ORIGINAL ARTICLE

In vitro evaluation of frictional forces between archwires and ceramic brackets

Clarice Nishio, DDS,[a] Andréa Fonseca Jardim da Motta, DDS, MS,[b] Carlos Nelson Elias, PhD,[c] and José Nelson Mucha, DDS, MS, PhD[d]

Rio de Janeiro, Brazil

The aim of this study was to evaluate the frictional force between orthodontic brackets and archwires. The differences in magnitude of the frictional forces generated by ceramic brackets, ceramic brackets with metal reinforced slot, and stainless steel brackets in combination with stainless steel, nickel-titanium, and beta-titanium orthodontic archwires were investigated. Brackets and wire were tested with tip angulations of 0° and 10°. Friction testing was done with the Emic DL 10000 testing machine (São José do Rio Preto, PR, Brazil), and the wires were pulled from the slot brackets with a speed of 0.5 cm/min for 2 minutes. The ligation force between the bracket and the wire was 200 g. According to the data obtained, the brackets had frictional force values that were statistically significant in this progressive order: stainless steel bracket, ceramic bracket with a metal reinforced slot, and traditional ceramic bracket with a ceramic slot. The beta-titanium wire showed the highest statistically significant frictional force value, followed by the nickel-titanium and the stainless steel archwires, in decreasing order. The frictional force values were directly proportional to the angulation increase between the bracket and the wire. (Am J Orthod Dentofacial Orthop 2004;125:56-64)

Ceramic brackets were introduced in orthodontics to meet increasing esthetic demands,[1,2] 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.[3-6]

Friction is defined as a force that delays or resists the relative motion of 2 objects in contact, and its direction is tangential to the common interface of the 2 surfaces.[5,7,8] There are 2 types of friction: kinetic (dynamic), which occurs during the motion, and static, which prevents the motion.[8-11]

Under normal conditions, the frictional force is proportional to the applied load, depending on the nature of the sliding surfaces,[9] and independent of the contact area between the surfaces and the sliding speed (except at very low speeds).[5] The friction coefficient of a given material couple is the ratio between the tangential force (frictional force) and the normal or perpendicular load applied during the relative motion.[5,12]

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.[5,8,9] 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.[5,6,13] 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.[5,14-17]

Clinically, when stainless steel brackets are used on posterior teeth, in combination with ceramic brackets on anterior teeth, the difference in friction between the steel and the ceramic brackets can result in faster movement of the posterior teeth; this would cause an undesired anchorage loss[7,10,18,19] and an increase of the overbite.[4] If this occurs, posterior anchorage should be

---

[a] Former resident, Department of Orthodontics, Universidade Federal Fluminense, Niteroi, RJ, Brazil; private practice, Rio de Janeiro.

[b] Professor, Department of Orthodontics, Universidade Federal Fluminense, Niteroi, RJ, Brazil.

[c] Professor, Department of Metallurgy Engineering, Universidade Federal Fluminense, Volta Redonda, RJ, Brazil.

[d] Professor and chairman, Department of Orthodontics, Universidade Federal Fluminense, Niteroi, RJ, Brazil.

Reprint requests to: Dr Clarice Nishio, Rua Sacopa 209/501-Lagoa, Rio de Janeiro RJ, Brazil 22471-180; e-mail, cnishio@unisys.com.br.

Submitted, August 2002; revised and accepted, January 2003.
0889-5406/$30.00

doi:10.1016/j.ajodo.2003.01.005

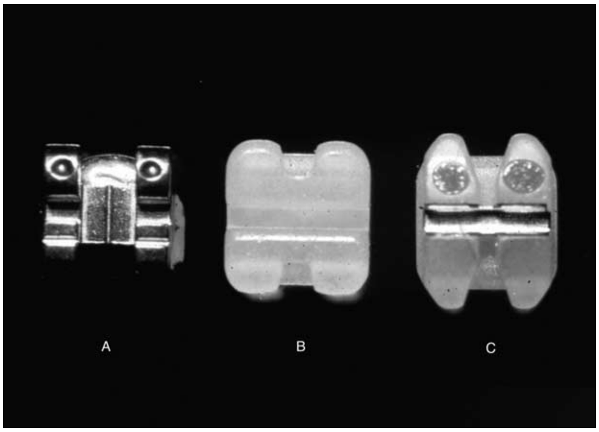

Fig 1. Tested brackets: *A*, stainless steel; *B*, ceramic; *C*, ceramic/metal slot.

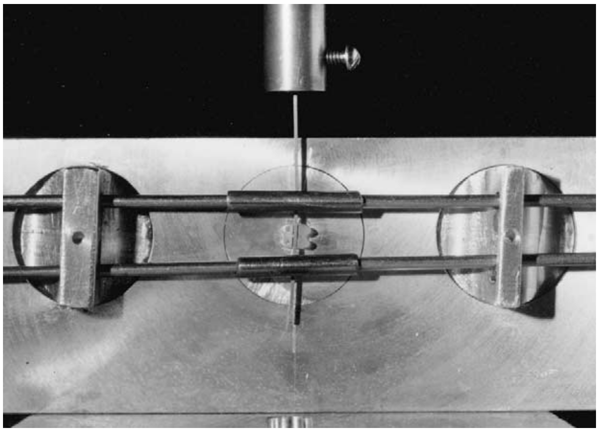

Fig 2. Bracket orientation and method of ligation between bracket and wire.

Table I. Distribution of brackets, wires, sample of brackets, and wires, and mechanical tests of each combination

		Samples		*Mechanical tests*	
		Angulation		*Angulation*	
Brackets	*Orthodontic wires*	*0°*	*10°*	*0°*	*10°*
Stainless steel*	Stainless steel[†]	5	5	25	25
	Nickel-titanium[††]	5	5	25	25
	Beta-titanium[†††]	5	5	25	25
Ceramic/metal slot**	Stainless steel[†]	5	5	25	25
	Nickel-titanium[††]	5	5	25	25
	Beta-titanium[†††]	5	5	25	25
Ceramic***	Stainless steel[†]	5	5	25	25
	Nickel-titanium[††]	5	5	25	25
	Beta-titanium[†††]	5	5	25	25
Total		45	45	225	225

*Victory Series.
**Clarity.
***Transcend series 6000.
[†]-Permachrome Resilient Archwire.
[††]-Nickel-Titanium Super-Elastic Archwire.
[†††]-Beta III Titanium.
All brackets and wires from 3M/Unitek, Monrovia, Calif.

strengthened with devices such as headgear, palatal bars, or Nance holding arches. To decrease the overbite, heavier wires or compensating moments should be used to resist this side effect.[4,20]

Therefore, to reduce the undesirable effects of frictional force, some authors suggest developing ceramic brackets with smoother slot surfaces to decrease any possible effects of static fatigue.[4,6] Recently, a new ceramic bracket was designed with a metal-lined archwire slot,[3] but the studies do not prove its efficiency in reducing frictional force in sliding mechanics.

Thus, we intended to evaluate the frictional force of ceramic brackets, ceramic brackets with metal reinforced slots, and stainless steel brackets using stainless steel, nickel-titanium, and beta-titanium orthodontic archwires, with angulations of 0° and 10° between the bracket and the wire.

MATERIAL AND METHODS

In this study, 30 brackets of each type were used: stainless steel brackets (Victory Series, 3M/Unitek, Monrovia, Calif), ceramic brackets with metal reinforced slot (Clarity, 3M/Unitek), and ceramic brackets (Transcend series 6000, 3M/Unitek). All brackets were .022 × .028-in, standard edgewise canines, with no built-in torque or tip (Fig 1).

Ninety archwire segments, with a 019 × .025-in dimension and 4.0 cm length, of each type were tested: stainless steel (Permachrome Resilient Archwire, 3M/Unitek), nickel-titanium (Nickel-Titanium Super-Elastic Archwire, 3M/Unitek), and beta-titanium (Beta III Titanium, 3M/Unitek).

The wires' displacement resistance was caused by the sliding frictional force produced by the contact between the bracket and the wire surfaces. Five samples of each kind of material were randomly selected to be mechanically tested (Table I).

The bracket-wire combinations were submitted to mechanical tests with the Emic testing instrument (São José do Rio Preto, PR, Brazil), with tip angulations of 0° and 10°. Each bracket and archwire were changed after 5 tests with both angulations. A testing apparatus (Fig 2) constructed of stainless steel was designed to hold the bracket during the mechanical test. Each archwire segment was fixed to a device, which was connected to a load cell of 2.0 kilogram force. The

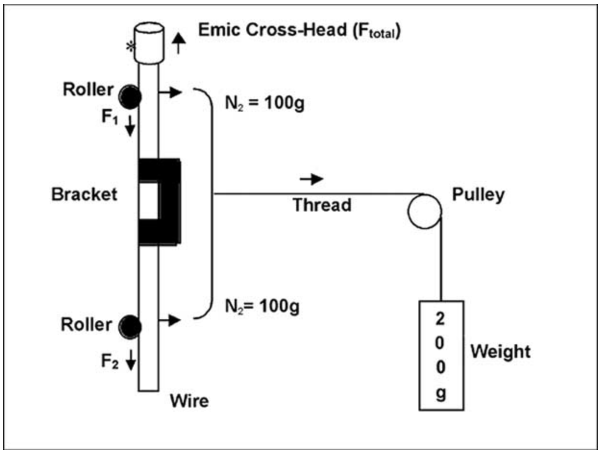

Fig 3. Diagram of testing apparatus and different components of force over bracket and wire. Total compressed force was 200 gf, where: $N_1 = N_2 = 100$ gf; $F = \mu N$; $F_{TOTAL} = F_1 + F_2$; $F_{TOTAL} = \mu_1 N_1 + \mu_2 N_2$; $F_{TOTAL} = \mu_1 100 + \mu_2 100$; $F_{TOTAL} = 200\mu$.

bracket bases were glued to the center of a rotary cylinder with an instantaneous glue (Super Bonder, Loctite Brasil Ltda, São Paulo, Brazil), and the wire segments were positioned perpendicularly in contact with the slot base. Two connected horizontal and parallel steel rollers, which could rotate freely on fine steel supporting rods, were positioned, 1 at each end of the bracket, to pull the archwire against the slot base. For the mechanical tests with 0° angulation, the brackets were placed vertically, so that the wire segments passively touched the bracket slot. After a 10° angulation was evaluated, angles were marked on the rotary cylinder so that the brackets could be placed to achieve an angle of 10° with the wire axle.

The ligature system of the wire to the bracket was standardized, so that the pressure force between the bracket and the wire was constant and equal to 200 gram force (Fig 3). The crosshead speed was 0.5 cm/min, and each test was carried out for 2 minutes. The load cell registered the maximum force level (gram force). This datum was stored on a personal computer and submitted to statistical analysis, applying parametric tests such as Snedecor's F- test, the Bonferroni adjustment ($P < .05$), and the Student *t* test ($P < .05$).[21]

RESULTS

The ceramic bracket showed the highest frictional force value with statistical significance ($P < .05$), followed in decreasing order by the ceramic bracket with metal reinforced slot and the stainless steel bracket (Figs 4 and 5).

The stainless steel archwire had the lowest frictional force values with statistical significance ($P < .05$), followed in increasing order by the nickel-titanium and the beta-titanium archwires. The verified frictional force values were directly proportional to the angle increase between the bracket and the wire (Tables II to IV and Figs 4 and 5).

Figure 3 shows that there are different force components acting on the bracket and the wire. The frictional coefficient could be calculated, because the ligature force between the bracket and the wire was previously determined and patterned with the force of 200 gf. The frictional coefficient had the same pattern as the maximum force means (gf), when used as a frictional force value, at 0° angulation between bracket and wire.

However, when a 10° angulation between bracket and wire was used, other friction components were produced. In addition to the 2 friction resistances that occur when the wire is displaced from the bottom of the bracket, new friction arises when the wire touches the bracket edges (F_3 and F_4), as shown in Figure 6. Because these forces are hard to measure, this frictional coefficient is also difficult to calculate at a 10° angulation between bracket and wire.

DISCUSSION

Many variables can affect the magnitude of the frictional force between the bracket and the wire: (1) archwire: active torque,[5,8,9,13] thickness or vertical dimension,[18,20,22,23] cross-sectional shape and size,[13,24] composition,[25,26] surface texture,[2,10,17,27] elastic properties,[1,13,20] intrinsic lubrication,[17] abrasive wear resistance,[5,15] and manufacturing quality[9,25]; (2) bracket: material,[5,7,28] width,[23,29] dimension,[29] superficial texture,[6,8-10] stiffness,[10] and abrasive wear resistance[5,10,16]; (3) ligation of archwire to bracket: force and ligature type[3,14]; (4) intraoral variables: saliva,[11,12,28,30] plaque,[13,20] acquired pellicle,[13] corrosion,[25] mastication,[31] bone density, tooth number, anatomic configuration, root surface area, and oclusion[20]; and (5) orthodontic appliance: bracket-wire angulation,[11,18,26,32] interbracket distance,[13,23] level of bracket slots between adjacent teeth, forces applied for retraction,[13] and point of force application.[6,29]

In relation to the bracket-wire angulation, the results obtained indicated that the frictional force values were, in all combinations, directly proportional and statistically significant to the angulation increase, suggesting that this factor influences the magnitude of the friction between bracket and wire.[8,18,24,32]

Before the frictional resistance test, the dimensions of 21 units of each type of bracket were measured (width, height, and slot depth) with a projector profile,

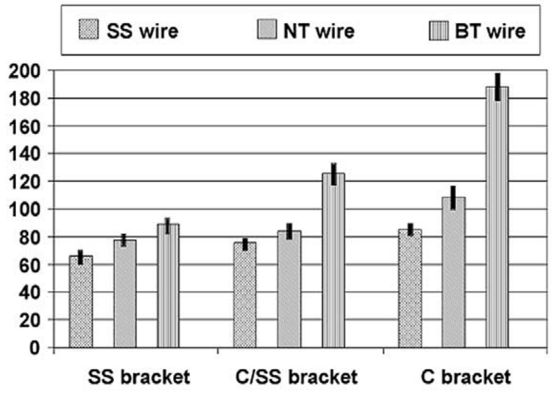

Fig 4. Comparison of frictional force values of stainless steel, nickel-titanium, and beta-titanium wires with 0° bracket-wire angulation.

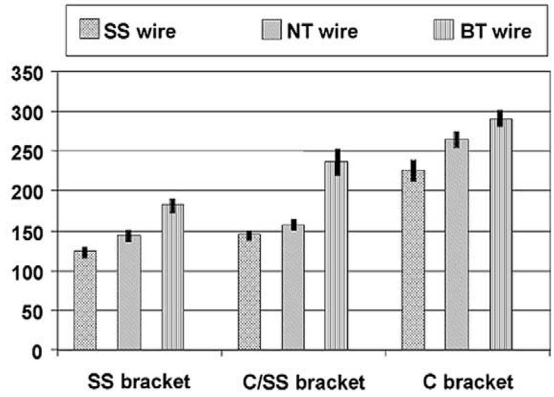

Fig 5. Comparison of frictional force values of stainless steel, nickel-titanium, and beta-titanium wires with 10° bracket-wire angulation.

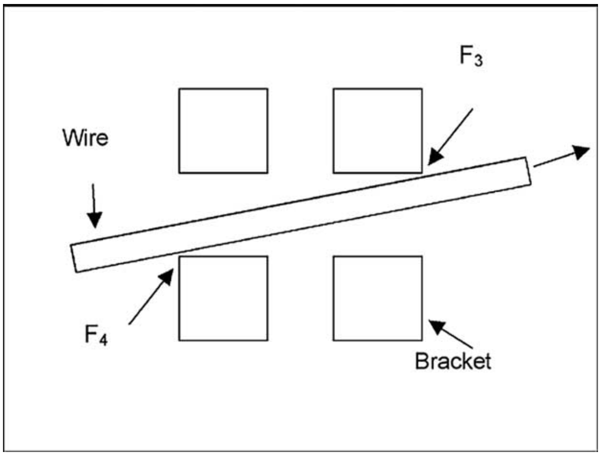

Fig 6. New friction components (F_3 and F_4) produced by 10° angulation between bracket and wire.

and the variations between brackets were evaluated. The slot depth does not seem to influence frictional resistance values; the ligation force between bracket and wire does not depend on this dimension. Although the ceramic brackets are esthetically more pleasing than the metal ones, they are bulkier and, therefore, can be uncomfortable to the patient.

According to these results, in all combinations, the ceramic brackets show the highest level of friction force. They are also the largest in mesiodistal dimension and the smallest in slot height. One cause for the increase of frictional force could be that the ceramic slot is slightly shorter. Although some authors state that the frictional force does not depend on the contact area between the surfaces,[5] others believe that this interferes with the frictional force level.[10,20,23] Larger brackets could offer more contact area between bracket and wire, and could cause small wire inclinations in the slot walls during their displacement, thus creating more attrition components and increasing the frictional force. On the other hand, slots with narrower mesiodistal dimensions could lead to a larger dental inclination, because the mesiodistal movements would be less controlled. Thus, the bracket-wire angulation would be increased, aggravating the attrition between these 2 surfaces. We could not define whether there is a relationship between slot width and frictional force. Consequently, we suggest further research.

Brackets and wires were submitted to electronic micrograph scanning to evaluate the surface morphology. In relation to the brackets, roughness increases in the following order: stainless steel, ceramic bracket with metal reinforced slot, and traditional ceramic, as can be seen in Figures 7, 8, and 9, respectively. The larger frictional force values produced by traditional ceramic brackets, in all combinations and angulations, could be attributed to some ceramic bracket characteristics, such as hardness and stiffness. Manufacturing procedure, finishing, and polishing are difficult to do; this might explain the granular and pitted surface of the ceramic brackets. The ceramic bracket with metal reinforced slot showed the intermediate values of the frictional force, probably because its slot is reinforced with metal, which prevents direct contact between ceramic and wire. The stainless steel brackets had the lowest and statistically most significant frictional force value, maybe because the characteristic of the metal allows better polishing and a smoother surface. The difference of the frictional force values between the ceramic bracket with the metal reinforced slot and

Table II. Frictional force means and standard deviations with 0° and 10° bracket/wire tip angulation

Wire	*Brackets*	*0°*		*10°*	
		Mean	*SD*	*Mean*	*SD*
Stainless steel	SS	65.72	4.77	123.39	7.09
	C-SS	75.47	4.05	144.83	5.82
	C	85.71	4.31	226.04	13.60
Nickel-titanium	SS	77.58	3.91	143.92	7.30
	C-SS	83.96	5.21	157.41	7.27
	C	108.02	8.29	265.69	9.02
Beta-titanium	SS	88.62	5.86	182.53	8.26
	C-SS	125.63	7.88	237.00	7.23
	C	188.12	10.02	291.01	9.07

SD, Standard deviation.
SS, Stainless steel.
C-SS, Ceramic/metal slot.
C, Ceramic.

Table III. Comparison of frictional force between groups with 0° and 10° bracket/wire tip angulation (*Bonferroni* adjustment)

Comparison between groups		*Values*	
		0°	*10°*
Stainless steel	SS × C-SS	9.75*	21.45*
	SS × C	19.99*	102.65*
	C-SS × C	10.24*	81.21*
Nickel-titanium	SS × C-SS	6.38*	13.48*
	SS × C	30.44*	121.77*
	C-SS × C	24.06*	108.28*
Beta-titanium	SS × C-SS	37.01*	54.47*
	SS × C	99.50*	108.48*
	C-SS × C	62.49*	54.01*

*Statistically significant difference, $P < .05$.
SS, Stainless steel; *C-SS,* ceramic/metal slot; *C,* ceramic.

Table IV. Comparison of maximum frictional forces means (gf), between 0° and 10° Student *t* test

Description		*Mean*		t values
		0°	*10°*	
Stainless steel	SS	65.72	123.38	33.73*
	C-SS	75.47	144.83	48.91*
	C	85.71	226.04	49.18*
Nickel-titanium	SS	77.58	143.92	40.05*
	C-SS	83.96	157.41	41.06*
	C	108.02	265.69	64.35*
Beta-titanium	SS	88.62	182.53	46.36*
	C-SS	125.63	237.00	52.07*
	C	188.12	291.00	38.08*

*Statistically significant difference, $P < .05$.
SS, Stainless steel; *C-SS,* ceramic/metal slot; *C,* ceramic.

the stainless steel brackets can be due to the difficulty in adjusting the metal to the ceramic and to their different expansion coefficients. Therefore, it is believed that smoother surfaces can produce less frictional force when in contact with a similar surface morphology. Several studies corroborate the current results.[2,7-9,17,22,28,33]

When orthodontic wires were submitted to electronic micrograph scanning, it was observed that the rougher surfaces, in increasing order, were stainless steel, nickel-titanium, and beta-titanium (Fig 10). As the frictional force results in the same increasing order, it seems to exert an influence on the wire surface roughness, about which many authors agree.[2,8,9,13,17,18,20,22,33] In addition, it is believed that wire surface roughness also affects sliding mechanics, causes corrosion, and jeopardizes esthetics and biocompatibility.[34]

Some authors state that the increasing thickness of the wire produces greater frictional force values, and that rectangular wire generally shows higher values than the round wires, because there is a larger contact area between slot and wire surfaces.[8,9,13,18,20,22-24] Others believe that frictional force does not depend on the contact area.[5] This variable could not be analyzed because we used rectangular wires in this study. However, this should be studied, because thinner wires could increase the bracket-wire angulation and, consequently, increase the frictional force.

Before the frictional force test, the thickness and the width of the wire were measured by a digital pachymeter at 3 standard points. All the samples had the same dimensions (0.019 × 0.025 in) between the reference points. Therefore, the frictional force values were probably influenced by the surface morphology and, later, by the thickness variation, because all wires showed homogeneity in dimension and in manufacturing quality.

With more flexible orthodontic wires, the frictional force magnitude could present a slight increase. Some authors justify this relationship based on the supposition that less rigid wires could cause a greater dental inclination and a larger contact area between bracket and wire.[2,20] On the other hand, more rigid wires could cause higher friction, because the lack of flexibility could create sharper angles and increase the sliding mechanics displacement resistance. The elastic properties do not seem to explain the behavior of the beta-titanium, because this alloy is more rigid than nickel-titanium and more flexible than stainless steel, demonstrating greater friction force values in all combinations and angulations, in

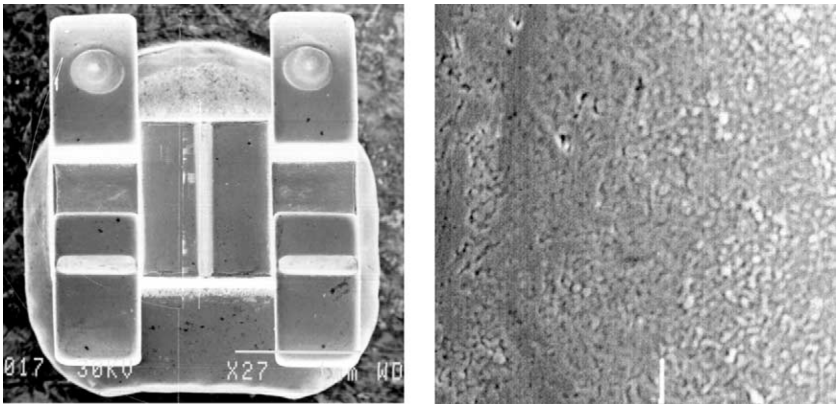

Fig 7. Surface morphology of stainless steel bracket: **A**, front view (27×), and, **B**, slot (200×).

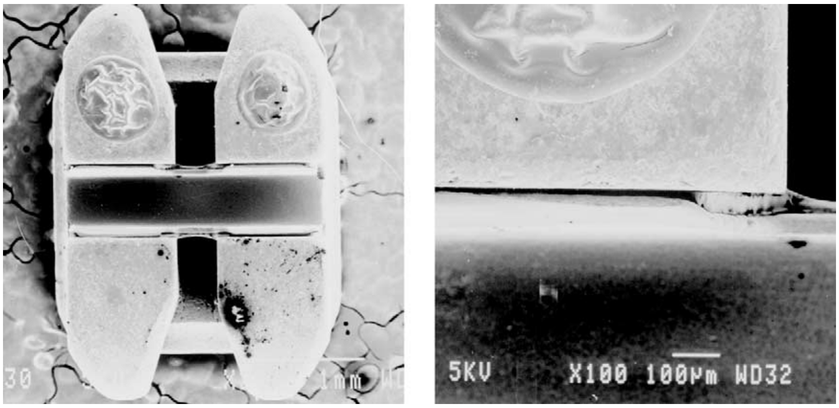

Fig 8. Surface morphology of ceramic bracket with metal reinforced slot: **A**, front view (27×), and, **B**, bracket/slot (100×).

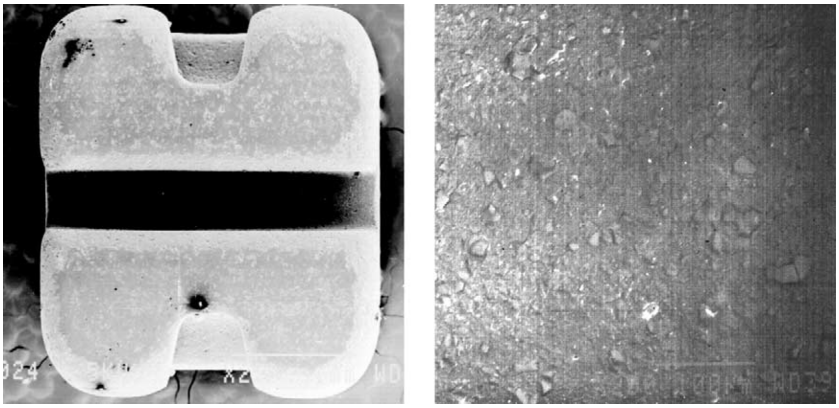

Fig 9. Surface morphology of ceramic bracket: **A**, front view (27×), and, **B**, slot (200×).

accordance with the literature.[2,20] Stainless steel wires, despite their lower flexibility, show the lowest friction force values. Therefore, it seems that the elastic properties of the wire are secondary, and the surface texture has more influence on frictional force.

Each bracket-wire combination was submitted 5 times to the mechanical test to evaluate material wear

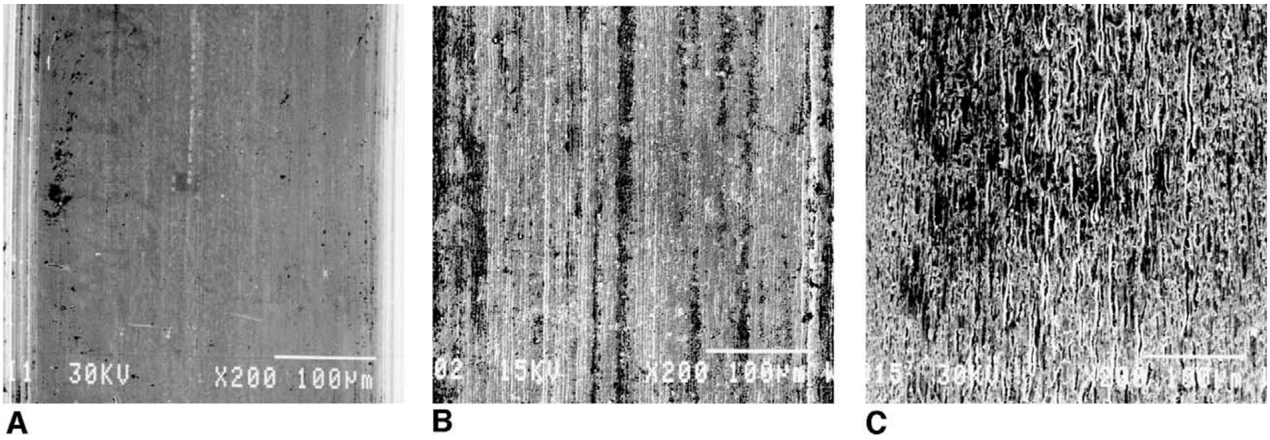

Fig 10. Surface morphologies of **A**, stainless steel archwire (200×), **B**, nickel-titanium archwire (200×), and **C**, beta-titanium archwire (200×).

resistance. This methodology was adopted because, in clinical conditions and during sliding mechanics, the same bracket slides on the wire, or vice versa, several times in a period determined by the treatment objectives. Some authors believe that repeated use could cause wear to the bracket or wire surface,[5,15] making them smoother and, consequently, decreasing the frictional force. Others believe that repeated use produces grooves and surface wear, thus the materials become rougher and the frictional force increases.[2] Our results showed that there was no difference in the frictional force values with repeated use, suggesting that there is no correlation between these 2 factors.

The ligation between bracket and wire is another variable that could influence the frictional force level. Authors are unanimous in reporting that the force used through stainless steel ligature is subjective, varying according to the orthodontist,[7,10] and it can fracture ceramic brackets.[35] On the other hand, elastomeric ligature loses elasticity with time and can alter the frictional force values. In this study, the ligation between bracket and wire was standardized to eliminate this variable.

Ceramic brackets, mainly the polycrystalline ones, can be improved to decrease the frictional force by reducing the alumina particle dimensions to prevent the loosening of fragments, applying a glazed surface on the ceramic slot, inserting either a metal or a gold slot into the ceramic bracket, eliminating the flaws inherent to its size,[27] and making the bracket edges smoother and rounder, not sharply rectangular.[6] Even with ceramic bracket advancements, some clinical complications, such as enamel abrasion and ceramic stiffness, are still a challenge.

The ceramic bracket with metal reinforced slot seems to be a promising option to lessen the clinical complications of ceramic brackets. The advantages of a stainless steel slot are to minimize the superficial friction and to help strengthen the bracket to withstand routine orthodontic torque forces. Furthermore, the bracket base also incorporates a vertical slot, designed to help create a consistent bracket failure mode during debonding.[3] Essentially, this new bracket is meant to combine the esthetic advantages of ceramic and the functional advantages of metal brackets.[36] However, more studies are necessary to allow the orthodontist to use this accessory safely and efficiently. When this bracket was submitted to electronic micrograph scanning, a gap between the bracket and metal slot was observed (Fig 8, *B*). Perhaps it occurred because of the difficulty in adjusting the metal to the ceramic and the different expansion coefficients of the materials. Therefore, it is doubtful that this flaw in adaptation can influence the frictional force magnitude, or even if it can cause pigmentation between the bracket and metal slot, by either extrinsic factors or metal corrosion.

Until the use of ceramic brackets is safe and efficient, orthodontists must apply weightless and continuous forces during sliding mechanics,[13,14,17,18] as close as possible to the center of resistance, to prevent dental inclination and to reduce the frictional force between bracket and wire.[6]

Because frictional force is caused by several factors, which are usually correlated and dependent, these factors can also influence and create undesirable behavior in the frictional force values. Moreover, it is difficult to compare studies, because of different methodologies; these variables can be considered as influencing factors in data registers.

Intraoral variables such as saliva, plaque, acquired pellicle, corrosion, chewing, bone density, tooth number, anatomic configuration, root surface area, and occlusion were not evaluated in this study, but they can influence frictional force values.

In vitro studies do not correspond to what really happens during dental movement, and, therefore, readers must be careful when evaluating the results from this research. The friction magnitude recorded is substantially different from the applied forces in clinical orthodontic movement. The values recorded should be used to compare the effects of different factors, rather than to quantify in vivo friction.

CONCLUSIONS

Under the conditions of the experiment, it can be inferred that:

1. The stainless steel bracket had the lowest statistically significant frictional force values ($P < .05$), followed by ceramic bracket with metal reinforced slot. The traditional ceramic bracket showed the greatest statistically significant frictional resistance values ($P < .05$) in all tested combinations.
2. The stainless steel archwires had the lowest statistically significant frictional force values ($P < .05$), followed, in increasing order, by nickel-titanium and beta-titanium archwires, in all evaluated combinations.
3. The magnitude forces (gf) to displace the wires in the brackets were directly proportional and significant to the angle increase between the bracket and the wire. The values were higher in the 10° angulation between the bracket and the wire than in the 0° angulation.
4. The ceramic bracket with metal reinforced slot had a lower frictional force value than did the traditional ceramic bracket, and it seems to be a promising alternative to solve the problem of friction.
5. The difference in frictional force values between the ceramic bracket with metal reinforced slot and the stainless steel bracket is probably caused by the lack of a perfect adjustment and a gap between the metal slot and the ceramic bracket.
6. Additional studies are necessary to improve the metal slot adjustment in the ceramic bracket, as well as its clinical performance, which influences the frictional resistance values.

We thank 3M Unitek Corporation, Engineering Military Institute/Brazil, Metallurgical Engineering School-UFF/Brazil, and Research and Development Army Institute/Brazil for their support of this study.

REFERENCES

1. Mundstock KS, Sadowsky PL, Lacefield W, Bae S. An in vitro evaluation of a metal reinforced orthodontic ceramic bracket. Am J Orthod Dentofacial Orthop 1999;116:635-41.
2. Loftus BP, Årtun J, Nicholls JI, Alonzo TA, Stoner JA. Evaluation of friction during sliding tooth movement in various bracket-arch wire combinations. Am J Orthod Dentofacial Orthop 1999;116:336-45.
3. Bishara SE, Olsen ME, VonWald L, Jakobsen JR. Comparison of the debonding characteristics of two innovative ceramic bracket designs. Am J Orthod Dentofacial Orthop 1999;116:86-92.
4. Ghafari J. Problems associated with ceramic brackets suggest limiting use of selected teeth. Angle Orthod 1992;62:145-52.
5. Keith O, Jones SP, Davies EH. The influence of bracket material, ligation force and wear on frictional resistance of orthodontic brackets. Br J Orthod 1993;20:109-15.
6. Tanne K, Matsubara S, Hotel Y, Sakuda M, Yoshida M. Frictional forces and surface topography of a new ceramic bracket. Am J Orthod Dentofacial Orthop 1994;106:273-8.
7. Bednar JR, Gruendeman GW, Sandrik JL. A comparative study of frictional forces between orthodontic brackets and archwires. Am J Orthod Dentofacial Orthop 1991;100:513-22.
8. Ho KS, West VC. Frictional resistance between edgewise brackets and archwires. Aust Orthod J 1991;12:95-9.
9. Downing A, McCabe JF, Gordon PH. A study of frictional forces between orthodontic brackets and archwires. Br J Orthod 1994; 21:349-57.
10. Omana HM, Moore RN, Bagby MD. Frictional properties of metal and ceramic brackets. J Clin Orthod 1992;26:425-32.
11. Tselepis M, Brockhurst P, West VC. Frictional resistance between brackets and archwires. Am J Orthod Dentofacial Orthop 1994;106:131-8.
12. Baker KL, Nieberg LG, Weimer AD. Frictional changes in force values caused by saliva substitution. Am J Orthod Dentofacial Orthop 1987;91:316-20.
13. Vaughan JL, Duncanson MG, Nanda RS, Currier GF. Relative kinetic frictional forces between sintered stainless steel brackets and orthodontic wires. Am J Orthod Dentofacial Orthop 1995; 107:20-7.
14. Bazakidou E, Nanda RS, Duncanson MG, Sinha P. Evaluation of frictional resistance in esthetic brackets. Am J Orthod Dentofacial Orthop 1997;112:138-44.
15. Kapur R, Sinha P, Nanda RS. Comparison of frictional resistance in titanium and stainless steel brackets. Am J Orthod Dentofacial Orthop 1999;116:271-4.
16. Kapur R, Sinha P, Nanda RS. Frictional resistance in orthodontic brackets with repeated use. Am J Orthod Dentofacial Orthop 1999;116:400-4.
17. Pratten DH, Popil K, Germane N, Gunsolley JC. Frictional resistance of ceramic and stainless steel orthodontic brackets. Am J Orthod Dentofacial Orthop 1990;98:398-403.
18. Ogata RH, Nanda RS, Duncanson MG, Sinha PK, Currier GF. Frictional resistances in stainless steel bracket-wire combinations with effects of vertical deflections. Am J Orthod Dentofacial Orthop 1996;109:535-42.
19. Taylor NG, Ison K. Frictional resistance between orthodontic brackets and archwires in the buccal segments. Angle Orthod 1996;66:215-22.
20. Drescher D, Bourauel C, Schumacher HA. Frictional forces between bracket and arch wire. Am J Orthod Dentofacial Orthop 1989;96:397-404.
21. Rodrigues PC. Bioestatística. Niterói: Eduff; 1993.
22. Angolkar PV, Kapila S, Duncanson MG, Nanda RS. Evaluation

of friction between ceramic brackets and orthodontic wires of four alloys. Am J Orthod Dentofacial Orthop 1990;98:499-506.

23. Frank CA, Nikolai RJ. A comparative study of frictional resistances between orthodontic bracket and arch wire. Am J Orthod Dentofacial Orthop 1980;78:593-609.
24. Pizzoni L, Ravnholt G, Melsen B. Frictional forces related to self-ligating brackets. Eur J Orthod 1998;20:283-91.
25. Bourauel C, Drescher D, Plietsch R. Surface roughness of orthodontic wires via atomic force microscopy, laser specular reflectance, and profilometry. Eur J Orthod 1998;20:79-92.
26. Dickson JA, Jones SP, Davies EH. A comparison of the frictional characteristics of five initial alignment wires and stainless steel brackets at three bracket to wire angulations—an in vitro study. Br J Orthod 1994;21:15-22.
27. Kusy RP, Whitley JQ, Mayhew MJ, Buckthal JE. Surface roughness of orthodontic archwires. Angle Orthod 1988;58:33-45.
28. Kusy RP, Whitley JQ. Influence of fluid media on the frictional coefficients in orthodontic sliding [abstract]. J Dent Res 1992; 71:169.
29. Yamaguchi K, Nanda RS, Morimoto N, Oda Y. A study of force application, amount of retarding force, and bracket width in sliding mechanics. Am J Orthod Dentofacial Orthop 1996;109: 50-6.
30. Downing A, McCabe JF, Gordon PH. The effect of artificial saliva on the frictional forces between orthodontic brackets and archwires. Br J Orthod 1995;22:41-6.
31. Braun S, Bluestein M, Moore K, Benson G. Friction in perspective. Am J Orthod Dentofacial Orthop 1999;115:619-27.
32. Ward G, Jones SP, Davies EH. Comparison of the static frictional resistance of self-ligating and stainless-steel ligated systems [abstract]. J Dent Res 1995;74:839.
33. Ireland AJ, Sherriff M, McDonald F. Effect of bracket and wire composition on frictional forces. Eur J Orthod 1991;13:322-8.
34. Bordeaux JM, Moore RN, Bagby MD. Comparative evaluation of ceramic bracket base designs. Am J Orthod Dentofacial Orthop 1994;105:552-60.
35. Swartz ML. Ceramic brackets. J Clin Orthod 1988;22:82-8.
36. Bishara SE, Olsen ME, VonWald L. Evaluation of debonding characteristics of a new collapsible ceramic bracket. Am J Orthod Dentofacial Orthop 1997;112:552-9.