

RESEARCH PAPER

Evaluation of frictional resistance of Stainless steel and Beta Titanium arch wires in three different ceramic self-ligating brackets in an simulated oral environment: An *in vitro* comparative study

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Abstract

Aim: To evaluate and compare the frictional resistance of Stainless Steel and Beta Titanium arch wires in three different ceramic self-ligating brackets in an simulated oral environment.

Materials and Methods: Three types of commercially available passive ceramic self-ligating brackets were used. They were JJ Selfy Clear ceramic, Metro Snowy ceramic and Garmy Sapphire ceramic. All these brackets were Upper left canine (UL3), upper left second premolar (UL5), and lateral incisor bracket (UL2) and rectangular 0.019" x 0.025" SS and 0.019" x 0.025" TMA archwires with MBT prescription of the same tip and torque values. To simulate the oral environment, thermocycling was used. The frictional force was measured using a Kalpak Universal Testing Machine at a speed of 5 mm per minute with a maximum load of 100 N.

Results: The results were analysed using paired t-tests and one-way ANOVA. Group III had the highest mean frictional resistance of each arch wire, followed by Group I and then the least with Group II. The differences between these groups of brackets are not statistically significant. But in all three bracket systems, TMA wires exhibited more frictional resistance than SS wires.

Conclusion: Passive ceramic self-ligating brackets decreased friction during sliding mechanics in an simulated oral environment. TMA wires exhibited significantly highest frictional resistance than SS wires. Therefore by reducing friction in passive ceramic self-ligating bracket systems with SS arch wires can enhance treatment efficacy, especially when space closure or sliding mechanics are required.

Keywords: Friction, Ceramic self-ligating brackets, Orthodontic arch wires, thermocycling

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Introduction

The goal of orthodontics is to straighten and reposition teeth to enhance their occlusion and esthetics. Orthodontic treatment involves biomechanical forces that will interact with the brackets to move the teeth with the use of archwires. Friction is present in every aspect of sliding

mechanics, including leveling, alignment, space closure, and retraction.

In orthodontics, friction is used to describe the force that resists orthodontic brackets from moving along an archwire. Kusy and Whitely described the resistance to sliding as binding, notching, and classical friction (static or kinetic) [1].

The frictional resistance produced in sliding mechanics is influenced by several factors, which include biological elements like saliva, debris, and plaque, as well as bracket-archwire materials, bracket slot sizes, interbracket spans, archwire sizes, and intraoral thermal changes and wet and dry conditions [2, 3, 4].

Factors such as temperature, humidity, pH, and the presence of saliva alter the surface characteristics of brackets and wires, thereby impacting frictional resistance [5, 6]. To correctly simulate clinical situations, it is imperative to mimic the oral environment in *in vitro* research findings.

The surface roughness and elasticity of these wires contribute to differences in frictional resistance when paired with various bracket systems [7]. Many studies have analysed the frictional properties of ceramic and stainless steel brackets, with the results demonstrating that ceramic had improved static friction [8, 9]. Ceramic self-ligating brackets are becoming more prevalent in this field because they eliminate the need for traditional elastic or metal

ligatures by incorporating a clip to secure the archwire, potentially reducing friction and improving esthetics. The study's main objective is to evaluate the frictional resistance of Stainless Steel and beta-titanium archwires in three different ceramic self-ligating brackets in a simulated oral environment. The null hypothesis posits that there is no distinction in the frictional resistance of Stainless Steel and beta-titanium archwires when evaluated in three different passive ceramic self-ligating brackets in a simulated oral environment.

Materials and Methods:

The Institutional Ethical Committee of Vivekanandha Dental College for Women, Tiruchengode (VDCW/IEC/446/2024) approved this *in vitro* research. The G*Power software application was used to determine the sample size. (20 in each group was needed to detect a moderate effect (0.50) with 80% power.

Groups	Brackets (n) Fig 1	Archwires (n) Fig 2
I	JJ Selfy Clear ceramic self-ligating brackets (0.022"x0.028") (n=20)	I A, 0.019 "x0.025" SS (Morelli) (n=10)
		I B, 0.019"x0.025" TMA (Morelli) (n=10)
II	Metro Snowy ceramic self-ligating brackets (0.022"x0.028") (n=20)	II A, 0.019 "x0.025" SS (Morelli) (n=10)
		II B, 0.019"x0.025" TMA (Morelli) (n=10)
III	Garmy Sapphire Self ceramic self-ligating brackets(0.022"x0.028) (n=20)	III A, 0.019 "x0.025" SS (Morelli) (n=10)
		III B, 0.019"× 0.025" TMA (Morelli) (n=10)

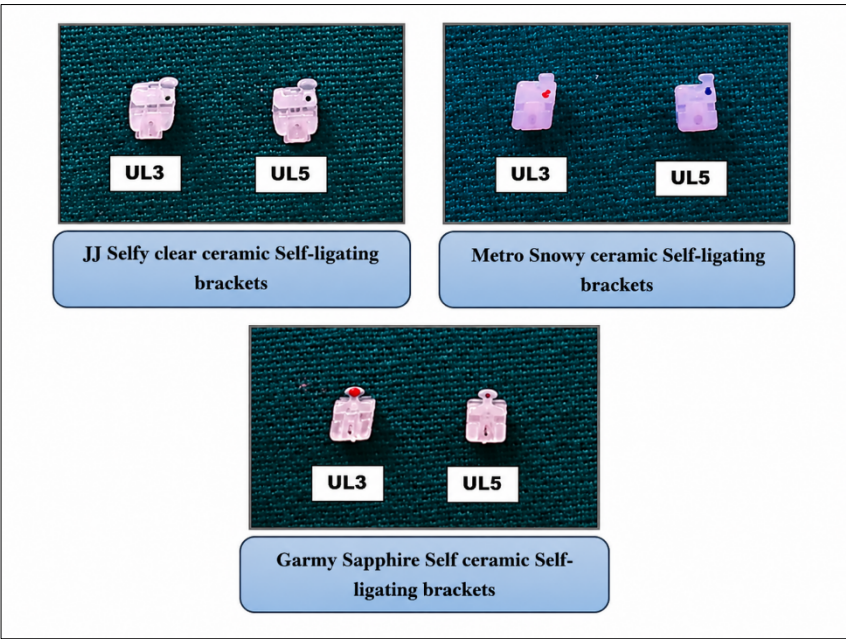


Fig 1: Brackets

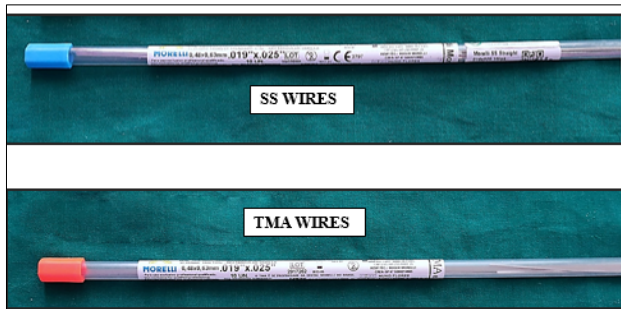


Fig 2: Archwires

Construction of the Jig:

A custom-made plexiglass jig measuring 4" × 2" was used to assess friction between the brackets and the arch wires. Tidy's experimental setup served as the basis for making the testing jig¹⁰. The plexiglass was labelled with the horizontal

and vertical reference lines. Upper left canine (UL3), upper left second premolar (UL5), and lateral incisor bracket (UL2), having a slot size of 0.022" × 0.028" were bonded at this point and would be mounted vertically on the plexiglass and stabilised using cyanoacrylate adhesive (Fevikwik) at 8 mm intervals, simulating a half-arch fixed appliance. A 16 mm space is left at the centre to allow sliding of the tested self-ligating canine bracket to simulate canine retraction. The arch wires would be washed with isopropyl alcohol and dried with compressed air.

Thermocycling:

To simulate the oral environment and its thermal changes, the samples would be stored in distilled water for 1 week at 37 °C and then subjected to thermocycling in a Thermocycler with 1000 thermal cycles [Holmarc (HOTH01)] Fig. 3 with a dwell time of 30s and transfer time of 15s⁴ using distilled water in a transport medium



Fig 3: Thermocycler (Holmarc (HOTH01))

Friction Testing:

After 3 days of simulated ageing, the upper left canine brackets are suspended from the load cell of the testing machine and secured to the Kobayashi hook Fig 4. A 100 g load should be applied perpendicular to the bracket to represent the centre of resistance of the teeth. The archwires

were secured with the bracket in a vertical position, and all the samples were tested. The frictional resistance was tested using the Kalpak Universal Testing Machine. The Plexiglass should be attached to the fixed lower jaw of the testing machine, ensuring that the bracket slot is placed perpendicular to the base of the machine.

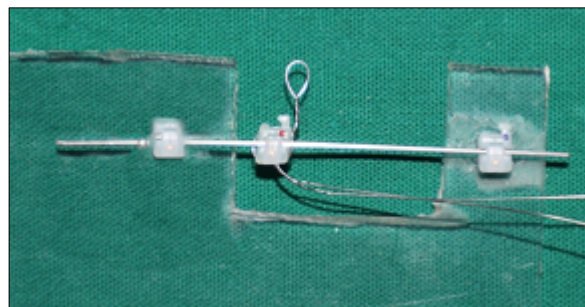


Fig 4: Mounting plate with brackets attached

Keep the lower jaw of the Kalpak Universal testing machine Fig 6 stationary while the free end of the arch wire is fixed to the upper jaw (moving arm); an 8 cm straight length of wire is taken. The frictional force was measured when the arch wire was pulled through the brackets at a speed of 5 mm per minute over a distance of 10 mm while being

subjected to a load of 100 N Fig. 5. The force levels were measured in newtons on a digital readout, and this load cell was connected to an in-built computer with Kalpak software Fig. 7 that recorded all the data and presented it as a Load-displacement graph



Fig 5, 6: 100 g Load, Kalpak Universal testing Machine Machine



Fig 7: Testing machine with mounting template with test brackets

Results:

All obtained data were statistically analysed using SPSS Version 27 (IBM Corp., Armonk, NY, USA) software. The

results obtained were analysed with different statistical analyses to determine the order of frictional resistance offered by different test groups.

Table 1: Comparison of mean frictional resistance of SS arch wire and TMA wire in three different passive ceramic self-ligating brackets using one-way ANOVA test

Wire	Group	N	Mean	Std. Deviation	Minimum	Maximum	F	P Value
SS wire (N)	Group I	10	4.290	.7894		5.4	1.868	0.174
	Group II	10	3.920	.5750	2.9	4.8		
	Group III	10	4.500	.6566	3.7	5.5		
TMA wire (N)	Group I	10	5.190	.3784	4.7	5.8	2.746	0.082
	Group II	10	5.040	.5358	3.9	6.0		
	Group III	10	5.490	.3784	4.9	6.0		

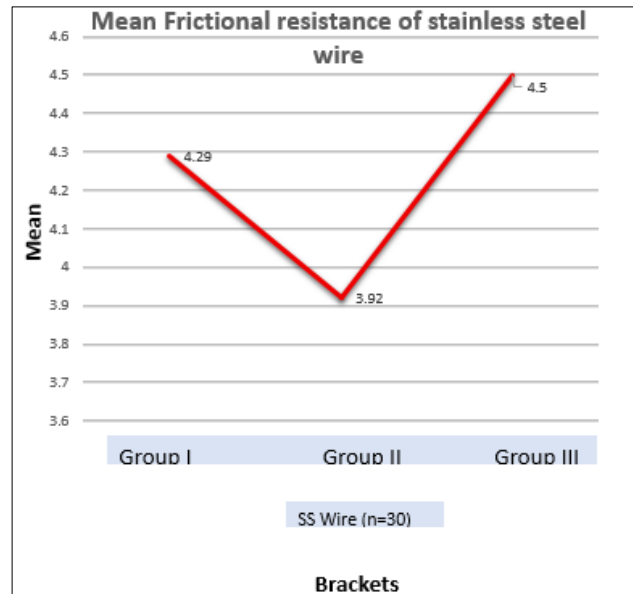
*p<0.05 is statistically significant , **p<0.01 is statistically highly significant

Table 1 compares the mean frictional resistance of SS wire (N) and TMA wire (N) across study groups using a one-way ANOVA test. Among the Stainless steel (SS) archwires, IJDDT, Volume 16 Issue 84s, 2026

Group III recorded the highest mean frictional resistance (4.50 ± 0.66 N; 95% CI: 4.030–4.970), followed by Group I (4.29 ± 0.79 N; 95% CI: 3.725–4.855) and Group II (3.92

± 0.58 N; 95% CI: 3.509–4.331). Therefore, there was no statistically significant difference in the overall frictional resistance between the three brackets with SS wires ($F = 1.868$, $p = 0.174$). For Beta titanium (TMA) archwires, Group III again showed the highest mean frictional

resistance (5.49 ± 0.38 N; 95% CI: 5.219–5.761), followed by Group I (5.19 ± 0.38 N; 95% CI: 4.919–5.461), and Group II (5.04 ± 0.54 N; 95% CI: 4.657–5.423). The ANOVA indicated no statistically significant difference among these groups ($F = 2.746$, $p = 0.082$).



Graph 1: Shows the comparison of mean frictional resistance of SS wire (N) between three passive Ceramic self ligating brackets

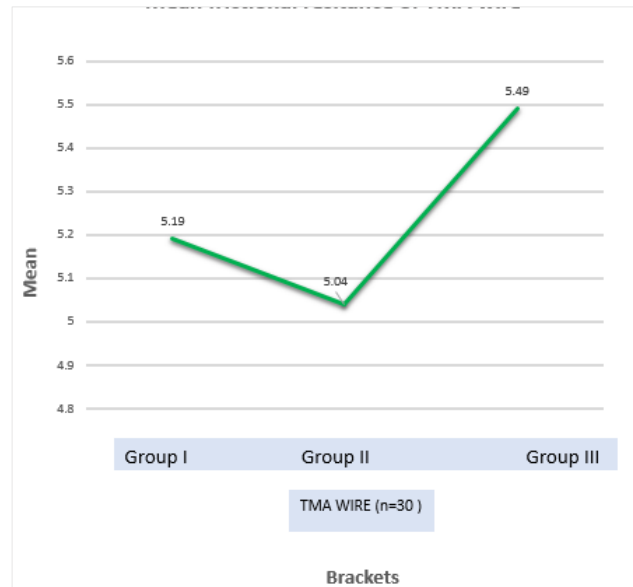
Table 2 shows the comparison of frictional resistance between SS wire and TMA wire in each bracket group performed using a paired t-test. In Group I, the mean frictional resistance for SS wire was 3.59 ± 0.79 N, whereas for TMA wire it was 5.59 ± 0.38 N. The mean difference was -2.00 N with a 95% confidence interval ranging from -2.486 to -1.514 , which was statistically significant ($p < 0.001$). In Group II, SS wire recorded a mean of 3.92 ± 0.58 N, while TMA wire demonstrated a higher mean of 5.04 ± 0.54 N. The mean difference was -1.12 N, with the 95%

confidence interval between -1.507 and -0.733 , also showing strong statistical significance ($p < 0.001$). In Group III, SS wire exhibited a mean frictional resistance of 4.50 ± 0.66 N, compared to 5.49 ± 0.38 N for TMA wire. Again, the difference proved highly significant ($p < 0.001$), with a mean of -0.99 N and a 95% confidence interval of -1.390 to -0.590 . These findings clearly show that TMA wires produced noticeably more frictional resistance than SS wires across all tested bracket types.

Table 2: Comparison of mean frictional resistance between SS wire and TMA wire in each bracket group using a paired t-test

Groups	n	Mean	Std. Deviation	Mean difference	Std. Deviation difference	95% Confidence Interval of the Difference		t	p value
						Lower	Upper		
Group I (n=20)	SS wire (n=10)	3.590	0.789	-2.000	0.680	-2.486	-1.514	-9.303	<0.001**
	TMA wire (n=10)	5.590	0.378						
Group II (n=20)	SS wire (n=10)	3.920	0.575	-1.120	0.541	-1.507	-0.733	-6.544	<0.001**
	TMA wire (n=10)	5.040	0.536						
Group III (n=20)	SS wire (n=10)	4.500	0.657	-0.990	0.559	-1.390	-0.590	-5.604	<0.001**
	TMA wire (n=10)	5.490	0.378						

* $p < 0.05$ is statistically significant, ** $p < 0.01$ is statistically highly significant



Graph 2: Shows the comparison of mean frictional resistance of TMA wire (N) between three passive Ceramic self ligating brackets

Discussion

Friction during orthodontic treatment is clinically challenging, particularly during sliding mechanics. It can be found between the ligation system, archwire, and bracket slot in orthodontics. It accounts for roughly 60% of the applied force, resulting in anchorage loss and extended treatment duration [6, 12]. Self-ligating brackets were introduced in the mid-1930s to address the limitations of conventional ligation. In the passive one, the archwire cover is not pressed upon by the self-ligating clip, thereby decreasing binding and friction.

The present study evaluated the mean frictional resistance generated between three passive ceramic self-ligating brackets with SS and TMA archwires. These brackets were Group I (JJ Selfy Clear ceramic self-ligating brackets), Group II (Metro Snowy ceramic self-ligating brackets), and Group III (Garmy Sapphire ceramic self-ligating brackets). The results showed that passive self-ligating brackets had lower frictional resistance because there was less binding between the arch wire and bracket slot. There is no significant difference among these groups. These similar findings were correlated with studies by Thorstenson and Kusy et al [12] and Krishnan et al [13].

During orthodontic therapy, arch wires undergo significant temperature variations in the patient's oral cavity. To simulate the intraoral environment, the present study used thermocycling, which involves 1000 thermal cycles in distilled water for one week at 37 °C with a dwell time of 30 seconds and transfer times of 15 seconds. It reduced friction during tooth movement by changing the surface roughness of orthodontic arch wires and mimicking the oral conditions. These results align with studies by Shamaa et al. [4] and Abi Dergham et al [14].

According to our study, determine the mean frictional resistance between the three bracket groups within each wire type. In the SS arch wire, Group III exhibited the

highest mean frictional resistance, followed by Group I and the least mean frictional resistance in Group II brackets. These groups did not differ significantly from the other groups. In the TMA arch wire, Group III exhibited the highest mean frictional resistance, followed by Group I and the least mean frictional resistance in Group II brackets. The results obtained showed no significant difference among these bracket groups. These findings accord with a study conducted by Cacciafesta et al. [15].

To summarise, in passive ceramic SLBs, the SS archwire acts as a smoother, stiffer, and less adhesive contact material than the TMA archwire, which has a rougher surface and more friction. These findings suggest that lowering friction in passive ceramic self-ligating bracket systems with SS archwires can improve treatment effectiveness, particularly in situations requiring sliding mechanics or space closure.

Conclusion:

1. Garmy ceramic SLBs had the highest mean frictional resistance when compared to SS archwires, followed by JJ Ceramic SLBs and the least with Metro ceramic SLBs. However, there is no statistically significant difference between these bracket groups.
2. Garmy ceramic SLBs showed the highest mean frictional resistance when compared to TMA archwires, followed by JJ Ceramic SLBs and the lowest with Metro ceramic SLBs. However, there is no statistically significant difference between these bracket groups.
3. TMA wires consistently illustrated more frictional resistance than SS wires in all three bracket systems, and this difference was highly statistically significant.

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