

Frictional resistances of different bracket – wire combinations

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Background: It has been suggested that the frictional resistance of ceramic brackets can be reduced by either lining the slots with stainless steel or by contouring the base of the slot.

Objectives: The objectives of this investigation were to compare *in vitro* the static and kinetic frictional resistances of ceramic brackets with metal lined slots ("Clarity", CL), stainless steel brackets ("Miniature Twin", MT), and two ceramic brackets with different slot designs ("Contour", CO; "Transcend", TR).

Method: Two sizes (0.018 x 0.025 inch; 0.021 x 0.025 inch) of stainless steel (SS), nickel titanium (NiTi) and β titanium (β -Ti) wires were drawn through the brackets. All brackets had 0.022 inch slots, and the brackets and wires were used once. The brackets were of different widths: CL, 0.180 inch; CO, 0.114 inch; MT, 0.118 inch; TR, 0.138 inch. An Instron Universal Testing Machine was used in this study.

Results: There were no significant static or kinetic frictional differences when the smaller 0.018 x 0.025 inch wires were drawn through the brackets. There were no statistically significant static or kinetic frictional differences between the CL-CO, CL-MT and CO-MT bracket pairs when the 0.021 x 0.025 inch wires (SS, NiTi, β -Ti) were used. There were no significant kinetic frictional resistance differences between the CL-TR and MT-TR when the SS wires were used. In general the static and kinetic resistances of the 0.021 x 0.025 inch wires of NiTi wire < SS wire < β -Ti wire. Regardless of wire type some of the lowest kinetic resistances were found with the narrow CO brackets with the rounded slot bases. The highest static and kinetic frictional resistances were found with the wide TR bracket, and with stainless steel and β -Ti wires.

Conclusion: The high static and kinetic frictional resistances of ceramic brackets can be reduced either by lining the slots with stainless steel or by reducing the bracket width and rounding the slot base.

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Introduction

Orthodontic brackets play an essential role in transferring forces from archwires to the teeth and the periodontal ligaments. Frictional resistance between brackets and archwires can reduce the force transmitted to the teeth, and may be an important factor determining the amount of force used, particularly during sliding mechanics. The frictional resistance of stainless steel, ceramic, titanium and plastic brackets has been reported to vary.^{1–35} For example, ceramic brackets offer greater resistance to sliding than metal brackets.^{4,5,8,15}

When ceramic brackets were introduced in the 1980's they were readily accepted by the profession and patients because they were less visible than stainless steel brackets, and were stronger and more stain resistant than plastic brackets.⁴ However, ceramic brackets have other limitations. Because they are made of

alumina they are more brittle than metal brackets, and if they fracture during treatment, chair-time may be increased. Furthermore, a potential health risk can exist if fragments are inhaled or swallowed because alumina is radiolucent, and difficult to locate radiographically.¹⁴ To overcome the high frictional resistance of ceramic brackets the slot bases have been either contoured or lined with stainless steel. The latter is supposed to reduce the frictional resistance found with ceramic brackets by providing metal on metal sliding.

The purpose of this study was to compare the static and kinetic frictional resistances of a ceramic bracket with a metal lined slot, two selected ceramic brackets (one with a contoured slot base), and a stainless steel orthodontic bracket. The underlying hypotheses are that ceramic brackets with metal lined slots have similar static and kinetic frictional resistances to all

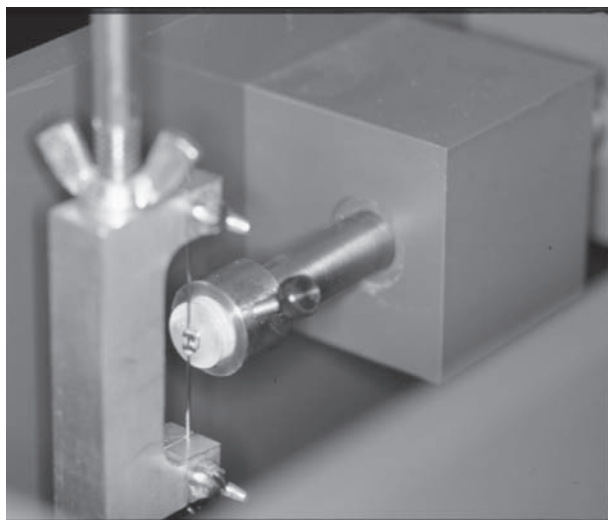


Figure 1. Close-up view of a wire mounted in the C-shaped frame, and a bracket attached to a plastic pedestal.

metal brackets, and less frictional resistance than conventional ceramic brackets.

Materials and methods

This was a dry study conducted at room temperature. To eliminate the influence of wear, each bracket was tested only once and each wire specimen was drawn through one bracket only. Two hundred and forty maxillary premolar brackets with -7 degree torque, 0 degree angulation and 0.022 inch horizontal slots were used. There were equal numbers of: "Clarity" (CL) brackets (3M Unitek, USA), a polycrystalline ceramic bracket with a stainless steel lined slot and a width of 0.180 inch; "Contour" (CO) brackets (ClassOne Zulauf Inc, USA), a ceramic bracket with a rounded slot base and a width of 0.114 inch; "Transend" (TR) brackets (3M, Unitek, USA), a conventional polycrystalline bracket with a width of 0.138 inch; and "Miniature Twin" (MT) brackets (3M Unitek, USA), a sintered stainless steel bracket with a width of 0.118 inch. Straight lengths of resilient stainless steel wire (SS), beta titanium wire (β -Ti) and nickel titanium wire (NiTi) in two sizes, 0.018×0.025 inch and 0.021×0.025 inch, were used (ClassOne Zulauf Inc. USA). All wires were 80 mm in length and were tested only once.

Each bracket was bonded to the centre of a plastic pedestal with "Ducocement" (Devo Consumer products, Rivera beach, Florida, USA), and left overnight to allow the full bond strength to be attained. The

pedestals were then secured in the transverse beam of the Instron Universal Testing Machine (Model # 4468 Instron Corporation, Canton, MA) fitted with a 10 pound tension load cell (Figure 1). The wires were secured in the brackets with elastomeric power modules (TP Orthodontics, La Porte, Indiana, USA) placed with a ligature gun ("Straight-Shooter", TP Orthodontics, La Porte, Indiana, USA) to ensure the modules were stretched uniformly. Each bracket – wire specimen was secured at the top of a specially designed and machined C-shaped frame (University of Pittsburgh, School of Engineering, Pittsburgh, USA), and tensioned by suspending a 300 gm weight from a hook bent into the bottom end of the wire. The lower screw of the C-rod was then tightened, and the weight removed from the hook. The C-frame was then placed in the test apparatus fitted with a Jacobs chuck. To compensate for torque in the brackets the Jacobs chuck was rotated until the test wire was passive in the bracket slot. The Jacobs chuck also allowed the bracket – wire specimen to self-align during each run.

The data acquisition was initiated at least one second before the run began. Each run lasted for two minutes, and the rate of movement of the wire through the bracket was 0.02 inch/minute. The Instron was calibrated before each run. Ten non-repeated measurements were made for each wire – bracket combination. Static frictional force (gm) was the initial maximum resistance, and kinetic frictional force (gm) was calculated from the plateau of resistances as a wire was drawn through a bracket.

A multivariate analysis of variance (MANOVA) was used to compare the static and kinetic frictional resistance of the four bracket types, the three wire alloy combinations and the two wire sizes. The BMDP Release 7.1 (BMDP Statistical Software, Inc. Los Angeles, California, USA) and the SPSS Release 6.1 (SPSS, Inc. Chicago, Illinois, USA) statistical packages were used to perform these comparisons.

Results

The mean static and kinetic frictional forces produced by the different bracket types are given in Table I. Static and kinetic friction were noticeably less for the smaller 0.018×0.025 inch wires compared to the 0.021×0.025 inch wires. There were no significant static or kinetic frictional differences when the

Table 1. Mean static and kinetic frictional forces, in grams.

Static friction 0.022 inch slot							
Bracket	0.018 x 0.025 inch wire size Wire material			Bracket	0.021 x 0.025 inch wire size Wire material		
	SS Mean	NiTi Mean	β -Ti Mean		SS Mean	NiTi Mean	β -Ti Mean
CL	31.0	33.9	65.9	CL	132.8	121.1	271.8
CO	30.7	61.2	65.2	CO	190.8	91.6	217.5
MT	28.8	72.9	51.0	MT	163.1	66.5	321.2
TR	62.4	49.0	79.2	TR	523.4	292.5	797.8
Pairwise comparison				Pairwise comparison			
CL-CO	NS	NS	NS	CL-CO	NS	NS	NS
CL-MT	NS	NS	NS	CL-MT	NS	NS	NS
CL-TR	NS	NS	NS	CL-TR	*	*	*
CO-MT	NS	NS	NS	CO-MT	NS	NS	NS
CO-TR	NS	NS	NS	CO-TR	*	*	*
MT-TR	NS	NS	NS	MT-TR	*	*	*
Kinetic friction 0.022 inch slot							
Bracket	0.018 x 0.025 inch wire size Wire material			Bracket	0.021 x 0.025 inch wire size Wire material		
	SS Mean	NiTi Mean	β -Ti Mean		SS Mean	NiTi Mean	β -Ti Mean
CL	50.3	38.8	117.6	CL	273.8	235.6	626.5
CO	57.2	83.1	126.8	CO	264.7	173.7	325.1
MT	32.3	104.6	90.8	MT	347.9	144.0	526.9
TR	97.4	76.6	142.4	TR	661.1	636.7	1223.5
Pairwise comparison				Pairwise comparison			
CL-CO	NS	NS	NS	CL-CO	NS	NS	NS
CL-MT	NS	NS	NS	CL-MT	NS	NS	NS
CL-TR	NS	NS	NS	CL-TR	NS	*	*
CO-MT	NS	NS	NS	CO-MT	NS	NS	NS
CO-TR	NS	NS	NS	CO-TR	*	*	*
MT-TR	NS	NS	NS	MT-TR	NS	*	*

 * $p < 0.05$

NS, no significant difference

smaller 0.018 x 0.025 inch wires were drawn through the brackets.

When the 0.021 x 0.025 inch wires were tested, the TR brackets had significantly higher static frictional forces than the CL, CO and the MT brackets for all wire types ($p < 0.05$). In general both the

static and kinetic resistances of NiTi wire < SS wire < β -Ti wire.

The mean kinetic resistance for the conventional ceramic bracket (TR) was significantly different from the mean kinetic resistances for the CL, CO and MT brackets when NiTi and β -Ti wires were tested. There

were no statistically significant differences between the CL-TR and MT-TR bracket pairs when the 0.021 x 0.025 inch stainless steel wires were drawn through the brackets. Some of the lowest kinetic resistances were found with the CO brackets with the rounded slot bases.

The β -Ti wire had higher static and kinetic frictional forces for all bracket types than the SS and NiTi wires ($p < 0.05$). In most cases both static and kinetic frictional resistances of this wire were approximately twice those found with the SS and NiTi wires.

Discussion

Sliding mechanics are often used during orthodontic treatment as the major method of tooth movement. When using these mechanics it is important to have an estimate of the frictional resistance of different bracket – wire combinations because the applied force must overcome the frictional force before tooth movement can occur. The present study confirms that the static and kinetic frictional resistances of selected ceramic and metal orthodontic brackets differ, and that brackets with metal lined slots and narrow ceramic brackets with rounded slot bases have less frictional resistance than conventional ceramic brackets. It indicates that while the composition of the bracket is important, other factors, such as the composition and size of the wires, the design of the slot base and, possibly, the width of the brackets may influence frictional resistance.

Several studies have reported that ceramic brackets have a higher frictional resistance than stainless steel brackets.^{2,4–12} The addition of stainless steel inserts to the ceramic CL brackets allowed metal on metal sliding, and appears to have been responsible for reducing the static and kinetic frictional forces to levels found with the narrower all-metal MT brackets. However, our results indicate that the frictional resistance of a narrow all-ceramic bracket with a rounded slot base, such as the CO, was comparable to the frictional resistances of wider brackets with a metal lined slots (CL, MT). The present study does not separate the contributions made to frictional resistance by bracket width, the design of the slot base and manufacturing variations in the wires and brackets.

Previous studies have reported that ceramic brackets have rougher and more porous surfaces and edges than metal brackets. This roughness is thought to

account for the greater frictional resistance of these brackets.⁸ “Remarkable and deep scratches” have been observed on the surfaces of wires drawn through ceramic brackets, whereas wires drawn through metal brackets were only slightly damaged. While the high frictional resistance associated with the all-ceramic TR brackets may be primarily due to mechanical abrasion of the wires, the contribution made to frictional resistance by slot width and other factors cannot be discounted.^{6–9}

Surface roughness of arch wires may be another factor contributing to frictional resistance. For example, nickel titanium wires from different manufacturers have been reported to vary in surface roughness and frictional resistance.²¹ Thus, variations in the manufacturing process of these wires can affect the surface finish and may, as a result, influence the frictional behaviour. Several studies have reported that nickel titanium arch wires have rougher surfaces than β titanium arch wires, although the latter wires have higher static and kinetic frictional forces.^{13–26} It has been suggested that adhesion is primarily responsible for the high coefficient of friction found with β titanium wires.^{20–24}

Several studies support our finding that the frictional resistance of nickel titanium wires are similar to, or slightly less than, that of stainless steel wires,^{17,20} whereas other studies have reported that stainless steel wires have significantly less frictional resistance than nickel titanium and β titanium arch wires.^{15,16} Surface roughness may contribute to these differences, but it is not the only factor. For example, Loftus *et al.*²⁶ attributed the lower frictional force of nickel titanium wires, as compared with stainless steel wires, to differences in the stiffness/flexibility of the two wires. Thus, the greater stiffness of the larger wires may account for the increased frictional resistance of these wires. In the present study no significant differences were found between different bracket – wire combinations with the smaller 0.018 x 0.025 inch wires, but several significant differences were found with the larger, and stiffer, 0.021 x 0.025 inch wires. In agreement with the present study others have reported that frictional forces increase with an increase in wire size,^{21–32} but even this may be an oversimplification. Others, for example, have reported that wire size had a negligible effect on friction providing a wire was not angled to the bracket slot.²⁰

Summary and conclusions

1. The CL ("Clarity") brackets had similar static and kinetic frictional force values to the narrower MT ("Miniature Twin") brackets for both wire sizes, and all wire types.
2. There were no statistically significant frictional differences between the CL, CO ("Contour"), and MT brackets.
3. The TR brackets had significantly higher static and kinetic frictional forces than the CL, CO, and MT brackets when NiTi and β -Ti wires were used.
4. β -Ti wires were associated with higher static and kinetic frictional forces than the SS and NiTi wires in most bracket – wire combinations.
5. Static and kinetic frictional forces increased as wire size increased in most bracket – wire combinations.
6. This study was unable to separate the influence of bracket width and slot contour on frictional resistance.

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