In vitro assessment of competency for different lingual brackets in sliding mechanics

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ABSTRACT

Aim: To determine the static frictional resistance of different lingual brackets at different second order angulations when coupled with stainless steel (SS) archwire in dry and wet conditions.

Materials and Methods: Using a modified jig, frictional resistance was evaluated under different conditions for a total of 270 upper premolar lingual brackets (0.018″ × 0.025″ - conventional - 7th generation and STb, self-ligating – evolution) with no in-built tip or torque together with 0.016″ × 0.022″ straight length SS archwires. For conventional brackets, the archwire was secured with 0.008″ preformed SS short ligature ties.

Statistical Analysis: One way analysis of variance with Tukey HSD as *post-hoc* test was applied for degree wise and bracket wise comparison within dry condition and wet condition. For pair wise comparison Student's *t*-test was used.

Results: Under both conditions the static frictional resistance is significantly higher for self-ligating brackets at 0°, while at 5° and 10° it is higher for 7th generation brackets. Statistically, significant difference does not exist at 0° between conventional brackets and the same was found at 5° and 10° between STb and self-ligating brackets. With an increase in second order angulations, all the evaluated samples exhibited an increased frictional value. Wet condition samples obtained a higher value than their corresponding dry condition.

Conclusion: The self-ligating bracket evaluated in this *in vitro* study is not beneficial in reducing friction during en-mass retraction due to its interactive clip type.

Key words: Friction, lingual brackets, sliding mechanics

INTRODUCTION

In orthodontics, achieving an efficient extraction space closure using frictional mechanics depends to a large extent on the ability of orthodontic archwire to slide through brackets and tubes. Friction and binding reduce the efficiency of fixed appliance whether labial or lingual. Friction between archwire and bracket is multi-factorial such as archwire size/shape/material, angulation of bracket to wire, ligation force, bracket width/material/design, lubrication, surface roughness. Among the above said factors, a modification in the bracket design might reduce the friction and an endeavor to reduce the friction by modifying the bracket design resulted in the development of labial self-ligating brackets. The use of labial self-ligation brackets in lingual orthodontics was introduced by Newman and Holtgrave[1] in 1999, which was followed with the introduction of various lingual self-ligating brackets.

Friction in the perspective of ligation force and second order bracket angulations were extensively studied for labial brackets[2-15] but very few studies have been published on frictional behavior of lingual brackets[16,17] hence the aim and objectives of the present study are to evaluate and compare the frictional resistance of different lingual brackets at different second order angulations when coupled with stainless steel (SS) archwire in dry and wet conditions.

MATERIALS AND METHODS

A total of 270 upper premolar lingual brackets with zero degree tip/torque and a slot size of 0.018″ × 0.025″ were

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used for this study.The types of brackets included in the study were one self-ligating and two conventional brackets namely Evolution (Adenta, GmbH, Germany), STb and 7th generation (Ormco corporation, CA, USA), respectively. Friction test was carried out by sliding 270 rectangular 0.016″ ×0.022″ straight length SS archwires (American orthodontics, USA) through the brackets. For conventional brackets the wire was secured using 180 preformed short SS ligature ties of 0.008″ diameter (DB orthodontics, United Kingdom).The brackets were divided into three groups, and each group was subdivided into six subgroups [Figure 1].

A modified version[10,18] of custom made jig was used in this study. It consists of three parts, plastic slide [Figure 2], center piece [Figure 3], and container [Figure 4]. On a custom made plastic slide, one horizontal reference line of 1.5 cm away from one end was drawn and three vertical reference lines of 0°, 5° and 10° were transferred from a graph template [Figure 2]. Color coded (Clear-G1-7th generation, Green-G2-STb, Red-G3-evolution) cylinder shaped acrylic buttons were made with a height of 1 cm. It was fixed at the intersection point of horizontal and vertical lines. Two hundred and seventy nine such plastic slides were prepared out of which on nine plastic slides, three holes were made, corresponding to 0°, 5° and 10°angulations. Brackets were bonded on these nine plastic slides using a guide wire with 90° bend at one end (0.017″ × 0.025″ SS of 5 cm in length excluding the bent portion). The bent portion was inserted into the corresponding hole, and the bracket was seated passively onto the center of the flat surface of the acrylic button and bonded [Figure 5]. This prevented any inadvertent torque buildup during bonding of the brackets. These nine plastic slides were considered as master templates. After removing the guide wire, from each master template, two negative replicas of the bonded brackets were made using putty material loaded (AquasilTM, Soft Putty/Regular set, Dentsply, Detrey) acrylic transfer tray resulting in 18 such acrylic transfer trays. Only fifteen brackets were transferred using each transfer tray and bonded to the respective slides (18 transfer trays × 15 brackets = 270 brackets).

All the samples were visually inspected for the parallelism between plastic slide, bracket base and slot base. The plastic slide was reshaped to fit into the center piece [Figure 6].

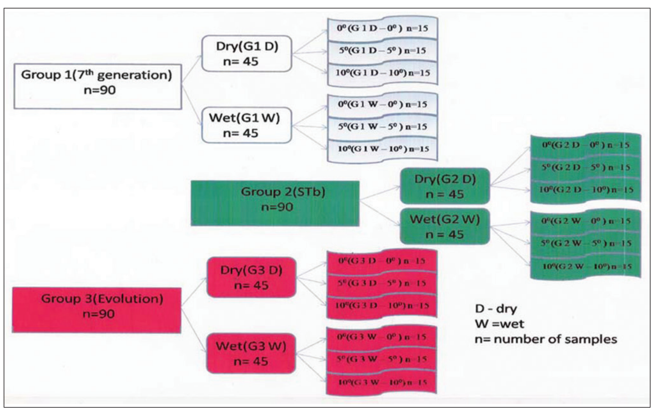

Figure 1: Grouping of samples

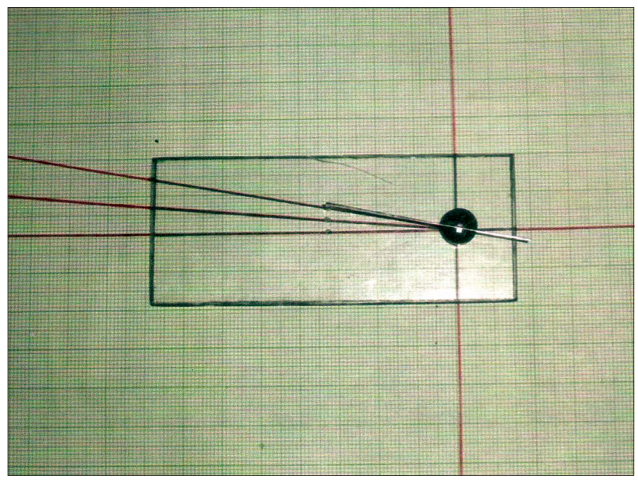

Figure 2: Plastic slide

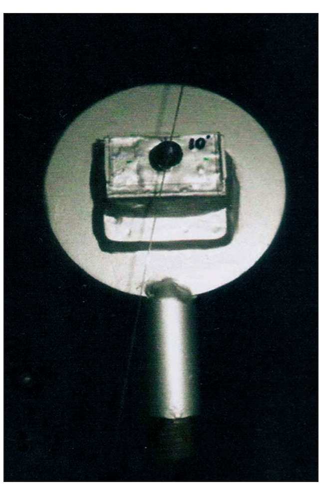

Figure 3: Center piece

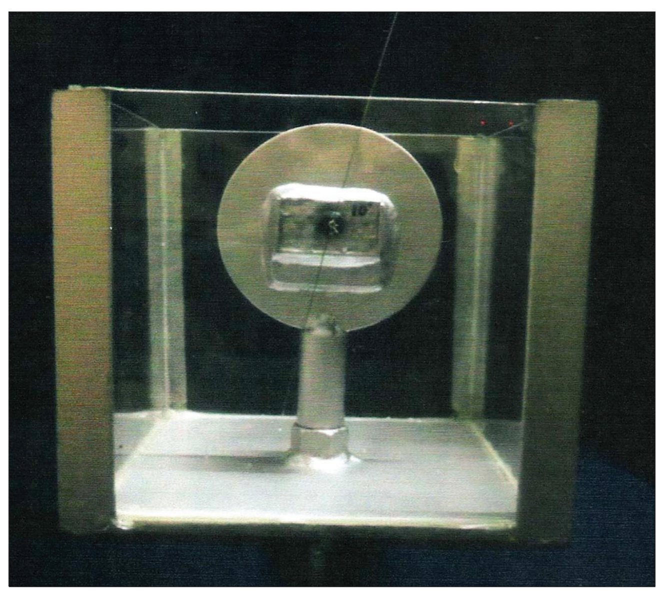

Figure 4: Container

The center piece with guide groves to receive the plastic slide was screwed on to a nut welded at the center of the four-walled transparent container. For conventional brackets, the archwire was secured[19,20] with the use of preformed SS short ligature ties of 0.008″ in diameter.[21] For self-ligating brackets, the instrument supplied by the manufacturer was used to open and close the spring clip to secure the archwire.

Most of the experimental studies on orthodontic friction have used a model where archwires were pulled through slots of brackets bonded to simulated teeth mounted on to a fixed medium[11,22-28] the same was adopted in this study. The experiment was carried out using Instron universal testing machine with 20 Newton load cell capacity [Figure 7]. The archwire size and material has been standardized as 0.016″ × 0.022″ SS because it was widely used for space closure during sliding mechanics.[21] The archwires were cut into segments[17] of 25 cm each; two "U" shaped hooks (3.5 cm) were bent at the cut ends of the archwires. One was meant for hanging 200 g of counter weight[17] and the other was hooked to an acrylic block interface that was clamped to the movable upper crosshead arm. This pivoting joint like connection prevents any undue twist in the archwire during traction. The remaining archwire (18 cm) was divided into three equal portions, and the middle portion was made to slide through the bracket. The cross head speed of the upper arm was set to move upward at a rate of 1 mm/min. For each sample, the experiment was allowed to run for a total of 2 min. The testing machine was calibrated and set to zero before each test was conducted. The experiment was conducted both under dry and wet state (Fusayama artificial saliva[16]). To prevent inter operator dependent errors; all the experimental procedures were carried out by a single operator.

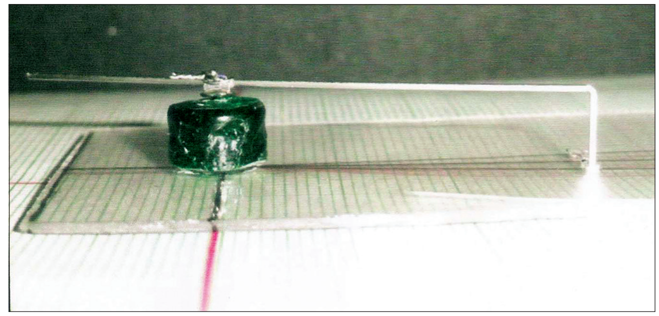

Figure 5: Bracket positioned using guide wire (lateral view)

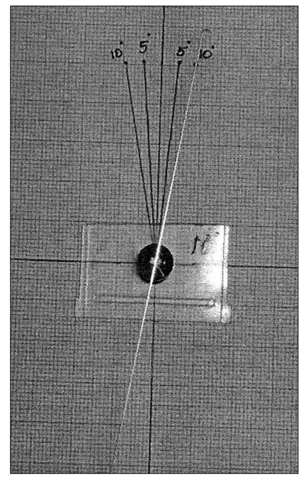

Figure 6: Reshaped plastic slide

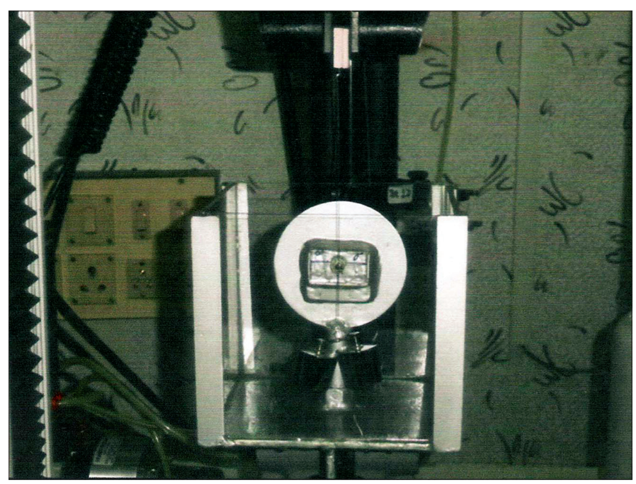

Figure 7: Experiment conducted using Instron universal testing machine

RESULTS

All analyses were performed using SPSS (SPSS Inc., Chicago, IL, USA).The descriptive statistical values obtained from dry and wet conditions were represented as mean and standard deviation. One way analysis of variance with Tukey HSD as *post-hoc* test was applied for degree wise and bracket wise comparison within dry condition [Table 1] and wet condition [Table 2]. The statistical significance was established only if $P < 0.05$. The mean values of the wet condition for any given archwire/bracket angulations was compared with its corresponding dry condition using Student's *t*-test and the results were considered as significant at $P < 0.005$ [Table 3].

After analyzing the data for degree wise comparison, irrespective of the design, all the evaluated groups resulted in an increased frictional value under dry and wet conditions with an increase in bracket/archwire angulations.

For bracket wise comparison under both dry and wet conditions, at 0°, group 1 and group 2 exhibited less frictional characteristics when compared with group 3, whereas the difference between group 1 and group 2 is not significant. At 5° and 10°, group 2 and group 3 showed less frictional characteristics when compared to group 1, but the difference between group 2 and group 3 is not significant. In all pair wise comparisons between dry and wet condition, the evaluated groups in wet condition demonstrated increased frictional characteristics than in dry condition.

Table 1: Degree wise and bracket wise comparison under dry condition

Degree wise comparison				Tukey HSD-*post-hoc*						Bracket wise comparison	Tukey HSD-*post-hoc*						
Groups	**Mean**	**SD**	**ANOVA (*P*)**	**G1D-5°**	**G1D-10°**	**G2D-5°**	**G2D-10°**	**G3D-5°**	**G3D-10°**	**Groups**	**ANOVA (*P*)**	**G2D-0°**	**G3D-0°**	**G2D-5°**	**G3D-5°**	**G2D-10°**	**G3D-10°**
G1D-0°	0.622	0.0184	**	*	**					G1D-0°	**	NS	**				
G1D-5°	3.507	0.0251			**					G2D-0°			**				
G1D-10°	5.600	0.0398								G3D-0°							
G2D-0°	0.602	0.0123	**			**	**			G1D-5°	***			*	*		
G2D-5°	2.391	0.0341					**			G2D-5°					NS		
G2D-10°	4.306	0.0129								G3D-5°							
G3D-0°	1.401	0.0118	**					*	**	G1D-10°	***					**	*
G3D-5°	2.404	0.0276							*	G2D-10°							NS
G3D-10°	4.504	0.0255								G3D-10°							

n=15 in each group. G1 – Group 1 (7th generation); G2 – Group 2 (STb); G3 – Group 3 (evolution); D – Dry; NS – Not significant; SD – Standard deviation; HSD – High standard deviation; ANOVA – Analysis of variance. **P*<0.05, ***P*<0.01, ****P*<0.001

Table 2: Degree wise and bracket wise comparison under wet condition

Degree wise comparison				Tukey *post-hoc*						Bracket wise comparison	Tukey *post-hoc*						
Groups	**Mean**	**SD**	**ANOVA (*P*)**	**G1W-5°**	**G1W-10°**	**G2W-5°**	**G2W-10°**	**G3W-5°**	**G3W-10°**	**Groups**	**ANOVA (*P*)**	**G2W-0°**	**G3W-0°**	**G2W-5°**	**G3W-5°**	**G2W-10°**	**G3W-10°**
G1W-0°	1.710	0.0260	**	*	**					G1W-0°	**	NS	**				
G1W-5°	4.590	0.0273			**					G2W-0°			**				
G1W-10°	6.690	0.0287								G3W-0°							
G2W-0°	1.690	0.0261	**			**	**			G1W-5°	***			*	*		
G2W-5°	3.480	0.0186					*			G2W-5°					NS		
G2W-10°	5.390	0.0127								G3W-5°							
G3W-0°	2.490	0.0131	**					**	**	G1W-10°	**					**	*
G3W-5°	3.491	0.0162							*	G2W-10°							NS
G3W-10°	5.590	0.0156								G3W-10°							

n=15 in each group. G1 – Group 1 (7th generation); G2 – Group 2 (STb); G3 – Group 3 (evolution); W – Wet; NS – Not significant; SD – Standard deviation; ANOVA – Analysis of variance. **P*<0.05, ***P*<0.01, ****P*<0.001

Table 3: Student's *t*-test for pair-wise comparison between dry and wet condition

Groups	G1D-0°	G1W-0°	G1D-5°	G1W-5°	G1D-10°	G1W-10°	G2D-0°	G2W-0°	G2D-5°	G2W-5°	G2D-10°	G2W-10°	G3D-0°	G3W-0°	G3D-5°	G3W-5°	G3D-10°	G3W-10°
T	132.01		112.86		85.94		145.63		108.40		231.08		238.36		131.24		140.28	
P	***		***		***		***		***		***		***		***		***	

n=15 in each group. G1 – Group 1 (7th generation); G2 – Group 2 (STb); G3 – Group 3 (evolution); D – Dry; W – Wet; NS – Not significant; T – Table value; ANOVA – Analysis of variance. ****P*<0.005

DISCUSSION

Friction is the force that resists against the movement of one surface in relation to another and that acts on the opposite direction of the desired movement.[29] Since we are dealing with a quasi-static thermodynamic process[30] in sliding mechanics, static friction is more important than kinetic friction during space closure[10,23,29,31,32] and hence in the present study only static friction was taken into consideration. Since the method of ligation[33] and bracket design[23,29,34] does have an effect on friction, in lingual orthodontics, to achieve an efficient treatment result equivalent to that of labial orthodontics the frictional characteristics of lingual brackets should also be studied. In labial orthodontics premolar extraction space closure can be carried out either by canine retraction or by enmass retraction whereas in lingual orthodontics enmass retraction is preferred because within the available short inter bracket span between canine and premolar the presence of archwire inset bend distal to canine would further interfere with space closure.[35] Even though, conflicting results have been reported[2,14,25,32,34,41] for labial orthodontics under wet condition (artificial saliva), studying the same in lingual orthodontics is essential as the lingual brackets are bathed in saliva than labial.[33]

An interactive type of self-ligating lingual brackets used in this study acts as a passive self-ligating bracket for wire dimension up to 0.016″ inch. When the dimension exceeds, it transforms into an active self-ligating and exerts about 650 g of archwire seating force.[36] The ligation force for conventional lingual brackets could be around 300–350 g.[19]

At passive configuration (θ =0°) the classic friction is directly proportional to applied normal force (ligation force) which was about twice more in the self-ligating bracket used in this study. This excess applied normal force from the spring clip would have contributed an increase in the frictional value at passive configuration under both conditions. This might help in preventing torque loss in anteriors during enmass retraction where as this is not necessary for a premolar bracket through which the wire slides along during enmass retraction.

The above results are in accordance with the previous studies done on labial brackets by Redlich[10] *et al*., Thorstenson and Kusy,[3,4,6] Khambay[37] *et al*., Pizzoni[38] *et al*. However our findings are not in agreement with the general statement that self-ligating brackets generate lower frictional resistance than conventional brackets.[6,19,34,37-39] However, the differences in frictional value between the conventional brackets were not statistically significant under both conditions. This result is in accordance with Ozturk Ortan[17] *et al*. but in contrary to our study, their self-ligating lingual brackets exhibited lower frictional resistance. The variation in bracket design and archwire seating force might contribute the variance in results.

At active configuration (5° and 10°), under both conditions conventional bracket (7th Generation) obtained the highest frictional values however there was no significant difference among conventional (STb) and self-ligating brackets.

The increase in frictional behavior of different lingual brackets in active configuration could be explained with the help of a mathematical formula proposed by Kusy and Whitley[40] for the determination of critical contact angle for any given archwire/bracket couple. According to them, in active configuration, bracket width is inversely proportional to critical contact angle (θ_c) that is wider the bracket, the lesser the θ_c and higher the frictional value. Our results are in agreement with the above concept since the wider (three millimeter) 7th generation bracket obtained higher frictional values than other two brackets (STb-1.5 mm, Evolution-2 mm) at active configuration under both conditions. Similar results were reported by Pacheco[29] *et al*., Frank and Nikolai[23], and Kapila[34] *et al*., who observed increased frictional resistance for wider brackets than narrow brackets.

At both passive and active configuration, for all archwire/bracket couples when angulations increased so does the friction and our results were in accordance with the previous studies done with labial brackets[3,6-9,15,23,41] and lingual brackets.[17] Even though all the evaluated archwire/bracket couples at all angulations under wet condition exhibited the same ranking and order of frictional values similar to dry condition, they showed higher values when compared with their corresponding dry condition.

Our results support the findings of Pratten[24] *et al*., Stannard[42] *et al*., Kapila[34] *et al*. and Downing[43] *et al*. While using whole human saliva, Kusy and Whitley[13] also experienced higher values for SS archwire/bracket couples in the wet condition. According to Pratten[24] *et al*. at high loads, saliva may be expelled out from bracket/archwire contacts resulting in frictional increase. However Tselepis[11] *et al*. did not agree with this statement. To overcome this difference of opinion, Kusy[27] *et al*., Thorstenson and Kusy,[3,6] Whitley and Kusy[8] suggested peristaltic pump to apply saliva to the samples and Park[16] *et al*., Prososki[44] *et al*., Guuerrero[2] *et al*. advised to immerse the samples in a bath of saliva. We adopted the later method to test the samples under wet condition. Another reason behind the conflicting findings may be related to the difference in the formulation of artificial saliva among the studies.

We used modified Fusayama saliva[16] which contains Mucin, the chief surface active protein of natural saliva. Mucin has a high molecular weight, minimum surface tension (~30 mN/m)[45] similar to natural saliva (~24.85 mN/m) and the viscoelasticity of artificial saliva is primarily due to the Mucin content.[46] The Mucin present in the artificial saliva of our study have acted as an adhesive for the SS couple rather than as a lubricant resulting in an increase in frictional value.

In overall, self ligating lingual brackets were designed for the convenience of the practitioners, and patients in the terms of ease of ligation, less chair side time, less irritation to the oral tissues, improved oral hygiene maintenance, with the additional benefit of reduced friction generated from archwire and bracket combination. However at a given wire dimension of 0.016″ ×0.022″ self-ligating lingual bracket (Evolution) used in this study had no extra added advantage in the terms of friction.

Since the present study was designed to evaluate the static frictional resistance of lingual brackets during enmass retraction, we did not consider the lower dimension archwires. According to the manufacturer, the spring clip design of the self ligating bracket (Evolution) will be passive up to 0.016 inch archwire which might help in reducing the friction during initial leveling and aligning. Recently, Luca Lombardo[47] *et al*. compared the frictional efficiency of various labial and lingual brackets during initial leveling and aligning. In their study STb brackets exhibited least frictional value whereas In-ovation L brackets produced highest frictional values. However, frictional behavior of Evolution brackets for the reduced dimension wires has yet to be studied.

CONCLUSIONS

Under the present experimental setup, for a given SS wire dimension of 0.016″ ×0.022″, under wet and dry state:

- The self-ligating brackets (Evolution) exhibited an increased static friction at 0°
- Conventional bracket (7th generation) exhibited an increased static friction at 5° and 10°

- Irrespective of design, friction increased with an increase in second order angulations.

When compared with its corresponding samples under dry condition, wet condition samples exhibited increased static frictional value.

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