ORIGINAL ARTICLE

Evaluation of friction of conventional and metal-insert ceramic brackets in various bracket-archwire combinations

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The purpose of the study was to measure and compare the level of frictional resistance generated between conventional ceramic brackets (Transcend Series 6000, 3M Unitek, Monrovia, Calif), ceramic brackets with stainless steel slot (Clarity, 3M Unitek), conventional stainless steel brackets (Victory Series, 3M Unitek), and 3 different orthodontic wire alloys: stainless steel (stainless steel, SDS Ormco, Glendora, Calif), nickel-titanium (Ni-Ti, SDS Ormco), and beta-titanium (TMA, SDS Ormco). All brackets had a 0.022-in slot, and orthodontic wire alloys were tested in 3 different sections: 0.016 in, 0.017 × 0.025 in, and 0.019 × 0.025 in. Each of the 27 bracket-archwire combinations was tested 10 times, and each test was performed with a new bracket-wire sample. Static and kinetic friction were measured on a specially designed apparatus. All data were statistically analyzed (analysis of variance and Scheffé for the bracket effect, Kruskal-Wallis and Mann Whitney for the alloy and section effects). Metal-insert ceramic brackets generated significantly lower frictional forces than did conventional ceramic brackets, but higher values than stainless steel brackets, in agreement with the findings of the few previous reports. Beta-titanium archwires had higher frictional resistances than did stainless steel and nickel-titanium archwires. No significant differences were found between stainless steel and nickel-titanium archwires. All the brackets showed higher static and kinetic frictional forces as the wire size increased. Metal-insert ceramic brackets are not only visually pleasing, but also a valuable alternative to conventional stainless steel brackets in patients with esthetic demands. (Am J Orthod Dentofacial Orthop 2003;124:403-9)

Friction is defined as the resistance to motion when 1 object moves tangentially against 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 1 solid object over another at a constant speed.[1-4]

During sliding mechanics, the factor of frictional resistance is an important counterforce 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.[5]

Studies have shown that the portion of applied force lost due to resistance to sliding can range from 12% to 60%.[6-7] 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.[8-9]

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 self-ligating brackets, interbracket distance, saliva, and influence of oral functions.[10-13]

Ceramic brackets were developed to improve esthetics during orthodontic treatment. 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.[14-21] Polycrystalline ceramic brackets with stainless steel inserts in the slot were recently developed to

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Table I. Study design

Wire alloys	Wire sections (in)	Brackets (n) Victory	Transcend 6000	Clarity
Stainless steel	0.016	10	10	10
	0.017 × 0.025	10	10	10
	0.019 × 0.025	10	10	10
Beta-titanium	0.016	10	10	10
	0.017 × 0.025	10	10	10
	0.019 × 0.025	10	10	10
Nickel-titanium	0.016	10	10	10
	0.017 × 0.025	10	10	10
	0.019 × 0.025	10	10	10

combine the frictional characteristics of stainless steel with the esthetics of ceramics.[22]

Because previous studies on those modified ceramic brackets were carried out with either 1 type of wire material[22,23] or different wire alloys having the same sections,[4] a pertinent question is: how do these brackets compare with conventional ceramic and stainless steel brackets in different bracket-archwire combinations?

Therefore, the purpose of the present study was to compare the frictional forces generated by 3 types of brackets (stainless steel, conventional ceramic, and metal-insert ceramic) combined with 3 wire alloys (stainless steel, nickel-titanium, and beta-titanium) of 3 different sections (0.016 in, 0.017 × 0.025 in, and 0.019 × 0.025 in).

MATERIAL AND METHODS

Three types of preadjusted maxillary canine brackets were tested: conventional ceramic (Transcend Series 6000, 3M Unitek, Monrovia, Calif), metal-insert ceramic (Clarity, 3M Unitek), and conventional stainless steel brackets (Victory Series, 3M Unitek). Three types of orthodontic wire alloys were tested: stainless steel (Stainless Steel, SDS Ormco, Glendora, Calif), nickel-titanium (Ni-Ti, SDS Ormco), and beta-titanium (TMA, SDS Ormco). All the brackets had a 0.022-in slot and were tested with each type of wire alloy of 3 different sections: 0.016 in, 0.017 × 0.025 in, and 0.019 × 0.025 in.

A total of 270 bracket-wire samples were studied (Table I). Each bracket was tested once, and each wire specimen was drawn through 1 bracket only, to eliminate the influence of wear.[5]

A testing machine with a 10-lb tension load cell, set on a range of 1 lb and calibrated from 0 to 1000 g was used. It allowed sliding a bracket along an orthodontic wire and recording the frictional forces. Each bracket

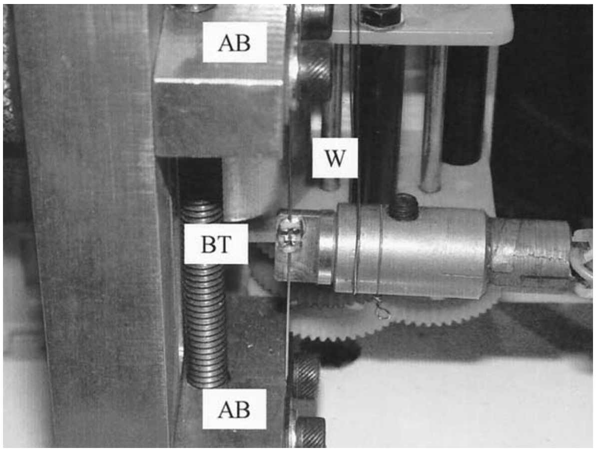

Fig 1. Test apparatus. Bracket being tested (BT) restrains archwire (W) and is 20 mm from 2 simulated adjacent brackets (AB).

was mounted to eliminate the effects of the prescription on a steel bar attached to the crosshead of the machine. To aid in aligning the bracket slot through the wire, so that friction was not induced by adverse tipping or torsion movements, the brackets were supported on a 0.021 × 0.025-in stainless steel wire jig while the epoxy adhesive hardened. This allowed the slot axis of the bracket to be perpendicular to the surface of the steel bar. Metal bearings simulated adjacent brackets at interbracket distances of 20 mm above and below the test bracket. Straight lengths of wire to be tested were fixed to the metal bearings (to mantain correct wire tension) and then fitted to the bracket slot and ligated passively to the tie wings with elastomeric ligatures (Leone, Florence, Italy). The elastomeric rings were placed immediately before each test run, to avoid ligature force decay. The rate of movement was 2.5 mm per minute, and each test was carried out for 2 minutes. After each test, the testing machine was stopped, the bracket and wire assembly were removed, and a new assembly was placed. This was done for 10 nonrepeated evaluations of each bracket-wire combination (Fig 1). The study was carried out in dry conditions, to achieve results in noncontaminated conditions, as shown in many previous studies.[3-5,7,9,13,21]

The load cell registered the force levels needed to move the bracket along the wire; the force levels were transmitted to a computer hard disk. The data were recorded on an XY recorder. The X axis recorded bracket movement in millimeters and time in seconds. The Y axis recorded the frictional force in grams between the bracket and the archwire.

Static friction was calculated at the initial peak of

Table II. Descriptive statistics of static frictional forces (g)

Variables	*Number of observations*	*Mean*	*SD*	*Minimum*	*Median*	*Maximum*
Bracket						
Clarity	90	152.5	53.6	64.9	144.9	273.2
Transcend 6000	90	202.5	66.3	84.1	191.9	385.3
Victory	90	116.6	56.4	32.0	104.2	267.7
Wire alloy						
Ni-Ti	90	136.2	66.3	31.9	139.3	298.9
SS	90	129.4	50.2	48.0	118.4	299.4
TMA	90	206.1	60.6	58.8	196.0	385.3
Wire section (in)						
0.016"	90	133.8	56.8	38.2	130.3	276.3
0.017" × 0.025"	90	150.8	56.5	46.1	150.6	276.6
0.019" × 0.025"	90	187.0	79.4	31.9	176.4	385.3

Table III. Descriptive statistics of kinetic frictional forces (g)

Variables	*Number of observations*	*Mean*	*SD*	*Minimum*	*Median*	*Maximum*
Bracket						
Clarity	90	132.6	45.2	59.9	129.3	239.6
Transcend 6000	90	177.0	56.1	72.8	177.6	325.8
Victory	90	100.1	50.7	25.1	90.2	249.8
Wire alloy						
Ni-Ti	90	119.0	61.8	25.1	118.8	268.0
SS	90	116.1	43.9	44.1	104.5	221.1
TMA	90	174.5	53.2	33.9	169.3	325.8
Wire section (in)						
0.016"	90	112.7	49.3	30.9	108.0	234.1
0.017" × 0.025"	90	133.4	52.4	28.8	130.3	256.1
0.019" × 0.025"	90	163.6	65.4	25.1	158.6	325.8

movement. Kinetic friction was calculated by averaging 10 recordings 5 seconds apart on the Y axis after the static friction peak.

Descriptive statistics including the mean, standard deviation (SD), median, and minimum and maximum values were calculated for each bracket-archwire combination. An analysis of variance (ANOVA) was used to evaluate the effects of bracket type on frictional resistance. For the post hoc test, the Scheffé test was applied. A Kruskal-Wallis test was used to investigate the effect of wire alloy and section on frictional resistance. For the post hoc test, the Mann-Whitney test was used, and the Bonferroni adjustment was applied.

Subsequently, a generalized linear regression model was fitted to evaluate the combined effect of the 3 variables (bracket, alloy, and section) and their interactions. The level of significance for all the tests was set at $P < .05$.

All statistical analyses were performed with the Stata 7 Program (Stata, College Station, Tex).

RESULTS

The following variables were examined: bracket type, wire alloy, and section. The descriptive statistics of static and kinetic frictional forces for each bracket-archwire combination are given in Tables II and III, respectively.

ANOVA showed a significant bracket effect ($P < .001$). Post hoc pairwise comparisons showed that the stainless steel brackets produced significantly lower frictional forces than did the conventional and metal-insert ceramic brackets, for both static and kinetic friction ($P < .001$). The comparison between conventional and modified ceramic brackets showed that Clarity brackets generated significantly lower frictional resistances than the Transcend 6000 brackets, for both static and kinetic friction ($P < .001$) (Fig 2).

Kruskal-Wallis tests showed a significant wire alloy effect ($P < .001$). Post hoc pairwise comparisons showed that the beta-titanium wires produced significantly higher frictional forces with all bracket types

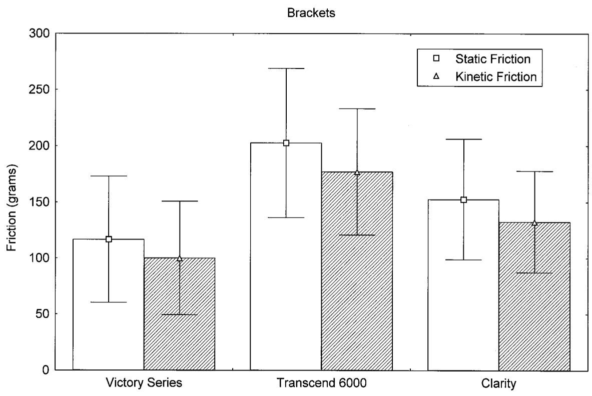

Fig 2. Static and kinetic mean friction (grams) and SD of 3 brackets tested.

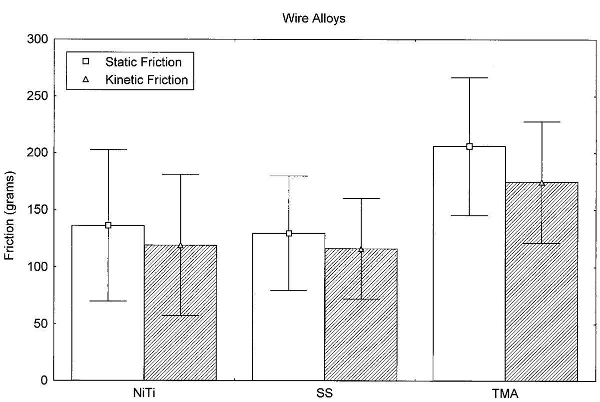

Fig 3. Static and kinetic mean friction (grams) and SD of 3 wire alloys tested.

than did stainless steel and nickel-titanium wires ($P <$ .001). No significant differences were found between nickel-titanium and stainless steel archwires, for both static ($P = 1.80$) and kinetic friction ($P = 2.92$) (Fig 3).

Kruskal-Wallis tests showed a significant wire section effect ($P <$ .001). Post hoc pairwise comparisons showed that 0.019 × 0.025-in archwires produced significantly higher frictional forces with all bracket types than did 0.016 in ($P <$ .001) and 0.017 × 0.025-in archwires ($P =$ .008), for both static and kinetic friction. Also, the 0.017 × 0.025-in archwires produced significantly higher frictional forces than did the 0.016-in arch wires ($P =$ .02) for kinetic friction. The same trend was observed for static friction, although the difference was not statistically significant ($P =$ .12) (Fig 4).

The generalized linear regression model showed independent effects of the 3 variables and interactions among them. All brackets, alloys, and sections were associated with the amount of friction measured. The

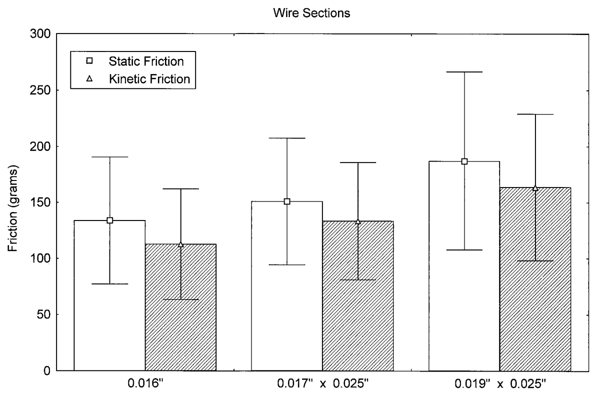

Fig 4. Static and kinetic mean friction (grams) and SD of 3 wire sections tested.

interactions explored in particular whether the effect of alloy was different in combination with the 3 types of brackets.

For static friction, the interactions of bracket/section, bracket/alloy, and alloy/section were statistically significant ($P <$ .05), particularly for the alloy effect with the 3 bracket types ($P <$ .001) (Fig 5, *A*).

For kinetic friction, only the interaction of bracket/alloy was statistically significant ($P <$ .001). No significant differences were found for the interactions of bracket/section and alloy/section ($P =$ .22 and $P =$ .06, respectively) (Fig 5, *B*).

The static frictional forces were greater than the kinetic ones in all bracket-archwire combinations, but no significant differences were found between static and kinetic frictional forces ($P >$ .05).

DISCUSSION

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. 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.[9] To explain the friction between wire and bracket, several variables, such as bracket material, wire material and wire section, should be studied.[8]

The results of this study showed that the Clarity brackets produced significantly lower static and kinetic

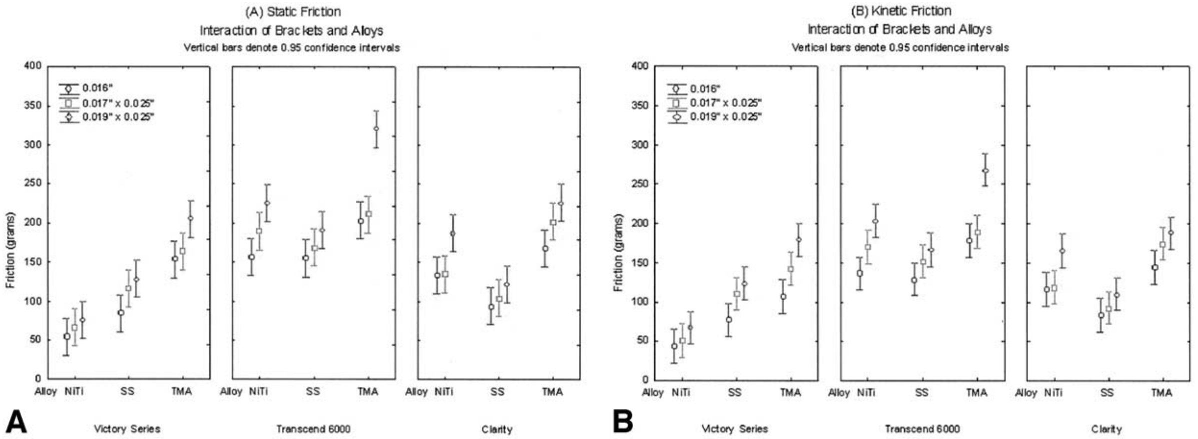

Fig 5. A, Mean static, and **B**, kinetic friction values and SD of interactions of bracket-alloy for 3 sections tested.

frictional resistances than the Transcend 6000 brackets, but higher resistances than the Victory brackets. Our results agree with those of previous studies that found that conventional ceramic brackets generated higher frictional resistances than didstainless steel brackets.[4,16,17,20-22,24,25] Also, our results with ceramic brackets with a metal slot confirm those reported by the few previous studies that metal-insert ceramic brackets produce lower frictional resistance than conventional ceramic brackets.[4,22] 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.[1,12,16,17,19,25,26] On the contrary, the metal slot appears to cause the ceramic bracket to behave more like a stainless steel bracket than a conventional ceramic bracket in terms of static and kinetic frictional resistance, as reported by Dickson and Jones.[22]

The present study also demonstrated that wire alloy has a significant influence on friction: beta-titanium archwires generated higher friction than both stainless steel and nickel-titanium archwires for all bracket-archwire combinations. These findings confirm those of previous studies.[4,7,27-30] One explanation for the increased friction with beta-titanium wires could be the adherence of the wire to the material of the bracket slot during the experiment.[31] Some authors have also reported that ceramic brackets are hard enough to dig grooves when sliding along the different archwire alloys.[20,25]

On the other hand, no significant differences were found between nickel-titanium and stainless steel archwires. This agrees with the findings of Loftus et al,[4] and Articolo and Kusy.[7] However, previous studies comparing the frictional resistance of those 2 alloys have shown conflicting results: some studies found higher frictional forces with stainless steel wires,[16,29,32] and others with nickel-titanium wires.[1,33,34] This variability is probably due to the differences in experimental settings and acquisition systems,[27] the different point of force application,[35] and the different angulation between bracket and wire that in many studies is not zero.[9,32] Therefore, a direct comparison of the various studies on this topic is complex.

For effect of wire section, the results of the present study showed that each of the 3 wire alloys had higher frictional force values as the wire size increased. Similar findings about the effect of wire size have been reported in other studies.[3,9-11,13,21,27,34,36,37]

The generalized linear regression model used in this study showed an independent effect of the 3 variables (bracket, wire alloy, wire section) and interactions among them. The interaction of bracket/alloy was highly significant for both static and kinetic friction. This can be considered an expression of a different behavior of each bracket type in combination with each of the 3 different wire alloys.

Finally, the static frictional forces were generally greater than the kinetic ones in all bracket-archwire combinations, confirming previous studies[25,38,39]; in the present investigation, however, the difference was not significant, in agreement with previous findings.[5,30] The high SD observed in this study, like those reported in previous studies that evaluated several different bracket-archwire combinations,[4,5,21] can be explained by the wide sample population and also because the summary measures refer to different wires and brackets, with their intrinsic large variability, pooled together. The large SD in the bracket frictional forces can be due to the different wire alloys and sizes investigated, whereas the SD in the wire frictional forces can be due to the different bracket slot materials used.

CONCLUSIONS

This study demonstrated that metal-insert ceramic brackets generate significantly lower frictional forces than do conventional ceramic brackets but higher forces than stainless steel brackets. Beta-titanium archwires had higher frictional resistances than stainless steel and nickel-titanium archwires. No significant differences were found between stainless steel and nickel-titanium archwires. All brackets showed higher static and kinetic frictional forces as the wire size increased. Metal-insert ceramic brackets are not only visually pleasing, but also a valuable alternative to conventional stainless steel brackets in patients with esthetic demands.

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