Frictional Resistance of Three Types of Ceramic Brackets

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ABSTRACT

Objectives: To investigate the static frictional resistance at the bracket/archwire interface in two recently introduced bracket systems and compare them to conventional ceramic and conventional metal bracket systems. Three variables were considered including the bracket system, archwire type and archwire angulation.
Material and Methods: Four bracket systems were tested *in vitro*: Self ligating ceramic, ceramic with metal slot and module, conventional ceramic with module and conventional metal with module. A specially constructed jig and an Instron testing machine were used to measure the static frictional resistance for 0.014 inches round and 0.018 x 0.025 inches rectangular stainless steel wires at 0° and 7° angulations.
Main outcome measures: Static frictional force at the bracket/archwire interface; recorded and measured in units of force (Newtons).
Results: Self ligating ceramic and metal slot ceramic bracket systems generated significantly less static frictional resistance than conventional ceramic bracket systems with the wire at both angulations ($P < 0.05$). Changing the wire from 0.014 round to 0.018 x 0.025 rectangular wire significantly increased frictional forces for metal slot ceramic and conventional metal bracket systems ($P < 0.01$). Increasing wire angulation significantly increased frictional resistance at the bracket/archwire interface for all four types of bracket systems tested ($P < 0.001$).
Conclusions: Compared to conventional ceramic, self ligating ceramic and metal slot ceramic bracket systems should give improved clinical performance, matching that of conventional metal brackets.

Keywords: friction; ceramics; orthodontic brackets; corrective orthodontics; orthodontic wires.

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INTRODUCTION

Orthodontic tooth movement relies upon sliding mechanics. Sliding mechanics refers to the sliding between the bracket and the archwire. Whenever sliding occurs, frictional resistance needs to be overcome to initiate tooth movement (static frictional resistance) then maintain tooth movement (kinetic frictional resistance) [1]. Tooth movement requires sufficient applied force to overcome this frictional resistance. Studies have shown that up to 60% of the applied force is lost in overcoming frictional resistance [2].

The total force applied to orthodontic brackets has to be twice that needed to produce an effective force in the absence of friction [3].

Frictional resistance is undesirable in orthodontic tooth movement for several reasons. Friction may result in binding of the archwire in the bracket slot which in turn results in a reduction or inhibition of tooth movement [4]. Friction may result in bowing of the archwire as the retraction force fails to overcome friction resulting in unwanted tilting of teeth [5]. Furthermore, friction may result in anchorage taxation leading to undesirable tooth movement and space loss [6,7].

As a result of this undesirable frictional resistance, bracket systems have attempted to reduce the frictional resistance component in a number of different ways including changes in the surface finish/material of the bracket and different methods of ligation. Added pressure comes from the demand for aesthetic bracket systems which often rely on the use of ceramic brackets. Ceramic brackets have been found to produce significantly more friction than stainless steel ones [6,8]. Previous studies have investigated some of the variables that are thought to influence the frictional force at the bracket/archwire interface. Pizzoni et al. [9] found the selection of bracket design, wire material and wire cross section to significantly influence the forces acting in a continuous arch system. Schumacher et al. [10] suggested that friction was determined mostly by the nature of ligation and not by the dimensions of different archwires. Ligation force may be altered by changing the ligation material or by using self ligating brackets. Pizzoni et al. [9] found that self ligating brackets had a markedly lower friction than conventional brackets at 3°, 6°, 9° and 12° angulations Read-Ward et al. [11] demonstrated that both increases in wire size and bracket/archwire angulation resulted in increased static frictional resistance using three different self ligating brackets and a conventional stainless steel ligated bracket. The same study found saliva, thought to act as a lubricant, to have an inconsistent effect. This effect of salivary lubrication is controversial, Kusy and Saunders [12] stating that experiments conducted in artificial saliva were invalid. Downing et al. [13] found artificial saliva had the effect of increasing the frictional force when compared with the dry state. A number of studies have found that friction is increased by human saliva [12,14], whilst other studies have found saliva to play an insignificant role [15].

Two previously introduced ceramic bracket systems (Clarity™; 3M Unitek, Monrovia, CA, USA and Mystique®; GAC International, Bohemia, NY, USA) have been designed in an attempt to reduce frictional resistance at the bracket archwire interface. Clarity™ ceramic brackets incorporate a metal slot insert along which the archwire slides. Mystique® ceramic bracket system incorporates a self ligating `neoclip' which passively, as opposed to actively with an elastomeric module, holds the archwire in place.

The aims of this study were to investigate the static frictional resistance of three different ceramic bracket systems: self ligating ceramic Mystique®, metal slot ceramic with module Clarity™, conventional ceramic with module (GAC International, Bohemia, NY, USA) and compare them to a conventional metal bracket system (GAC International, Bohemia, NY, USA) with modules. Three different variables were investigated separately including bracket system, archwire angulation and archwire type. The hypothesis tested was that Clarity™ and Mystique® bracket systems would have reduced resistance to sliding compared to conventional ceramic systems.

MATERIAL AND METHODS

Four different bracket systems were tested using 0.022 premolar brackets to eliminate bracket slot size as a variable:

1. A self ligating ceramic bracket system Mystique® using a passive clip (neoclip).
2. A metal slot ceramic bracket system Clarity™ using a conventional elastomeric module.
3. A conventional ceramic bracket system using a conventional elastomeric module.
4. A conventional metal bracket system using a conventional elastomeric module.

Two different variables were investigated:

1. Bracket archwire angulation: each bracket system was tested with 0.018 x 0.025 inches stainless steel wires angulated at 0° and 7°.

Archwire type: round 0.014 inches stainless steel wires and rectangular 0.018 x 0.025 inches stainless steel wires at 0° were tested with each bracket system.

Friction testing

Test brackets were temporarily bonded to blocks of Perspex using superglue and appropriate archwire ligated in place. Care was taken, when ligating the 0.018 x 0.025 wires not to introduce any torque in to the system by ensuring that the wire lay flat in the slot. Each bracket with its associated ligated test strip of arch wire was then carefully removed from the Perspex and the bracket and ligated archwire were cleaned with 95% ethanol to remove any traces of finger grease, then transferred to a specially constructed jig.

The specially constructed jig was used in conjunction with a universal lnstron testing machine to record static frictional resistances. The jig consisted of two metal blocks that were able to slide freely over two internal metal rods (Figure 1). An adjustable screw accommodated for different heights of the brackets ensuring that the test wire lay flat each time. In order to produce consistent alignment of the archwire, one bracket was bonded to the test platform of the jig (Figure 1). Two further brackets, described here as ‘static aligning brackets’, were then bonded in line with the test bracket, using a 0.022 wire gauge to ensure that all 3 brackets were glued in a straight line with the gauge perpendicular to the edge of the test block (Figure 2). The bracket on the test platform was then removed and the remaining 2 static aligning brackets were left in place to aid alignment on placement of the test bracket systems. All bracket systems were tested initially using 0.014 and 0.018 x 0.025 wires at 0° angulation. The wire angulation was then changed to 7° by mounting the static aligning brackets so that the wire lay at 7° from the perpendicular (Figure 2).

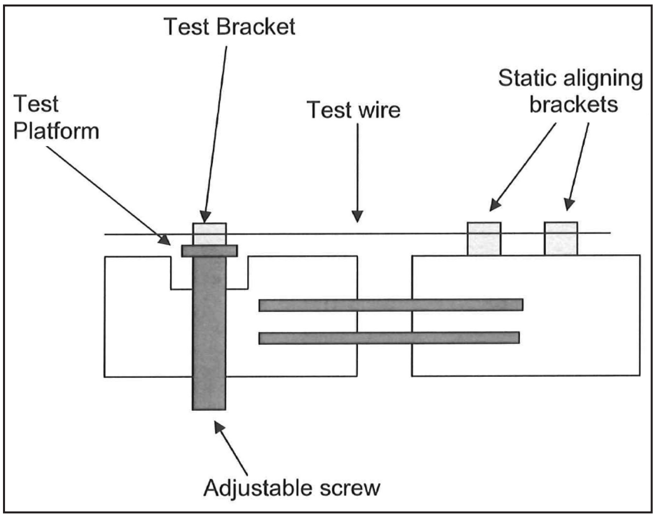

Figure 1. Lateral view of the specially constructed jig.

All brackets and archwires were used from the same batch and each archwire was only used for a single test. 50 frictional tests were undertaken for each bracket system tested with each type of wire at 0° and 7°. This sample size was achieved by using 5 new bracket, ligature and archwire setups and testing the same bracket system ten times with a new archwire. Alignment was checked before each test. The lnstron crosshead speed was set at 0.5 mm/min based on previous work [16].

The force levels were recorded by a computer and displayed as a force displacement graph (Figure 3). The force required to commence movement of the bracket relative to the archwire was taken from a consistent point, the initial peak value (Figure 3). Force values recorded were used to compare the relative influence of each bracket system on resistance to sliding.

Statistical analysis

The effect on static friction of the bracket system was investigated using analysis of variance (ANOVA) and Post Hoc Tukey comparison tests. An unpaired t test was used to analyse the effect of the two variables; wire angulation and wire dimension.

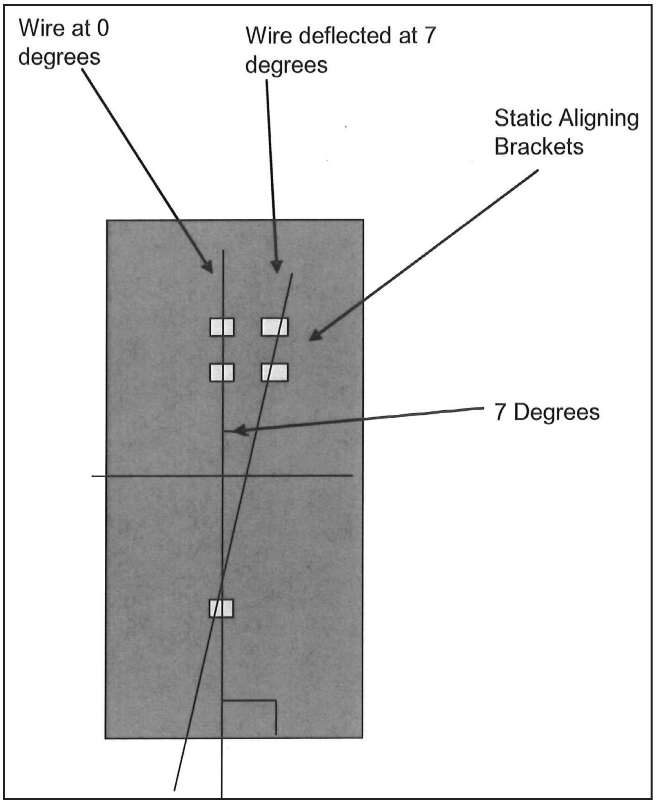

Figure 2. Superior view of the specially constructed jig showing wire without deflection at 0° and deflected at 7°.

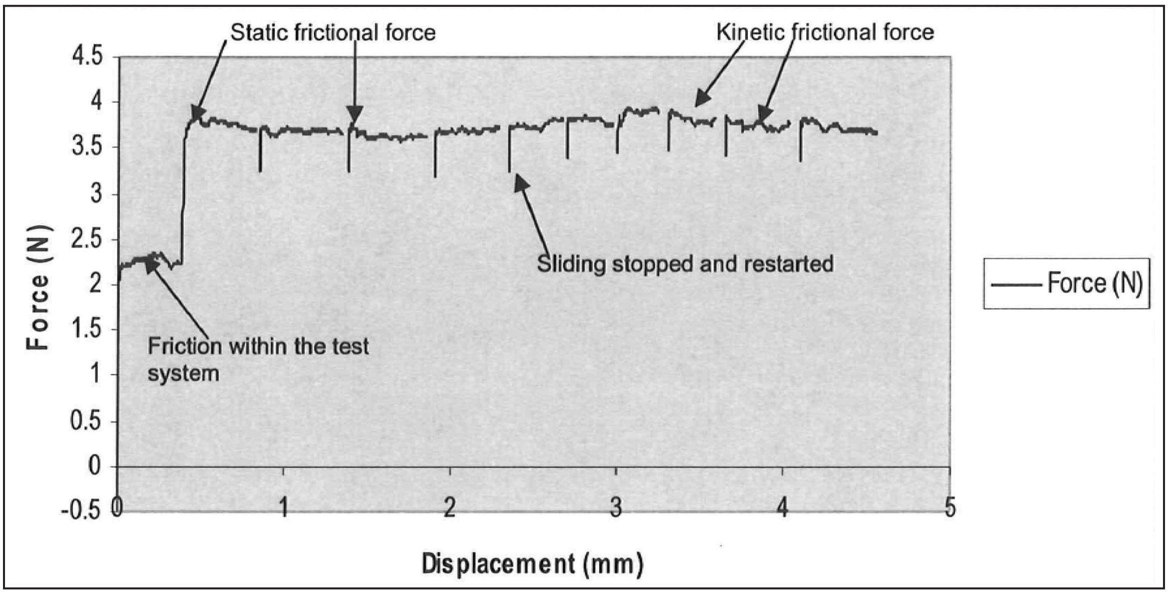

Figure 3. Example of the force-displacement graph pattern using the same bracket (conventional metal) over new stretches of wire. The initial rise in force represents the friction within the test system.

RESULTS

Results are given in Table 1. Figure 3 illustrates an example of a typical graph pattern obtained and shows the point where the static frictional force measurement was taken.

Table 1 shows, using 0.014 wires at 0°, conventional ceramic brackets had the highest static frictional resistance (4.34 N). Static frictional resistances for the self ligating ceramic, metal slot ceramic and conventional metal brackets, using 0.014 wires at 0°, were significantly lower than for conventional ceramic brackets. There was no significant difference in the static frictional forces between conventional metal, self ligating ceramic and metal slot ceramic bracket systems using 0.014 wires at 0° ($P < 0.05$).

Table 1 further showed that with 0.018 x 0.025 wires at 0°, conventional ceramic brackets had the highest static frictional force (4.68 N); this was significantly higher than for conventional metal, metal slot ceramic and self ligating ceramic brackets. Metal slot ceramic and self ligating ceramic, with 0.018 x 0.025 wires at 0°, had the lowest frictional force and no significant difference was found between these two bracket systems. Conventional metal had a significantly higher frictional force than metal slot ceramic and self ligating ceramic with 0.018 x 0.025 wires at 0°.

Using 0.018 x 0.025 wires angulated at 7°, the conventional ceramic had the highest static frictional resistance (9.2 N) followed by metal slot ceramic (8 N) then metal (7.7 N) then self ligating ceramic (6.5 N) (Table 1). Using ANOVA and Post Hoc Tukeys comparison tests, a statistically significant difference was found between all bracket types' frictional values with 0.018 x 0.025 wires angulated at 7°. An unpaired t test ($P < 0.001$) found that, for each type of bracket tested, the mean static frictional force was highly significantly greater with the wires at 7° angulations compared to 0° angulations (Table 1).

The static frictional force values for the 0.014 and 0.018 x 0.025 wire at 0° angulation showed that for conventional ceramic and self ligating ceramic bracket systems there was no significant difference between the mean frictional force values ($P > 0.05$). In contrast, the frictional force values for the metal slot ceramic bracket system were found to be significantly greater with 0.018 x 0.025 wires compared to 0.014 wires ($P < 0.01$). Frictional force values for the metal bracket system were found to be significantly greater with 0.018 x 0.025 wires compared to 0.014 wires ($P < 0.001$) (Table 1).

Table 1. Mean static frictional resistance of 4 bracket systems using 0.014 and 0.018 x 0.025 archwires at 0° and 7°

Bracket system	Mean force (N)* [standard deviation]		
	0° Angulation		7°Angulation
	0.014 wire	0.018 x 0.025	0.018 x 0.025
Self ligating ceramic	2.28^{a} [0.7]	2.92^{c} [0.5]	6.5^{f} [0.1]
Metal slot ceramic	1.76^{a} [0.4]	2.55^{c} [1.1]	8.0^{g} [0.2]
Conventional ceramic	4.34^{b} [0.4]	4.68^{c} [0.6]	9.2^{h} [0.3]
Conventional metal	1.74^{a} [0.4]	3.63^{d} [0.3]	7.7^{i} [0.1]

*Means with the same superscript are not significantly different ($P > 0.05$) using ANOVA and Tukey's multiple comparisons ($N = 50$).

DISCUSSION

This trial took an *in vitro* approach, keeping the method as simple as possible so as not to introduce unneccessary variables. Results obtained mostly compliment previous research suggesting a valid method was employed. However, as expected in most trials of this nature, some variability in the results was found. This may be due to archwire alignment being slightly different each time a new bracket archwire combination was used. The size of the slot is greater than the size of the archwire and with the wire at 0° and not fitting snugly to the sides of the bracket, the wire should only be in contact with the base of the bracket and friction will occur as a result of the wire sliding over this surface. If the wire angulation is increased, more than one surface of the bracket slot will potentially be in contact with the wire and contribute to the frictional force value obtained. Studies have shown the effect of increasing archwire alignment on increasing frictional force values [11,17-21]. This effect was confirmed through the results of this trial where, for each type of bracket tested, the mean frictional force was approximately twice its value for the 7° archwire angulation compared to the 0° archwire angulation (Table 1). Bearing this in mind, the results obtained with the wire purposefully angulated, to create binding of the archwire in the bracket slot, are considered to be more significant than those obtained at 0° where it cannot be guaranteed that the wire is only ever in contact with the base of the bracket.

By using 5 new bracket set ups for each type of bracket, variations in the surface finish or angulation have been accounted for. Brackets were used from the same batch to eliminate manufacturing variations in surfaces finishes. Brackets were retested a maximum of ten times and new brackets of each type were tested. No particular trend was seen on analysis of the force displacement graphs and therefore reuse of the brackets was not considered to affect the validity of the results (Figure 3). Furthermore, it has been shown previously that multiple testing has no adverse effects on wire/bracket couples [22].

The two wires tested had two different variables: archwire size and archwire cross sectional shape. It is therefore not possible to conclude as to whether it is the influence of the size or shape of the wire affecting the force values obtained. Wires would more ideally be compared with the variation either in cross section or in size and at a set increased angulation where it is accepted that binding will occur.

The frictional force is the product of the coefficient of friction and the normal force [23]. The frictional force values obtained and referred to in this trial represent the resistance to sliding. Resistance to sliding may be partitioned into 3 components: classical friction, binding and notching [24]. In a passive configuration, where the contact angle between archwire and bracket slot is less than the critical contact angle, only classical friction is important because binding [17,4] and notching [25] are non existent.

For both types of wire used, the conventional ceramic bracket had the highest frictional force at both wire angulations. This is expected since the nature of ceramic material provides a rougher surface impeding movement of the wire through the bracket slot. It may be predicted that the frictional force for the self ligating bracket, which also has a ceramic slot, would be high. However, results show this is not the case (Table 1). The significantly lower static frictional force value found for the self ligating ceramic bracket system compared to the conventional ceramic bracket is most likely as a result of the ligation method; a self ligating, passive clip (neoclip) being used instead of an elastic module. This passive, as opposed to active, method of ligation is claimed to reduce the frictional force at the bracket archwire interface by reducing the normal force component of friction. This finding confirms previous reports which compared self ligating with conventional ligation using both metal [9] and ceramic brackets [26]. Investigators of the latter study found Mystique® with neoclip produced much less friction than Mystique® used with conventional elastomeric ligatures to level and align a canine with different degrees of severity *in vitro*. This lends further support to the above explanation that the reduced friction of Mystique® with neoclip was due to the self ligating mechanism rather than the type of ceramic.

The results seen in Table 1 show that the metal bracket and metal slot ceramic bracket had lower frictional forces than the conventional ceramic bracket. The metal slot has a smoother surface than ceramic and therefore it will create less frictional resistance to sliding. This agrees with many previous investigations that have shown frictional resistance was reduced by lining the slots of conventional ceramic brackets with stainless steel inserts [27-30]. An unexpected finding was that conventional metal had a significantly higher frictional force than both the metal slot ceramic and self ligating ceramic using rectangular wires at 0° angulation.

Rectangular wires showed a significantly higher frictional force value than round wires for metal and metal slot ceramic bracket systems. This finding confirms previous studies which have shown that frictional forces increase as archwire size increases [4,15,18-21,31,32]. However, change in wire type has given inconsistent results. No significant change in the frictional force value was found, when changing from a round to a rectangular wire using conventional ceramic and self ligating ceramic bracket systems. This may be accounted for by possible errors in archwire angulation with brackets tested at 0° as discussed earlier.

The findings clearly have clinical significance as movement during orthodontic treatment involves a number of tipping and uprighting phases [6] in which static friction creates an unwanted resistance to sliding. Binding will occur between the archwire and the bracket at increased wire angulations; this results in a reduction or inhibition of tooth movement [4].

CONCLUSIONS

- Self ligating ceramic bracket system (Mystique® and neoclip, GAC International, Bohemia, NY, USA) and metal slot ceramic bracket system (Clarity™; 3M Unitek, Monrovia, CA, USA) generate significantly less resistance to sliding than conventional ceramic bracket systems (GAC International, Bohemia, NY, USA) with both 0° and 7° wire angulations. The friction level is comparable with that of conventional metal bracket systems.
- Increasing wire angulation significantly increases resistance to sliding at the bracket/archwire interface. This is of interest when considering how teeth move along the arch wire in a series of tilting and uprighting phases. Results obtained with the wire purposefully angulated at 7° are probably more meaningful than those obtained with the wire at 0°.
- Changing the wire from 0.014 round to 0.018 x 0.025 rectangular wires has significantly increased resistance to sliding for metal and metal slot ceramic bracket systems.

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The author report no conflicts of interest related to this study.

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