Statistical Analysis of Sliding Resistance of Braided Glass Fiber Reinforced Composite Orthodontic Brackets and Archwires

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Abstract

A biomechanical and tribological study for lubrication and composite materials is investigated statistically. The study is designed to simulate clinical sliding mechanics, which is conducted as part of an effort to determine the biocompatibility and suitability of aesthetic composite brackets and archwires (combination) using SPSS. The sliding force involved in a ligated combination is measured by custom made self-designed jig. Initial examination of the data was to determine the mean, standard deviation and 95% confidence intervals. One-way ANOVA analysis was used to identify any significant differences among groups. With data sampling functioning continuously at two samples per second, each trial yielded 288 measures of the sliding force for a combination. The mean of these values were calculated to produce a discrete estimation of the sliding resistance of the couple for each trial. In general, the aesthetic braided composite combination demonstrated the lowest mean friction in comparison to other combination and statistically significant ($p < 0.05$). The main contribution is that the presence of saliva had a consistent effect to increase the sliding resistance, which is counter to the inconsistent effect reported in the literatures. Consequently, the soft matrix is regarded as an incompatibility to the clinical acceptability of composite combination.

Keywords: Biomechanics; Aesthetic; Tribology; Soft Matrix; Braided Composite; Bracket and Archwires; Statistics.

1. Introduction

Friction, retards or resists the relative motion, is a force between two objects which are in contact (Kumar et al. 2014). The direction of friction of the two surfaces which are in contact is tangential to the common boundary (Nanda 1997). Friction encountered during tooth movement can be considered to occur in two distinct phases. Static friction - the resistance that prevents initial tooth movement. Kinetic/Dynamic friction - acts during period of motion only that replaces the static friction or resists movement already initiated (Hain et al. 2003). Most deem static friction as most important in orthodontics, more likely that movement occurs in short tipping and uprighting movements, because tooth movement is not believed to be fluid (Read-Ward et al. 1997).

Friction influences a significant role in the sliding mechanics of orthodontic (Reddick 2007). Hence, about 50% of the force applied by using certain types of mechanics is used purely to overcome the friction of the system (Proffit and Fields 1993). Stainless steel ligatures can be loosely or strongly tied by the operator which may demonstrate lower or higher level of classical friction. Although the total friction of the system is dependent on a number of factors, friction from ligation (classical friction) is an important component. Elastomeric ligation is very fast, but disadvantages include permanent deformation, decomposition, and force decay (Voudouris 1997). However, classical friction may not be the primary contributor of this resistance to sliding reported by Kusy and Whitley (1997).

The critical factor in determining the efficiency of biological tooth movement during fixed appliance therapy, friction generated at the bracket/wire and wire/ligature interfaces are paramount (Vito et al. 2013; Frank and Nikolai 1980). Hence, friction may be demonstrated by tangential movement of an object pushed against another one which triggered the resistance to motion (Cacciafesta et al. 2003). The different factors may influence the frictional characterisitics by such as the environmental conditions (i.e., temperature, lubricants, etc.) and the surface topography (Rossouw 2003).

Sliding mechanics in orthodontic tooth movement may engage the following for a relative displacement of wire through bracket slots causing raised frictional resistance whenever sliding occurs. It is postulated that during the elementary stage of treatment lower frictional force may be required when all the teeth move at the same time/phase and the wire slides through less number of brackets and tubes. For this purpose, there are several proposed different methodology to limit frictional forces at the bracket/wire and wire/ligature interfaces. As such several studies already are: (i) loosely tied SS ligatures (Hain et al. 2003), (ii) nonconventional ligature systems (Thorstenson and Kusy 2003; Franchi et al. 2008), (iii) self-ligating brackets (Kim et al. 2008), and (iv) low-friction brackets (Redlich et al. 2003).

The nature of friction in orthodontics is derived from both mechanical and biological factors which is multifactorial. Variables affecting resistance in orthodontics sliding mechanics include the followings. Among those physical/ mechanical factors are such as: i) Archwire properties: material, cross sectional shape/size, surface texture and stiffness, ii) Bracket to archwire ligation: ligatures, wires, elastomerics and method of ligation, iii) Bracket properties: material, surface treatment, manufacturing process, slot width and depth, bracket design, bracket prescription, interbracket distance, level of bracket slots between teeth and forces applied for retraction (Kumar et al. 2014).

Recently, new low-friction systems brackets, with differentiated performances according to their manufacturers, were introduced in trading (Simona et al. 2011). When the bracket and archwire are in active situation then binding parameter becomes important. It is reported by Tidy (1989) as the stiffness of the wire and the angle of entry into the bracket slot increase hence binding becomes increasingly important. However, a passive system that eliminates binding as a factor already demonstrated frictional studies, while in other investigations binding becomes more of a factor due to increase the angles of entry of the wire (Reddick 2007). The notion that friction decreases with the use of self-ligating brackets versus conventional edgewise brackets is supported by the overwhelming majority of frictional studies (Tidy 1989; Read-Ward et al. 1997; Thorstenson and Kusy 2001; Thorstenson and Kusy 2003)

There is a presumption that frictional differences depend on the bracket designs, methods of testing, statistical analysis and the binding (SS or elastomer) introduced into the system. However, the effects from ligation method are not significant due to the increase in the binding variable at large angles of entry (Pizzoni et al. 1998; Sims et al. 1994; Thorstenson and Kusy 2002). Friction plays a role in routine treatment, but it varies on the type of sliding mechanics used. Sliding mechanics involves sliding brackets along the archwire and friction plays an important role in this type of space closure (Andreasen and Quevedo 1970). The initial stages of leveling and aligning still rely heavily on the ability of the wire to slide freely through the bracket slots although friction independent mechanics may be employed for space closure. So friction an important aspect of every edgewise appliance, at least in the early phases of treatment. The results from previous studies did not show a significant difference in alignment between the types of brackets. Although teeth ligated with elastomeric rings exhibited slightly greater numbers of microorganisms than teeth ligated with SS ligature wires, the differences were not statistically significant. The two ligation techniques showed no significant differences in index, bonded bracket index, or pocket depths of the bonded teeth (Reddick 2007).

It is also reported that the population size of practicing Orthodontists is approximately 7,700 in the US per to the Bureau of Labor Statistics (2011). A total of 600 participants were targeted as the sample size from this population to achieve a power of 0.80, $p = 0.05$, $d = 0.20$, (Cohen 1998). While this is not as great a jump from 2002 to 2008, there is still an overall increase in their usage (Beuhler 2011). Apart from positive or negative experience with the bracket, many different options could be given as to why a bracket is or is not satisfactory. A question is what motivating factors were behind the choice of brackets as well as the use and satisfaction of specific brackets by manufacturer.

There are more or less significant differences among the various brackets and archwires in terms of force generated, when these brackets are coupled with the different types of archwires. The purpose of this study is to quantitatively determine the frictional resistance to sliding with statistically significant ($p < 0.05$), which occurs during the transition between initial leveling and aligning phase of orthodontic treatment, utilizing the aesthetic braided composite bracket and archwire combinations. This study compares the frictional characteristics of the aesthetic braided composite bracket and archwires combination tied with elastomeric and SS ligatures. This study will be the first of its kind to independently evaluate the frictional characteristics of aesthetic braided composite bracket and archwires combination and compare it with other esthetic archwires within different esthetic bracket systems available to currently in practice.

2. Experimental Procedure and Statistical Methods

2.1 Mechanical testing

In this investigation, we included developed and conventional brackets (trades), according to the classification made in this study. The brackets tested were:

- (i) Braided Composite (PMC) without metal slot insert; NUS, Singapore - 119260
- (ii) Composite (PMC) with metal slot insert (Spirit MB; Ormco Corp., Orange, CA, USA)
- (iii) Stainless steel (Victory; 3M Unitek, South Peck Road Monrovia, CA, USA)
- (iv) Metal reinforced ceramic - metal slot insert (Clarity; 3M Unitek, South Peck Road Monrovia, CA, USA)
- (v) Composite (PMC) with metal slot insert (Elan; GAC, Knickerbocker Ave Bohemia, NY, USA)
- (vi) Polycrystalline ceramic (Transcend, PCA; 3M Unitek, South Peck Road Monrovia, CA, USA)
- (vii) Monocrystalline ceramic (Inspire, SCA; Ormco Corp., Orange, CA, USA)

For each group, a single model was used six (three in case of NUS-developed) times to test the same bracket-archwire combination with all the brackets ligated. The archwires tested were:

- i. SRE-OR; stainless steel (SS) rectangular (0.019″ × 0.025″) - Ormco Corp., Orange, CA, USA
- ii. SSQ-OR; SS square (0.018″ × 0.018″) - Ormco Corp., Orange, CA, USA
- iii. CRO-OR; SS round (0.018″ - diameter) - Ormco Corp., Orange, CA, USA
- iv. CRO-AW; SS round (0.018″ - diameter) - Australian Wilcock, New Delhi - 110020, India
- v. CRO-NUS; GFRC aesthetic round archwires (0.018″ - diameter) - NUS, Singapore - 119260

The testing model and the number of procedures was evaluated using a test for the calculation of sample numerosity on the basis of α value (confidence level) fixed at 0.05, considering the minimum detectable difference and the number of groups. Alignment of the brackets without ligation was obtained through preliminary insertion of a 0.019″ × 0.025″ SS archwire into the slots of the brackets. The comparison among models is useful because if the comparison was among different types of brackets coupled with the same or different archwire.

The wires were pulled through the bracket slots in a mechanical testing machine (Instron 4302; Canton, MA, USA) at a cross-head speed of 0.5 mm/min until a displacement of 2 mm. The friction was measured under dry/wet conditions and at room temperature (20°C±2°C). The values of maximum force (N) produced were recorded by the software and then statistically analyzed. The load cell registered the force levels needed to move the wire along the aligned brackets, and these levels were transmitted to a computer.

2.2 Statistical Design and Methods

The study was designed to examine the relationship between types of bracket and arch wire. Initial examination of the data was to determine the mean, std. dev. and 95% confidence intervals. The results were entered onto the SPSS program. One-way ANOVA analysis ($p = 0.05$) was used to identify any significant differences among groups.

2.3 Analysis of Data

Estimation of frictional resistance for each bracket/wire couple for all trials was determined from an average of the kinetic frictional force encountered during displacement of the wire relative to the bracket. This occurred after 0.3 mm once departed from static frictional force (Kamelchuk 1998). Subsequently, displacement the wire relative to the bracket was another 1.7 mm. With data sampling functioning continuously at 2 samples per second, each trial yielded 1644 measures of the frictional force. A complete factorial plan was drawn up, assessing three factors: (i) degree of the malalignment, (ii) diameter of the wire, (iii) design of the slot, and (iv) bracket/ligature combination. A p of ≤ 0.05 was considered significant**.**

Research Question 1: What were the characteristics and practices composite brackets and wires in the practice of orthodontic treatment? *Descriptive Statistics was reported on select demographic variables collected in the study.*

Research Question 2: Of the factors identified in the literature, which factors were reported by treatment as being “very influential” or “extremely influential” in their decision to use composite brackets and wires versus conventional brackets and archwires? *Descriptive Statistics were reported on various factors selected in these two groups.*

Research Question 3: Which of the brackets and wires systems on the market did treatment report greatest satisfaction in use? *Descriptive Statistics were reported on the positive and negative experiences in the bracket and wires systems.*

Research Question 4: Was there a difference between overall satisfaction and efficiency of brackets and archwires systems? **(**Beuhler, 2011**)**

2.4 Establishment of a model for frictional resistance evaluation with sliding mechanics using quantified simulation

(i) Comparison of friction using static retraction models

A one-way analysis of variance (ANOVA) was performed with different frictional resistances during sliding mechanics. The level of statistical significance was set at $p < 0.05$ for the one-way ANOVA.

(ii) Comparison of the friction effect of saliva with on archwires of using an in vitro model

One-way ANOVA was performed to determine if saliva affected the frictional resistance of bracket/archwire for retraction model. The level of statistical significance was set at $p < 0.05$ for the one-way ANOVA.

(iii) Frictional resistance evaluation of various brackets and archwires with sliding mechanics using quantified simulation

Multiple analyses of variance (ANOVA) with general linear models procedure was performed to determine if orthodontic bracket type, orthodontic archwire type, orthodontic archwire shape, including pair-wise interactions of these factors were associated with different frictional resistances during sliding mechanics using an *in vitro* model. The level of statistical significance was set at $p < 0.05$ for the one-way multiple MANOVA (Sadique, 2004).

3. Results and Discussion

Seven brackets and five different wires were tested. At each arch wire/bracket/condition/degree combination, 6 measurements were taken for 264 bracket/archwire combinations and 3 measurements were taken for 20 bracket/archwire combinations, resulting 1644 measurements in total. Analyses of the mean frictional resistances are presented in Table I. The results were plotted on the basis of max load. Comparison of the brackets was made with four different archwires at 0°, 5° and 10° angulation under dry and wet conditions (Figure 1). The mean frictional force for the bracket/wire combinations varied from a low of 0.41 Newton to a high of 4.07 Newton. Descriptives statistics from one way ANOVA analysis under various angulations for SS rectangular for the level of friction for various brackets and archwires, dry/wet conditions and angulations are summarized in Table II.

Multiple analyses of variance (ANOVA) with general linear models procedure illustrated the effects of the wire type, environment, ligature material and angulation on the friction outcome. First, the all cases were found to have a significant effect on the level of friction ($p < > 0.05$). These pair-wise interactions indicated that the frictional characteristics differed either in direction or magnitude of effect for one of the factors depending on the specific combination. The means of the frictional force for various bracket materials, archwire alloys, arch wire sizes, archwire geometries were compared to determine whether they differed significantly with a P value < 0.05. It was apparent from Tables II and III that standard deviations and distributions of all bracket-arch wire combinations were not similar.

First of all, bracket/archwire interactions revealed the following observations for performance of brackets with specific archwires. It was noted that overall frictional performances of ceramic brackets with and without metal slots were different. The ceramic brackets with a metal slot insert had a significantly lower level of mean friction ($P \geq 0.05$; 1.55 N to 2.74 N for SRO-AW) but a significantly lower level of friction when coupled with SRO-OR archwires ($p < 0.05$). Typically, SS brackets had less frictional resistance than ceramic brackets with and without metal slots ($p < 0.05$ except SRO-AW). With all wire sizes, Elan composite brackets had comparatively more mean friction (Range: 1.19 N to 2.20 N for SRO-OR) than composite (Spirit MB) under dry and wet states for elastomeric ligatures.

The three angulations exhibited different friction characteristics and they are graphically shown in Figure 1. It is evident that 5-degree angulation displayed higher levels of friction than 0^0 and similar nature of sliding behavior noticed for all bracket types. Higher levels of friction were observed with elastomeric ligatures in the 10-degree angulation with the highest level of mean friction measured at 4.07 N ($p < 0.05$ except 0 degree angulation). In general when tied with elastomeric ligatures, during angulation, rectangular/square SS wires had more friction than round SS wires. The two ceramic graphs behaved differently. Typically, the ceramic bracket without metal slot (Transcend) (in the range of 1.59 N to 4.07 for SRO-AW) produced the highest level of friction and the Inspire in the range of mean friction 1.67 N to 3.08 N SRO-AW showed the lower friction at 10 degree but behavior was reversed at 0° and 5°.

Only static friction, the force that must be overcome so that dental movement can be initiated in treatment, was evaluated as it. For the maintenance of movement kinetic force is only required hence static friction is greater than the kinetic one. The large std. dev. observed in statistical descriptions was also found in previous studies that evaluated different combinations of brackets/wires (Kim et al. 2008) and it can be explained by the mean max forces that refer to different brackets, wires and angles together with the heterogeneity inherent to each one (Maria et al. 2014).

Table 4.1: Mean frictional force (Newtons) and % standard deviation (SD) for bracket/archwire combinations under elastomeric ligatures (based on 6 observations per entry)

Bracket	*Archwire*	*Bracket/archwire angulation*											
		Dry condition						*Wet condition*					
		0^0		*5^0*		*10^0*		*0^0*		*5^0*		*10^0*	
		Mean	*(SD)*	*Mean*	*(SD)*	*Mean*	*(SD)*	*Mean*	*(SD)*	*Mean*	*(SD)*	*Mean*	*(SD)*
Victory	SRE	1.23	0.21	1.75	0.19	2.68	0.37	1.55	0.16	1.90	0.22	3.09	0.60
	SSQ	1.21	0.16	1.67	0.26	2.58	0.14	1.48	0.13	1.82	0.28	2.98	0.50
	SRO-AW	1.44	0.18	2.18	0.11	2.58	0.27	1.62	0.18	2.30	0.18	2.98	0.63
	SRO-OR	1.15	0.22	1.55	0.18	2.20	0.37	1.35	0.13	1.74	0.19	2.80	0.34
Clarity	SRE	1.36	0.15	1.95	0.18	2.61	0.24	1.60	0.15	2.08	0.29	3.00	0.44
	SSQ	1.32	0.11	1.78	0.24	2.55	0.26	1.47	0.10	1.83	0.14	2.84	0.42
	SRO-AW	1.55	0.14	1.63	0.20	2.43	0.27	1.69	0.15	1.97	0.33	2.74	0.45
	SRO-OR	1.33	0.18	1.52	0.22	2.37	0.23	1.38	0.21	1.78	0.14	2.56	0.49
Inspire	SRE	1.67	0.12	2.57	0.39	2.86	0.35	1.80	0.18	2.78	0.37	3.10	0.50
	SSQ	1.62	0.07	2.28	0.27	2.85	0.20	1.71	0.15	2.41	0.22	2.93	0.23
	SRO-AW	1.67	0.19	1.95	0.13	2.62	0.42	1.82	0.28	2.25	0.37	3.08	0.39
	SRO-OR	1.53	0.16	1.67	0.14	2.61	0.25	1.53	0.20	2.05	0.34	2.87	0.21
Trans-cend	SRE	1.56	0.10	2.67	0.36	3.40	0.60	1.74	0.12	2.72	0.33	3.80	0.58
	SSQ	1.42	0.10	1.92	0.29	3.20	0.81	1.58	0.10	2.12	0.36	3.81	0.68
	SRO-AW	1.59	0.13	1.73	0.25	3.57	0.24	1.72	0.11	1.92	0.24	4.07	0.30
	SRO-OR	1.38	0.17	1.64	0.20	3.04	0.28	1.56	0.10	1.81	0.15	3.22	0.36
Spirit MB	SRE	1.15	0.17	1.68	0.29	2.20	0.39	1.31	0.11	1.95	0.28	2.34	0.49
	SSQ	1.09	0.14	1.38	0.25	2.00	0.28	1.29	0.13	1.68	0.25	2.23	0.36
	SRO-AW	1.28	0.21	1.47	0.09	2.28	0.31	1.48	0.07	1.70	0.18	2.68	0.34
	SRO-OR	1.18	0.07	1.33	0.07	1.88	0.37	1.39	0.20	1.43	0.14	2.03	0.29
Elan	SRE	1.37	0.12	2.00	0.41	2.75	0.49	1.56	0.14	2.23	0.36	3.14	0.49
	SSQ	1.39	0.09	1.54	0.11	2.55	0.28	1.60	0.10	1.78	0.24	2.96	0.45
	SRO-AW	1.41	0.27	1.68	0.09	2.40	0.48	1.66	0.12	1.85	0.17	2.83	0.50
	SRO-OR	1.19	0.21	1.42	0.10	2.12	0.12	1.45	0.26	1.50	0.19	2.20	0.19

[SRE: Rectangular (Ormco Corp., Orange, CA, USA); SSQ: Square (Ormco Corp., Orange, CA, USA); SRO-OR: Round (Ormco Corp., Orange, CA, USA) and SRO-AW: Round (Australian Wilcock, New Delhi - 110020, India)]

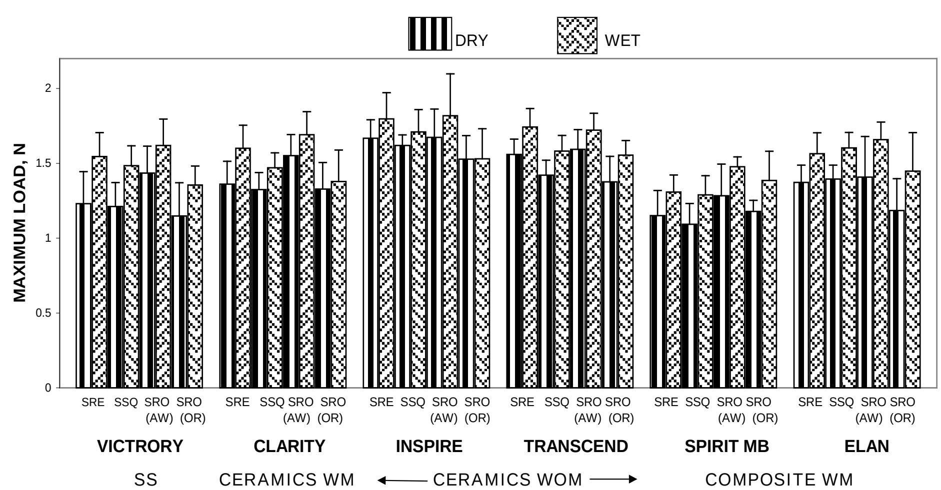

Figure 1: Bar chart of the data illustrating the effect of dry and wet condition for rectangular (SRE), square (SSQ), round (SRO-AW) and round (SRO-OR) stainless steel archwire size with all six bracket types for 0 degree angulation and with elastomeric ligatures. [SS- Stainless steel, WM- With metal slot, WOM-Without metal slot.]

It is reported that frictional values were directly proportional to the increase in angulation with statistically significant in conventional brackets, a finding also corroborated elsewhere with regard to the angulation between bracket and wire (Cacciafesta et al. 2003; Teccoa et al. 2009). On the other hand, conventional brackets causes the wire to be in contact with lateral walls of the slot with the ligation force, thus yielding binary forces that increase the friction.

Table 4.2: Descriptives statistics from one way ANOVA analysis under various angulations for stainless steel rectangular (SRE; Ormco Corp., Orange, CA, USA) archwires, stainless steel square (SSQ; Ormco Corp., Orange, CA, USA) archwires, stainless steel round (SRO-AW; Australian Wilcock, New Delhi - 110020, India) archwires, and stainless steel round (SRO-OR; Ormco Corp., Orange, CA, USA) archwires for elastomeric ligatures with all six bracket types under dry and wet conditions.

Types of archwire	Conditions	F			d.f.			Significance		
		0°	5°	10°	0°	5°	10°	0°	5°	10°
SRE	Dry	10.026	4.781	4.259	5	5	5	0.000	0.002	0.005
	Wet	8.362	3.400	3.705	5	5	5	0.000	0.015	0.010
SSQ	Dry	9.545	8.331	5.065	5	5	5	0.000	0.000	0.002
	Wet	6.598	5.725	5.602	5	5	5	0.000	0.001	0.001
SRO-AW	Dry	2.690	12.550	9.377	5	5	5	0.040	0.000	0.000
	Wet	2.336	4.043	6.722	5	5	5	0.066	0.006	0.000
SRO-OR	Dry	3.544	3.141	10.490	5	5	5	0.012	0.021	0.000
	Wet	0.993	6.203	9.188	5	5	5	0.439	0.000	0.000

Table 3: Descriptives statistics from one way ANOVA analysis under various angulations for stainless steel rectangular (SRE), stainless steel square (SSQ), stainless steel round (SRO-AW), and stainless steel round (SRO-OR) wires for elastomeric ligatures with six bracket types under dry and wet conditions.

Types of Wire	Conditions	F			d.f.			Significance		
		0^0	5^0	10^0	0^0	5^0	10^0	0^0	5^0	10^0
SRE	Dry	10.026	4.781	4.259	5	5	5	0.000	0.002	0.005
	Wet	8.362	3.400	3.705	5	5	5	0.000	0.015	0.010
SSQ	Dry	9.545	8.331	5.065	5	5	5	0.000	0.000	0.002
	Wet	6.598	5.725	5.602	5	5	5	0.000	0.001	0.001
SRO-AW	Dry	2.690	12.550	9.377	5	5	5	0.040	0.000	0.000
	Wet	2.336	4.043	6.722	5	5	5	0.066	0.006	0.000
SRO-OR	Dry	3.544	3.141	10.490	5	5	5	0.012	0.021	0.000
	Wet	0.993	6.203	9.188	5	5	5	0.039	0.000	0.000

In general, the aesthetic braided composite bracket demonstrated the lowest mean friction in comparison to stainless steel brackets (Victory) and ceramic brackets and statistically significant ($p < 0.05$). As shown in Tables IV - VI, aesthetic braided composite bracket and aesthetic composite archwire (CRO-NUS) combinations demonstrated higher mean frictional forces (1.25 N, $p < 0.05$) than round stainless steel archwires under elastomeric ligatures for 0 degree angulation. Whereas this composite couple had lower mean frictional forces compared to SS (Victory: 1.43 N, $p < 0.05$) and ceramic brackets (Transcend: 2.08 N, $p < 0.05$) under dry conditions. SS archwires had 0.79 N and 0.88 N frictional forces respectively of friction for 0 degree angulation and dry conditions.

A significant increase in frictional resistance was reported when changing the angulation from 0 to 10 degree. For example the highest friction measured (3.69 N, $p < 0.05$) for Transcend bracket and the aesthetic composite archwire (CRO-NUS) combination under wet conditions with a 10 degree angulation. The aesthetic braided composite bracket produced 2.21 N mean frictional forces for the same conditions and combinations. Aesthetic composite archwires (CRO-NUS) produced the second highest frictional resistance at 10-degree angulation whereas it had the highest friction (significance, $p < 0.05$, Table VI) for 0 degree angulation compared to stainless steel archwires. Saliva had a consistent effect of increasing the friction values for each and every combination.

Table 4: Mean frictional force (N) and %standard deviation (SD) for composite/SS/ceramic (PCA) bracket vs aesthetic composite archwire (CRO-NUS, NUS, Singapore - 119260) combinations under elastomeric ligatures (based on 3 observations per entry)

Bracket	*Arcwhire*	*Bracket/archwire angulation*							
		Dry condition				*Wet condition*			
		0°		*10°*		*0°*		*10°*	
		Mean	*(SD)*	*Mean*	*(SD)*	*Mean*	*(SD)*	*Mean*	*(SD)*
Composite (braided glass fiber)	Developed composite archwire (glass fiber reinforced)	1.25	0.20	2.07	0.24	1.41	0.29	2.21	0.21
Victory (SS)		1.43	0.33	2.94	0.46	1.64	0.27	3.37	0.12
Transcend (Ceramic)		2.08	0.16	3.54	0.12	2.40	0.28	3.69	0.13

Table 5: Mean frictional force (N) and %standard deviation (SD) for aesthetic braided composite bracket (NUS, Singapore - 119260) vs aesthetic composite (NUS, Singapore - 119260)/SS archwire combinations under elastomeric ligatures (based on 3 observations per entry)

Bracket	*Archwire*	*Bracket/Archwire angulation*							
		Dry condition				*Wet condition*			
		0°		*10°*		*0°*		*10°*	
		Mean	*(SD)*	*Mean*	*(SD)*	*Mean*	*(SD)*	*Mean*	*(SD)*
Developed composite bracket (Epoxy - braided glass fiber)	CRO-NUS	1.25	0.20	2.07	0.24	1.41	0.29	2.21	0.21
	SRO-OR	0.79	0.13	1.35	0.30	0.87	0.21	1.43	0.12
	SRO-AW	0.88	0.16	2.37	0.34	1.13	0.18	2.72	0.06

3.1 Ligatures

All mean static frictional forces were less with SS ligatures than with elastomeric ligatures (Figure 1) for all bracket/wire combinations except for a few cases of ceramic without metal slot brackets (Inspire - SCA and Transcend - PCA). The most of the comparisons with increase angulations were statistically different. Overall, for the 0.022-inch slot size (Victory, Clarity, Inspire, Transcend and Spirit brackets) the elastomeric ligation showed significantly higher mean frictional values for 116 of the 120 combinations of bracket and archwire types (Table I), whereas the SS ligation demonstrated significantly higher frictional values for 4 combinations out of 120 combinations (Table II).

Variability was more or less same for both SS ligation and elastomeric ligation where the std. dev. ranged from 0.07 to 0.81. For all brackets, no trend was noted between mode of ligation and friction. The lowest frictional force produced for the SS ligation was 0.41 N with Spirit MB bracket and 0.018″ SS archwire (SRO-OR), whereas the highest was 4.07 N for the ceramic bracket without a metal slot (Transcend) with 0.018″ SS archwire (SRO-AW). The std. dev. for SS ligation ranged from 0.09 for Clarity bracket with rectangular/square SS wire under dry condition and 0° angulation to 0.79 for Transcend bracket - 0.018″ SS wire combination under wet condition and 10° angulation.

Statistically significantly lower frictional resistance than did conventional ligatures observed by low-friction ligatures with round wires when coupled with 0.016 - 0.022″ NiTi and SS, no statistically significant difference was observed among the groups. In contrast, low-friction ligatures showed statistically significantly greater frictional resistance than was seen with conventional ligatures when coupled with 0.017 - 0.025″ wires. In general, no significant difference was assessed among low-friction ligatures of different sizes (Teccoa et al. 2009). The statistical differences in alignment-force magnitudes were small, but the differences obtained could be caused by one or a combination of parameters such as (i) bracket-slot, (ii) mechanical-lock, (iii) alloy-composition and design, (iv) and interbracket distances (Frugé, 2008).

Table 6: Descriptives statistics from multiple analyses of variance (ANOVA) for aesthetic composite round (CRO-NUS, NUS, Singapore - 119260) archwires, under 0 and 10 degree angulation for elastomeric ligatures with all three bracket types under dry and wet conditions.

Types of Archwire	Conditions	F		d.f.		Significance	
		0°	10°	0°	10°	0°	10°
CRO-NUS	Dry	6.395	11.624	2	2	0.033	0.009
	Wet	6.756	47.048	2	2	0.029	0.000

The design of the slot of the Inspire bracket is divided in two parts. Hence, a small deviation in the slot parts may cause firm contact of this ceramic bracket with the wire. Accordingly the recording of the highest friction ($p < 0.05$) is in combination with rectangular or square SS wires for 0° angulation. The SCA ceramic bracket (Inspire) with its smooth slot surface would be expected to produce lower frictional resistance ($p < 0.05$). The two ceramic brackets without metal slot are found to be significantly different from all of the other brackets and usually exhibited the highest frictional resistances ($p < 0.05$) (Tselepis et al. 1994). The ceramic bracket with a metal slot (Clarity) possesses relatively lower frictional force ($p < 0.05$) due to the metallic contact with the archwire for 0 degree angulation.

Rectangular and square wires may also increase sliding resistance ($p < 0.05$; Table III-VI) due to the large width of those wires compared to round wires ($p < 0.05$). Also, from the surface topography of the five archwires (SRE, SSQ, SRO-AW, SRO-OR and CRO-NUS tested in the present study); there is similarity with the surface profile of the Spirit MB bracket perhaps another reason for the decreased friction ($p < 0.05$) measures compared to the Elan bracket. A model for predicting the wear rate, when hard asperities penetrate the soft coating and produce grooves in the substrate is developed. The above observation can be implicated for the higher frictional force ($p < 0.05$) in the case of round SS archwires (SRO-AW) where a soft coating is dominating on the surface as a byproduct during the processing of matensitic SS. The soft coating accumulates in the form of specks on the base of aesthetic composite bracket, which create more friction ($p < 0.05$). As two soft materials in this case are different and the particles of the material of two soft surfaces change during sliding which causes shearing deformation and ultimately damaged the contact surfaces of composite matrix of braided aesthetic composite bracket due to adhesion.

Under dry conditions, as indicated at the beginning of the discussion, contact points increase due to divisions in the slot of Victory bracket hence frictional force ($p < 0.05$) increases in a similar fashion. In addition, major point contacts could occur at the sharp edges for both rectangular and square archwires and the vertical edges brackets compared to round archwires ($p < 0.05$), which are responsible for increased frictional forces. The exception is with the Australian Wilcock archwire, where the highest frictional forces ($p < 0.05$) may be attributed to dissimilar metallic contact. As several points of contacts occurring between the slot and the archwire, this will result in it the highest friction with rectangular/square archwires ($p < 0.05$) for 5 and 10-degree angulations. Also one side of the bracket slot is slightly curved which may cause the round archwires to slide easily due to an absence of sharp contacts, and producing comparatively lower frictional force for round archwires. The highest friction ($p < 0.05$) observed with rectangular archwire (0.019″ × 0.025″) is due to increasing potential of contact as compared with other archwires which have reduced cross-sectional thickness (0.018″ × 0.018″, square and round, 0.018″) and low stiffness as well.

The highest friction ($p < 0.05$) observed with rectangular archwire (0.019″ × 0.025″) is due to increasing potential of contact as compared with other archwires which have reduced cross-sectional thickness (0.018″ × 0.018″, square and round, 0.018″) and low stiffness as well. The decreasing tendency of frictional force in case of and round archwires ($p < 0.05$) is due to dissimilar contact area between the bracket slot and the archwire. Friction may be increased when if the archwire touches at the vertical sides of the grips. This observation is attributed to rectangular and square archwires increasing sliding resistance ($p < 0.05$). It is due to large contact of those compare to round archwires.
The true metallic contact between archwire and SS ligatures is conducive to a reduced friction, while the elastomeric ligatures represent a significantly higher frictional force ($p < 0.05$). Elastomers are known to exhibit strain rate sensitivity, stress relaxation and poor strength. More friction ($p < 0.05$) is found with the aesthetic composite archwire

compared to SS archwire. In the wear tests, a ball-on-flat wear test on composite resin (Metafil) demonstrates high friction coefficient and brittle fracture by debonding of fillers and matrix. The reason is that Metafil has lower hardness and fracture toughness, and therefore, frets heavily in the abrasive process (Ren et al. 2003). The specific values for initial frictional resistance to sliding (IRS) for each bracket and archwire combination have been have not been statistically proven (strictly the mean frictional values obtained from the study). It is important to note that a statistically significant result may not imply clinical orthodontic relevance if there were variations in frictional resistance among each of the bracket-archwire systems (Gallagher, 2011).

4. Conclusion

The brackets could be categorized in order from lowest to highest friction when tested with elastomeric ligatures: Braided Composite (PMC) without metal slot insert; NUS, Singapore - 119260, Composite (PMC) with metal slot insert (Spirit MB; Ormco Corp., Orange, CA, USA), Stainless steel (Victory; 3M Unitek, South Peck Road Monrovia, CA, USA), Metal reinforced ceramic with metal slot insert (Clarity; 3M Unitek, South Peck Road Monrovia, CA, USA), Composite (PMC) with metal slot insert (Elan; GAC, Knickerbocker Ave Bohemia, NY, USA), Polycrystalline ceramic (Transcend, PCA; 3M Unitek, South Peck Road Monrovia, CA, USA) and Monocrystalline ceramic (Inspire, SCA; Ormco Corp., Orange, CA, USA). The conventional brackets exhibited a higher frictional force times than the force generated by the aesthetic composite brackets. Despite very high standard deviation values for the conventional brackets, there were statistically significant differences between the friction forces generated by these brackets as compared to the others.

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Biography

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