Evaluation of frictional forces between ceramic brackets and archwires of different alloys compared with metal brackets

Ariana Pulido Guerrero[a]
Odilon Guariza Filho[b]
Orlando Tanaka[c]
Elisa Souza Camargo[b]
Sérgio Vieira[c]

[a] Postgraduate Student, Master of Science in Orthodontics at the Pontifical Catholic University of Paraná, Curitiba, PR, Brazil.

[b] Associate Professor; [c] Senior Professor – Dental Program at the Pontifical Catholic University of Paraná, Curitiba, PR, Brazil.

Abstract: The aim of this study was to evaluate, *in vitro*, frictional forces produced by ceramic brackets and arch wires of different alloys. Frictional tests were performed on three ceramic brackets: monocrystalline (Inspire ICE), polycrystalline (InVu), polycrystalline with metal slot (Clarity), and one stainless steel bracket (Dyna-Lock). Thirty brackets of each were tested, all with .022” slots, in combination with stainless steel and nickel-titanium wires .019” × .025”, at 0° and 10° angulation, in artificial saliva. Arch wires were pulled through the slots at a crosshead speed of 10 mm/min. There were statistically significant differences between the groups of brackets and wires studied ($p < .05$). The polycrystalline brackets with metal slots had values similar to those of conventional polycrystalline brackets, and the monocrystalline brackets had the highest frictional forces. The nickel-titanium wires produced the lowest friction. The addition of metal slots in the polycrystalline brackets did not significantly decrease frictional values. Nickel-titanium wires produced lower friction than those of stainless steel.

Descriptors: Orthodontic brackets; Orthodontic wires; Friction.

Introduction

Although more than 70 years have passed since the introduction of stainless steel (SS) brackets, these continue to be the most used in orthodontic practice, owing to their superior working qualities,[1] their only disadvantage, perhaps, being their lack of esthetic appearance.

Nevertheless, ceramic brackets currently represent an esthetic alternative, although their use is limited. They abrade the enamel, and fracture more easily, and they have a higher coefficient of friction, increasing resistance to sliding.[2] Despite manufacturers’ efforts to improve their qualities by incorporating metal slots, dulling the slot edges, and glazing their surfaces, the physical properties of ceramic brackets are still inferior.[3,4] Up to 60% of the force applied for dental movement can be lost as the result of ceramic bracket resistance to sliding,[5-8] leading to a longer treatment period.

In orthodontics, contact between the surfaces of the bracket-wire-ligation set produces a resistance force against the desired dental movement, called friction.[9,10] When there is clearance and no rotations or

Corresponding author:
Sérgio Vieira
Pontifícia Universidade Católica do Paraná
Rua Imaculada Conceição, 1155
Curitiba - PR - Brazil
CEP: 80215-901
E-mail: *s.vieira@pucpr.br*

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inclinations are present, only classic friction is observed.[9,11,12] When there is no clearance, and deflections and damage to the wire are introduced, resistance to sliding is the result of classic friction plus elastic deformation (binding) and plastic deformation (notching),[9,12] which is three times higher in ceramic brackets.[6]

The aim of this study was to evaluate, *in vitro*, frictional forces produced by one metal bracket and three types of ceramic brackets: monocrystalline, polycrystalline, and polycrystalline with metal slots, combined with wires of different alloys.

Material and Methods

Frictional tests were performed on three ceramic brackets and one metal bracket (SS), used as a control (Figure 1). Roth prescription, .022” lower incisor brackets were tested in combination with rectangular wires of two alloys: nickel-titanium (Ni-Ti) and SS, .019” × .025” (Table 1). Each bracket was tested four times and each wire twice.

All testing samples were assembled in a standard way by gluing the brackets with slot-tip angulations of 0° and 10° onto acrylic bases (Figure 2, A, B, C). The 6-cm wire segments were secured into the slots by Super Slick elastomeric ligatures (TP Orthodontics, LaPorte, IN, USA).

Before testing, all samples were cleaned with

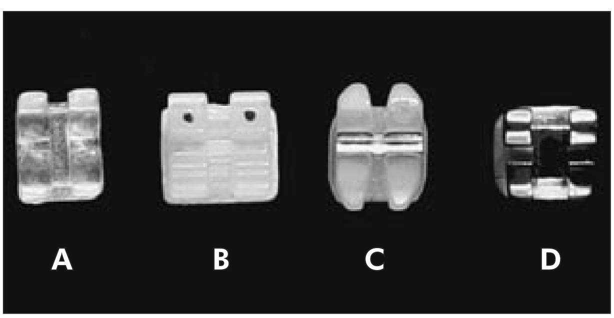

Figure 1 - Brackets described in Table 1.

Table 1 - Materials Used in the Study.

	Material	Composition	N
Bracket	A-Inspire Ice / .022″*	Ceramic/monocrystalline	30
	B-InVu / .022″**	Ceramic/polycrystalline	30
	C-Clarity / .022″***	Polycrystalline/metal slot	30
	D-DynaLock / .022″***	Metal/stainless steel (SS)	30
Wire	.019″ × .025″****	SS	120
	.019″ × .025″****	Nickel titanium (Ni-Ti)	120

* Ormco Corporation, Glendora, CA, USA. **TP Orthodontics, LaPorte, IN, USA. ***3M Unitek Orthodontic Products, Monrovia, CA, USA. **** GAC International Inc., Bohemia, NY, USA.

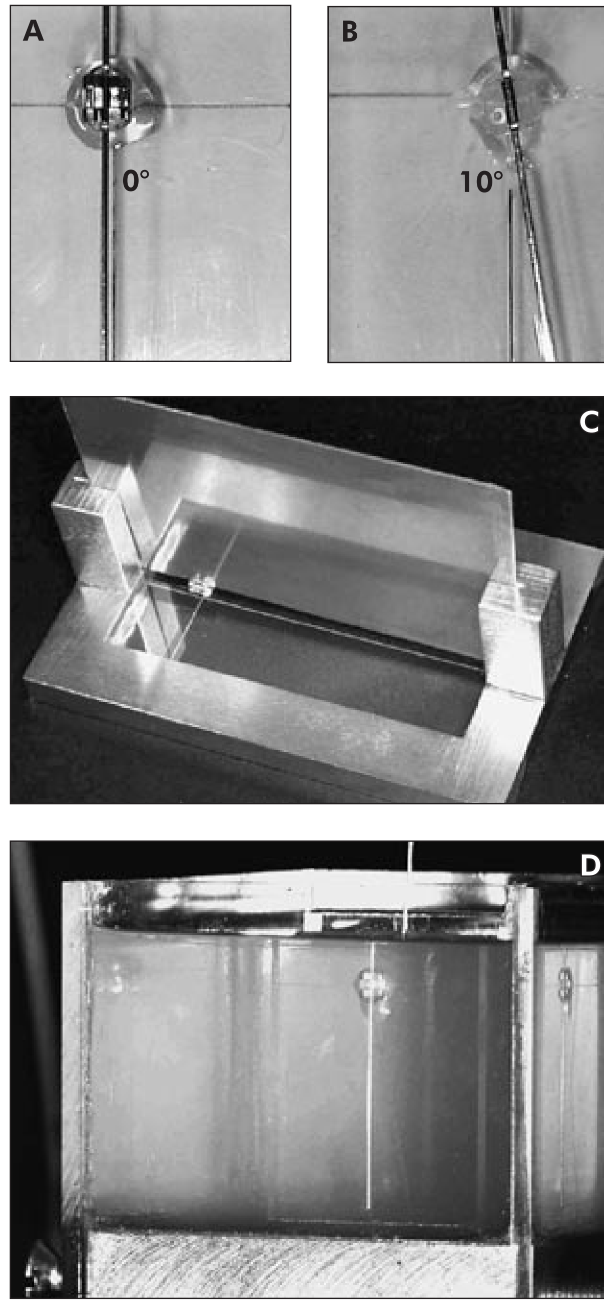

Figure 2 - A. Acrylic bases with slot tip angulations of 0° and 10°; **B**. Bracket positioner with vertical and horizontal reference lines; **C**. Bracket in position; **D**. Glass dowel and sample positioned in artificial saliva.

70% alcohol to eliminate any residue and immersed in saliva for 5 minutes to ensure complete lubrication of the bracket-wire-ligature set. A device was built to allow testing in artificial saliva (0.084% sodium chloride, 0.12% potassium chloride, 0.005% magnesium chloride, 0.015% calcium chloride, 1% carboxymethylcellulose, 100 mL distilled water, 0.18% methylparaben; pH 6.24) (Figure 2, D). The device was adapted to a testing machine, and wires were pulled through the slots at a crosshead speed of 10 mm/min by a clamp connected to a 10-kg load cell that registered static friction values in Newtons (N). The position of the clamp was standardized at a distance of 2 cm from the acrylic base.

Three-way ANOVA with full factorial model was used to evaluate the results of the study. Initially, tests were conducted to assess normality of the variable friction for all groups (Kolmogorov-Smirnov test) and homogeneity of variance between the groups (Levene test). When ANOVA indicated a statistically significant difference, the Games-Howell test for heterogenic variances was used to identify which treatments differed from one another.

Results

From the 16 groups studied, 5 did not show normal distribution because $p < .05$. The Levene test indicated absence of homogeneity of variance between the groups. ANOVA indicated that there were statistically significant differences between the groups ($p < .05$).

Table 2 shows descriptive statistics of the variable friction between nonangulated brackets and the arch wires. We observed that the metal bracket, Dyna-Lock, with the SS wire showed the lowest mean values. There was difference between the groups of Clarity with SS and Ni-Ti, but there was no difference between Dyna-Lock with Ni-Ti, and InVu with SS and Ni-Ti wire combinations. The highest mean values were observed in the Inspire ICE bracket with both alloys. The groups presented significant differences ($p < .05$).

Table 3 shows descriptive statistics of the variable static friction between the 10° brackets and the wires. In this group, the wires were observed to behave differently with the brackets when compared with the 0-angulation group. The lowest mean value was observed in the Dyna-Lock–Ni-Ti wire combination, followed by the InVu with Ni-Ti. Continuing in increasing order, there was no significant difference between the Dyna-Lock with SS, and Clarity and Inspire ICE with Ni-Ti wire combinations. The highest values were observed in the Inspire ICE, Clarity, and InVu brackets with the SS wire alloy, presenting significant differences ($p < .05$).

Tables 4 and 5 show descriptive statistics of the variable static friction between the 10° brackets and the wires, showing differences between the groups ($p < .05$). It was observed that between the alloys tested, Ni-Ti wires produced the lowest mean val-

Table 2 - Descriptive statistics of the variable friction between nonangulated brackets and the arch wires.

Variable	n	N, Mean (*)	SD
DynaLock/SS/0°	30	2.79 a	± 0.51
Clarity/SS/0°	30	3.41 b	± 0.73
InVu/Ni-Ti/0°	30	3.38 b	± 0.49
DynaLock/Ni-Ti/0°	30	3.41 b	± 0.76
InVu/SS/0°	30	3.74 bc	± 0.5
Clarity/Ni-Ti/0°	30	4.02 cd	± 0.65
Inspire/Ni-Ti/0°	30	4.24 de	± 0.64
Inspire/SS/0°	30	4.53 e	± 0.68

Note: (*) Different letters to the right of the means indicate that there were statistically significant differences ($p < .05$) between the groups. SD: standard deviation.

Table 3 - Descriptive Statistics of Variable Static Friction (N), Using 10°-Brackets.

Variable	n	N, Mean (*)	SD
DynaLock/Ni-Ti/10°	30	5.09 a	± 0.67
InVu/Ni-Ti/10°	30	7.54 b	± 0.42
Clarity/Ni-Ti/10°	30	8.40 c	± 1.19
Inspire/Ni-Ti/10°	30	8.63 cd	± 0.69
DynaLock/SS/10°	30	9.14 d	± 1.33
Inspire/SS/10°	30	10.91 e	± 1.02
Clarity/SS/10°	30	11.54 e	± 0.83
InVu/SS/10°	30	11.56 e	± 0.88

Note: (*) Different letters to the right of the means indicate that there were statistically significant differences ($p < .05$) between the groups. SD: standard deviation.

Table 4 - Descriptive Statistics of the Variable Static Friction (N) According to the Wire.

Wire	n	N, Mean (*)	SD
SS	240	7.20 a	± 3.78
Ni-Ti	240	5.59 b	± 2.22

Note: (*) Different letters to the right of the means indicate that there were statistically significant differences ($p < .05$) between the groups. SD: standard deviation.

Table 5 - Descriptive Statistics of the Variable Static Friction (N) According to Angulation.

Angle	n	N, Mean (*)	SD
0°	240	3.69 a	± 0.81
10°	240	9.10 b	± 2.27

Note: (*) Different letters to the right of the means indicate that there were statistically significant differences ($p < .05$) between the groups. SD: standard deviation.

ues, and that friction was approximately doubled for these wires and three times for the SS ones, when the angulation went from 0° to 10°.

Discussion

To start movement between two objects, the static friction produced between them has to be overcome. So, too, does dynamic friction – which is always less than static – so the objects will continue to move. Dental movement is not a continuous event, but it takes place at very slow speeds and for very short distances.[13-15] Therefore, in this study, we considered it more relevant to evaluate static frictional forces than dynamic frictional ones.

Studies that evaluate the friction produced by different brackets and wires diverge a great deal, because of the variety of methodologies,[3,4] variety of alloys tested from different companies,[16] different bracket and wire combinations, medium for testing (dry environment, saliva or substitutes),[17] and whether simulating second- or third-order angulations.[1,4,7,15] This makes it difficult to compare results.

According to other researches, the repeated use of brackets and wires when performing friction tests to evaluate the resistance to sliding forces did not influence the outcomes,[1] and because of this, no trend toward increase or decrease in frictional values has been established.[18,19]

In the present study, all tests were performed in artificial saliva to better simulate oral conditions. Lubricants have a varying effect, depending on the alloy type.[18] In SS alloys, lubricants react with the chromium oxide layer, which provides the wire with a lower coefficient of friction, modifying their surface tension and consequently producing an adhesive effect.[20] In Ni-Ti alloys, they behave differently, providing a lubricating effect that prevents creating strong contacts between surfaces.[20,21]

With respect to wire angulation, the results of this study are in agreement with those of other studies, in which similar or somewhat lower frictional forces were observed for SS wires compared with Ni-Ti wires, when no second order angulation was present.[3,4,18,20,22] When angulations are incorporated, frictional forces increase proportionately, as does the gap between alloys, with the SS wires producing the highest values.[23,24] Despite the rougher surfaces of Ni-Ti wires, they produce lower friction, because other properties, such as hardness and deflection of the wire, help create softer contacts and decrease binding.[21,23,24] Some authors did not find any relation between roughness of the wire and the amount of friction created;[14] however, other studies show different results.[1,25,26]

The composition of the slot is perhaps the most important factor, since the coefficient of friction, which is specific for each pair of materials, depends on it.[6] The present study shows results similar to those of other investigators, who point to SS brackets as the ones producing the lowest frictional forces.[1,3,20,27] This is attributable to the physical properties of the metal, which provide a low coefficient of friction and allow a good surface finish. For this reason, one of the methods used by manufacturers to improve friction levels in ceramic brackets is to incorporate metal slots.

Many studies show that ceramic brackets with SS slots have superior frictional qualities compared with those of conventional ceramic; however, they are not as efficient as metal brackets.[1,4,3,27] Nonetheless, in this study, friction values for ceramic brackets with metal slots (Clarity) were similar to those of conventional ceramic brackets (InVu). This could be because of several factors. Studies have shown that friction in Clarity brackets increases in the wet state.[28] By scanning microscopy, it was also observed that the metal inserts of the brackets do not have a constant width along the slot nor do they extend to the top of it.[29]

There are divergent results regarding mono- and polycrystalline ceramic brackets. Some studies have shown similar friction between metallic and polycrystalline brackets. Other works show similar frictional force between mono- and polycrystalline, or less friction in the polycrystalline than that in the monocristalline, also less friction in the monocristalline.[18,24,25,30] In our study, the highest frictional values were observed in the monocrystalline brackets. Although they have smoother surfaces than the polycrystalline brackets, studies suggest that higher frictional values could be produced by sharp and hard edges created at the intersection of the base and walls of the slot with the external surface of the bracket.[18]

In the present study, Super Slick elastomeric ligatures were used for ligation. They were chosen for the ease of achieving consistency and the reduction of up to 60% of friction at the wire/ligature interface reported when used with saliva, when compared with conventional elastomeric modules.[13] The few studies of these modules present divergent results.[23,30]

The amount of orthodontic force required to move a tooth depends on the amount of friction created. If light forces are desired, the friction level must be kept as low as possible, since heavy loads are difficult to control.[8] Selection of materials with a low coefficient of friction is required to optimize treatment. Frictional values remained high for the ceramic brackets tested when compared with SS. In view of this, cases to be treated with ceramic brackets must be selected with caution, so as not to compromise treatment progress, and the possibilities of and limitations to using ceramic brackets must be discussed with the patient.

Conclusions

1. Metal brackets produced the lowest frictional forces.
2. Metal slots in the ceramic brackets (Clarity) did not effectively reduce friction.
3. Monocrystalline ceramic brackets (Inspire ICE) produced the highest resistance to sliding forces.
4. Resistance to sliding was proportional to the angle created between the bracket and the wire.
5. Ni-Ti wires had the lowest mean frictional force values.

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