Frictional resistances using Teflon-coated ligatures with various bracket-archwire combinations

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Orthodontic tooth movement is dependent upon the ability of a clinician to use controlled mechanical forces to stimulate biologic responses within the periodontium. Although various techniques are available to effectuate tooth movement, the most common consists of an edgewise bracket that slides along a continuous archwire. The sliding arch-guided system, generally referred to as sliding mechanics, can be influenced by counteracting frictional forces at the interface of the bracket, archwire, and ligature.[1] The friction between two or more materials can be represented as $F_F = \mu \Sigma N$, where ΣN is defined as the sum of the contacting forces (or normal forces) in all planes of space, and μ is the coefficient of friction between the materials. Hence, the two determining factors of friction during sliding mechanics are the coefficient of friction between the contacting surfaces and the forces applied between those surfaces.

Ceramic brackets have come into widespread use because of their outstanding esthetic characteristics, despite many problems associated with their clinical use.[2] Researchers have indentified higher coefficients of friction[3-4] among ceramic brackets, along with greater frictional resistances,[4-9] rougher surfaces,[3,5-10] and the ability to retard tooth movements[10] when compared to stainless steel brackets.

Ligatures commonly used in orthodontics are either heat-treated stainless steel or elastomeric rings. The friction arising from a ligature depends upon its coefficient of friction and the

Abstract

Static frictional resistances were compared between Teflon-coated stainless steel and clear elastomeric ligatures used with various combinations of brackets and archwires. Stainless steel metal, polycrystalline ceramic and single crystal ceramic 0.022-inch slot brackets were used in combination with stainless steel and nickel titanium archwires, 0.018 inch and 0.016 x 0.022 inch. Friction was measured in the dry state at bracket-archwire angulations of 0, 5, 10, and 15 degrees. Moments induced by engagement of the archwires into the brackets were measured for each archwire type and bracket-archwire angulation. Teflon-coated ligatures produced less friction than elastomers for all bracket-archwire combinations. The ceramic brackets generally elicited greater frictional resistances than stainless steel brackets. Regarding both friction and control of tooth movement, these data suggest that sliding mechanics are best executed with stainless steel brackets and stainless steel archwires. Moreover, these data reveal the usefulness of Teflon-coated ligatures in minimizing the high friction of ceramic brackets when an esthetic appliance is imperative.

Key Words

Friction • Teflon • Elastomers • Ceramic • Nitinol

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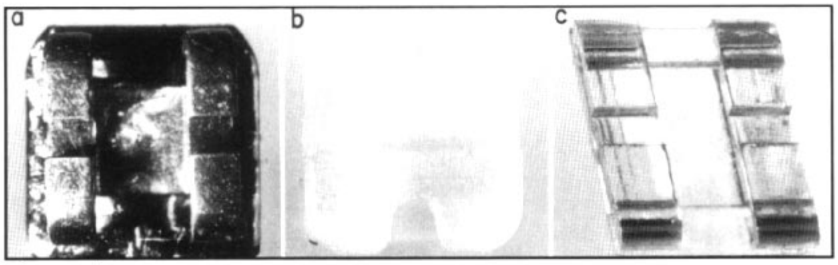

Figure 1

Figure 1
Orthodontic brackets: a) stainless steel, b) polycrystalline ceramic, and c) single crystal ceramic.

Figure 2
The force (grams) perpendicular to an 0.040 wire cemented to the Plexiglass pedestal was measured with a Correx gauge at a distance 25 mm from the bracket slot. Moments (gram·mm) produced within the bracket by the various archwires at 5, 10, and 15 degree bracket-wire angulations were calculated.

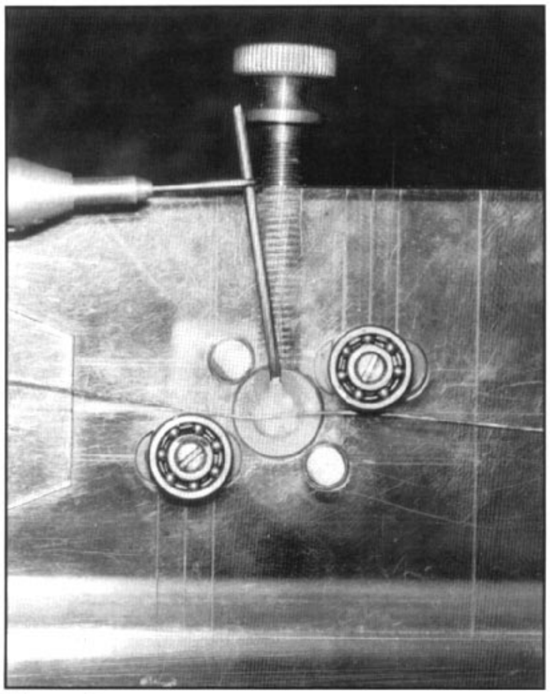

Figure 2

forces it exerts on the bracket and archwire. Riley et al.[11] showed that steel ligatures produce greater friction than elastomers. In contrast, Frank et al.[12] compared frictional resistances between elastomeric and steel ligations of 225 grams of force and found no differences. Using slightly slackened steel ligatures, Bednar et al.[8] showed elastomers induce greater friction than steel ligatures. In addition, Echols[13] demonstrated that elastomeric ligatures yield high friction which intensified with increased wire dimensions and with nickel titanium archwires.

Both clear elastomerics and Teflon-coated stainless steel ligatures are esthetically appropriate for use with ceramic brackets. Since Teflon has a low coefficient of friction,[14] Teflon-coated ligatures may invoke lower forces of friction than either elastomeric or uncoated steel ligatures. The purposes of this study were to explore the Teflon-coated stainless steel ligature as a low-friction esthetic ligature and to further investigate friction in ceramic brackets.

Materials and methods

Three different brackets were studied: stainless steel (SS) (Unitek-3M Corporation, Monrovia, Calif); Transcend (Unitek-3M Corporation, Monrovia, Calif) polycrystalline alumina (PC); and Starfire (A-Company Inc., San Diego, Calif) single crystal alumina (SC) (Figure 1). Each bracket had an 0.022 inch occlusogingival slot, a zero degree tip and zero degree torque. Brackets were selected to be similar in width; however, minor differences existed (SS=3.3 mm, PC=3.5 mm, and SC=3.4 mm). Two esthetic ligatures were used: clear elastomers (Ormco Corporation, Glendora, Calif) and Teflon-coated stainless steel (A-Company Inc., San Diego, Calif). In addition, archwires differing in both composition and size were tested: stainless steel (Unitek-3M Corporation, Monrovia, Calif) and Nitinol (Unitek-3M Corporation, Monrovia, Calif) archwires, 0.018 inch and 0.016 x 0.022 inch.

A Plexiglass friction apparatus, kindly provided by Dr. Robert Nikolai, St. Louis University, Missouri, was used in this study to simulate the distal movement of a canine directed by an archwire as previously described.[12] Brackets were bonded to plastic pedestals with 3M Concise (Unitek-3M Corporation, Monrovia, Calif) orthodontic resin. The pedestals were inserted into the friction apparatus, the bracket was positioned at the appropriate angle with an 0.022-inch wire key, and the pedestal was secured. An archwire was engaged into the bracket slot and ligated with either a Teflon-coated or an elastomeric ligature. Using a Mathieu ligature-tying instrument, the Teflon-coated ligatures were pulled tightly and twisted to the point at which the pigtail began to double back on itself. Consequently, the pigtail was cut and bent under the archwire.

The moment produced within the bracket by engagement of the archwire was determined for each archwire and angulation with a specially designed pedestal (Figure 2). The pedestal had an 0.040 inch rigid stainless steel wire attached perpendicular to the bracket slot. A notch was placed in the 0.040 inch wire 25 mm from the center of the bracket slot. The pedestal was inserted into the friction apparatus, but not secured, and an archwire was inserted into the bracket. The force necessary to posi-

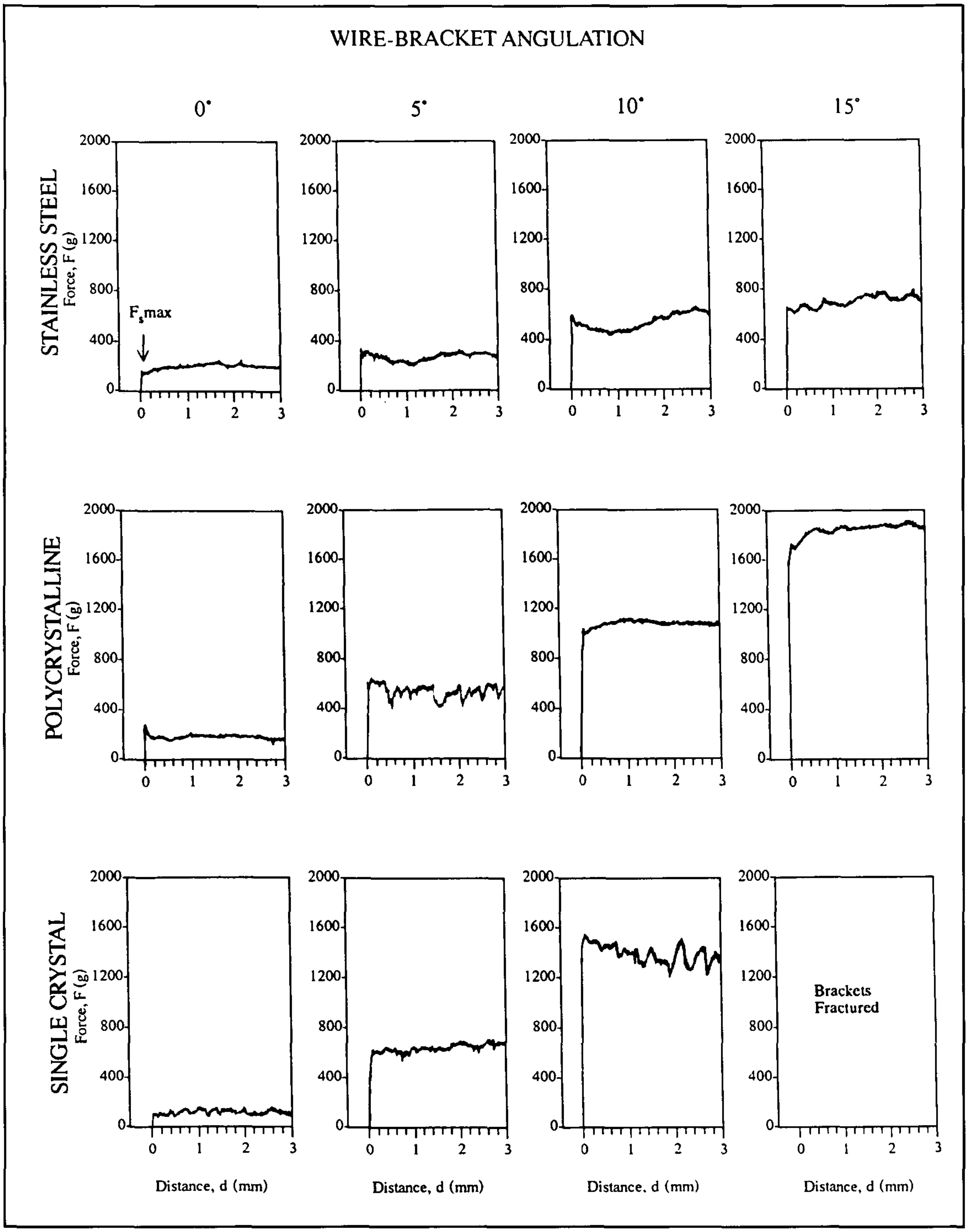

Figure 3
Representative friction (F) profiles for an 0.018 inch stainless steel arch wire passing a distance (d) of 3 mm through three different 0.022 inch slot bracket types: stainless steel, polycrystalline, and single crystal. Archwires were ligated with Teflon-coated stainless steel. Friction was measured at four bracket-wire angulations: 0, 5, 10, and 15 degrees. Maximal static frictional forces ($F_s$max) were obtained from the force-distance curves.

tion the bracket slot to the specified angle was measured eight times with a Correx gauge at a distance 25 mm perpendicular to the bracket slot. Moments were calculated by multiplying the measured force by 25, and were expressed in gram·mm. A single operator performed all adjustments, ligations and measurements to ensure consistency.

The friction apparatus was mounted on a Unite-O-Matic FM-20 in order to pull the archwire through the bracket slot. The load transducer of the tensometer measured the applied force, representing the force of friction while the extensometer recorded the cross-head travel, corresponding to the archwire movement. The output of both devices was plotted on an X-Y recorder. The cross-head travel rate was 0.625 mm/min, the lowest controlled rate achievable.

Each test consisted of drawing 3 mm of arch-

Figure 4
Influence of bracket-archwire angulation (degrees) on friction (grams) for various combinations of ligatures, brackets, and 0.018 inch archwires. Ligatures: Teflon-coated stainless steel (Tef), clear elastomers (Ela). Brackets: stainless steel (SS), polycrystalline (PC), single crystal (SC). Archwires: stainless steel (SS), Nitinol (Nit).

Figure 5
Influence of bracket-archwire angulation (degrees) on friction (grams) for various combinations of ligatures, brackets, and 0.016 x 0.022 inch archwires. Ligatures: Teflon-coated stainless steel (Tef), clear elastomers (Ela). Brackets: stainless steel (SS), polycrystalline (PC), single crystal (SC). Archwires: stainless steel (SS), Nitinol (Nit).

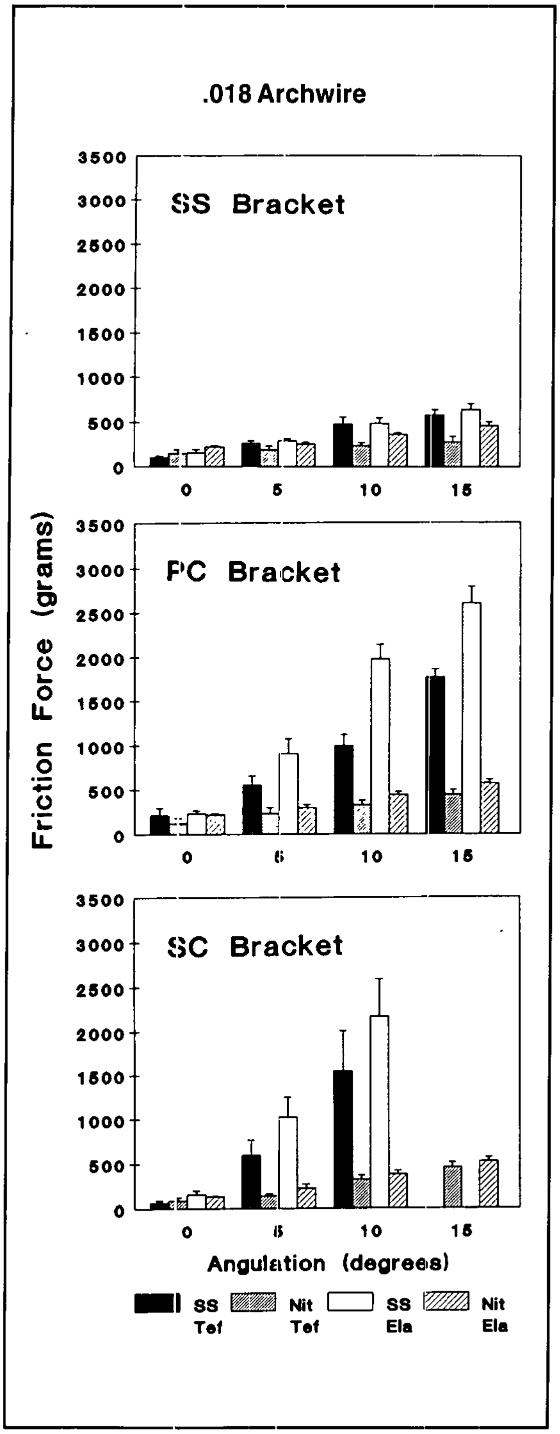

Figure 4

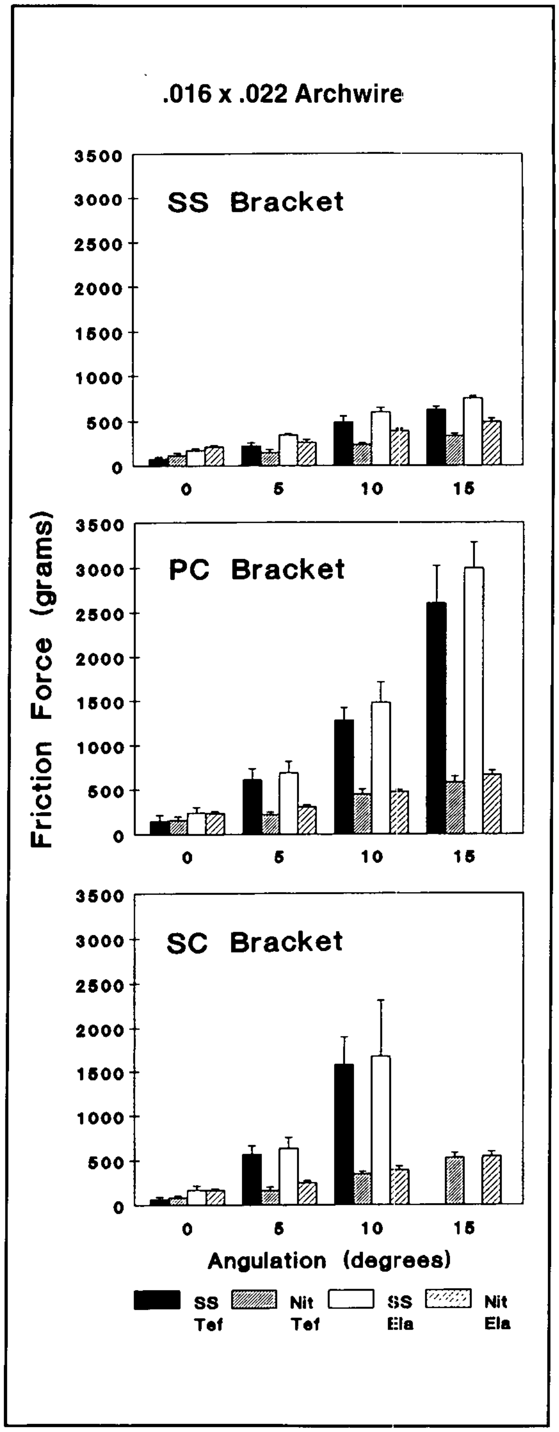

Figure 5

wire through the bracket slot. A sample size of six was chosen for each bracket/archwire/ligature/anglulation combination, yielding 564 separate measurements. One bracket was used to test a single archwire and ligature at 0, 5, 10, and 15 degrees and then discarded. That is, none of the brackets was employed for more than 24 measurements. A new section of archwire and a new ligature were used for each test.

The testing apparatus measured and recorded both initial static forces of friction and dynamic forces of friction within the system over a distance of 3 mm. The data for the present study included only the maximal static frictional force ($F_S$max) which was determined to be the point at which the archwire first moved in the bracket; namely, the point on the X-Y plot where the trace departed from a vertical direction (Figure 3).

Table I
Tukey tests for ligation comparison: Teflon-coated stainless steel vs. elastomeric ligature

Bracket Angulation (degrees)	Stainless Steel Archwire .018	Stainless Steel Archwire .016 x .022	Nitinol Archwire .018	Nitinol Archwire .016 x .022
Stainless Steel Bracket				
0	+	++	++	++
5	—	++	++	++
10	—	+	++	++
15	—	++	++	++
Polycrystalline Bracket				
0	—	+	++	++
5	+	—	—	++
10	++	—	++	—
15	++	—	++	+
Single Crystal Bracket				
0	++	++	+	++
5	++	—	++	++
10	++	—	+	—
15	F	F	+	—

Note that all mean static friction force values were lower with Teflon-coated stainless steel as compared with elastomeric ligation
F = Brackets fractured; df=11
— No significant difference; + $p<0.05$; ++ $p<0.01$

Table II
One-way ANOVA with Tukey tests for paired bracket comparisons ligated with Teflon-coated stainless steel

Bracket Angulation (degrees)	F Ratio	SS/PC	SS/SC	PC/SC
.018 Stainless Steel Archwire				
0	14.1	++ (SS)	—	+ (SC)
5	14.2	++ (SS)	++ (SS)	—
10	21.2	+ (SS)	++ (SS)	+ (PC)
15	F	F	F	F
.016 X .022 Stainless Steel Archwire				
0	6.2	+ (SS)	—	+ (SC)
5	25.2	++ (SS)	++ (SS)	—
10	43.9	++ (SS)	++ (SS)	—
15	F	F	F	F
.018 Nitinol Archwire				
0	2.7	—	—	—
5	5.6	—	—	+ (SC)
10	8.7	++ (SS)	+ (SS)	—
15	16.6	++ (SS)	++ (SS)	—
.016 X .022 Nitinol Archwire				
0	6.9	—	—	++ (SC)
5	7.2	++ (SS)	—	+ (SC)
10	39.6	++ (SS)	++ (SS)	++ (SC)
15	37.0	++ (SS)	++ (SS)	—

Abbreviations for brackets:
SS (Stainless Steel), PC (Polycrystalline), SC (Single Crystal)
Bracket type in parentheses produced less friction
F = Brackets fractured; df=17
— No significant difference; + $p<0.05$; ++ $p<0.01$

The single factor analysis of variance (ANOVA) was used to detect statistical differences among the three groups, whereas the Tukey-Kramer honestly significant difference test was used to compare individual groups to each other.

Results

Mean static frictional forces for the various bracket, archwire, and ligature combinations are graphically presented in Figure 4 for the 0.018 inch archwires and in Figure 5 for the 0.016 x 0.022 inch archwires. The single crystal brackets fractured with stainless steel archwires engaged at 15 degrees, and therefore, no values are shown for these combinations.

Ligatures

All mean static frictional forces were less with Teflon-coated stainless steel ligatures than with elastomeric ligatures (Figures 4 and 5). The majority of the comparisons were statistically different (Table I).

Brackets

In general, less friction was elicited by stainless steel brackets than by ceramic brackets, irrespective of archwire size, archwire composition, or ligation method. Significant differences by one-way analysis of variance are shown in Tables II and III. A tendency for less friction was noted with single crystal brackets as compared with polycrystalline brackets, yet these differences were not statistically significant for every comparison.

The polycrystalline bracket engaged by an 0.016 x 0.022 inch stainless steel archwire, at an angulation of 15 degrees, yielded the highest force of friction irrespective of the ligature. The lowest frictional force was found with a single crystal bracket engaged by an 0.018 inch stainless steel archwire at 0 degrees angulation, ligated with a Teflon-coated ligature. The

Table III
One-way ANOVA with Tukey tests for paired bracket comparisons ligated with elastomers

Bracket Angulation (degrees)	F Ratio	SS/PC	SS/SC	PC/SC
.018 Stainless Steel Archwire				
0	8.9	++ (SS)	—	++ (SC)
5	35.5	++ (SS)	++ (SS)	—
10	75.5	++ (SS)	++ (SS)	—
15	F	F	F	F
.016 X .022 Stainless Steel Archwire				
0	4.8	+ (SS)	—	+ (SC)
5	19.1	++ (SS)	++ (SS)	—
10	12.5	++ (SS)	++ (SS)	—
15	F	F	F	F
.018 Nitinol Archwire				
0	98.3	—	++ (SC)	++ (SC)
5	6.7	—	—	++ (SC)
10	7.8	++ (SS)	—	+ (SC)
5	7.8	++ (SS)	—	—
.016 X .022 Nitinol Archwire				
0	21.0	—	++ (SC)	++ (SC)
5	9.2	+ (SS)	—	++ (SC)
10	13.5	++ (SS)	—	++ (SC)
15	19.9	++ (SS)	—	++ (SC)

Abbreviations for brackets:
SS (Stainless Steel), PC (Polycrystalline), SC (Single Crystal)
Bracket type in parentheses produced less friction
F = Brackets fractured; df=17
— No significant difference; + $p<0.05$; ++ $p<0.01$

Table IV
Tukey tests for wire comparison: Stainless steel vs. Nitinol

Bracket Composition	Bracket Angulation (degrees)	Archwire Dimension .018	Archwire Dimension .016 X .022
Teflon-coated ligatures			
Stainless Steel	0	+ (SS)	+ (SS)
	5	++ (Nit)	++ (Nit)
	10	++ (Nit)	++ (Nit)
	15	++ (Nit)	++ (Nit)
Polycrystalline	0	—	—
	5	++ (Nit)	++ (Nit)
	10	++ (Nit)	++ (Nit)
	15	++ (Nit)	++ (Nit)
Single Crystal	0	—	—
	5	++ (Nit)	++ (Nit)
	10	++ (Nit)	++ (Nit)
	15	F	F
Elastomeric ligatures			
Stainless Steel	0	++ (SS)	++ (SS)
	5	+ (Nit)	++ (Nit)
	10	++ (Nit)	++ (Nit)
	15	++ (Nit)	++ (Nit)
Polycrystalline	0	—	—
	5	++ (Nit)	++ (Nit)
	10	++ (Nit)	++ (Nit)
	15	++ (Nit)	++ (Nit)
Single Crystal	0	—	—
	5	++ (Nit)	++ (Nit)
	10	++ (Nit)	++ (Nit)
	15	F	F

Abbreviations for archwires: SS (stainless steel), Nit (Nitinol)
Wire type in parentheses produced less friction
F = Brackets fractured
— No significant difference; + $p<0.05$; ++ $p<0.01$

single crystal brackets, however, produced significantly higher friction than stainless steel brackets at other angulations (Tables II and III).

Archwires

Stainless steel archwires generated greater friction than Nitinol archwires at all angulations except 0 degrees (Figures 4 and 5). Frictional forces were significantly lower for stainless steel archwires than for Nitinol when they were engaged in stainless steel brackets at a 0 degree bracket-wire angulation (Table IV).

Angulations and moments

Frictional resistances increased with increasing bracket-archwire angulations (Figures 4 and 5). In addition, the moment or couple produced within the bracket was augmented as the angulation increased (Table V). Nitinol archwires produced smaller moments than stainless steel archwires. For each wire dimension, the moment generated by the stainless steel archwire was approximately three times that of the Nitinol archwire. Even the 0.018 inch stainless steel archwire produced moments more than double in magnitude those of the 0.016 x 0.022 inch Nitinol archwire at 5, 10, and 15 degrees angulation (Table V).

Discussion

Static frictional resistances were observed for various combinations of brackets, archwires, and ligatures at four different bracket-archwire angulations. Overall, lower friction was demonstrated with Teflon-coated stainless steel ligatures when compared with elastomers and with stainless steel brackets when compared with ceramic brackets.

Biomechanics

Regardless of the appliance, the type of tooth movement depends upon the ratio of the applied moment to the applied force (M/F ratio), generally calculated at the bracket in the orthodontic literature.[15] In order to achieve bodily tooth movement (or translation), the M/F ratio must be equivalent to the distance of the bracket slot to the center of resistance of the tooth. For instance, if this distance is 10 mm, then a M/F ratio of 10 mm is needed for translation. Describing translation in perhaps simpler terms, the antitip moment created by the archwire contacting the bracket slot must be equal in magnitude and opposite in direction to the tipping moment caused by the mesiodistal force. Therefore, sliding mechanics yield translatory tooth movements only when sufficient antitip moments (i.e., adequate M/F ratios) are created by the archwire contacting the bracket.

In vitro model

The experimental model used in this and other studies[12,16-18] pulls an archwire through a bracket at various bracket-archwire angulations. This model focuses on the second order tipping of the bracket to the archwire but does not consider the effects of rotation or torque. Although this model does not recreate sliding mechanics, it does at least consider the fact that a second order angle between the bracket slot and the archwire is prerequisite to achieving bodily tooth movement. Many other studies measured forces of friction only at a bracket-wire angulation of 0 degrees,[3,4,6,7,9,11,19-22] and thus are valid for the specific type of tooth movement defined as uncontrolled tipping,[15] where the M/F ratio is 0 mm.

In our study, bracket-archwire angulations ranged from 0 to 15 degrees and produced an array of moments from 0 to 7472 g·mm (Table V). Disparate types of tooth movement can therefore be elicited by this experimental model, depending upon the moment generated within the bracket by the archwire. When the bracket-archwire angulation is 0 degrees, a moment is not produced in the system; the M/F ratio is therefore 0 mm and uncontrolled tipping is simulated. However, as the angle increases between the archwire and bracket slot, a moment is evoked which alters the type of tooth movement. Translatory tooth movement would be simulated only when a large enough moment is created that would yield a M/F ratio of approximately 10 mm. A major disadvantage of the model used in our study is that the applied mesiodistal force is unknown; therefore, the M/F ratio cannot be calculated. Furthermore, at specific bracket-archwire angulations other than 0 degrees, disparate types of tooth movement may be simulated, depending upon the size and composition of the archwire. For this reason, comparing the friction of archwires at given angulations rather than at given moments can be misleading.

Table V
Moments produced in bracket upon insertion of archwire

Bracket Angulation (degrees)	Stainless Steel Archwire		Nitinol Archwire	
	.018	.016 x .022	.018	.016 x .022
0	*	*	*	*
5	1813 ± 77	2038 ±119	622 ± 49	719 ± 57
10	3925 ±138	4603 ±128	1156 ± 65	1375 ± 83
15	5819 ±109	7472 ±114	1959 ± 73	2331 ±108

Mean ± S.D., n=8
* Not detectable

A more desirable friction model measures the force necessary to pull a bracket along an archwire where the bracket is attached to a tooth with a periodontal-type resistance.[5,8,23-26] The most sophisticated of these in vitro models, described by Drescher et al.,[26] simulates sliding mechanics in three dimensions and therefore includes the frictional contribution of rotation as well as torque.

Other in vivo factors not represented in our in vitro model may affect friction. For example, intermittent occlusal forces may cause the bracket-archwire complex to vibrate, reducing static frictional forces.[17] Additionally, it is unclear whether saliva behaves as a lubricant on the edgewise appliance. For example, both decreased friction[20] and increased friction[6,14] have been reported in the presence of artificial saliva. Kusy et al.[4] demonstrated that human saliva reduced friction of beta-titanium archwires yet elevated friction of stainless steel archwires. Others have shown no significant differences between wet and dry conditions.[9,11,17] Because of these inconsistent data regarding saliva, we opted to measure friction only in the dry state.

Ligatures

Teflon-coated stainless steel ligatures invariably produced less friction than elastomeric ligatures (Figures 4 and 5) and statistical analyses reveal that the great majority of these comparisons are significant (Table I). Most likely, the lower friction values were the result of the Teflon material possessing a lower coefficient of friction than the polyurethane elastomer. Another possible explanation would be that the Teflon-coated ligatures generated lighter forces of engagement of the archwire into the bracket slot. In these experiments, the actual ligation force differences between elastomers and Teflon-coated ligatures were not measured. However, the Teflon-coated ligatures were tightly tied and a single operator placed all of the ligatures in the same fashion as they would be placed clinically.

Uncoated stainless steel ligatures were not included in this study because they were thought to be esthetically unacceptable with ceramic brackets. Contrary to popular belief, they are frequently used clinically with ceramic brackets; their frictional data would have been useful and would have better elucidated the effect of Teflon coating.

The friction contributed by the ligature should be most significant at low bracket-archwire angulations.[12] As the angulation increases, sizable forces of friction between the archwire and bracket develop (Figures 4 and 5) and prevail over the friction contributed by the ligature. Surprisingly, differences were still noted between the two types of ligatures tested at even the higher angulations (Table I); therefore, the ligature effect appears to be significant irrespective of bracket-archwire angulation.

Brackets

Stainless steel brackets had lower forces of friction than polycrystalline or single crystal ceramic brackets for most of the comparisons (Tables II and III). Other studies similarly demonstrated reduced friction by stainless steel brackets.[4-8,10] With respect to friction, esthetic ceramic brackets are unfortunately similar to their plastic predecessors, which were also shown to induce more friction than metal brackets.[11] Of the ceramic brackets, single crystal brackets tended to be lower in friction than polycrystalline brackets, particularly when used with Nitinol archwires (Tables II and III). This finding is in agreement with the scanning electron microscopy data of Shumacher et al.,[5] demonstrating smoother surfaces on single crystal brackets than on polycrystalline brackets; yet it opposes their friction data showing greater friction in single crystal brackets.

Interestingly, the reduced friction of stainless steel brackets as compared with single crystal ceramic brackets was not observed when using Nitinol archwires ligated with elastomers (Table III). At the 0 degree angulation, the single crystal bracket actually had lower friction, which may be attributed to a lighter ligature force generated by the elastomer with the single crystal bracket. The single crystal bracket oriented at an angulation of 15 degrees invariably fractured as stainless steel archwires were pulled through the slot. The bracket wing contacting the archwire proximally to the pulling or tensile force consistently failed. This observation is in agreement with the principle that ceramic material is more tolerant of compressive forces than of tensile forces. It should be noted, however, that a 15-degree bracket-wire angulation is unrealistic for canine retraction by sliding mechanics with a stainless steel archwire; therefore, this failure should not constitute a common clinical problem.

Archwires

An increase in frictional resistance concomitant with an increase in archwire size, from 0.018 inch to 0.016 X 0.022 inch, was generally noted, particularly at higher angulations (Figures 4 and 5). This observation is consistent with other studies relating archwire dimension to friction.[7,11,12,17-19,22,23,26] With regard to tooth movement rather than friction, increasing wire dimensions were similarly shown to reduce movement in vitro.[10] In contrast to these data, Huffman et al.,[27] studying in vivo canine retraction, reported no significant decrease in tooth movement but less tipping with an 0.020 inch compared to an 0.016 inch round wire.

Nickel titanium archwires, in agreement with other reports,[3,4,6,7,9,14,19,22,25,26,28] produced greater friction than stainless steel archwires when used with stainless steel brackets at the 0 degree bracket-wire angulation. Although uncontrolled tipping may be an undesirable type of tooth movement, comparisons at 0 degrees are valid because neither the stainless steel nor the Nitinol archwires induce an antitip moment in the absence of a bracket-wire angulation.

As seen in Table IV, Nitinol was clearly lower in friction than stainless steel when compared at angulations of 5, 10, and 15 degrees. These data are similar to those of Frank et al.[12] and Peterson et al.[18] who, using similar models for testing, showed Nitinol to be greater in friction than stainless steel at low bracket-wire angulations due to its rougher surface, and lower in friction at high angulations because of its reduced stiffness. It is misleading, however, to make comparisons of these archwires at specific angulations because the normal forces acting at the bracket are unequal, producing unequal antitip moments (Table V). For example, at the 10 degree bracket-archwire angulation, the 0.018 inch Nitinol archwire generated a moment of 1156 $\pm$ 65 g·mm while the 0.018 inch stainless steel archwire generated a moment of 3925 $\pm$ 138 g·mm. The Nitinol archwire, producing weaker normal forces on the bracket and hence a weaker antitip moment, would permit a greater amount of tipping than the stainless steel archwire. These two archwires, differing only in composition, therefore, can effectuate different types of tooth movement.

In addition to the 0 degree angulation mentioned above, it would be legitimate to compare the friction of the stainless steel archwire at 5 degrees to the Nitinol at 15 degrees. For instance, the 0.016 X 0.022 inch stainless steel archwire exerted a moment of approximately 2000 g·mm at 5 degrees and produced a frictional force of 216.2 $\pm$ 40.3 in the stainless steel bracket ligated with a Teflon-coated ligature; whereas the 0.016 x 0.022 inch Nitinol archwire exerted a similar moment at 15 degrees yet a frictional force of 331.1 $\pm$ 27.4 (Figure 5 and Table V). When making comparisons in this manner, rather than at specific bracket-archwire angulations, Nitinol archwires demonstrated higher friction than stainless steel archwires with stainless steel brackets. In contrast, differences in friction were not seen between Nitinol and stainless steel archwires in the ceramic brackets at either the 0 degree angulation or when making other valid comparisons based on moments.

Conclusions

Teflon-coated stainless steel ligatures produce less friction than elastomeric ligatures regardless of bracket type, archwire type, or bracket-archwire angulation. The more esthetic ceramic brackets are most often higher in friction than metal brackets. Use of the esthetically acceptable Teflon-coated ligature as an alternative to the clear elastomeric ligature appears to partly reduce the high frictional resistance of ceramic brackets.

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