

A comparative study of frictional resistance during simulated canine retraction on tyodont model

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ABSTRACT

Objectives: Frictional resistance is an important counterforce to orthodontic tooth movement during sliding mechanics. This study was carried out to evaluate the effect of different bracket-archwire-ligation combinations on “resistance to sliding” during simulated canine retraction on tyodont model.

Materials and Methods: the frictional resistance was tested between three modern orthodontic brackets-stainless steel, ceramic, and ceramic with metal slot (0.022-inch), and seven different archwires (0.019 × 0.025-inch)-stainless steel, nickel-titanium, Teflon coated stainless steel, stainless steel with the reverse curve of spee (RCS), Teflon coated stainless steel with RCS, Teflon coated nickel-titanium and nickel-titanium with RCS ligated with stainless steel ligature wire and regular clear elastomeric modules. All tests were carried out in a dry state on an Instron universal testing machine (crosshead speed: 0.5 mm/min). 10 measurements were made from each bracket-archwire-ligature combinations.

Results: The highest mean frictional resistance was found in ceramic brackets with nickel-titanium RCS archwire ligated with elastomeric modules while minimum frictional resistance was found in stainless steel brackets with Teflon coated stainless steel archwire ligated with stainless steel ligature. Metal slot ceramic brackets generated significantly lower frictional forces than ceramic brackets, but higher values than stainless steel brackets. Teflon coated archwires shows highly significant reduction of the frictional resistance than their corresponding uncoated archwires. Archwires with RCS had the higher frictional resistance than normal counterpart archwires.

Conclusion: Ceramic brackets with metal slot and Teflon coated SS archwires seem to be a good alternative to conventional stainless steel brackets and archwires in space closure with sliding mechanics in patients with esthetic demands.

Key words: Archwires, brackets, canine retraction, friction, sliding

INTRODUCTION

Friction is the force that resists against the movement of one surface in relation to another and that acts on the opposite direction of the desired movement. This frictional force is always parallel to the surfaces that are in contact and its magnitude is dependent upon the amount of the normal force pushing the two surfaces together.^[1,2]

The nature of friction in orthodontics is multifactorial, derived from both a multitude of mechanical and biological factors.^[3] Many studies have been carried out to evaluate the factors that influence frictional resistance: Bracket and archwire

materials,^[4,5] surface structure of archwire,^[5] surface condition of the archwire and the bracket slot,^[6] bracket width, archwire size and shape,^[5,6] torque at the wire-bracket interface,^[7] type and amount of force exerted by ligation,^[8] use of self-ligating brackets,^[9] number of brackets^[9] inter bracket distance, saliva, and influence of “oral functions, etc.”^[10]

In modern society, the esthetic aspect of orthodontic therapy is important due to the number of adults undergoing orthodontic therapy are increasing. Therefore, the development of appliance that combines both esthetic and adequate technical performance is an important goal. Ceramic brackets were

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developed to improve the esthetics during orthodontic treatment; however, in clinical use, they have high frictional resistance to sliding mechanics.^[6,11] Ceramic brackets with metal slot were recently developed to minimize the frictional characteristics of ceramics brackets.^[12] Coating or refining the wire surface with other materials has an influence on frictional behavior. Since Teflon has a low coefficient of friction, so archwires with Teflon coating could possibly reduce frictional resistance at the bracket-archwire interface.^[13]

There were limited numbers of studies on frictional behavior of Teflon coated archwires and metal slot ceramic brackets. Therefore, the purpose of the present study was to evaluate and compare the frictional resistance generated by three types of brackets (stainless steel, ceramic, and metal slot ceramic) with seven different archwires (stainless steel, Teflon coated stainless steel, stainless steel with the reverse curve of spee (RCS), Teflon coated stainless steel with RCS, Nickel-Titanium (NiTi), Teflon coated NiTi, NiTi RCS) ligated by two different ligation materials (Stainless steel ligature and elastomeric modules).

MATERIALS AND METHODS

On the basis of bracket material, three types of brackets of MBT prescription with 0.022×0.028 inch slot were used: Stainless steel brackets (Di-MIM, Mini-Twin Brackets, Ortho Organizers, San Marcos, CA), Ceramic brackets (Illusion Plus, Ortho Organizers, San Marcos CA) and Ceramic brackets with metal slot (Metal Slot Illusion Plus, Ortho Organizers, San Marcos, CA) [Figure 1].

Seven different rectangular archwires of 0.019×0.025 inch were used in the study as follows: low: Stainless steel, Teflon coated Stainless steel, Stainless steel with RCS, Teflon coated Stainless steel with RCS, NiTi, Teflon coated NiTi, NiTi RCS (All archwires from Ortho Organizers, San Marcos, CA).

The Ligation materials used were: Stainless steel ligature 0.009 inch (Ortho Organizers, San Marcos, CA) and regular

clear elastomeric module, 0.120 inch (Ortho Organizers, San Marcos, CA). A total of 420 bracket-archwire-ligation combinations were studied. Frictional resistance was measured in grams with a universal testing machine (Model 3382, Instron, Canton, MA, USA).

Testing Model Preparation

To simulate fixed appliance in the oral cavity a typodont model (API, Ashoo Sons, New Delhi, India) was taken as a testing model. Testing models were prepared the maxillary jaw of typodont model. For canine retraction mechanics, testing models were prepared by removing 1st premolars from their position to simulate the condition of an extraction case. The canines were cut at the level of cervical line to facilitate its distal movement during sliding mechanics over the archwire. On the typodont model's teeth (central incisors, lateral incisors, canines, and 2nd premolars) brackets and buccal tubes (1st molars) were bonded at the clinically appropriate position using a cyanoacrylate adhesive (Fevi Kwik, Pidilite Industrial Ltd, Mumbai, India). Similarly testing models were prepared for all the combinations [Figure 2].

Brackets and archwires were cleaned with acetone wipe to remove any surface impurities. The archwires to be tested were ligated to the brackets by stainless steel ligature and elastomeric module. For all the tests, ligation was done by the same individual. The stainless steel ligatures were initially fully tightened and then slightly slackened to allow the bracket to slide freely, the end of the ligature was then tucked in under the archwire.^[14] In case of elastomeric ligature, the elastomeric modules were placed immediately before each test run to avoid ligature force decay.^[12]

Testing

The testing model was positioned vertically on the lower fixed member of the floor mounted universal testing machine. For the movement of canine, a loop of 0.018 SS was made and loop was engaged in the hook of canine bracket. Free end of 0.018 SS wire was held by upper cross head of testing machine

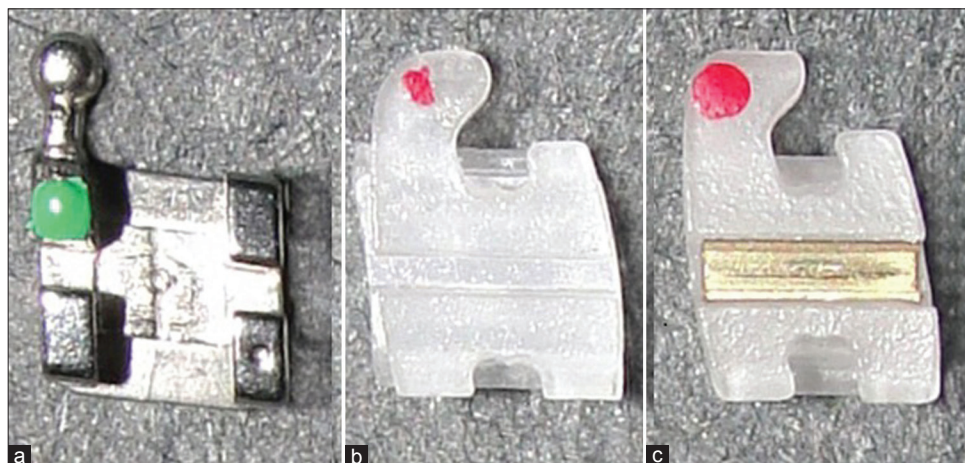


Figure 1: Tested brackets: (a) stainless steel; (b) ceramic; (c) ceramic with metal slot

during testing [Figure 3]. The upper cross head member of the testing machine was adjusted to move upwards at a constant speed of 0.5 mm/min.^[6] Movement was started when canine was in contact with the distal surface of lateral incisor and stopped when canine just touched the mesial surface of 1st premolar. Total distance bracket travelled was 7.5 mm as recorded on computer. The resulting frictional resistance was recorded on a computer in the form of a force-distance graph. Similarly, frictional resistance was recorded for all bracket-ligation-archwire combinations. The tests were carried out in dry condition (to achieve the result in non-contaminated condition) and at room temperature.^[6,12]

Statistical Analysis

The data thus obtained were summarized as Mean±SD The

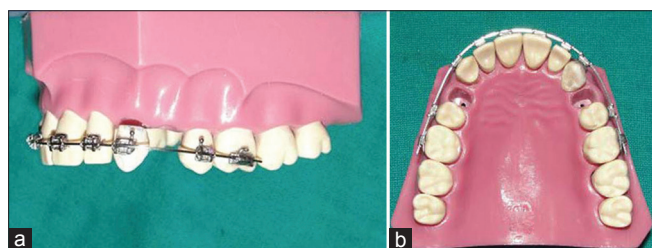


Figure 2: Study model used in the study: (a) side view; (b) occlusal view



Figure 3: Testing model on universal testing machine

effect of variables (bracket materials, ligation materials and seven different archwires) on frictional resistance were observed and compared together by three-way way analysis of variance and the significance of mean difference between the groups was done by Duncan multiple range test after ascertaining the normality and homogeneity of variance by Shapiro Wilk test and Levene's test, respectively. The frictional resistance was found normally distributed after square root transformation and thus analyzed on transformed data. A two-tailed ($\alpha=2$) probability P value less than 0.05 was considered statistically significant. All analysis was performed on GraphPad Prism software (windows version 5.0).

RESULTS

The mean friction and standard deviation for each bracket-archwire-ligation combination is summarized in Table 1. The highest mean frictional resistance was found in ceramic brackets with NiTi RCS archwire (279.60 ± 6.35 g) ligated with elastomeric modules while minimum frictional resistance was found in stainless steel brackets with TC SS archwire (65.20 ± 4.66 g) ligated with SS ligature.

There was a statistically significant interaction ($P<0.0001$) between the archwires, brackets and ligation which indicates that the frictional characteristics depending on the particular combination used. This required that an individual comparison be made of each combination to identify differences [Table 2].

The Duncan's multiple range test showed a significant bracket, archwire and ligature effect ($P<0.001$). The ceramic bracket had the highest frictional force value (181.58 ± 54.15 g), with statistical significance ($P<0.001$), followed in decreasing order by the ceramic bracket with metal reinforced slot (136.44 ± 40.63 g) and the stainless steel bracket (129.83 ± 41.57 g) [Table 3].

Nickel Titanium RCS archwires exhibited the highest mean frictional resistance ($P<0.001$), followed in decreasing order by Nickel Titanium, Stainless steel RCS, Stainless steel, Teflon Coated Nickel Titanium, Teflon Coated Stainless steel RCS and Teflon Coated Stainless steel archwires with the least mean frictional resistance [Table 3].

Table 1: Mean (\pm SD) frictional resistance (g) of the bracket-ligature-archwire combinations

| Arch wires | Bracket | | | | | |
|------------|------------------------------|-------------------------------------|------------------------------|-------------------------------------|------------------------------|-------------------------------------|
| | Stainless steel | | Ceramic | | Ceramic with metal slot | |
| | SS ligature mean \pm SD | Elastomeric module mean \pm SD | SS ligature mean \pm SD | Elastomeric module mean \pm SD | SS ligature mean \pm SD | Elastomeric module mean \pm SD |
| SS | 96.80 \pm 4.97 | 158.20 \pm 4.87 | 141.40 \pm 7.77 | 230.40 \pm 6.11 | 103.40 \pm 7.64 | 162.80 \pm 5.89 |
| TC SS | 65.20 \pm 4.66 | 137.40 \pm 4.93 | 107.40 \pm 6.19 | 178.20 \pm 5.40 | 71.20 \pm 6.80 | 139.60 \pm 5.27 |
| SS RCS | 100.60 \pm 5.73 | 179.80 \pm 6.38 | 150.80 \pm 5.89 | 247.80 \pm 6.06 | 110.40 \pm 7.60 | 189.60 \pm 7.16 |
| TC SS RCS | 71.60 \pm 5.86 | 141.20 \pm 6.80 | 115.80 \pm 4.15 | 179.00 \pm 6.78 | 80.60 \pm 7.16 | 149.80 \pm 6.53 |
| NiTi | 116.80 \pm 5.40 | 183.60 \pm 6.18 | 161.80 \pm 6.02 | 260.80 \pm 6.46 | 125.40 \pm 7.09 | 189.60 \pm 6.50 |
| TC NiTi | 87.20 \pm 4.21 | 150.80 \pm 4.92 | 116.60 \pm 4.93 | 199.80 \pm 6.10 | 93.40 \pm 6.07 | 160.00 \pm 6.52 |
| NiTi RCS | 128.60 \pm 5.94 | 199.80 \pm 5.89 | 172.80 \pm 4.92 | 279.60 \pm 6.35 | 133.00 \pm 5.39 | 201.40 \pm 6.66 |

SS – Stainless steel; RCS – Reverse curve of spee; NiTi – Nickel-titanium; TC – Teflon coated

Table 2: The effect of bracket materials, ligature materials and different archwires on frictional resistance by three way ANOVA

| Source of variation | Sum of squares | Degree of freedom | Mean square | F value | P value |
|----------------------------------|----------------|-------------------|-------------|----------|---------|
| Brackets | 177.50 | 2 | 88.75 | 9265.66 | <0.0001 |
| Ligatures | 504.42 | 1 | 504.42 | 29547.71 | <0.0001 |
| Archwires | 209.86 | 6 | 34.98 | 4467.47 | <0.0001 |
| Brackets × ligatures | 0.70 | 2 | 0.35 | 1093.48 | <0.0001 |
| Brackets × archwires | 3.27 | 12 | 0.27 | 48.74 | <0.0001 |
| Ligatures × archwires | 1.67 | 6 | 0.28 | 13.16 | <0.0001 |
| Brackets × ligatures × archwires | 3.98 | 12 | 0.33 | 3.26 | <0.0003 |
| Errors | 8.92 | 168 | 0.05 | - | - |
| Total | 910.32 | 209 | 629.43 | - | - |

ANOVA – Analysis of variance

Table 3: Descriptive statistics of frictional resistance (g)

| Variables | No. of observations | Mean | SD |
|-------------------------|---------------------|--------|-------|
| Bracket material | | | |
| Stainless steel | 140 | 129.83 | 41.57 |
| Ceramic | 140 | 181.58 | 54.15 |
| Ceramic with metal slot | 140 | 136.44 | 40.63 |
| Ligation material | | | |
| SS ligature | 210 | 111.94 | 31.22 |
| Elastomeric module | 210 | 186.63 | 39.55 |
| Archwires | | | |
| SS | 60 | 148.83 | 45.33 |
| TC SS | 60 | 116.5 | 40.85 |
| SS RCS | 60 | 163.16 | 51.05 |
| TC SS RCS | 60 | 123 | 38.95 |
| NiTi | 60 | 173 | 48.80 |
| TC NiTi | 60 | 134.63 | 50.57 |
| NiTi RCS | 60 | 185.86 | 51.96 |

SS – Stainless steel; RCS – Reverse curve of spee; NiTi – Nickel-titanium; TC –Teflon coated

Among all the bracket materials with different archwires when ligated with stainless steel ligature showed significantly less ($P<0.001$) frictional resistance than elastomeric module [Table 3].

DISCUSSION

Orthodontic tooth movement is dependent on the ability of the clinician to use controlled mechanical forces to stimulate biologic responses within the periodontium.^[15] The clinician should be aware of the characteristics of the orthodontic appliances, wires and ligature material that contribute to friction during sliding mechanics and the extent of the amount of force expected to be reduced by friction.^[4,7]

In the present study, the effect of three variables-bracket material, ligation material, and different archwires on frictional resistance was studied. Since frictional resistance at the bracket-archwire interface is mostly affected by these variables.

Majority of investigators used straight length archwire and fixed the bracket over models and draw the straight length archwire through the brackets in the Instron universal testing

machine^[4-15] only few studies used typodont model.^[16,17] This does not fully simulate the clinical reality, because clinically moving teeth during sliding mechanics do not occur in a straight line. The method used in the present study was designed to closely reproduce the clinical situation. A typodont model was used as testing model to simulate orthodontic appliance. The present study was carried out in dry conditions; to achieve results in non-contaminated conditions, as observed in many previous studies.^[6,7,10,12]

The variety of experimental methods used throughout the literature makes it difficult to compare the results of different studies of this type. Frictional resistances measured in the present study were comparable in magnitude and range with those reported by other investigators.^[5,12,18,19]

The ceramic brackets showed the significantly higher frictional resistance ($P<0.001$) compared with stainless steel brackets and ceramic brackets with metal slot. A possible explanation is that ceramics have a higher coefficient of friction than stainless steel because of increased surface roughness, hardness, stiffness and porosity of the material surface. Manufacturing process, finishing, and polishing are also difficult; this might explain the granular and pitted surface of the ceramic brackets.^[20] The ceramic bracket with metal slot showed the intermediate values of the frictional resistance, probably because its slot is reinforced with metal, which prevents direct contact between ceramic and archwire. The metal slot appears to cause the ceramic bracket to behave more like a stainless steel bracket than a conventional ceramic bracket in terms of static and kinetic frictional resistance as reported by Dickson and Jones.^[21] The difference of the frictional force values between the ceramic bracket with the metal slot and the stainless steel brackets can be due to the difficulty in adjusting the metal to the ceramic and to their different expansion coefficients.^[18]

The mode of ligation has significantly influenced the frictional values. Among all the bracket materials with different archwires when ligated with stainless steel ligature showed significantly less frictional resistance than elastomeric module, this finding was in correlation with certain previous studies.^[14,22] Stainless steel ligature tying is subjective and can be variable, but in

the present study all the ligations were done by the same individual and by the same pattern.^[14] In the present study, the bracket-archwire combinations were tested immediately after ligation with elastomeric modules so not much of force decay would have occurred.^[12]

The present study also demonstrated that different archwires used in the study have a significant influence on frictional resistance. Significant differences were found between stainless steel and nickel-titanium archwires in the present study. Nickel-titanium archwires shows higher frictional resistance ($P < 0.001$) than stainless steel archwires these findings were in accordance with the findings of previous studies.^[18,19,23]

Stainless steel archwires have the smoother surface than nickel-titanium so they have less frictional resistance. NiTi archwires have greater surface roughness than compared with stainless steel archwires.^[9,20,23] NiTi archwires are more flexible than stainless steel archwires so they can bind during sliding mechanics and produce more resistance to movement. In the present study, the archwires with RCS shows increased frictional resistance than normal counterpart archwire. One determinant of friction is the angulation of the archwire to the bracket that might create more contact areas or friction components. Redlich *et al.*, reported that higher frictional forces are developed when bracket-archwire angulations increases. Since the bracket-wire angulation was higher in the curved archwire (RCS) compared with the flat archwire, the higher frictional forces with the former could be attributed to that.^[24] Nishio *et al.*, also stated that the magnitude of frictional forces is directly proportional to the angulation increase between the bracket and the archwire.^[18]

Husmann reported that Teflon coating of archwire significantly reduced the frictional resistance compared with uncoated archwire of the same alloy.^[25] This finding was consistent in the present study for both stainless steel and NiTi Teflon coated archwires. This result of the present study was also in agreement with the result of few previous studies.^[13,26] From an orthodontic point of view, Teflon is an anti-adherent and aesthetic material that has excellent chemical inertia as well as good mechanical stability. Since Teflon has a low coefficient of friction, archwires with Teflon coating could possibly reduce frictional resistance.

The practical relevance of this finding might be interesting, given that coating with Teflon has excellent aesthetic properties: The tooth-like colour of Teflon-coated archwires, together with their improved frictional performance, may lead to widespread use of this type of archwires in future orthodontic practice.

CONCLUSIONS

1. The least frictional resistance was observed between stainless steel bracket and Teflon-coated-Stainless-Steel archwire combination ligated by Stainless steel ligature
2. The highest frictional resistance was observed between

Ceramic bracket and NiTi RCS archwire combination ligated by Elastomeric module

3. Ceramic brackets with metal slot and Teflon coated SS archwires seem to be a good alternative to conventional stainless steel brackets and archwires in space closure with sliding mechanics in patients with esthetic demands
4. The archwires with RCS significantly increase the frictional resistance and therefore, other means should be used to control the bite deepening during sliding mechanics, instead of using them.

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