Comparison of the frictional resistance between archwire and different bracket system: An in vitro study

Ajith R. Pillai, Anil Gangadharan, Satheesh Kumar, and Anwar Shah

Department of Orthodontics and Dentofacial Orthopaedics, Azeezia College of Dental Sciences and Research, Kollam, Kerala, India

Address for correspondence: Dr. Ajith R. Pillai, E-mail: ajith_rpillai@yahoo.co.in

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Abstract

Background and Objectives:
The purpose of this study is to evaluate the frictional resistance generated by conventional stainless steel, radiance ceramic bracket, self-ligating and composite brackets using a 0.019 × 0.025 stainless steel straight length wires in a 022 slot and to select brackets based on their frictional characteristic.

Methodology:
In order to conduct this study, four different types of bracket system were selected of the mclaughlin-bennet-trevesi (MBT) discipline. They are Group 1 - stainless steel, Group 2 - composite bracket Group 3 - (American Orthodontics) radiance ceramic bracket Group 4 - self-ligating bracket (SLB) (Empower). In this study, five maxillary brackets of an arch of each type were used. All brackets are 0.022 × 0.028 in preadjusted edgewise appliance which simulates the dental arch. Five brackets were bonded to a stainless steel bar of dimension 150 mm × 25 mm × 3 mm. The bracket-arch wire units were submitted to mechanical test with an Instron universal testing machine 3365. A testing apparatus or holding jig was designed to hold the bracket during the mechanical test. Each sample was pulled at a speed of 6 mm for 1 min. Descriptive statistical information including mean and standard deviation of maximum friction force was calculated for each bracket wire combination.

Interpretation and Conclusion:
The SLB has the least friction among the four groups. The ceramic bracket showed the highest friction followed by stainless steel bracket, composite bracket, and SLB.

KEY WORDS: Instron, orthodontic brackets, stainless steel arch wire

Friction is a force that resists the motion of two objects in contact. Friction has been reported in the orthodontic literature as early as 1960's. The classical works regarding the laws of friction were credited to Coulomb and Morin. Friction exists in two forms - static and dynamic or kinetic friction. Static friction is defined as the force required in initiating a movement, kinetic, or dynamic friction is the force that resists motion. From an orthodontic viewpoint, when a force is applied the static frictional force is the initial force that is generated between the archwire and the bracket; and is one that must be overcome to initiate tooth movement. Dynamic frictional force is the force generated by the sliding of the archwire through the bracket slot, as the tooth is moving in the direction of the applied force. In fixed orthodontic therapy, teeth can be moved by using either retraction archwires, involving minimal friction, or sliding mechanics, in which friction is very considerable. Friction is a factor in sliding mechanics, such as during the retraction of the teeth into an extraction area, active torque, leveling, and alignment, when the archwire must slide through the bracket slots and tubes. During sliding mechanics, the biologic tissues respond,
and tooth movement occurs only when the forces applied exceed the friction on the bracket wire interface. High levels of frictional force could result in the debonding of the bracket, associated with either a small dental movement or no movement at all.

When friction prevents the movement of the tooth to which the bracket is attached, friction can reduce the available force by almost 40%, resulting in an anchorage loss. Therefore, it is essential to understand the impact of friction between the bracket and the wire so that the proper force can be applied to obtain adequate dental movement and optimum biologic tissue response. Friction is a clinical challenge particularly in sliding mechanics. Frictional studies on different parameters such as bracket composition, bracket size, bracket width, interbracket distance, and slot size, second order angulations, ligatio, wet, and dry environment have been carried out.

Composite brackets were introduced during the early 1980's. They are made of acrylics, nylons, epoxies, polysulfones and polycarbonates. They are mainly used for esthetic reasons. They can be used in situations of minimal force and treatment of short duration particularly in adults. Ceramic brackets were first made available in the late 1980s, to overcome the esthetic limitations of the plastic brackets and they are quite durable. Ceramic brackets were introduced in orthodontics to meet increasing esthetic demands, but their incorrect use or their wrong indication can lead to several problems, such as the high friction coefficient between the bracket and the archwire; this can interfere in the orthodontic treatment. All currently available ceramic brackets are composing of aluminum oxide. However, because of their distinct differences during fabrication, there are two types of ceramic brackets, namely, the polycrystalline alumina and the single crystal alumina.[1,2,3,4] The manufacturing process plays a very important role in the clinical performance of the ceramic brackets. The presence of pores, machining interferences, and propagation lines contribute to compromises of bracket use anytime during clinical use.[5] Because production of polycrystalline brackets is less complicated, these brackets are more readily available at present.[2] The most apparent difference between polycrystalline and monocrystalline brackets is in their optical clarity. Single crystal brackets are noticeably clearer than polycrystalline brackets, which tend to be translucent. Fortunately, both monocrystalline and polycrystalline brackets resist staining and discoloration.[2,6]

Self-ligating brackets (SLB) are ligature less system that minimizes the normal force caused by ligation, thereby decreases the resistance to sliding. There are two types of SLB, namely the active one and passive one. The active one has a spring clip that presses against the archwire and the passive one in which the self-ligating clip does not press against the archwire cover.[7] The disadvantage of self-ligation is high friction, high initial force, and slow sliding mechanics due to binding of the archwire.

This study aims to evaluate the friction produced by composite brackets, radiance ceramic brackets where the manufactures claim less friction and conventional brackets (CB) and SLB, in dry fields.

**Methodology**

In order to conduct this study four different types of American Orthodontics bracket system were selected. They are:

1. Group 1: Stainless steel
2. Group 2: Composite bracket
3. Group 3: Ceramic bracket
4. Group 4: SLB.

In this study, five maxillary brackets of each type were used. All brackets are 0.022 × 0.028 in preadjusted edgewise appliance which simulates the dental arch (i.e. the central and lateral incisor, canine, 1st and 2nd premolar brackets). Five brackets were bonded to a stainless steel bar of dimension 150 mm × 25 mm × 3 mm. A gap of 5 mm was maintained between the brackets. Each steel bar had a line scribed parallel to its long axis. This was to aid in aligning the pull of the wire through the bracket so that friction was not induced by adverse tipping or torsion moments. Each bracket was supported on a 0.019 × 0.025 inch stainless steel wire, while the adhesive hardened. This enabled the bracket slot to be aligned along the length of the steel bar and parallel to it. This allowed the slot axis of the bracket to be perpendicular to the surface of the steel bar.

Twenty straight length stainless steel straight length wires which are 0.019 × 0.025-in dimension and 10 cm length were used. That is, one for each sample of five brackets. The brackets were engaged to the arch wire with 3M Unitek elastic module.
The bracket–archwire was submitted to mechanical test with an Instron 3365 Universal testing machine. [Graph 1]. A testing apparatus or holding jig was designed to hold the bracket during the mechanical test. Each sample was pulled at a speed of 6 mm for 1 min. Descriptive statistical information including mean and standard deviation of maximum friction force was calculated for each bracket wire combination.

A new set of bracket and a 10 cm length wire were used for each test run to prevent any distortion of the bracket slot or archwire surface. Each bracket/archwire slot was cleaned with methylated spirit and then dried with compressed air 5 min before each test. The elastomeric ring was placed immediately before each test. A probe was used to close the cover of the bracket vertically for the SLB. In total, 20 test runs were carried out. All tests were done at room temperature.

**Results**

The test result shows that the mean average friction for stainless steel bracket was 9.67, for composite bracket were 8.42, for ceramic 11.41, and for SLB was 6.50. The ceramic bracket showed the highest friction followed by stainless steel bracket, composite bracket and SLB. The SLB showed the least friction. The descriptive of one-way analysis shows that the mean values of friction for conventional stainless steel bracket is (9.67), composite is (8.42), ceramic is (11.4), and self-ligating is (6.5). The confidence interval shows the minimum and maximum friction for the brackets. The value shows that the ceramic brackets are having the highest friction among the four brackets. The SLB show the least friction among the four. The friction in decreasing order is ceramic, conventional stainless steel, composite, and SLB.

**Statistical analysis**

The statistical analysis was performed using SPSS IBM version 20 (Chicago, USA) systems. Then the following analysis was employed to statistically evaluate the results [Tables 1 and 2]:

- ANOVA
- $t$-test.

Since the $P$ value of significance is 0.000 ($P = 0.001$), ANOVA test shows high significance between groups. That is, there is significant difference in friction between conventional stainless steel, composite, ceramic, and SLB.

$t$-test between stainless steel and self-ligating, composite, and ceramic and ceramic and self-ligating shows a high significance.

There was high significant difference in friction between stainless steel and SLB, composite and ceramic brackets, stainless steel and SLB.

**Discussion**

Friction is defined as the resistance to motion when one object moves tangentially to another. A distinction is made between static frictional force—the smallest force needed to start the motion—and kinetic frictional force—the force needed to resist the sliding motion of a solid object over another at a constant speed.[8,9] During sliding mechanics, the factor of frictional resistance is an important counter force to orthodontic tooth movement, and it must be controlled so that lower optimal forces can be applied. Higher frictional resistance requires increasing the orthodontic forces.[10] Studies have shown that the portion of applied force lost due to resistance to sliding can range from 12% to 60%, respectively.[11,12] If the causes of resistance to sliding are better managed and minimized, the reproducibility of the appliance is enhanced, and the resultant increase in predictability reduces chair time.[13,14] Many studies have been carried out to evaluate the factors that influence frictional resistance: Bracket and wire materials, surface conditions of the archwires and the bracket slot, wire section, torque at the wire-bracket interface, type and force of ligation, use of SLB, interbracket distance, saliva, and influence of oral functions.[15]

Friction is a factor associated in all forms of sliding mechanics.[16] Most of the fixed appliances involve some degree of sliding between the bracket and the archwire. Sliding mechanics is employed for space closure in orthodontics for the retraction of individual tooth or a segment of teeth. During overjet reduction, a distally directed force retracts the anterior teeth by sliding an archwire through brackets and tubes in the buccal segments. Significant resistance to movement may arise due to the frictional force that is generated.[17] This force slows or
resists the movement of the archwire through the bracket slots as anterior teeth are retracted and may additionally transmit excessive forces to the posterior anchor teeth which results in a loss of anchorage.[17] 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, increases in forces produce no appreciable increases 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.[18] 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. To explain the friction between wire and bracket, several variables, such as bracket material, wire material and wire section, should be studied. Whenever, sliding occurs frictional resistance is encountered.[19] Friction between the archwire and the bracket is multi factorial which increase or vary with wire size, angulation of wire to bracket, change in wire shape, and change in wire material, bracket width, lubrication, surface roughness, and ligature design. Several techniques have been used to measure the frictional resistance between the archwire and brackets such as dynamometer, a weighted basket or bucket, a force gauge and universal testing machine.[16] In this study, the tests were carried out by Instron universal testing machine. The specific objective of this study is to investigate the influence of frictional resistance by different bracket types. When the leveling of bracket slots is complete, frictional forces may also arise due to other mechanical factors such as increased archwire size,[8] use of rectangular than round archwires,[20] torque present in the archwire, second order displacements,[21] ligation method,[22] force of ligation,[23] and surface roughness.[24]

A variety of experimental models have been used in in vitro frictional studies. Most model systems using fewer than three brackets have not provided sufficient data.[17,21,25,26] Thus, an experimental model using groups of five brackets was designed for this study to simulate the buccal segment of the dental arch. Experiments using models with straight aligned brackets may neglect the influence of the binding effect.[27,28,29]

In an oral environment, brackets and archwires are bathed in saliva. Thus, three-body friction needs to be considered.[30] Kusy and Schafer[31] found that saliva increases frictional coefficients. However, one study found that a significant difference between dry and wet states exists only for a specific combination of brackets and malocclusion.[32] In their study, Kusy and Whiteley[33] they found that human saliva lowered the frictional coefficient for TMA archwires against alumina brackets. Thus, the effects of saliva on frictional force remain unclear.

Bracket design can also additionally influence frictional forces and many studies have shown reduced frictional forces with SLB when compared to CB SLB were introduced in mid-1930’s in the form of Russell attachment, which was intended to reduce ligation time and improve operator efficiency.[34] These SLB are basically ligature less bracket systems and are of two types namely active and passive. Active and passive self-ligation refers to the action of the locking slide or clip on the wire.[15] The aim of the active ligation through the action of a spring clip is to seat the archwire against the back of the bracket slot for rotation and torque control. This results in a reduction in the dimension of the archwire slot and is the reason for a greater percentage of friction when sliding mechanics with active clips are employed where a larger working wire is actively seated to the base of the slot.[35] On the other hand, the passive type of SLB have passive slides, which when closed maintains the lumen of the bracket slot in a full size itself, which in principle aims to minimize friction during all stages of treatment.[35]

In a literature review, studies on frictional characteristics have used numerous test models to mimic the clinical environment, with the predominant test model in most of these studies being a model or bracket assembly having archwires pulled through a single bracket slot only.[36,37] It must be emphasized here that in the actual clinical situation when sliding mechanics are employed, the friction arising from archwire contact when anterior teeth are retracted results not from a single bracket; but more relevantly through the contact in the buccal segment attachments (canine, premolar and first molar buccal tube) or triple bracket assembly.[38,39] To overcome this shortcoming in the interpretation of previous frictional studies with single bracket assemblies, this study evaluated the frictional forces arising between five brackets considering one side of the arch.

Several studies have indicated that passive SLB generate lower frictional forces than active SLB, modified ligatures, and CB systems. Currently, the orthodontic market includes several different types of SLB. Manufacturers and advocates of SLB claim that SLB offers advantages over CB. The most advantageous features proposed with SLB are reduced friction between the archwire and the bracket and full archwire engagement, resulting in faster alignment and space closure. Unfortunately, the literature provides conflicting findings with regard
to friction and treatment efficiency with the use of SLB. While some studies\cite{40} have reported less friction with SLB regardless of bracket angulation, others\cite{22,41} have found that when tipping and angulation are accounted for, these brackets produce similar or higher friction compared with CB.\cite{42,43} Furthermore, a recent systematic review\cite{44} concluded that, in comparison to CB, SLB maintain lower friction only when coupled with small round archwires in an ideally aligned arch. Sufficient evidence; however, has not been found to claim that SLB produce lower friction with large rectangular wires in the presence of tipping and/or torque and in arches with considerable malocclusion. This study shows that the friction produced by the SLB is less compared with others.

Ceramic brackets are currently under development and were originally introduced because of increasing esthetic demands from orthodontic patients. However, their high coefficient of friction has limited their use.\cite{45,22,14} It has been reported that the friction resistance of ceramic brackets is increased by their rough surface conditions. In addition, the chemical characteristics of alumina on a ceramic surface can cause a metal wire to adhere to the alumina surface. In clinical use, however, they have problems including brittleness leading to bracket or tie-wing failure, iatrogenic enamel damage during debonding, enamel wear of opposing teeth, and high frictional resistance to sliding mechanics. Radiance plus is the clearest twin bracket. It proves to be much clearer than other monocrystalline or polycrystalline ceramic system. Each radiance plus bracket is created from a single crystal of pure growth sapphire. It is one of the hardest materials in nature second only to diamond. It is nickel free also. Our results agree with those of previous studies that found that conventional ceramic brackets generated higher frictional resistances than the stainless steel brackets. A possible explanation is that ceramics have a higher coefficient of friction than stainless steel because of increased roughness and porosity of the material surface.\cite{45,46,47}

Eleni bazakidou conducted a study to evaluate the frictional resistance in esthetic brackets and concluded that the composite brackets were found to offer lower frictional resistance than the ceramic and stainless steel brackets, regardless of the wire size, wire alloy, and type of ligation, which is in concurrence with the current study.

Frictional resistance may, however, be an important consideration when an arch wire must simultaneously move through several in-line brackets during extraction site closure. In the present study the brackets compared are conventional stainless steel, composite, ceramic, and SLB. The results show that the ceramic brackets are having more friction and the least for the SLB. The conventional stainless steel bracket is having less friction than ceramic, but more than SLB. While comparing the esthetic brackets composite and ceramic the ceramic brackets are having more friction than composite. However, the long-term efficiency of composite bracket is questionable. In this study, a passive SLB is used, which may be the reason for the reduced friction.

**Conclusion**

This study was carried out to comparatively evaluate the dynamic frictional resistance generated by the conventional, SLB, composite and radiance ceramic bracket with stainless steel archwire under dry testing condition. The result of this study revealed the following findings:

The overall frictional resistance of 0.022 inch slot self-ligating PEA brackets demonstrated the least level of frictional value when compared to other brackets.

- The frictional resistance of ceramic brackets is more than all other brackets.
- Composite brackets are having less friction when compared to conventional stainless steel and ceramic brackets.
- Conventional stainless steel brackets are having less friction than ceramic, but more than composite.

**Summary**

Friction is a parameter that must be overcome when translatory orthodontic movement is desired to better control the desired movement of each tooth by applied force, the frictional contribution of each component of system namely the bracket wire and the environment.

There are so many materials system available to the orthodontist, but in selecting the appliance to a patient we should consider all the factors, since we are dealing with a biologic system. A mutually protected occlusion with maximal intercuspidation in centric relation and incisor and canine guidance during excursions is required for proper function.
It should be always better to select an appliance to the patient according to the anchorage values. In this study, the radiance ceramic brackets show acceptable frictional values so that we can consider this bracket when esthetics is concerned. The orthodontist who begins treatment with the end goals in mind may increase productivity and efficiency by implementing different system into practice. Although, the advantages of the system may improve any treatment approach, the practice that uses predefined goals, specific treatment sequences and individual patient procedures and mechanics should be used.

Footnotes

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Conflict of Interest: None declared.

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Figures and Tables
Comparison of friction between four groups of bracket

Graph 1

Comparison of friction between four groups of bracket
Table 1
ANOVA: Comparison of friction between four groups (ANOVA test)

|                      | Sum of squares | Degrees of freedom | Mean square | F     | Significant |
|----------------------|----------------|--------------------|-------------|-------|-------------|
| Between groups       | 64.04          | 3                  | 21.35       | 49.69 | 0.000       |
| Within groups        | 6.87           | 16                 | 0.430       |       |             |
| Total                | 70.91          | 19                 |             |       |             |

ANOVA: Analysis of variance
Table 2

Within group comparison of friction (t test)

| Groups                          | $T$  | $P$    | Inference         |
|---------------------------------|------|--------|-------------------|
| Stainless steel and composite   | 3    | 0.031  | Significant       |
| Stainless steel and ceramic     | −3.669 | 0.006 | Significant       |
| Stainless steel and self-ligating| 6.204 | 0.000 | Highly significant |
| Composite and ceramic           | −10.348 | 0.000 | Highly significant |
| Composite and self-ligating     | 5.536 | 0.002  | Highly significant |
| Ceramic and self-ligating       | 11.904 | 0.000 | Highly significant |

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