

Comparative Evaluation of Friction Resistance of Titanium, Stainless Steel, Ceramic and Ceramic with Metal Insert Brackets with Varying Dimensions of Stainless Steel Wire: An *In vitro* Multi-center Study

B Sunil Kumar¹, Suresh Miryala², K Kiran Kumar³, K Shameem⁴, Ravindra Reddy Regalla⁵

Contributors:

¹Professor and Head, Department of Orthodontics and Dentofacial Orthopedics, Saraswati Dhanwantari Dental College and Hospital, Parbhani, Maharashtra, India; ²Professor and Head, Department of Orthodontics and Dentofacial Orthopedics, HKES SN Institute of Dental Sciences and Research, Gulbarga, Karnataka, India; ³Professor and Head, Department of Orthodontics and Dentofacial Orthopedics, SB Patil Dental College and Hospital, Naubad, Bidar, Karnataka, India; ⁴Reader, Department of Orthodontics and Dentofacial Orthopedics, SB Patil Dental College and Hospital, Naubad, Bidar, Karnataka, India; ⁵Professor and Head, Department of Orthodontics and Dentofacial Orthopedics, Rajiv Gandhi Institute of Medical Sciences, Adilabad, Andhra Pradesh, India.

Correspondence:

DR. Kumar BS. Department of Orthodontics and Dentofacial Orthopedics, Saraswati Dhanwantari Dental College and Hospital, Parbhani - 431 401, Maharashtra, India. Phone: +91-9849283910. Email: drsunil_ortho@yahoo.co.in

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Abstract:

Background: The orthodontist seeks an archwire-bracket combination that has both good biocompatibility and low friction. Hence, the aim of this multicenter *in vitro* study was to evaluate and compare the frictional resistance generated between titanium (Ti), stainless steel (SS), ceramic and ceramic with metal insert (CMI) brackets with SS wires of varying dimensions in a specially designed apparatus.

Materials and Methods: The material used in this study were Ti, SS, Ceramic and CMI with 0.018" slot manufactured with zero degree tip and -7° torque premolar brackets (3M, Unitek) and SS wires of varying dimensions (0.016" round, 0.016 × 0.016" square, 0.016 × 0.022" rectangular and 0.017 × 0.025" rectangular) used. The frictional resistance was measured using Instron Universal testing machine (Model no. 4301). The specimen population in each center composed each of 160 brackets and wires. Differences among the all bracket/wire combinations were tested using (one-way) ANOVA, followed by the student Newman Keuls multiple comparisons of means ranking (at $P < 0.05$) for the determination of differences among the groups.

Results: Ti bracket in combination with 0.017 × 0.025" SS rectangular wire produced significant force levels for an optimum orthodontic movement with least frictional resistance.

Conclusion: Ti brackets have least resistance and rectangular wires produced significant force. These can be used to avoid hazards of Nickel. SS brackets revealed higher static frictional force values as the wire dimension increased and showed lower static friction than Ti brackets for all wires except the thicker wire. Our study recommends the preclusion of brackets with rough surface texture (Ti brackets) with SS ligature wire for ligating bracket and archwire are better to reduce friction.

Key Words: Archwire, ceramic brackets, ceramic with metal insert brackets, friction resistance, instron machine, stainless steel brackets, titanium brackets

Introduction

Friction is defined as the force that retards or resists the relative motion of two subjects in contact and its direction is tangential to the common boundary of the two surfaces in contact.¹ Friction can be described by co-efficient of friction (μ), which is proportionality constant and depends on the surface characteristics of the material. The orthodontist seeks an archwire-bracket combination that has both good biocompatibility and low friction.

Currently, the stainless steel (SS) bracket-archwire couple considered as "gold standard." In earlier studies SS couple displayed the least amount of frictional forces, when the orthodontic wire and bracket are in the passive configuration.²⁻⁶ However, SS orthodontic appliances are no longer free of potential problems because a component of SS that is, nickel. Nickel is an allergen for some patients and, for a select few, a toxin.⁷ Therefore; the biomaterial community is seeking an orthodontic material that is more biocompatible. Titanium (Ti) is such an element as exemplified by root form implants and cervical spinal plates.⁷ Because of many current applications in dentistry and medicine, Ti is an obvious choice for a possible substitute material. Studies have shown that Ti is the most passive metal available for implant and explants.^{8,9} Due to the tenacious layer of rutile (TiO_2), Ti can protect itself with a hard ceramic layer that inhibits adsorption and absorption of foreign metal ions or additional oxygen atoms. As a consequence of its passivity over a broad pH range, its high breakdown potential, and its low current density to corrosion, Ti exhibits the minimum tissue response of all communal used metals.²

Since frictional resistance during orthodontic treatment is a key factor in determining the force systems required for moving the teeth, it is important to evaluate the static friction in Ti brackets against SS wires of different dimensions and cross sections and compare it to the SS, Ti, ceramic and ceramic with metal insert (CMI) brackets and to find out the most efficient bracket system and wire combination, which would produce the least frictional resistance to orthodontic movement.

Materials and Methods

Frictional properties of 0.018" slot Ti brackets (Rematitan, Dentaureum) were selected for the study and compared with (1) SS, (2) Ti, (3) ceramic, and (4) CMI brackets (3M, Unitek) in dry state against (1) 0.016" round, (2) 0.016 × 0.016" square, (3) 0.016 × 0.022" rectangular and (4) 0.017 × 0.025" rectangular SS wires (American orthodontics) with preformed ligature ties of 0.010" SS (American orthodontics) (Tables 1 and 2). All the brackets were of maxillary first premolar with 0.018" slot and manufactured with 0° tip and -7° torque.

Sample size was consisted a total of 160 bracket and wire each for the study. The samples were divided into 16 groups consisting 10 each (Groups 1, 5, 9, 13- SS Brackets, Groups 2, 6, 10, 14 - CMI Groups-3, 7, 11, 15- Titanium Brackets, and Groups 4, 8, 12, 16-Ceramic Brackets) the wires (D1-0.016" round, D2-0.016 × 0.016" square, D3-0.016 × 0.022" rectangular and D4-0.017 × 0.025" rectangular SS wires). Each bracket was tested only once to ensure the original properties of bracket wire system were preserved. A Universal Instron Testing Machine (Model no. 4301) (Figure 1) with 500 g load cell was used, and the force levels were measured in kilograms in digital read out of the machine.

A special design consisting of acrylic plates of 90 mm length, 25 mm width and 3 mm thickness was made. A line is drawn

perpendicular to the midline for all plates at 20 mm length where the bracket is bonded with adhesive (Anabond), so that the bracket slot and wire were parallel to the pull to avoid eccentric values. This acrylic plate was mounted in the lower grip and the archwire in the upper grip of the Instron machine and pulled upwards (Figure 2).

Bracket, wire and ligature wire were cleaned with 95% ethanol and then air dried to ensure an uncontaminated testing surface. The wire was held in the bracket slot with the help of 0.010" soft ligature wire. The bracket wire combination then mounted to the Instron machine. Each wire was pulled through the bracket slot by a distance of 5 mm at a constant speed of 0.5 mm/min. The force level was recorded from the digital meter at every mm and a total of 800 readings were obtained (Figure 3). The Instron machine also plotted the tracing graph as a digital readout is tenths of millimeters as the crosshead travels superiorly up the wire.

Observations and Results

The samples were divided into 16 groups based on alloy composition of the bracket, the varying dimension of wires viz. D1, D2, D3 and D4. The statistical analysis used to compare the mean force in different study groups were achieved by using the ANOVA (one-way) and student Newman Keuls multiple comparison tests ($P < 0.05$ was considered as the level of significance).

Multiple Comparison test using Student Newman Keuls procedure showed that the mean force in Group 1 and 2 (Graph 1) are significantly lower than the mean force in Groups 3 and 4

Materials	Alloy	Size	Manufacturer
Brackets	Ti	0.018"	Dentaureum
	SS	0.018"	3 M Unitek
	Ceramic	0.018"	3 M Unitek
	CMI	0.018"	3 M Unitek
Wires	SS (straight length)	0.016"	American orthodontics
		0.016×0.016"	
		0.016×0.022"	
		0.017×0.025"	
Ligature wire	SS	0.010"	American orthodontics

SS: Stainless steel, Ti: Titanium, CMI: Ceramic with metal insert

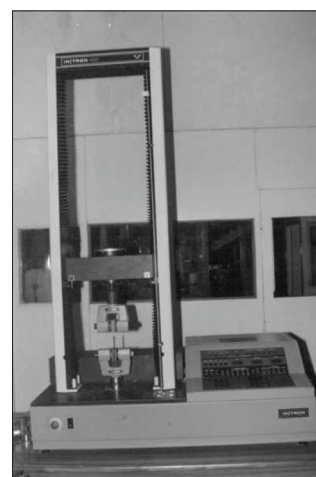


Figure 1: Instron Universal testing machine (Model no. 4301).

Archwire dimension	SS bracket	Ceramic with metal slot bracket	Ti bracket	Ceramic bracket
Round wire 0.016"	402±53.9 (Group 1)	444±58.7 (Group 2)	530±87.4 (Group 3)	604±39.2 (Group 4)
Square wire 0.016"×0.016"	474±64.8 (Group 5)	520±58.1 (Group 6)	610±34.0 (Group 7)	798±87.3 (Group 8)
Rectangular wire 0.016"×0.022"	624±48.4 (Group 9)	692±34.3 (Group 10)	624±34.4 (Group 11)	870±45.7 (Group 12)
Rectangular wire 0.017"×0.025"	760±41.1 (Group 13)	818±44.9 (Group 14)	596±28 (Group 15)	1008±78.4 (Group 16)

SS: Stainless steel, Ti: Titanium

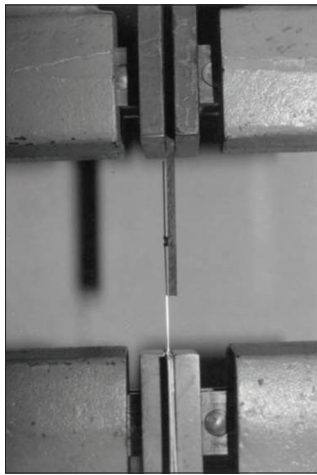


Figure 2: Mounted specimen in instron machine.

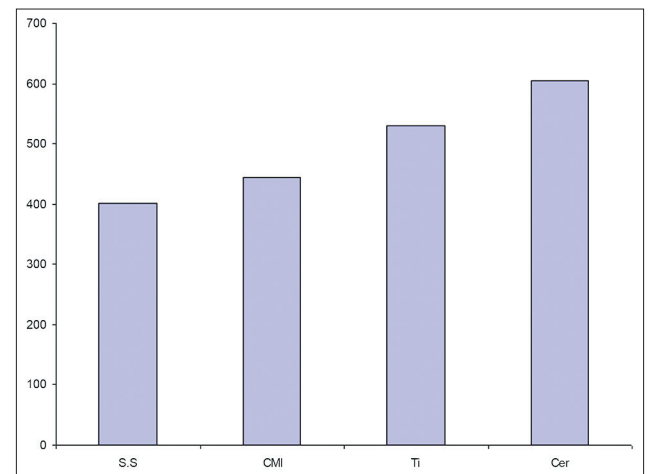


Figure 3: Digital read-out in instron machine.

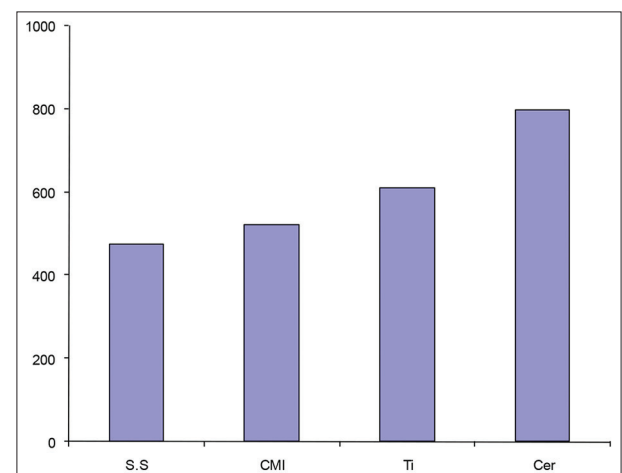
($P < 0.05$). Similarly Groups 5 and 6 (Graph 2) are significantly lower than the mean force in Groups 7 and 8 ($P < 0.05$). Furthermore, the mean force in Group 3 is significantly lower than group 4 ($P < 0.05$). Similarly, the mean force in Group 7 is significantly lower than Group 8 ($P < 0.05$). However, there is no significant difference between Groups 5 and 6 ($P > 0.05$).

Multiple Comparison test by Student Newman Keuls procedure showed that the mean force in Group 9 and Group 11 are significantly lower than the mean force in Groups 10 and Group 12 (Graph 3) similarly Group 15 is significantly lower than Groups 13, 14, and 16 (Graph 7). Also, the mean force in Group 10 is significantly lower than the mean force in Group 12 ($P < 0.05$). However, there is no significant difference between Groups 9 and 11 ($P > 0.05$). Also, the mean force in Group 13 (760 ± 41.1) is significantly lower than Groups 14 and 16 ($P < 0.05$). Further the mean force in Group 14 is significantly lower than the mean force in Group 16 ($P < 0.05$) (Graph 4).

The test showed that the mean force in all four dimensions is significantly different from each other ($P < 0.05$), i.e., the mean force in D1 (402 ± 53.9) is significantly lower than the mean



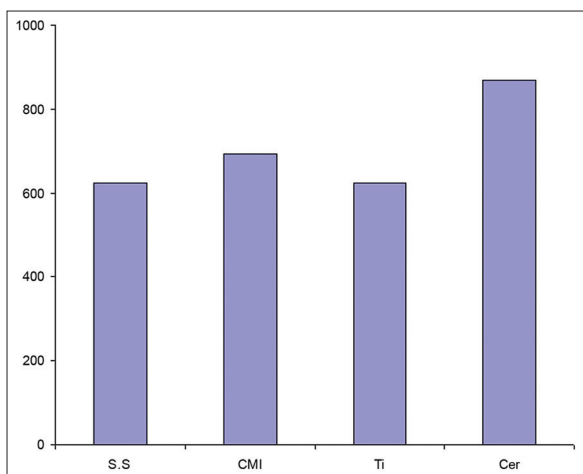
Graph 1: Comparison of mean static frictional force values of 0.016" round wire with different brackets (SS: Stainless steel, Ti: Titanium, CMI: Ceramic with metal insert, Cer: Ceramic).



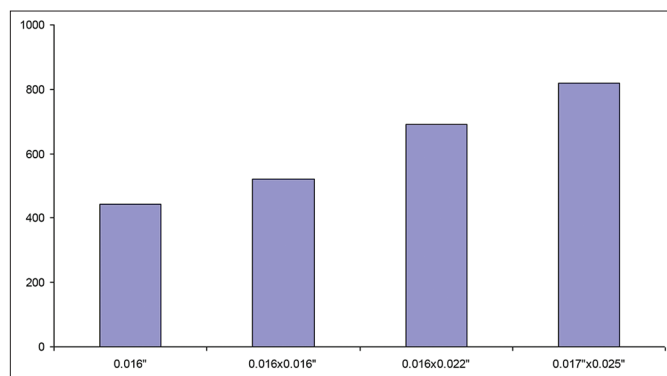
Graph 2: Comparison of mean static frictional force values of 0.016 x 0.016" square wire with different brackets (SS: Stainless steel, Ti: Titanium, CMI: Ceramic with metal insert, Cer: Ceramic).

force in D2, D3 and D4 ($P < 0.05$). Similarly, the mean force in D2 (474 ± 64.8) is significantly lower than the mean force in D3 and D4 ($P < 0.05$). Also, the mean force in D3 (624 ± 48.4) is significantly lower than the mean force in D4 (760 ± 41.4) ($P < 0.05$) (Graph 5). Multiple comparison test showed that the mean force in all 4 dimensions is significantly different from each other ($P < 0.05$) (Graph 6). Multiple comparison test showed that the mean force in D1 (530 ± 87.4) significantly lower than the mean force in D2, D3 and D4 ($P < 0.05$). However, no other contrasts are statistically significant ($P > 0.05$) (Graph 7). Multiple comparison test showed that the mean force in all 4 dimensions is significantly different from each other ($P < 0.05$) (Graph 8).

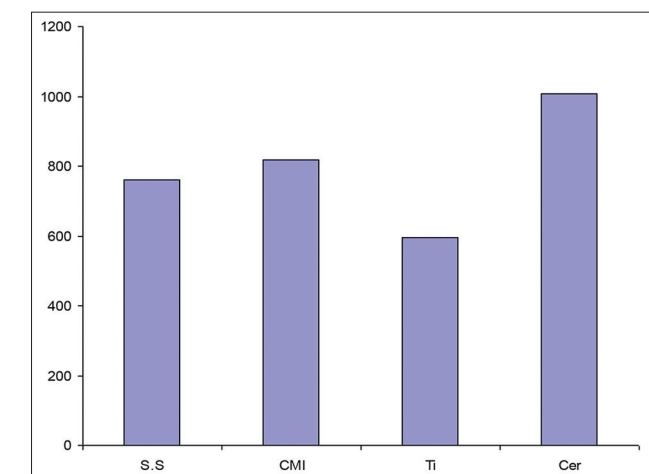
The frictional resistance in Ti bracket with 0.017 x 0.025" rectangular wire, Ceramic with 0.016 round wire, SS with 0.016 x 0.022" rectangular wire, Ti with 0.016 x 0.022" rectangular wire



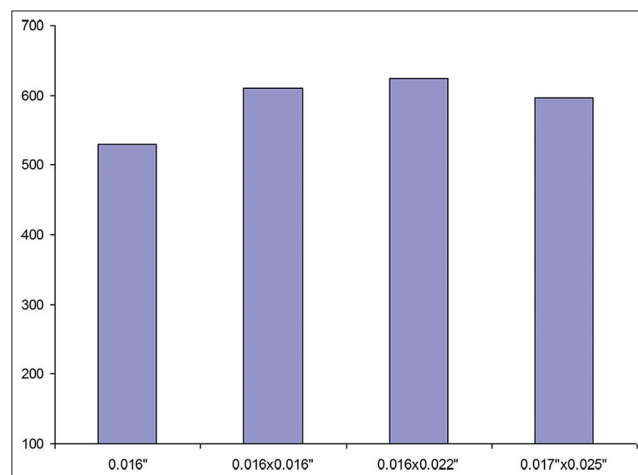
Graph 3: Comparison of mean static frictional force values of 0.016 × 0.022" rectangular wire with different brackets (SS: Stainless steel, Ti: Titanium, CMI: Ceramic with metal insert, Cer: Ceramic).



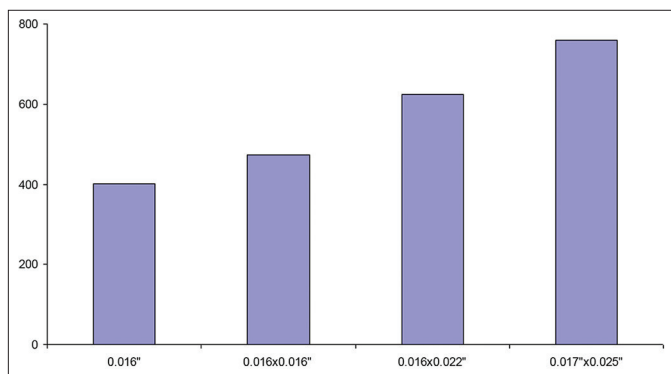
Graph 6: Comparison of mean static frictional force values of ceramic with metal insert brackets with varying dimensions of stainless steel wire.



Graph 4: Comparison of mean static frictional force values of 0.017 × 0.025" rectangular wire with different brackets (SS: Stainless steel, Ti: Titanium, CMI: Ceramic with metal insert, Cer: Ceramic).

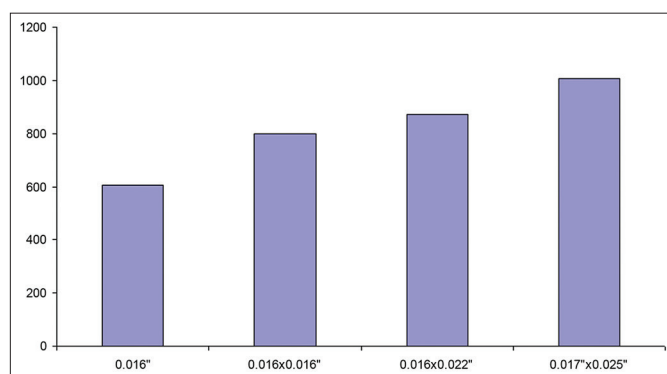


Graph 7: Comparison of mean static frictional force values of titanium with varying dimensions of stainless steel wire.



Graph 5: Comparison of mean static frictional force values of stainless steel brackets with varying dimensions wire.

and Ti with 0.016 × 0.016" square wire are significantly lower than the frictional resistance of Ceramic bracket with 0.016 × 0.016" wire CMI and Ceramic brackets with 0.016 × 0.022"



Graph 8: Comparison of mean static frictional force values of ceramic brackets with varying dimensions wire.

wire, SS, CMI and Ceramic brackets with 0.017 × 0.025" wire ($P < 0.05$). Also, the frictional resistance in CMI bracket with 0.016 × 0.022" rectangular wire is significantly lower than the frictional resistance in Ceramic bracket with 0.016 × 0.016" square and 0.016 × 0.022" rectangular wires, SS, CMI and Ceramic brackets with 0.017 × 0.025" rectangular wire ($P < 0.05$).

The frictional resistance in Ceramic bracket with 0.016 × 0.016" wire, SS and CMI brackets with 0.017 × 0.025" rectangular wire

are significantly lower than the frictional resistance in Ceramic bracket with 0.016×0.022 and 0.017×0.025 rectangular wires ($P < 0.05$). Further the frictional resistance in Ceramic bracket with 0.016×0.022 rectangular wire is significantly lower than the frictional resistance in Ceramic bracket with 0.017×0.025 rectangular wire ($P < 0.05$). However, no other contrasts are statistically significant ($P > 0.05$).

Discussion

The frictional resistance encountered during sliding mechanics has been well-established in the orthodontic literature, and it consists of complex interactions between the bracket, archwire, and method of ligation. The factors affecting the resistance to sliding are combination of classical friction, archwire-bracket binding, and archwire notching in orthodontic appliances.¹⁰ Friction is mainly due to classical friction, whereas binding and notching become more prominent at large bracket-archwire angulations. This results in a less efficient orthodontic appliance.

Extensive research has demonstrated that the bracket and archwire properties influence the frictional resistance between them. For example, studies have generally shown that SS brackets have decreased friction relative to ceramic brackets.^{1,3,11-14} With regard to archwires, beta-Ti wires generally resulted in less efficient sliding mechanics than SS wires, and frictional resistance generally increased with an increase in archwire size and rectangular wires generally produced more friction than round wires.^{1,4,5,11,12,15,16}

Expectations were that the Ti brackets would slide poorly; the aerospace and medical industries found many years ago that Ti was prone to fretting and galling, despite its excellent resistance to corrosion at physiological temperature and its high specific strength. Nonetheless, its proven biocompatibility in medical and dental applications and increasing concern to the allergenic and toxic indications of Nickel within the oral cavity, the production of commercially pure Ti brackets was inevitable with O_2 doping and Ca forming.²

The results of this study showed that there were distinct trend for the mean frictional force to be varying with different bracket wires combination. This study also confirms the hypothesis that the effect of bracket on the amount of friction in different bracket-wire combinations depends on the material makeup of the bracket slot.¹⁶ Of all the material tested so far in this study, the SS brackets revealed higher frictional values as the wire dimension increase. SS steel brackets were associated with less static friction than Ti brackets for all wires except the thicker wires.

It is noteworthy that the mesio-distal width of the 3M Unitek SS bracket was 0.30 mm smaller than the Dentaurem Ti Brackets, 3M Unitek ceramic and CMI. Being oversized

will facilitate engagement with all wires, which will increase clearance and reduce binding, but all, at the expense of some loss of control.

Ti brackets have a different chemical structure and hardness compared with SS Brackets. The electron spectroscopy for chemical analysis indicated that Ti metal does not dominate the bracket chemically for about the first 200-300 Å like SS brackets that slide on passivated layer of Cr and O, Ti bracket slide on a passivated layer of C, O, Ti and N, averaging 34%, 45%, 14% and 7% respectively.² The desirable mechanical properties of Ti for use in orthodontics are low rigidity, superelasticity and shape memory effect.¹⁷ Studies on load generation on Ti and SS brackets indicate that Ti Brackets present superior structure dimensional stability as a result of favorable properties.¹⁸

Ceramic brackets such as single crystal sapphire, polycrystalline alumina and zirconia were introduced and gained widespread popularity because of potential cosmetic benefits. However, their mechanical properties such as high frictional resistance, enamel abrasion of opposing teeth, tendency to fracture during treatment and debonding still need to be improved. With several previous studies, it was found that the slots of ceramic material generated more friction than SS brackets. The likely reason is that ceramics has an increased surface roughness and porosity.¹¹

The results of the study revealed that, the mean static frictional force value with a uniform load cell of 500 g of Ti brackets to be comparatively lesser with various bracket systems. As the wire dimension increased the cross-section of the wire as in around SS wire, the static frictional force value was less and in square, and rectangular wires as the wire size increased the static frictional resistance decreased and comparatively more than SS round wires.

Overall the statistical analysis of this study reveals that an ideal bracket-wire combination will be a 0.018 in slot Ti bracket with a mesiodistal width of 3.53 mm at 0° angulation and -7° torque of maxillary first premolar, bracket with a 0.017×0.025 -inch wire to produce clinically significant force levels for an optimum orthodontic movement with least frictional force resistance.

Conclusion

SS brackets revealed higher static frictional force values as the wire dimension increased and showed lower static friction than Ti brackets for all wires except the thicker wire. Ceramic brackets revealed significant higher mean static force values and Static Frictional Force value of CMI bracket was less compared with Ceramic brackets and higher in comparison with Stainless Steel brackets. Ti brackets in comparison with Ceramic brackets resulted with a significant lesser static frictional force values. Overall, the study revealed that Ti bracket (0.018" slot pre adjusted edge wise) in combination with 0.017×0.025 inch SS rectangular wire produced significant force levels

for an optimum orthodontic movement with least frictional force resistance. Use of the preclusion of brackets with rough surface texture is recommended. Proper selection of an archwire, bracket combination and suitable ligation technique that minimizes friction is necessary to conserve the available posterior critical anchorage in the corrections of large overjet.

A limitation of this study was the difficulty in extrapolating the values for friction determined *in vitro* to *in vivo* situation; may be due to the difficulty in reproducing oral conditions. Clinicians should use these findings with caution as the clinical performance observed might be quite different than those *in vitro* findings, but these are useful guide to anticipated clinical behavior. Our study warrants the model in wet condition to simulate the oral cavity.

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