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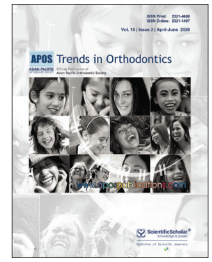

Original Article

Comparison of frictional resistance between four types of brackets in combination with stainless steel and beta-titanium archwires

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ABSTRACT

Objectives: The objective of the study was to evaluate and compare the frictional resistance generated by four different types of brackets in combination with stainless steel (SS) and titanium molybdenum alloy (TMA) archwires.

Materials and Methods: Maxillary premolar brackets were used in this study. These brackets were divided into eight groups comprising seven samples each. Of the eight groups, four groups were combined with SS and four groups were combined with TMA archwires. The testing was done in the presence of human saliva. The static frictional resistance was calculated for each group. One-way ANOVA and *post hoc* Tukey tests were done to compare the friction generated by each group.

Results: There was a statistically significant difference between the friction generated by the monocrystalline brackets and the other bracket groups ($P < 0.001$). There was no statistically significant difference in static friction generated between self-ligating and conventionally ligated brackets. There was a statistically significant difference between the frictional resistance produced by SS and TMA wires ($P = 0.02$) with regard to monocrystalline ceramic brackets only.

Conclusion: Monocrystalline ceramic brackets (Radiance) were found to generate the highest frictional resistance during sliding mechanics when compared to other brackets in combination with both SS and TMA wires. Self-ligating brackets did not show a statistically significant reduction in friction when compared to conventional ligation. There was a statistically significant difference between SS and TMA wires when used with monocrystalline brackets.

Keywords: Ceramic brackets, Friction, Orthodontic brackets, Orthodontic wires, Saliva, Self-ligation

INTRODUCTION

Friction is a clinical challenge, particularly with sliding mechanics, and must be dealt with efficiently to provide optimal orthodontic results.[1] Higher levels of friction during sliding mechanics require the application of higher orthodontic forces and may compromise the amount of orthodontic tooth movement obtained as well as complicate anchorage control.[2] The portion of the applied force lost due to the resistance to sliding can range from 12% to 60%.[3] According to Kusy and Whitely, resistance to sliding in orthodontics can be divided into classical friction (static or kinetic), binding, and notching.[4] Various factors affect the static frictional resistance generated during sliding mechanics. They include bracket material, archwire material, bracket slot size, interbracket span, archwire size, method of ligation, and biological factors such as saliva, debris, and plaque.[5] Variables such as bracket and archwire material are under the control of the orthodontist and control of friction begins with the appliance selection. Various types of brackets and archwires are available in the market. Orthodontists need to quantitatively assess the frictional forces encountered at the bracket-wire interface to achieve accurate force levels to overcome friction and to obtain an optimal biologic response for efficient tooth movement.[6,7]

Although various studies were done regarding friction between brackets and wire, enough evidence is not available in respect to new brackets available commercially in the presence of natural saliva. Hence, the aim of the study was to evaluate and compare the frictional resistance of four types of commercially available brackets – 3M Gemini stainless steel (SS) brackets (3M Unitek, Monrovia, California), 3M Clarity Advanced fine-grain polycrystalline brackets (3M Unitek, Monrovia, California), Radiance monocrystalline ceramic brackets (American Orthodontics, Sheboygan, USA), SL3 Smartclip SS self-ligating brackets (3M Unitek, Monrovia, California) with 0.019 × 0.025” SS and titanium molybdenum archwires (G&H Orthodontics, Franklin, USA) in the presence of natural saliva. The study also compared the effect of conventional elastomeric ligatures and self-ligation on the frictional resistance and the frictional resistance of rectangular 0.019 × 0.025” SS versus 0.019 × 0.025” titanium molybdenum alloy (TMA) archwire. The study tested the null hypothesis that there was no difference between the static frictional forces generated by the conventional metal brackets, ceramic brackets, and self-ligating brackets in combination with SS and TMA archwires.

MATERIALS AND METHODS

This *in vitro* experimental study done on 56 brackets and 56 wires in the presence of natural saliva to simulate oral conditions. The sample size was estimated using the G Power software (version 3.0.1.). Keeping the power of the study at 80%, effect size at 0.45, and the margin of the error at 5%, the total sample size needed was 56 for eight groups. Four types of commercially available brackets were used. They were 3M™ Clarity™ Advanced Ceramic Brackets (3M Unitek, Monrovia, California) – a fine-grain polycrystalline ceramic bracket, Radiance brackets (American Orthodontics, Sheboygan, USA) – a monocrystalline ceramic bracket, SL3 Smartclip™ (3M Unitek, Monrovia, California) – a SS self-ligating bracket, and Gemini Twin Brackets (3M Unitek, Monrovia, California) – a SS metal bracket. All these brackets were maxillary premolar brackets of MBT appliance of 0.022” slot. The brackets were combined with 0.019 × 0.025” SS wire (G&H Orthodontics, Franklin, USA) and 0.019 × 0.025” TMA (G&H Orthodontics, Franklin USA) straight length wires. Based on the bracket and archwire combinations, they were divided into eight groups of seven samples each.

Group 1 – Gemini SS brackets + 0.019 × 0.025″ SS
Group 2 – Gemini SS brackets + 0.019 × 0.025″ TMA
Group 3 – Clarity Advanced Brackets + 0.019 × 0.025″ SS
Group 4 – Clarity Advanced Brackets + 0.019 × 0.025″ TMA
Group 5 – Radiance brackets + 0.019 × 0.025″ SS
Group 6 – Radiance brackets + 0.019 × 0.025″ TMA
Group 7 – SL3 Brackets + 0.019 × 0.025″ SS
Group 8 – SL3 Brackets + 0.019 × 0.025″ TMA.

All the bracket and wire assemblies were ligated with Unistick clear elastomeric modules (American Orthodontics, Sheboygan, USA), except for the self-ligating brackets which have a nitinol self-ligating clip to hold the wire. The testing was done in a wet state using natural saliva. Ten milliliters of saliva were collected from a healthy adult before the testing. The bracket and archwire setup were soaked in the saliva for an hour before testing to simulate the intraoral effects of saliva on friction.[8]

The testing was done with a customized jig made of plexiglass [Figure 1]. The testing jig was fabricated based on tidy's experimental setup.[9] The brackets and wires were mounted vertically on the plexiglass with cyanoacrylate resin (Fevikwik-Pidilite) at 8 mm intervals. A span of 16 mm was left at the center for sliding the test bracket to simulate tooth movement. A 10 mm long power arm was attached to the test bracket. From the power arm, 100 g of weight was suspended to represent the single equivalent force acting on the center of resistance of the tooth. This load was maintained throughout the tests.

Friction testing

The friction testing was done using a universal testing machine (Mecmesin, Multitest 10-i, England and Wales) with a maximum load of 100 N [Figure 2]. 0.010” SS wire was connected to the test bracket and attached to the upper crosshead of the universal testing machine. The test bracket was

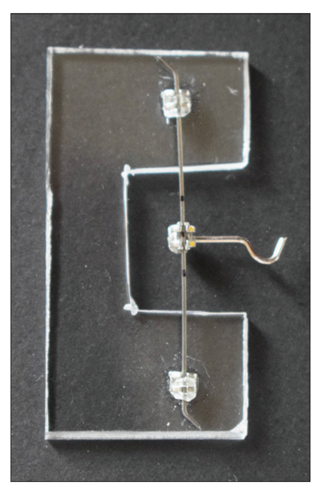

Figure 1: Test jig made of plexiglass.

moved along the archwire at a crosshead speed of 5 mm/min.[9] Tooth movement typically occurs at a rate of 1 mm/month; an approximate average speed of 2.3×10^{-5} mm/min. A speed of 5 mm/min was selected for experimentation because higher speeds did not represent the clinical situation. It was previously reported that SS and nickel-titanium wires were largely unaffected by changing sliding velocity.[5,9] A study compared the effect of varying crosshead speeds of Instron universal testing machine (0.5 up to 50 mm/min) on frictional resistance and the results revealed that there was no significant differences.[10] The static frictional resistance was recorded from the graph obtained and is measured in Newtons (N).

Statistical analysis

The data obtained were subjected to Kolmogorov–Smirnov and Shapiro–Wilk test to check for the normality. From the tests, it was observed that the data followed normal distribution, and hence, statistical analysis was performed using one-way ANOVA followed by Tukey's *post hoc* analysis to compare the mean frictional resistance between different study groups. The level of significance (P-value) was set at $P < 0.05$.

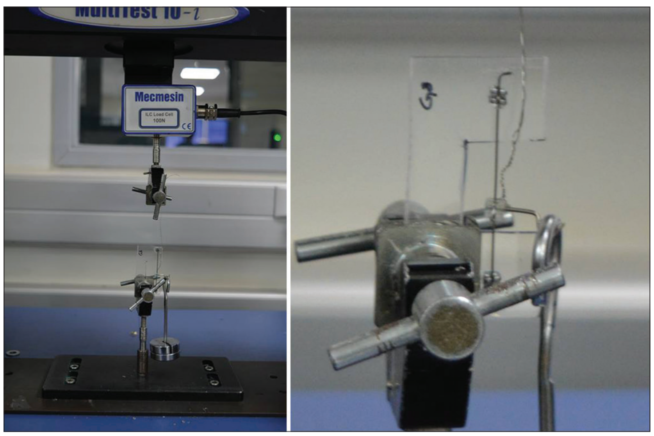

Figure 2: Test jig mounted on the universal testing machine for friction testing.

RESULTS

The highest mean frictional resistance of 5.810 ± 0.712 N was generated by Group 6 and the lowest mean frictional resistance of 2.550 ± 0.343 N was generated by Group 7. There was a statistically significant difference between the frictional resistance generated by the brackets with $P < 0.001$ [Table 1] and the null hypothesis was rejected.

[Table 2] shows pairwise comparison of the mean frictional resistance by *post hoc* Tukey test. On comparing the frictional resistance generated by polycrystalline and monocrystalline ceramic brackets, monocrystalline ceramic brackets produced higher values with TMA archwire which were statistically significant ($P = 0.01$). However, there was no significant difference when SS wires were used. Comparing the frictional resistance of self-ligation and conventional ligation on a metal bracket, there was no statistically significant difference between the two. There was no significant difference in the mean frictional resistance generated by SS and TMA wires with 3M Gemini Brackets, Clarity Advanced, and SL3 Brackets. However, there was a statistically significant difference between the friction generated by SS and TMA wires with regard to Radiance brackets ($P = 0.02$). [Figure 3] shows a graphical representation of the mean frictional resistance generated by all the groups.

Table 1: Comparison of mean frictional resistance between different study groups using one-way ANOVA test.

Comparison of mean Frictional Resistance (in N) between different study groups using One-way ANOVA Test							
Groups	N	Mean	SD	Min	Max	F	P-Value
Metal+SS	7	2.876	0.858	1.83	3.9	13.820	<0.001*
Metal+TMA	7	3.661	1.205	1.92	5.23		
Polycrystaline+SS	7	3.499	0.395	2.77	3.95		
Polycrystaline+TMA	7	4.286	0.854	2.92	5.51		
Monocrystaline+SS	7	4.324	1.023	2.83	5.94		
Monocrystaline+TMA	7	5.810	0.712	4.86	6.99		
Self ligating+ SS	7	2.550	0.343	2.11	3.17		
Self ligating+TMA	7	2.659	0.261	2.26	3.04		

Table 2: Pairwise comparison of mean difference in frictional resistance between different groups using Tukey's honestly significant difference *post hoc* analysis.

Pairwise comparison of mean difference in Frictional Resistance b/w different groups using Tukey's HSD Post hoc Analysis					
(I) Methods	(J) Methods	Mean Diff. (I-J)	95% CI for Difference		P-Value
			Lower	Upper	
Steel+SS	Steel+ TMA	-0.786	-2.099	0.528	0.56
	Polycrystaline+SS	-0.623	-1.936	0.691	0.80
	Polycrystaline+TMA	-1.410	-2.723	-0.097	0.03*
	Monocrystaline+SS	-1.449	-2.762	-0.135	0.02*
	Monocrystaline+TMA	-2.934	-4.248	-1.621	<0.001*
	Self-ligating+SS	0.326	-0.988	1.639	0.99
	Self-Ligating+TMA	0.217	-1.096	1.531	1.00
Steel+TMA	Polycrystaline+SS	0.163	-1.151	1.476	1.00
	Polycrystaline+TMA	-0.624	-1.938	0.689	0.80
	Monocrystaline+SS	-0.663	-1.976	0.651	0.75
	Monocrystaline+TMA	-2.149	-3.462	-0.835	<0.001*
	Self ligating+SS	1.111	-0.202	2.425	0.15
	Self ligating+TMA	1.003	-0.311	2.316	0.26
Polycrystaline+ SS	Polycrystaline+TMA	-0.787	-2.101	0.526	0.56
	Monocrystaline+SS	-0.826	-2.139	0.488	0.50
	Monocrystaline+TMA	-2.311	-3.625	-0.998	<0.001*
	Self ligating+SS	0.949	-0.365	2.262	0.32
	Self ligating+TMA	0.840	-0.473	2.153	0.48
Polycrystaline+TMA	Monocrystaline+SS	-0.039	-1.352	1.275	1.00
	Monocrystaline+TMA	-1.524	-2.838	-0.211	0.01*
	Self ligating+SS	1.736	0.422	3.049	0.003*
	Self ligating+TMA	1.627	0.314	2.941	0.006*
Monocrystaline+SS	Monocrystaline+TMA	-1.486	-2.799	-0.172	0.02*
	Self ligating+SS	1.774	0.461	3.088	0.002*
	Selfligating+ TMA	1.666	0.352	2.979	0.005*
Monocrystaline+TMA	Self ligating+SS	3.260	1.947	4.573	<0.001*
	Self Ligating+TMA	3.151	1.838	4.465	<0.001*
Self ligating+SS	Self ligating+TMA	-0.109	-1.422	1.205	1.00

DISCUSSION

Control of friction during sliding mechanics is essential to achieve treatment efficiency and prevent unwanted side effects. Among the components of resistance to sliding, the first component, classical friction (FR), is the force that resists the movement between two objects as the product of the normal load (N) and the coefficient of friction (μ).[11] The present study compared this friction generated by a conventional SS Bracket (Gemini Twin Brackets, 3M Unitek, Monrovia, California), monocrystalline ceramic brackets (Radiance brackets, American Orthodontics, Sheboygan, USA), polycrystalline ceramic brackets (Clarity Advanced, 3M Unitek, Monrovia, California), and passive self-ligating brackets (SL3 Smartclip, 3M Unitek, Monrovia, California) with 0.019 × 0.025" SS and TMA archwires (G&H Orthodontics, Franklin, USA).

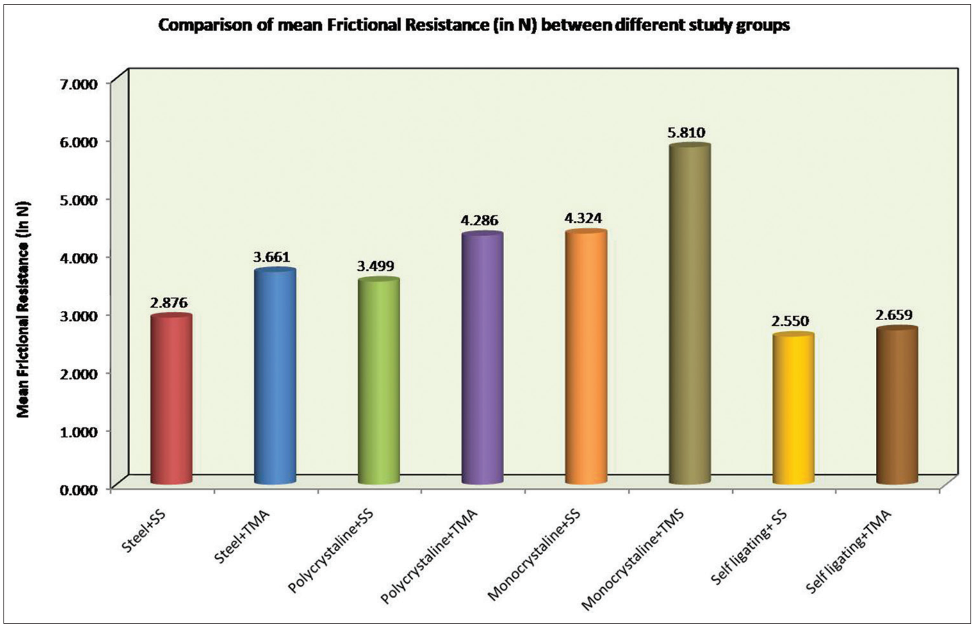

Figure 3: Graph comparing the frictional resistance between different study groups.

Ceramic brackets are widely used, as patient's demand for an esthetic appearance during treatment has increased. Ceramic brackets can be either monocrystalline or polycrystalline. Various studies have reported an increase in the friction associated with ceramic brackets.[12-15] Bishara reported 30% reduction in displacement mechanics during canine retraction when using ceramic brackets compared with SS brackets.[16] In the present study, polycrystalline brackets with TMA wire (P = 0.03) and monocrystalline brackets with SS (P = 0.02) and TMA (P < 0.01) wires demonstrate statistically significant higher friction when compared to conventional metal bracket with SS wire. Few studies have shown that due to the smooth surface of monocrystalline ceramic brackets, they show reduction in friction than polycrystalline brackets.[11,17,18] However, in the present study, the monocrystalline Radiance brackets (AO) produced the highest mean friction of 5.810 ± 0.712 N and showed statistically significant differences when compared to the other bracket groups. The monocrystalline brackets showed a statistically significant difference when compared to polycrystalline bracket in combination with TMA archwire (P = 0.01). There was no significant difference between polycrystalline and monocrystalline when combined with SS archwire. This was in agreement with the study conducted by Pimentel *et al.*[19] and Sadique *et al.*,[20] where monocrystalline brackets showed statistically higher friction for the dry setting tests than the other polycrystalline ceramic brackets even though monocrystalline brackets exhibited a smoother surface. The study by Loftus *et al.* corroborates to this finding when they emphasized that bracket superficial roughness might not result in significant differences in the frictional force.[21]

Another factor that influences friction is the force of ligation. Elastomeric ligatures are believed to exert 50–150 g of force at the time of seating, thereby contributing to the friction.[22] To minimize these forces contributing to friction, self-ligating brackets were introduced. The results of the present study on comparing SL3 self-ligating brackets with conventional metal bracket ligated with Unistick clear elastomeric modules (American Orthodontics, Sheboygan, USA) did not show any statistical difference in static friction. This result was in accordance with the study by Ehsani *et al.*[23] However, the Smartclip SL3 Brackets with SS wire produced the least mean frictional resistance (2.550 ± 0.343 N). SL3 Brackets with SS wire and TMA wire showed a statistically significant decrease in the frictional resistance when compared to Clarity Advanced Brackets with TMA wires (P = 0.003 and P = 0.006, respectively) and Radiance brackets with SS (P = 0.002 and 0.005, respectively) and TMA archwires (P < 0.001).

TMA archwire produced statistically significant increase in friction when compared to SS archwire in combination with monocrystalline brackets (P = 0.02) only. However, there was no significant difference in the mean frictional resistance generated by SS and TMA wires in 3M Gemini Brackets, Clarity Advanced, and SL3 Brackets. The study by Kusy and Whitley reported higher frictional values with TMA wires when combined with SS brackets.[3] It is suggested that the increased surface roughness and the greater elasticity of the titanium alloys to be the reason for high friction. However, the current study did not show any statistically significant difference between TMA and SS archwires when used with SS brackets.

The friction test between bracket and archwire was done in the presence of natural saliva compared to majority of studies that were done either under dry or in the presence of artificial saliva. Saliva substitutes *in vitro* were found to be questionable as a valid representation of the clinical situation.[5] The study by Kusy *et al*. concluded that only human saliva can be used to quantify the magnitude or to rank the efficiency or reproducibility of orthodontic sliding.[8]

Limitations of the study

The study was designed in such a way that the force to move the bracket was given to the power arm rather than the bracket itself. This simulates the clinical situation, in which power arm mechanics are used. This type of design is based on tidy's experimental setup.[8] However, the frictional resistance may differ when the force is directly applied to the bracket due to the effect of binding and notching. Hence, the results can apply in clinical situation where a power arm or a hook in the archwire is used for retraction.

Another limitation of the study is that the *in vitro* conditions may not simulate the actual intraoral conditions, as various biological factors influence the friction. Swartz suggests that the complex biomechanical interactions that happen intraorally may be simplified by *in vitro* studies, leading to overestimation of the friction that is generated.[24]

Future studies can be done *in vivo* that can detect the friction generated more accurately.

CONCLUSION

1. The results of the study demonstrated that the Smartclip SL3 self-ligating brackets combined with SS archwire produced the least friction and monocrystalline Radiance brackets with TMA wire produced the highest amount of mean frictional resistance compared to the other bracket wire combinations.
2. There was a statistically significant difference in the frictional resistance produced by monocrystalline Radiance brackets when compared with conventional Gemini Metal Brackets, polycrystalline Clarity Advanced Brackets, and self-ligating Smartclip SL3 Brackets.
3. Although self-ligating brackets produced the least recorded friction, there was no statistically significant difference in the friction between conventional metal and self-ligating brackets.
4. The study showed that there was a statistically significant difference between SS and TMA wires with regard to monocrystalline Radiance brackets only. The values were not significant for other brackets.
5. Being an *in vitro* study, the conditions do not exactly simulate the intraoral conditions. Various factors such as the absence of tooth during testing, crosshead speed, absence of intraoral factors (such as masticatory force, force decay, biomechanics, and biological factors) tend to overestimate the friction that is actually generated clinically. Hence, this study can act only as a guide during material selection to minimize any friction that can be expected due to material properties before their clinical use.

Declaration of patient consent

Patient's consent not required as patients identity is not disclosed or compromised.

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Conflicts of interest

There are no conflicts of interest.

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