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Evaluation of Frictional Resistance to Sliding of Coated Stainless Steel Arch Wires in Different Esthetic Brackets. An In-Vitro Study

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KEYWORDS

Friction, esthetic archwire, ceramic brackets.

ABSTRACT:

Objective: To assess and compare the Teflon-coated stainless steel arch wires' frictional resistance to sliding in several contemporary, aesthetically pleasing ceramic brackets. \

Materials and Methods: The current study examined the static and kinetic frictional resistance between four contemporary, aesthetically pleasing ceramic orthodontic brackets [0.022" x 0.028"]: Teflon-coated stainless steel archwire [0.019" X 0.025"] and polycrystalline ceramic with metal slot, monocrystalline ceramic, polycrystalline self-ligating ceramic with metal slot, and polycrystalline self-ligating ceramic without metal slot. Using a saliva substitute, static and kinetic friction were measured in a wet condition on a universal testing apparatus. ANOVA statistical test was used to compare the brackets.

Results: The least amount of friction was found overall in polycrystalline self-ligating ceramic brackets without metal slots. When it came to self-ligated brackets, polycrystalline without a metal slot had lower values than polycrystalline with one, but among traditionally ligated brackets, polycrystalline with a metal slot demonstrated significantly less [$p < 0.05$] friction than monocrystalline. Compared to ceramic brackets that were conventionally ligated, self-ligated brackets showed a much lower [$p < 0.001$] frictional resistance to sliding.

Conclusion: In conclusion, polycrystalline brackets with metal slots are a good substitute for monocrystalline brackets in traditionally ligated ceramic brackets. In order to reduce friction, self-ligating ceramic brackets offer a viable substitute for ceramic brackets that are traditionally ligated. When aesthetics and friction are taken into account in the case of labial orthodontics, the most promising bracket currently on the market is the polycrystalline self-ligating ceramic bracket without a metal slot.

1. Introduction

The ability of orthodontic wires to slide into bracket tubes and slots is a need for any successful orthodontic movement, and it is well recognized that the resistance to sliding between the archwire and bracket slot can affect the movement of the tooth. The sliding mechanism is crucial for both closing the gap and for the first stages of tooth alignment and levelling. Therefore, one of the key elements influencing how well orthodontic teeth move is frictional resistance. The orthodontic literature has established the frictional resistance that is experienced during sliding mechanics, which is made up of intricate interactions between the bracket, archwire, and ligation technique. In orthodontics, there are several mechanical and biological components that contribute to multifactorial friction. Rather than a continuous, smooth gliding action, tooth movement linked to sliding mechanics has been described as a sequence of brief phases including oscillating tooth tipping and uprighting.

Frictional resistance is influenced by several factors: The materials used for the bracket and archwire, their surface structure, the condition of their surfaces and the bracket slot, the width of the bracket, the size and shape of the archwire, the torque at the wire-bracket interface, the kind and quantity of force applied during ligation, the use of self-ligating brackets, the number of brackets, the distance between them, saliva, and the influence of "oral functions," among other factors.

The growing number of individuals receiving orthodontic therapy in the current period has made the aesthetic component of the treatment more significant. As a result, creating an appliance with acceptable technical performance and aesthetic appeal is a crucial objective.

Although ceramic brackets were created to enhance the aesthetics of orthodontic treatment, they are more resistant to sliding mechanics in clinical settings than traditional metal brackets. Consequently, metal-slotted ceramic brackets were created to reduce frictional resistance.

Frictional resistance to sliding mechanics is also influenced by the ligation material and procedure. As a result, manufacturers have started offering self-ligating brackets made of ceramic and regular stainless steel to lessen friction. The makers' assertion that self-ligating brackets reduce frictional resistance to sliding has been validated by several investigations [1-3].

Traditionally, sliding mechanics during space closure have involved the employment of rigid, rectangular stainless steel wires. The least amount of friction is encountered by the stainless steel wires. Manufacturers created coated aesthetic archwires as a complement to esthetic brackets as demand for aesthetics expanded. Frictional behaviour is affected when materials like Teflon are applied to the wire surface. The Teflon coating on archwires may lessen frictional resistance at the bracket-archwire interface since Teflon has a low coefficient of friction. Fewer researches have been done on the frictional behaviour of Teflon-coated archwires using various ceramic brackets. Therefore, the goal of this study is to assess and contrast the frictional resistance to coated archwire sliding in various self-ligated and conventionally ligated aesthetic ceramic brackets.

2. Methods

Four types of maxillary first premolar brackets of slot size 0.022” x 0.028” with MBT prescription were used & divided in 4 groups as follows:

Group 1: Monocrystalline ceramic [Radiance, American Orthodontics] [Figure 1 [a]],

Group 2: Polycrystalline ceramic with metal slot [Clarity, 3M Unitek] [Figure 1 [b]],

Group 3: Polycrystalline self-ligating ceramic with metal slot [Clarity SL, 3M Unitek] [Figure 1 [c]] and

Group 4: Polycrystalline self-ligating ceramic without metal slot [Trueklear, Forestadent] [Figure 1 [d]].

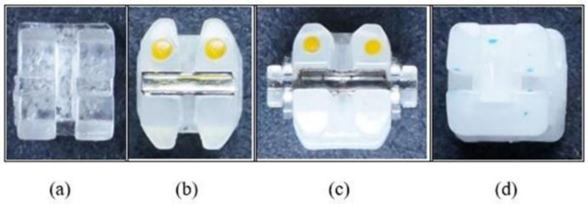

Figure 1: [a] Monocrystalline ceramic bracket, [b] Polycrystalline ceramic bracket with metal slot, [c] Polycrystalline self-ligating ceramic bracket with metal slot, [d] Polycrystalline self-ligating ceramic bracket without metal slot.

There were fifteen of each kind of bracket. Thus, sixty brackets in total were examined. Tested were posterior straight segments of prefabricated Teflon-coated stainless steel archwires with dimensions of 0.019" x 0.025" [Ortho-Direct, USA]. There were fifteen segments in each group out of a total of sixty archwire segments employed.Using an L-shaped 200 X 20 X 3 mm stainless steel [SS] plate on which brackets were mounted with cyanoacrylate adhesive, an experimental model [Figure 2] was created prior to evaluating various bracket-archwire combinations for frictional resistance during sliding mechanics. To serve as a reference for consistent bracket placement, a line was drawn in the middle of each stainless steel plate, parallel to the long axis of the plate. To position the brackets accurately on SS plate, a jig was prepared by using 0.021” X 0.028” stainless steel wire, as described by Thomas et al. [1]

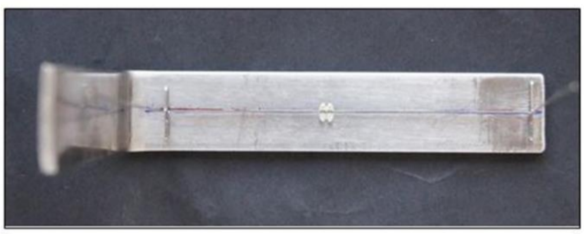

Figure 2: Experimental model for testing

The bracket base was coated with adhesive, and a jig was used to align the bracket slot with the line marked on the stainless steel plate. Once the adhesive cured, the Jig was

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removed. A Teflon-coated 0.019" X 0.025" stainless steel wire segment was subsequently fastened using elastic modules in the bracket slot prior to testing in brackets using traditional ligation. The wire segment might be secured in self-ligating brackets without the need of elastic modules.

A universal testing device [Star Testing System, India] was used to assess friction. Model No. STS 248 in a moist state at ambient temperature, simulating the oral environment with artificial saliva [Wet Mouth, ICPA Health Products Ltd]. Following the creation of an experimental model to ensure a consistent bond position, the bracket-wire assembly was placed vertically within the floor-mounted universal testing machine [Figure 3]. Using a syringe, the bracket-archwire assembly was moistened with synthetic saliva to replicate the oral environment. A 3 mm/minute archwire draw was made through the bracket. Every archwire had a length of 2.5 mm. The universal testing machine's computer monitor showed the frictional force in grams as a result, represented as a graph. Every time the bracket-archwire combination was checked, the tested bracket and wire were taken out and disposed of, and a new bracket was bonded in the same spot using a jig in the correct way. Every time, the frictional resistance data were noted. As a result, sixty bracket-archwire samples in total were examined. To remove the impact of wear, fresh bracket-archwire samples were used for each test.

Figure 3: Universal Testing Machine

3. Statistical Analysis

Descriptive statistics, including mean, standard deviation [SD], minimum and maximum values for static and kinetic friction were calculated for each bracket-archwire combination. Comparison between groups for investigating difference in means of static and kinetic friction was analyzed using ANOVA [analysis of variance]. For multiple comparison Bonferroni post-hoc test was done [Table 1 and 2 for static friction, table 3 and 4 for kinetic friction]. The level of significance for all tests was set to 5% [$p \leq 0.05$] and p- values ≤ 0.001 were considered to be highly significant. Difference in means of static and kinetic friction within each group was tested using two sampled t- test [Table 5].

4. Results

Monocrystalline ceramic brackets showed highest static and kinetic friction while polycrystalline self-ligating ceramic brackets without metal slot showed lowest static and kinetic friction. [Table 1 & 3, figure 4 & 5]

On inter-group comparison it was concluded that in conventionally ligated ceramic brackets, polycrystalline brackets with metal slot showed significantly lower [$p < 0.05$] static & kinetic friction than static & kinetic friction of monocrystalline brackets. [Table 2 & 4]

Self-ligating polycrystalline brackets with metal slot and without metal slot showed significantly lower [$p < 0.001$] static and kinetic friction than conventionally ligated monocrystalline and polycrystalline with metal slot brackets. [Table 2 & 4]

There was no significant difference in means of static & kinetic friction between self-ligating ceramic bracket groups. [Table 2 & 4]

On intra-group comparison the result showed that mean static friction was higher than mean kinetic friction in each of the four groups, however, only in polycrystalline self-ligating ceramic brackets without metal slot, mean static friction was significantly higher [$p < 0.05$] than mean kinetic friction. [Table 5, figure 6]

Group	Minimum [grams]	Maximum [grams]	Mean [grams]	SD
Group 1	180.00	410.00	259.23	74.77
Group 2	130.00	400.00	201.41	33.80

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Group 3	30.00	110.00	64.66	25.34
Group 4	30.00	70.00	46.66	14.47

Table 1: Descriptive statistics for Static Frictional Resistance [SFR] of 4 groups.

Group	Group 1	Group 2	Group 3	Group 4
Group 1	Nil	0.004*	0.000**	0.000**
Group 2	0.004*	Nil	0.000**	0.000**
Group 3	0.000**	0.000**	Nil	0.99
Group 4	0.000**	0.000**	0.99	Nil
** Highly significant [p < 0.001], * Significant [p < 0.05]				

Table 2: Values of significance [p- values] for differences in means according to groups compared for static frictional resistance.

Group	Minimum [grams]	Maximum [grams]	Mean [grams]	SD
Group 1	170.00	385.00	252.92	74.13
Group 2	148.00	342.00	198.46	35.50
Group 3	26.66	100.00	61.36	21.43
Group 4	20.00	58.00	35.22	10.67

Table 3: Descriptive statistics for Kinetic Frictional Resistance [KFR] of 4 groups.

Group	Group 1	Group 2	Group 3	Group 4
Group 1	Nil	0.014*	0.000**	0.000**
Group 2	0.014*	Nil	0.000**	0.000**
Group 3	0.000**	0.000**	Nil	0.523
Group 4	0.000**	0.000**	0.523	Nil
** Highly significant [p < 0.001], * Significant [p < 0.05]				

Table 4: Values of significance [p- values] for differences in means according to groups compared for kinetic frictional resistance.

	Static friction		Kinetic friction		
Group	Mean	SD	Mean	SD	P value
Group-1	259.23	74.77	252.92	74.13	0.831
Group-2	201.41	33.80	198.46	35.50	0.83
Group-3	64.66	25.34	61.36	21.43	0.703
Group-4	46.66	14.47	35.22	10.67	0.021*
* Significant [p < 0.05]					

Table 5: Intra-group comparison between Static and Kinetic friction of each group.

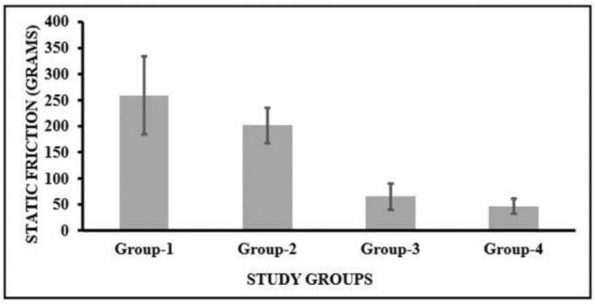

Figure 4: Graph showing inter-group comparison of Static friction between 4 groups

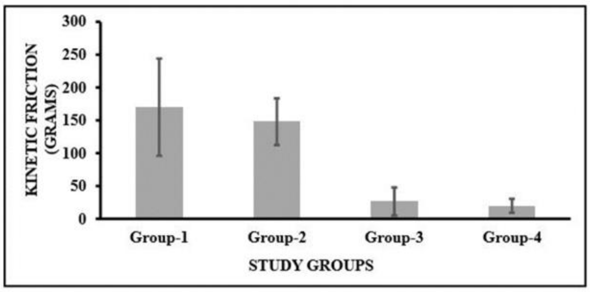

Figure 5: Graph showing inter-group comparison of Kinetic friction between 4 groups

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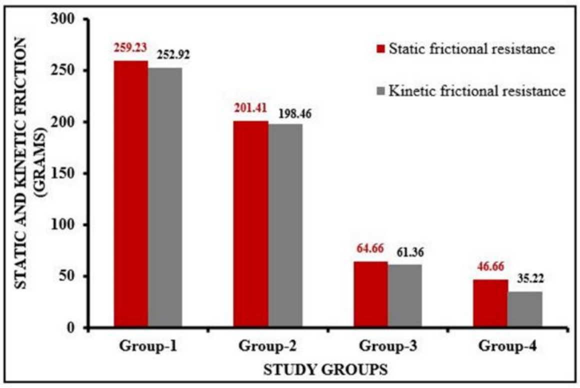

Figure 6: Graph showing intra-group comparison of Static and Kinetic friction of each group.

5. Discussion

Frictional resistance is one of the critical factors that determine the efficiency of orthodontic tooth movement in fixed mechanotherapy.

The proper magnitude of force during orthodontic treatment will result in optimal tissue response and rapid tooth movement. The rate of tooth movement increases as the force increases up to a certain point; after that, increase in force produces no appreciable increase in movement. During mechanotherapy involving movement of the bracket along the wire, friction at the bracket-archwire interface might prevent the attainment of optimal force levels in the supporting tissues. Therefore, an understanding of forces required to overcome friction is important so that the appropriate magnitude of force can be used to produce optimal biologic tooth movement. [4]

On inter-group comparison it was found in present study that in conventionally ligated ceramic brackets, polycrystalline brackets with metal slot showed significantly lower [$p < 0.05$] static & kinetic friction than static & kinetic friction of monocrystalline brackets confirming results of previous studies. [5-11] [Table 2 & 4]

According to Angolkar et al. [1990] [5] when viewed under electron microscope, ceramic slot surface shows numerous, more generalized small indentations, while the stainless steel bracket appears relatively smooth. In present study, the metal slot appears to cause the polycrystalline bracket to behave more like a stainless steel bracket than a conventional ceramic bracket in terms of static and kinetic frictional resistance, thus giving results similar to previous studies.

According to Nishio et al. [2004] [9], the higher frictional force values produced by traditional ceramic brackets, in all combinations and angulations, could be due to some ceramic bracket characteristics, such as hardness and stiffness. Manufacturing procedure, finishing, and polishing are difficult to do; this might explain the granular and pitted surface of the ceramic brackets. The ceramic bracket with metal reinforced slot showed lower values of the frictional force, probably because its slot is reinforced with metal, which prevents direct contact between ceramic and wire and maybe because the characteristic of the metal allows better polishing and a smoother surface.

Under scanning electron microscopic examination, Doshi et al. [2011] [10] found that smoothest surface was seen with the ceramic bracket with metal slot while the traditional ceramic bracket surface was roughest.

In present study self-ligating polycrystalline brackets with metal slot and without metal slot showed significantly lower [$p < 0.001$] static and kinetic friction than conventionally ligated monocrystalline and polycrystalline with metal slot brackets similar to previous study. [12] [Table 2 & 4]

In present study monocrystalline ceramic brackets and polycrystalline with metal slot brackets were ligated with elastomeric ligatures. These elastomeric ligatures were placed immediately before each test run, thus the forces recorded were expected to be at maximum as the tightness of the elastomeric ligatures would not have reduced significantly.

In study done by Hain et al. [2006] [13], self-ligating brackets produced lower frictional resistance than regular uncoated modules which is in agreement with present study.

In the present study polycrystalline self-ligating ceramic brackets with metal slot showed more static and kinetic friction than polycrystalline self-ligating without metal slot similar to study done by Voudouris et al. [2010] [14], however this difference is not significant. [Table 1 and 3]

According to Voudouris et al. [2010] [14], self-ligating brackets produced significantly lower frictional

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resistance than conventionally ligated brackets. In their study self-ligating bracket with an all-ceramic slot demonstrated lower friction than metal self-ligating bracket.

In present study there is single passive self-ligating clip in polycrystalline self- ligated bracket without metal slot [Trueklear, Forestadent] while in case of polycrystalline self-ligated bracket with metal slot [Clarity SL], ligating clip is 'active on demand' as claimed by manufacturer [3M Unitek] with two passive self-ligating clips. These two passive self-ligating clips may be applying higher force on wire than single passive sliding clip of polycrystalline self-ligated bracket without metal slot resulting in more friction.

In present study the static frictional forces were greater than the kinetic ones in all bracket-archwire combinations, confirming previous studies [8,15] however, the difference was significant [$p < 0.05$] only in polycrystalline self- ligating ceramic brackets without metal slot. [Table 5]

6. Conclusion

1. In conventionally ligated ceramic brackets, polycrystalline with metal slot brackets show significantly lower static and kinetic friction than monocrystalline brackets. Thus, polycrystalline ceramic brackets with metal slot are good alternative to monocrystalline ceramic brackets.
2. Self- ligated ceramic brackets with metal slot and without metal slot both show significantly lower static and kinetic friction than conventionally ligated monocrystalline and polycrystalline with metal slot brackets. Thus, self- ligating brackets are good alternative to conventionally ligated brackets.

3. There is no significant difference in static and kinetic friction between self- ligating polycrystalline brackets with and without metal slot.

4. Static friction is greater than kinetic friction in all the 4 groups but it is significantly higher only in polycrystalline self-ligating brackets without metal slot.

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