). Level of statistical significance, p-value was set at 0.05. If $p > 0.05$ signifies no difference between variable and if $p < 0.05$ denotes that there is significant difference.

Damon 3 brackets exhibited least kinetic frictional resistance to sliding movement for all the archwires tested followed by SmartClip, In-Ovation and Speed respectively. Maximum resistance was recorded for conventional twin brackets ligated with elastomeric modules (Table 1).

When comparing active versus passive self-ligating systems, it was noticed that the active systems displayed significantly higher frictional resistance than the passive systems. Among

Table 1: Kinetic frictional resistance in Newtons for bracket archwire couples

Bracket	Archwires	N	Mean (N)	SD	95% confidence interval for mean	
					Lower bound	Upper bound
Damon	0.018 SS	10	0.59200	0.056921	0.55128	0.63272
	0.020 SS	10	0.78500	0.031002	0.76282	0.80718
	0.017 × 0.025 SS	10	0.71500	0.025927	0.69645	0.73355
	0.019 × 0.025 SS	10	2.89900	0.060818	2.85549	2.94251
	0.021 × 0.025 SS	10	5.03100	0.069992	4.98093	5.08107
SmartClip	0.018 SS	10	0.62000	0.031623	0.59738	0.64262
	0.020 SS	10	1.68400	0.049710	1.64844	1.71956
	0.017 × 0.025 SS	10	1.29500	0.055227	1.25549	1.33451
	0.019 × 0.025 SS	10	2.99800	0.058271	2.95632	3.03968
	0.021 × 0.025 SS	10	5.12710	0.113593	5.04584	5.20836
Speed	0.018 SS	10	0.69300	0.022632	0.67681	0.70919
	0.020 SS	10	2.30700	0.072885	2.25486	2.35914
	0.017 × 0.025 SS	10	2.67470	0.150787	2.56683	2.78257
	0.019 × 0.025 SS	10	4.26200	0.136329	4.16448	4.35952
	0.021 × 0.025 SS	10	6.08600	0.162972	5.96942	6.20258
In-Ovation R	0.018 SS	10	0.65400	0.029889	0.63262	0.67538
	0.020 SS	10	2.12700	0.294771	1.91613	2.33787
	0.017 × 0.025 SS	10	2.16600	0.071988	2.11450	2.21750
	0.019 × 0.025 SS	10	4.06800	0.072999	4.01578	4.12022
	0.021 × 0.025 SS	10	5.85500	0.073824	5.80219	5.90781
Mini Ovation	0.018 SS	10	1.47560	0.047303	1.44176	1.50944
	0.020 SS	10	2.77400	0.099353	2.70293	2.84507
	0.017 × 0.025 SS	10	3.17330	0.105740	3.09766	3.24894
	0.019 × 0.025 SS	10	5.52900	0.142858	5.42681	5.63119
	0.021 × 0.025 SS	10	6.32110	0.035529	6.29568	6.34652

Table 2: Student's t-test comparison—active vs passive vs conventional brackets

Wire	Group	N	Mean	SD	p-value
0.018 SS	Active	20	0.67350	0.032650	<0.001
	Passive	20	0.60600	0.047061	
	Conventional	10	1.47560	0.047303	
0.020 SS	Active	20	2.21700	0.228475	<0.001
	Passive	20	1.23450	0.462937	
	Conventional	10	2.77400	0.099353	
0.017 × 0.025 SS	Active	20	2.42035	0.285173	<0.001
	Passive	20	1.00500	0.300482	
	Conventional	10	3.17330	0.105740	
0.019 × 0.025 SS	Active	20	4.16500	0.145712	<0.001
	Passive	20	2.94850	0.077070	
	Conventional	10	5.52900	0.142858	
0.021 × 0.025 SS	Active	20	5.97050	0.170895	<0.001
	Passive	20	5.07905	0.104226	
	Conventional	10	6.32110	0.035529	

the passive self-ligation group, Damon 3 brackets exhibited less frictional resistance than SmartClip and among the active self-ligating group, In-Ovation R exhibited less frictional resistance than Speed brackets. Conventional twin brackets revealed statistically significantly higher frictional resistance values when compared with self-ligating brackets (Table 2).

No significant difference in frictional resistance for 0.018 inch stainless steel wire was observed within the self-ligating bracket groups (active and passive) ($p > 0.05$).

With 0.020 inch stainless steel wire, no significant difference in the values were seen in active group (Speed, In-Ovation R) ($p > 0.05$), whereas all other groups (passive and conventional group) showed significant difference in frictional resistance ($p < 0.01$).

For 0.017 × 0.025 inch stainless steel wire, all the brackets tested (self-ligating and conventional) showed highly significant levels of difference in frictional resistance ($p < 0.001$). Damon 3 brackets showed least frictional resistance to sliding movement and the frictional resistance increased with SmartClip, In-Ovation and Speed respectively. Maximum resistance was recorded with conventional twin brackets ligated with elastomeric modules.

For 0.019 × 0.025 and 0.021 × 0.025 inch stainless steel wire, there was no significant difference in the frictional resistance between passive self-ligating groups (Damon 3, SmartClip) ($p > 0.05$). Other bracket groups (active and conventional) showed significant difference ($p < 0.01$) (Table 3).

Table 3: Tukey HSD for multiple comparisons for all the archwires tested

Wire	Bracket (I)	Bracket (J)	Mean difference (I-J)	p-value	
0.018 SS	Damon 3	SmartClip	-0.028000	0.520	
		Speed	-0.101000*	<0.001	
		In-Ovation R	-0.062000*	0.009	
		Mini Ovation	-0.883600*	<0.001	
	SmartClip	Speed	-0.073000*	<0.001	
		In-Ovation R	-0.034000	0.325	
		Mini Ovation	-0.855600*	<0.001	
		In-Ovation R	0.039000	0.200	
	Speed	Mini Ovation	-0.782600*	<0.001	
		Mini Ovation	-0.821600*	<0.001	
		Damon 3	SmartClip	-0.899000*	<0.001
		Speed	-1.522000*	<0.001	
0.020 SS	In-Ovation R	Mini Ovation	-1.342000*	<0.001	
		Mini Ovation	-1.989000*	<0.001	
		Speed	-0.623000*	<0.001	
		In-Ovation R	-0.443000*	<0.001	
	SmartClip	Mini Ovation	-1.090000*	<0.001	
		In-Ovation R	0.180000	0.059	
		Mini Ovation	-0.467000*	<0.001	
		Mini Ovation	-0.647000*	<0.001	
	Speed	Mini Ovation	-0.580000*	<0.001	
		Speed	-1.959700*	<0.001	
		In-Ovation R	-1.451000*	<0.001	
		Mini Ovation	-2.458300*	<0.001	
0.017 × 0.025 SS	SmartClip	Speed	-1.379700*	<0.001	
		In-Ovation R	-0.871000*	<0.001	
		Mini Ovation	-1.878300*	<0.001	
		In-Ovation R	0.508700*	<0.001	
	Speed	Mini Ovation	-0.498600*	<0.001	
		Mini Ovation	-1.007300*	<0.001	
		Damon 3	SmartClip	-0.099000	0.205
		Speed	-1.363000*	<0.001	
	0.019 × 0.025 SS	In-Ovation R	Mini Ovation	-1.169000*	<0.001
			Mini Ovation	-2.630000*	<0.001
			Speed	-1.264000*	<0.001
			In-Ovation R	-1.070000*	<0.001
SmartClip		Mini Ovation	-2.531000*	<0.001	
		In-Ovation R	0.194000*	<0.001	
		Mini Ovation	-1.267000*	<0.001	
		Mini Ovation	-1.461000*	<0.001	
Speed		Mini Ovation	-1.461000*	<0.001	
		Damon 3	SmartClip	-0.096100	0.227
		Speed	-1.055000*	<0.001	
		In-Ovation R	-0.824000*	<0.001	
0.021 × 0.025 SS	SmartClip	Mini Ovation	-1.290100*	<0.001	
		Speed	-0.958900*	<0.001	
		In-Ovation R	-0.727900*	<0.001	
		Mini Ovation	-1.194000*	<0.001	
	Speed	In-Ovation R	0.231000*	<0.001	
		Mini Ovation	-0.235100*	<0.001	
		Mini Ovation	-0.466100*	<0.001	
		In-Ovation R	Mini Ovation		

DISCUSSION

In the present study, self-ligating (SL) brackets were divided into active clip type (In-Ovation R and Speed) and passive clip type (Damon 3 and SmartClip) whereas preadjusted twin bracket (Mini Ovation) with elastomeric module ligation served as control.

The results disclosed that in both passive and active groups, frictional resistance properties exposed discernible variations as the dimension of the wires changed. Passive SL brackets had significantly lesser frictional forces than active SL brackets,

whereas twin brackets with conventional ligation exhibited the maximum values for all the archwires tested (Table 2). This was in accordance with previous studies done by Thorstenson et al¹³ and Harradine.¹⁴

Damon 3 has a labial slide to capture the archwire in the slot and the SmartClip bracket consist of two NiTi clips which open and close, when the archwire exerts force on the clip during archwire placement. The passive clips does not apply any ligation force to the archwire and facilitates free movement of the archwire inside the bracket, these factors may account for

the reduced frictional forces revealed by passive SL brackets.^{7,15} In-Ovation R incorporates a Cobalt-Chromium active clip, which encroaches on the slot, and the Speed bracket has an active NiTi clip that flexes and rolls over the archwire. This positive contact of the active spring clips with the archwire is likely to produce higher friction than the passive appliance designs.⁸

There was an increase in the frictional force value with increase in wire dimension; in this study 0.018 inch round wire exhibited the least friction, and 0.021×0.025 inch rectangular stainless steel wires showed the maximum friction (Table 1).^{2,16,17} With 0.018 inch stainless steel wire, frictional resistance between the different self-ligating brackets were not significant ($p > 0.05$) whereas conventional bracket system exhibited significant difference. This can be attributed to the fact that with thin round wires both active and passive clips of SL brackets will be passive in nature and will not exert any force on the archwire. This finding was in consonance with Harradine.¹⁴

Conversely, in the passive self-ligating group, it was observed that the frictional resistance was more with 0.020 inch wire than 0.017×0.025 inch wire (Table 2). This was contrary to the popular belief that round wires generate less friction than rectangular wires because round wires make a point contact with bracket slot whereas rectangular wire make line contact.¹⁷ Nevertheless this does not seem to hold true for all situations.

In SL brackets, when the clip is engaged, it is in contact with the archwire and at nonbinding angulations, the contact area between the bracket slot and archwire is the important factor in friction. Whereas at greater angulation of the bracket archwire assembly, the determining factor is the point at which the wire contacts the edge of the bracket. So, with round wires the bracket slot can 'bite' into the wire at one point, causing an indentation in the wire.¹⁴ On the other hand, with rectangular wires the force is distributed over a larger area, that is on the entire faciolingual dimension of the wire resulting in decreased pressure and therefore lesser resistance to movement.¹⁸ Thus, whether the clip is active or passive, friction depends on the size of the archwire relative to the size of the slot and also on the position of the archwire within the bracket.¹⁹⁻²¹

Within the passive self-ligation group, Damon 3 brackets exhibited significant less frictional resistance than SmartClip. In Damon 3, the labial slide is made of stainless steel whereas SmartClip bracket consists of NiTi clips to retain the archwire in the slot.¹⁵ According to Kusy et al, the surface roughness of stainless steel is less than nickel titanium and this may be attributed to the decrease in frictional resistance with Damon 3 than SmartClip brackets.²³

Among the active self-ligating group, In-Ovation R showed less frictional resistance than Speed brackets. Similar finding was observed in the study conducted by Budd.¹² The active clip of In-Ovation R brackets is fabricated with cobalt chromium alloy whereas the active clip of Speed bracket is made up of nickel titanium. According to Kapila et al²² and Kusy et al,²³

the surface roughness of nickel titanium is more than that of cobalt chromium alloy. This could be the possible reason for increase in frictional resistance with Speed brackets than In-Ovation R brackets. Higher the surface roughness more the friction.

Judicial use of SL brackets would be prudent in certain cases. Low friction brackets (passive SL brackets) will be useful where de-crowding, leveling and aligning is a priority. Because excessive levels of friction at this stage could tax the anchorage. High friction brackets (active SL), on the other hand, are useful, wherein retraction torque and rotation control are of primary importance in finishing and detailing.

Limitations of this study would be an interpretation of this *in vitro* study to an *in vivo* situation. However, with any testing situation, it is impossible to reproduce the exact condition one might encounter in the oral environment like influence of saliva and other oral conditions such as malocclusion and masticatory action which can alter the mean resultant force between bracket and wire.^{2,24,25} The effect of frictional resistance between bracket and archwire are also influenced by the other stages of orthodontic treatment like rotation correction, leveling and aligning, tipping and torqueing, etc. Hence, extensive clinical trials over long period are needed to evaluate the *in vivo* effects of the frictional characteristics and relative torque expression of SL brackets.

CONCLUSION

Based on the statistical results derived from this study, the following conclusions were drawn:

- Between self-ligating and conventional bracket systems, self-ligating brackets offered less frictional resistance.
- Passive bracket systems exhibited less frictional resistance than active bracket systems. Damon 3 brackets produced less frictional resistance than SmartClip brackets in the passive group and In-Ovation R produced less frictional resistance than Speed brackets in active group.
- There was an increase in the frictional resistance as the wire dimensions increased 0.018 inch round stainless steel wire showed the least friction while 0.021×0.025 inch rectangular stainless steel wires showed the maximum frictional resistance.
- Conventional twin brackets with elastomeric ligatures which are still popular generate more friction than self-ligating brackets.

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