ORIGINAL ARTICLE

Evaluation of friction of stainless steel and esthetic self-ligating brackets in various bracket-archwire combinations

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This study measured and compared the level of frictional resistance generated between stainless steel self-ligating brackets (Damon SL II, SDS Ormco, Glendora, Calif), polycarbonate self-ligating brackets (Oyster, Gestenco International, Göthenburg, Sweden), and conventional stainless steel brackets (Victory Series, 3M Unitek, Monrovia, Calif), and 3 different orthodontic wire alloys: stainless steel (Stainless Steel, SDS Ormco), nickel-titanium (Ni-Ti, SDS Ormco), and beta-titanium (TMA, SDS Ormco). All brackets had a .022-in slot, whereas the orthodontic wire alloys were tested in 3 different sections: .016, .017 × .025, and .019 × 0.025 in. Each of the 27 bracket and archwire combinations was tested 10 times, and each test was performed with a new bracket-wire sample. Both static and kinetic friction were measured on a custom-designed apparatus. All data were statistically analyzed (Kruskal-Wallis and Mann Whitney *U* tests). Stainless steel self-ligating brackets generated significantly lower static and kinetic frictional forces than both conventional stainless steel and polycarbonate self-ligating brackets, which showed no significant differences between them. 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. (Am J Orthod Dentofacial Orthop 2003;124:395-402)

Friction is 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]

For 1 object to slide against the other, the force application must overcome the frictional force; higher frictional resistance requires greater orthodontic forces.[5]

Many studies have evaluated the factors that influence frictional resistance: bracket and wire materials, surface conditions of archwires and 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.[6-9]

Schumacher et al[10] stated that friction was determined mostly by the nature of ligation. Self-ligating brackets were introduced in the mid-1930s in the form of the Russell attachment, which was intended to reduce ligation times and improve operator efficiency.[11,12] Self-ligating brackets are ligatureless bracket systems that have a mechanical device built into the bracket to close off the edgewise slot. From the patient's perspective, self-ligating brackets are generally smoother, more comfortable, and easier to clean because of the absence of wire ligature.[13] Reduced chair time is another significant advantage.[14] Two types of self-ligating brackets have been developed: those that have a spring clip that presses against the archwire, such as the In-Ovation (GAC International, Bohemia, NY), SPEED (Strite Industries, Cambridge, Ontario, Canada), and Time brackets (Adenta, Gilching/Munich, Germany), and those in which the self-ligating clip does not press against the wire, such as the Activa ("A" Company, San Diego, Calif), the TwinLock (Ormco/"A" Company, Orange, Calif), and the more recently developed Damon SL I (Ormco/"A" Company) brack-

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ets. With every self-ligating bracket, whether active or passive, the movable fourth wall of the bracket is used to convert the slot into a tube. Several studies have demonstrated a significant decrease in friction for self-ligating brackets, compared with conventional bracket designs.[3,15-20] Such a reduction in friction can help shorten overall treatment time, especially in extraction patients in whom tooth translation is achieved by sliding mechanics.

Recently, Damon SL II brackets have been introduced to improve the Damon SL I system. The difference between these 2 generations is that the first had a labial cover that straddled the tie wings, whereas the second incorporates a flat, rectangular slide between the tie wings.[21]

Newly introduced polycarbonate self-ligating brackets have been developed to improve esthetics during orthodontic treatment while maintaining the features of conventional self-ligating appliances. To date, however, to our knowledge, no studies have evaluated the friction produced by these new products. Accordingly, the purpose of this study was to compare the frictional forces generated by 3 types of brackets (conventional stainless steel, stainless steel self-ligating, and polycarbonate self-ligating) in combination with 3 different wire alloys (stainless steel, nickel-titanium, and beta-titanium) of 3 different sections (.016, .017 × .025, and .019 × .025 in).

Table I. Study design

Brackets	*Wire alloys*	*Wire sections (in)*
Victory	SS	.016
		.017 × .025
		.019 × .025
	Ni-Ti	.016
		.017 × .025
		.019 × .025
	TMA	.016
		.017 × .025
		.019 × .025
Damon SL II	SS	.016
		.017 × .025
		.019 × .025
	Ni-Ti	.016
		.017 × .025
		.019 × .025
	TMA	.016
		.017 × .025
		.019 × .025
Oyster	SS	.016
		.017 × .025
		.019 × .025
	Ni-Ti	.016
		.017 × .025
		.019 × .025
	TMA	.016
		.017 × .025
		.019 × .025

Each bracket–wire combination group consisted of 10 specimens.

MATERIAL AND METHODS

Three types of preadjusted maxillary canine brackets were tested: conventional stainless steel (Victory Series, 3M Unitek, Monrovia, Calif), stainless steel self-ligating (Damon SL II, SDS Ormco, Glendora, Calif), and polycarbonate self-ligating brackets (Oyster, Gestenco International, Göthenburg, Sweden). Three types of orthodontic wire alloys were tested: stainless steel (Stainless Steel, SDS Ormco), nickel-titanium (Ni-Ti, SDS Ormco) and beta-titanium (TMA, SDS Ormco). All the brackets had a .022-in slot and were tested with each type of wire alloy in 3 different sections: .016, .017 × .025, and .019 × .025 in.

A total of 270 bracket-wire samples were studied (Table I). Each bracket was tested only once, and each wire specimen was drawn through 1 bracket only, so as 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 in this experiment. It allowed sliding of a bracket along an orthodontic wire and recording of the frictional forces. The study was carried out in dry conditions. Each bracket was mounted on a jig that was attached to the crosshead of the testing machine. Straight lengths of wire to be tested were fitted to the bracket slot and ligated passively to the tie wings with elastic ligatures (Leone, Florence, Italy) for conventional stainless steel brackets or by closing the cap for self-ligating brackets. The rate of movement was 2.5 mm/minute, and each test was carried out for 2 minutes. After each test, the testing machine was stopped, the bracket and wire assembly was removed, and a new assembly was placed. This was done for 10 nonrepeated evaluations for each bracket-wire combination (Fig 1).

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

Static friction was calculated at the initial peak of 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, SD, me-

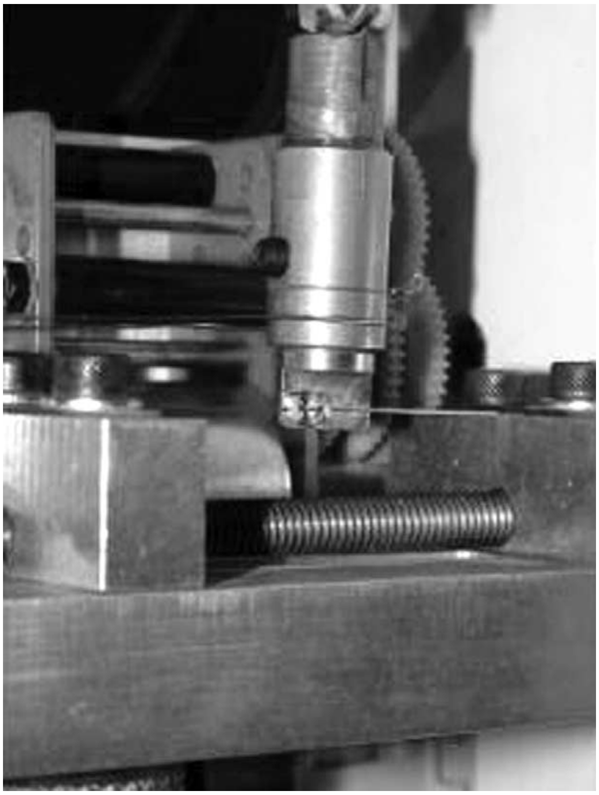

Fig 1. Test apparatus.

dian, minimum, and maximum values were calculated for each bracket-archwire combination. A Kruskal-Wallis test was used to study the effect of bracket type, wire alloy, and section on the frictional resistance. For the post hoc test, a Mann-Whitney *U* 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 Stata 7 software (Stata, College Station, Tex).

RESULTS

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

The Kruskal-Wallis test showed a significant bracket effect ($P = .0001$). Post hoc pairwise comparisons showed that the Damon SL II brackets produced significantly lower frictional forces than did conventional stainless steel and esthetic self-ligating brackets, for both static and kinetic friction ($P = .000$). No statistically significant differences were found between Victory and Oyster brackets, for static and kinetic friction ($P = 2.08$) (Fig 2).

The Kruskal-Wallis test showed a significant alloy effect ($P = .0001$). Post hoc pairwise comparisons showed that beta-titanium wires produced significantly higher static and kinetic frictional forces with all bracket types than stainless steel and nickel-titanium wires ($P = .000$). No significant differences were found between nickel-titanium and stainless steel archwires, for static ($P = .47$) and kinetic friction ($P = .34$) (Fig 3).

A significant wire section effect ($P = 0.0001$) was shown by Kruskal-Wallis test. Post hoc pairwise comparisons revealed that both rectangular archwires produced significantly higher frictional forces with all bracket types than did round archwires ($P < .023$), for static and kinetic friction. No statistically significant differences were found between the 2 different rectangular archwires (Fig 4).

The generalized linear regression model showed independent effects of the 3 variables and interactions among them.

For static friction, the interactions between bracket and section and between bracket and alloy were statistically significant ($P < .009$), particularly when evaluating the alloy effect with all 3 bracket types ($P = .000$) (Fig 5, *A*).

For kinetic friction, the interactions between bracket and section, between bracket and alloy, and between alloy and section were all statistically significant ($P < .004$). The alloy effect was highly significant with all 3 bracket types ($P = .000$) (Fig 5, *B*).

DISCUSSION

The proper magnitude of force during orthodontic treatment will result in optimal tissue response and rapid tooth movement. During mechanotherapy involving movement of the bracket along the wire, friction at the bracket-archwire interface might prevent attaining optimal force levels in the supporting tissues. Therefore, an understanding of the forces required to overcome friction is important so that the appropriate magnitude of force can be used to produce optimal biologic tooth movement.[22] To elucidate the nature of friction between wire and bracket, several variables, such as bracket material, wire material, and wire section should be studied.[23]

The results presented here showed that the Damon SL II brackets produced significantly lower static and kinetic frictional resistances than both conventional

Table II. Descriptive statistics of static frictional forces (in grams)

Variables	*No. of observations*	*Mean*	*SD*	*Minimum*	*Median*	*Maximum*
Bracket						
Damon SL II	90	46.53	24.47	10.88	41.81	136.61
Oyster	90	115.99	47.80	32.92	100.66	232.18
Victory	90	116.63	56.36	31.96	104.21	267.75
Wire alloy						
Ni-Ti	90	69.96	33.60	10.88	62.08	159.28
SS	90	82.37	49.34	12.33	80.85	229.04
TMA	90	126.82	63.02	29.75	134.31	267.75
Wire section (in)						
.016	90	72.39	43.04	12.33	67.96	202.94
.017 × .025	90	95.18	56.13	10.88	86.00	232.18
.019 × .025	90	111.57	59.63	16.06	93.58	267.75

Table III. Descriptive statistics of kinetic frictional forces (in grams)

Variables	*No. of observations*	*Mean*	*SD*	*Minimum*	*Median*	*Maximum*
Bracket						
Damon SL II	90	39.87	22.19	9.64	33.89	119.84
Oyster	90	91.04	42.74	21.04	79.48	201.70
Victory	90	100.06	50.75	25.13	90.23	249.79
Wire alloy						
Ni-Ti	90	56.99	29.36	9.64	51.37	138.71
SS	90	69.61	43.36	11.12	66.53	171.91
TMA	90	104.37	55.38	18.88	104.96	249.79
Wire section (in)						
.016	90	55.78	31.85	11.12	46.71	146.27
.017 × .025	90	78.81	49.18	9.64	68.53	201.70
.019 × .025	90	96.38	52.49	13.76	84.69	249.79

stainless steel and esthetic self-ligating brackets. Our findings agree with those of previous studies that found that stainless steel self-ligating brackets generated lower frictional resistances than did conventional stainless steel brackets.[3,13,16,17,19,20] The difference in friction levels between conventional stainless steel and polycarbonate self-ligating brackets could be explained by the difference in the structural design of each bracket body, in addition to the material composition of the bracket slot and cap.[13]

No statistically significant differences were found between Victory and Oyster brackets, for either static or kinetic friction. The few studies that have attempted to evaluate the frictional resistance of plastic brackets demonstrated that conventional polycarbonate brackets showed significantly higher frictional resistances than conventional stainless steel brackets.[24] To our knowledge, no published studies have evaluated the frictional resistance produced by recently introduced polycarbonate self-ligating brackets. A possible explanation for the reduced friction values is that the self-ligating cap does not press against the wire, and, when the cover is locked, the slot is essentially converted into a tube; consequently, friction values are similar to those produced by conventional stainless steel brackets. Therefore, in patients with esthetic demands, polycarbonate self-ligating brackets represent a valuable alternative to ceramic brackets, which have been found to produce higher frictional resistances than conventional stainless steel brackets.[4,25-31]

The present study also showed that the 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 reported in previous studies.[4,32-35] One explanation for the increased friction with beta-titanium wires might be adherence of the wire material to the material of the bracket slot during the experiment.[36]

Conversely, no significant differences were found

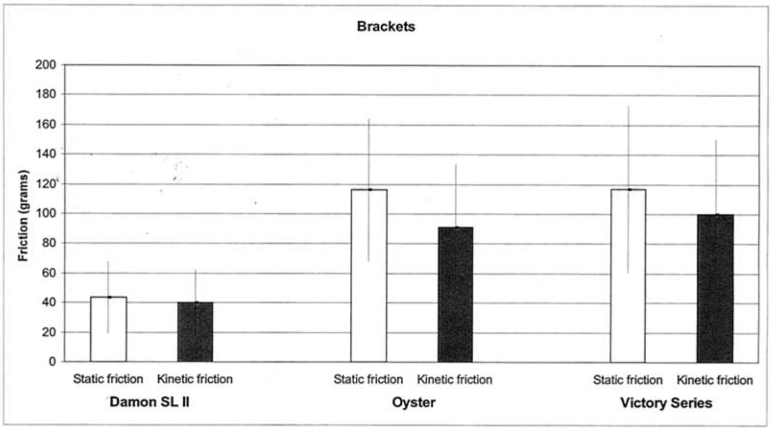

Fig 2. Static and kinetic mean frictions (in grams) and SD of 3 brackets tested.

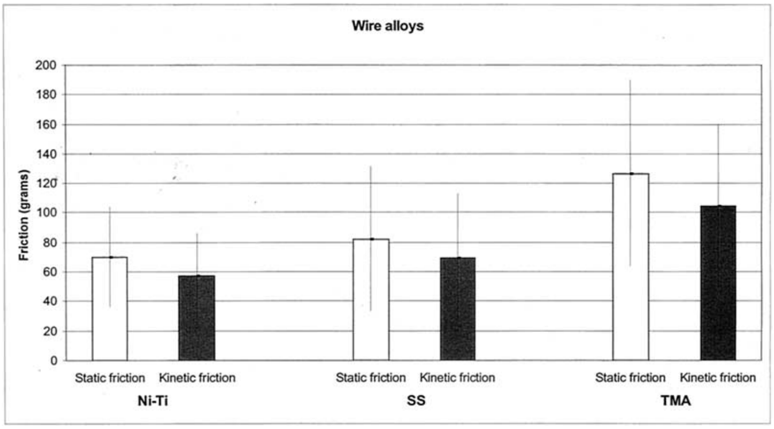

Fig 3. Static and kinetic mean frictions (in grams) and SD of 3 wire alloys tested.

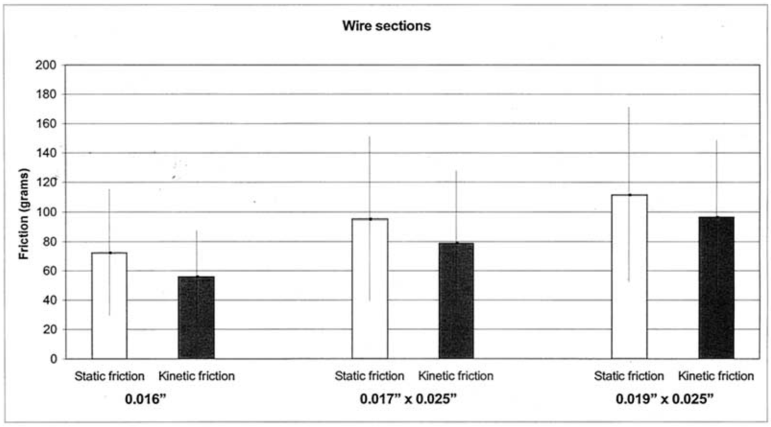

Fig 4. Static and kinetic mean frictions (in grams) and SD of 3 wire sections tested.

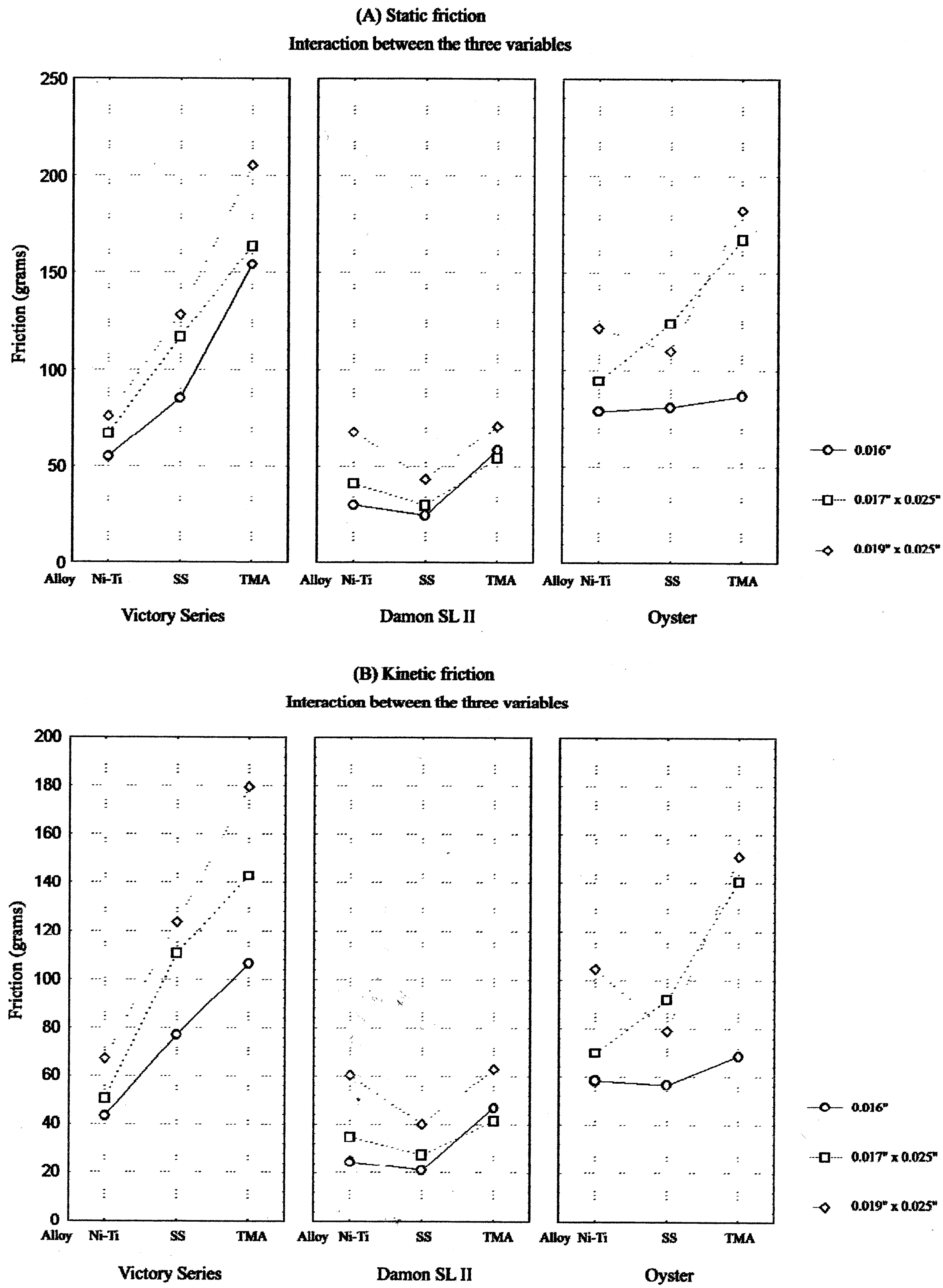

Fig 5. **A**, Mean static and, **B**, kinetic friction values of interactions between bracket and alloy for 3 sections investigated.

between nickel-titanium and stainless steel archwires. This agrees with the findings of Loftus et al.[4] However, previous studies in which the frictional resistance of those 2 alloys were compared have had conflicting results: some studies found higher frictional forces with stainless steel wires[24,25] and others with nickel-titanium wires.[1,37,38] This variability is probably due to differences in experimental settings and acquisition systems,[33] different point of force application,[39] and different angulation between bracket and wire, which in many studies is not zero.[22,24] Therefore, a direct comparison of the various published studies on this topic is complex.

Regarding the effect of the wire section, we found that each of the 3 wire alloys had higher frictional force values as the wire size increased. Similar findings were reported in many studies.[3,6,7,9,16,18,22,28,33,38,40,41]

The generalized linear regression model used in this study showed an independent effect of the 3 variables (bracket, wire alloy, and wire section) and interactions among them. In particular, the interaction between bracket and 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 greater than the kinetic ones in all bracket-archwire combinations, confirming what has been reported in previous studies.[31,42,43]

The high SD observed in this investigation, like those reported in previous studies that evaluated several different bracket-archwire combinations,[4,5,28] can be explained by the wide sample population and are related to the fact that the summary measures refer to different wires and brackets pooled together with their intrinsic great variability. The high SD in the bracket frictional forces could be due to the different wire alloys and sizes, whereas the SD in the wire frictional forces could be due to the different bracket slot materials.

This study was carried out under ideal conditions, in a passive frictional configuration, as shown in previous reports.[4,5,13,19,25,27,28,31,41,43] Frictional studies in an active configuration (with different bracket angulations) are still in progress at our department, and it will be useful in the future to compare those findings with those achieved in the passive state.

CONCLUSIONS

This study demonstrated that stainless steel self-ligating brackets generated significantly lower static and kinetic frictional forces than both conventional stainless steel and polycarbonate self-ligating brackets, which showed no significant differences between them. 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 brackets showed higher static and kinetic frictional forces as the wire size increased. In patients with esthetic demands, polycarbonate self-ligating brackets are a valuable alternative to conventional stainless steel and ceramic brackets.

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