Original Article

Influence of thermal or chemical degradation on the frictional force of an experimental coated NiTi wire

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ABSTRACT

Objective: To evaluate the friction force in sliding systems composed of coated NiTi archwires, coated NiTi subjected to thermal cycling, and coated NiTi subjected to acid solution immersion, and compare them to NiTi and polymeric wires. The null hypothesis is that there will be no difference among the wires as to friction force.

Materials and Methods: Samples of NiTi (n = 05), coated NiTi (n = 15), and OPTIS (n = 05) 0.016 inches in diameter and 50 mm long, in conjunction with Metafasix ligatures and saliva in InVu brackets, were submitted to friction testing. Among the 15 coated NiTi samples, 5 were submitted to thermal cycling for 3000 cycles; the other 5 samples were immersed in acid solution for 30 days. The results were statistically analyzed at $P > .05$ or $P > .01$. Microscopic analysis was performed in the coated NiTi wires before and after thermal cycling and acid solution immersion.

Results: The mean (± standard deviation) maximum friction force for NiTi, coated NiTi, and OPTIS was 105.20 ± (2.63); 99.65 ± (0.64); 59.76 ± (4.93) ($P = .000$), respectively. There was no significant difference in NiTi, coated NiTi, and acid-immersed coated NiTi ($P > .05$). Among the thermal-cycled or acid-immersed coated NiTi wires there was lower friction force in those undergoing thermal cycling ($P = .001$). The coated NiTi and the OPTIS presented homogeneous surfaces, whereas NiTi wires presented a heterogeneous surface. Fractures were observed in the coated NiTi wires that underwent thermal cycling.

Conclusion: OPTIS, thermal-cycled coated NiTi, coated NiTi, NiTi, and acid-immersed coated NiTi presented, respectively, increasing values of maximum friction force. (*Angle Orthod.* 2011;81:484–489.)

KEY WORDS: Esthetic; Orthodontic wires; Friction; Scanning electron microscopy; Epoxy coating

INTRODUCTION

The ever increasing use of sliding mechanics in orthodontics made friction control one of the major concerns for the success of a planned treatment.[1–3] Friction force can be defined as a force that opposes or delays the movement of two bodies in contact. Sliding is responsible for a considerable amount of friction in the interface bracket/orthodontic wire[4,5] this interaction being essential for the orthodontic movement.

Inherent local factors concerning the appliances used in orthodontic treatment, such as the brackets, the archwires, the type of alloy and ligature, the intensity of the orthodontic force, and the bracket/wire corrosion influence the friction force produced during tooth movement.[6–11] In addition, the conditions inherent to the buccal environment—temperature variation, pH variation, humidity, presence of dental biofilm—in

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Table 1. Characteristics of the Orthodontic Wires Investigated

Material	Diameter, inch	Length, cm	Manufacturer
NiTi (negative control)	0.016	25	Morelli
Epoxy resin-coated NiTi archwires (experimental)	0.016 + 0.001 (wire + coating)	75	Morelli
OPTIS (positive control)	0.016	25	TP Orthodontics

association with the aforementioned local factors, can alter the forces involved. All of these factors complicate the practitioner's choice of a system and make it difficult to predict treatment results.[1–3]

The increasing demand for esthetics has promoted the development of coated wires with polymeric materials and extruded wires made of polymer matrix fiberglass-reinforced plastic.[12] The surface and thickness of metallic-coated wires can be modified, which can affect corrosive properties, mechanic durability, and especially, friction forces.[11] Alternatively, all-polymer wires adequately match tooth color and present stiffness properties similar to those of metallic archwires, but wire fracture is their biggest drawback. Consequently,[13] durability is reduced, and the treatment course is hindered.

It is important to highlight the fact that in the sliding mechanics, the hardness between the surfaces in contact must be considered, especially in wet environments with temperature and pH variations—conditions that are present in the buccal cavity.[14,15] Nevertheless, in the literature consulted, no studies were found that assessed the friction force in coated wire when submitted to thermal cycling and acid solution immersion. Therefore, the objective of this study was to evaluate the friction force in the coated NiTi archwires in conjunction with Metafasix ligatures and saliva in InVu brackets when subjected to thermal cycling and acid solution immersion, and to compare them with the polymeric and NiTi wires. The null hypothesis is based on the assumption that there is no difference in friction force among the wires.

MATERIALS AND METHODS

Three types of rectified wires (Table 1) were used in this study. Five samples of NiTi wires, 5 samples of OPTIS (TP Orthodontics, LaPorte, IN), and 15 samples of coated NiTi wires (all 5 cm long) were obtained. The coated NiTi wires were divided into three groups according to the type of treatment. The coating was applied at the orthodontics company, Morelli (São Paulo, Brazil), by means of the electrostatic powder technique, using Tiger-89/10210 epoxy paint with Navetherm equipment (model CPN, S/N 01Fn), as proposed by Bandeira.[16]

Before the coating was applied, the surface was chemically prepared to promote adhesion, in accordance with the preparations tested by Bandeira.[16] The diameter of the coated wires was obtained from the mean in millimeters taken in five different regions in each wire with the help of a digital caliper rule (Mitutoyo Digmatic Micrometer IP54 (Mitutoyo Suzano, São Paulo, Brazil), 0–25 mm, 0.001 mm). For NiTi and OPTIS wires, the diameters provided by the manufacturers were used.

After the diameters of the coated wires were measured, three 25-cm segments, one control and two conditioned (thermal cycling and acid-solution immersion), were submitted to sliding mechanics. Conditioning was conducted in two different 25-cm segments. The first was submitted to thermal cycling in distilled water for 1 minute at temperatures of 5°C and 50°C for 3000 cycles with equipment model LBC521-6 (Nova Ética, São Paulo, Brazil). The second was immersed in Coca-Cola, (Jundai, São Paulo, Brazil) for 30 days. The acid environment was preserved through the use of containers sealed with plastic lids to minimize the loss of carbon dioxide, which is responsible for maintaining the environment acidity. Liquids were changed daily.

For the friction test, the wires were cut in 5-cm long segments to obtain 5 samples of NiTi archwires, 15 of coated NiTi, and 5 of OPTIS, and the universal testing machine EMIC DL 10000 (São José dos Pinhais, Paraná, Brazil) with a load cell of 20 N (2.04 kgf) was used. The device used (Figure 1A through C), as well as its assembly, was adapted from the experiments by Nishio[1] and Bandeira.[16] Artificial gel saliva was applied with a syringe.[17] A grip held onto EMIC's load cell grasped each wire segment, placed parallel to the bracket slot basis. The InVu bracket (TP Orthodontics, La Porte, Ind) was adhered to the center of a rotating cylinder with Super Bonder (Loctite Brasil Ltda, São Paulo, Brazil) to reduce any possible angulations between the slot and the wire. The orthodontic wires were tied to the brackets with metafasix elastomeric ligatures (TP Orthodontics). Each wire was pulled five times at a speed of 3 mm/min for one minute. Five maximum force values (gf) were obtained.

Descriptive statistical information, including means and standard deviation ($n = 5$) of the maximum friction forces, was calculated for each bracket/wire combination. For statistical analyses, the data normality was analyzed according to Jarque-Bera ($P > .05$) and compared with the one-way analysis of variance (ANOVA) testing ($P < .01$), which was completed with the use of statistical software (Statistical Package for

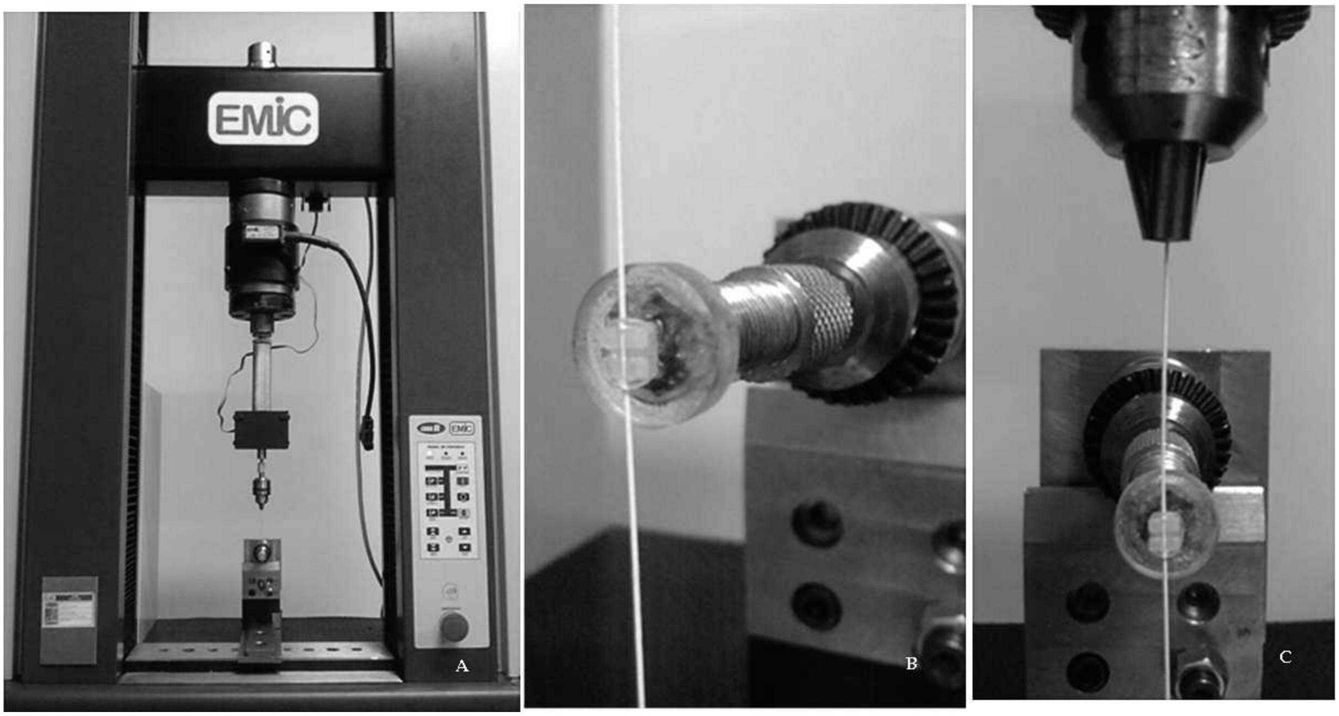

Figure 1. (A) Testing model and mechanical testing machine. (B) Lateral view. (C) Front view.

the Social Sciences [SPSS] for Windows, version 15.0, SPSS Inc, Chicago, Ill). Tukey's post hoc test ($P < .05$) was also applied.

The surface characterization of the wires and coatings was performed by scanning electron microscopy (JEOL USA, Inc, Peabody, MA, model JSM-6460 LV) magnified 200 times.

RESULTS

The final mean diameter of the NiTi coated wires was 0.0173 $\pm$ 0.0008 inches; the coating thickness was 0.0016 inches.

The maximum force values necessary to start the dynamic friction, measured in gf, are shown in Table 2.

Disregarding the thermal cycling and immersion tests, the maximum frictional force values for the tests in NiTi and coated NiTi wires were close, as shown in Table 2. For OPTIS wires, however, the maximum force values correspond to approximately 40% of the mean values of maximum force of the other wires.

Data normality was verified by Jarque-Bera's normality test ($P > .05$). The maximum force obtained presented a significant difference for the different wires ($P = .000$).

Table 3 shows that NiTi presented a significantly higher friction force in comparison with the thermal-cycled coated NiTi and the OPTIS wires. Yet the difference between coated NiTi and acid-immersed coated NiTi was not statistically significant. However, coated NiTi presented a significantly lower friction force compared with the acid-immersed coated NiTi treatment, and a higher friction force compared with OPTIS. The difference in relation to thermal-cycled coated NiTi wire was not statistically significant. Finally, acid-immersed coated NiTi showed a significantly higher friction force compared with OPTIS.

NiTi wires presented a homogeneous surface with scratches due to mechanical polishing during manufacturing process (Figure 2A). Coated NiTi wires showed a homogeneous surface throughout their length, as did OPTIS wires (Figures 2B,C). Cycling caused some cracks in the coating and some pullout of the epoxy resin layer (Figure 2D), which was not observed when submitted to acid solution (Figure 2E).

DISCUSSION

Coated wires form a group of innovative archwires whose main features are to benefit esthetics and to

Table 2. Mean Values of Maximum Friction Force (gf) in the 0.016-inch Wires

NiTi	Coated NiTi			
(Negative control)	Experimental	Experimental + Cycling	Experimental + Immersion	OPTIS
105.20 $\pm$ 2.63	99.65 $\pm$ 0.64	96.43 $\pm$ 1.84	106.47 $\pm$ 4.31	59.76 $\pm$ 4.93

Table 3. Comparison Among Orthodontic Wires Used in the Study According to Tukey Test[a]

(I) Treatment	(J) Treatment	Mean difference (I–J)	*P*
NiTi	**Coated NiTi**	**5.546**	**.093**
	Thermal-cycled coated NiTi	8.774	.003
	Acid-immersed coated NiTi	**−1.268**	**.971**
	OPTIS	45.434	.000
Coated NiTi	**Themal-cycled coated NiTi**	**3.228**	**.539**
	Acid-immersed coated NiTi	−6.814	.027
	OPTIS	39.888	.000
Thermal-cycled coated NiTi	Acid-immersed coated NiTi	−10.042	.001
	OPTIS	36.660	.000
Acid-immersed coated NiTi	OPTIS	46.702	.000

[a] Records in bold are not significant. * Records with $P < .03$ are statistically significant.

lower the friction force. Husmann et al.[11] reported that wires coated with Teflon and polyethylene by ion implantation reduce the friction coefficient compared with the uncoated wires by the same manufacturer. Nevertheless, Proffit[18] described this coat as nondurable. In this study the wire coating kept the friction force unchanged compared with the uncoated wires.

The frictional force values obtained in this study for NiTi wires are compatible with the values found in the literature. Usually, NiTi wires present higher maximum force than stainless steel wires, as discussed in several other studies.[1,16,19,20] Among the esthetic wires investigated, OPTIS wires have the advantage of presenting a significantly lower maximum force value (59.76 $\pm$ 4.93 gf) than the others, whose maximum force values are superior to 96.43 $\pm$ 1.84 gf. According to the manufacturer, mechanical properties of OPTIS wires are similar to those of NiTi wires as they present a good elastic recovery in bending tests like the NiTi wires. However, properties such as formability and weldability are still unknown.[21,22]

As for coated wires, their mechanical properties are determined by the NiTi wires, and the coating plays a solely esthetic role. Therefore, the only source of change in behavior lies in the change of the surface characteristics, where friction takes place between a ceramic surface (bracket) and a polymeric surface (epoxy), which have different hardness and chemical compositions. Yet, their superficial roughness can affect the sliding capacity.[16,23] According to Sadique et al.,[24] friction will increase with the increasing coating thickness for soft materials. However, if the roughness of the bracket surface is higher than the coating thickness, coating penetration will take place, leading to scratches and, consequently, to an increase in friction because sliding will be held back by the mechanics of deformation associated with the pullout of the coating. If the coating is developed and applied in adequate conditions, it may favor the sliding mechanics. The coating obtained in this study may have helped sliding because it did not present maximum force values that were much different vis-à-vis NiTi wire. Thus, it can be said that its behavior concerning the sliding mechanics was kept unchanged even in the presence of a polymer coating.

Another factor that must be considered is the final diameter of the wire that receives coating. Bandeira[16] observed epoxy resin coated wires by two different manufacturers and verified that the diameter variation of the substrate—the metallic wire that received the epoxy resin—interferes with the final diameter of the coated wire. In this study, the coating application was improved, resulting in a coated wire with a final diameter increase of only 0.001 inch in relation to the substrate diameter. It is essential to obtain a coating layer with small thickness and uniformity to preserve the dimensional proportion of the wire inside the slot.

The orthodontic archwire coating guarantees esthetic results. Nonetheless, the effect of the coating on the friction forces involved in the sliding mechanics is not a well-established parameter yet. Coated wires can produce higher friction compared with the uncoated ones because of the possibility of plastic deformation of less hard surfaces.[14,15]

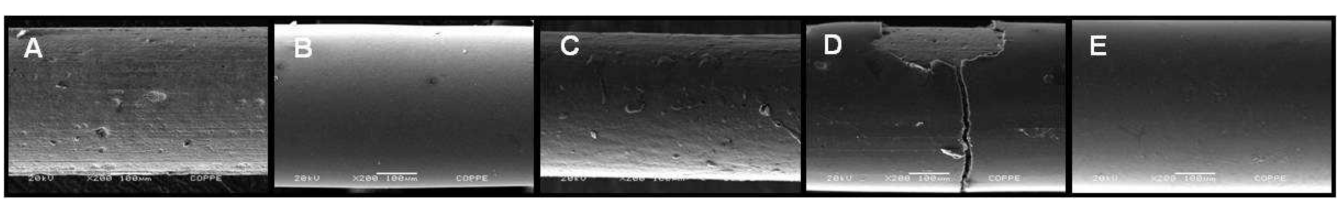

Figure 2. Micrography of (A) NiTi wire, (B) coated NiTi wires Morelli, (C) OPTIS wires, (D) thermal-cycled coated wires, and (E) acid-immersed coated wires (200× magnification).

Because the sliding mechanics depends on all the orthodontic system components, the surface characteristics of each one must be evaluated to identify which parameters are determinant for the force values.

The system used in this study consists of a ceramic bracket. One of the characteristics of ceramic brackets repeatedly mentioned in the literature is the uneven surface of the slot[6,25] resulting from the manufacturing process, which requires machining. The ceramic bracket utilized (InVu) is manufactured by an injection-molding process, and it was observed that its surface is quite regular and uniform—a feature that is common to the manufacturing process, and is also noted in MXi brackets.[16]

As for the elastomeric ligatures, three major parameters that affect the sliding mechanics were identified: geometry, type of polymer used and manufacturing process.[26,27] The ligatures determine the pressure that ties the wire to the bracket, and, consequently, the surface friction force of both accessories. Bortoly et al.[28] have reported that the ligatures surface did not have a significant influence over the friction force, contradicting the findings of other researchers. This work followed the ideas of the authors who confirm such influence. Besides, the ligature chosen for this study presented positive characteristics in relation to the sliding mechanics such as: round geometry, injection molding manufacturing with a polymer that slides easily when moistened, according to the fabricant TP Orthodontics.

The surfaces of the wires evaluated in this work showed clear-cut characteristics. NiTi wires presented an irregular surface, in accordance with the findings documented in the literature.[19] However, the coating application will alter that morphology. The esthetic OPTIS wire presented a more regular surface, which explains why it had the lowest friction force found in this study. In contrast, the coated NiTi wires produced a higher friction force when submitted to Coca-Cola solution, compared with thermal cycling (Table 3). The authors of the present study suggest that this might have occurred because the immersed coated wires demonstrated more superficial roughness resulting from Coca-Cola acid attacks, and hence higher friction. Another fact that must be pointed out is the possibility that volumetric alterations, such as contraction and/or imbibitions, occurred during the cycling process that might have influenced the friction force reduction positively.

CONCLUSIONS

- The null hypothesis was rejected. OPTIS, thermal-cycled coated NiTi, coated NiTi, NiTi, and acid-immersed coated NiTi wires presented, respectively, increasing values of maximum frictional force.
- Thermal cycling on the NiTi coated wire led to a decrease in frictional force compared with the coated NiTi wire that had no conditioning treatment. On the other hand, coated Niti wires subjected to immersion in Coca-Cola showed an increase in friction compared with the unconditioned coated wire, indicating that the medium immersion affects the coating surface.

REFERENCES

1. Nishio C. In vitro evaluation of frictional forces between archwires and ceramic brackets. *Am J Orthod Dentofacial Orthop*. 2004;125:56–64.
2. Pizzoni L, Ravnholt G, Melsen B. Frictional forces related to self-ligating brackets. *Eur J Orthod*. 1998;20:283–291.
3. Read-Ward GE, Jones SP, Davies EHA. Comparison of self-ligating and conventional orthodontic bracket systems. *Br J Orthod*. 1997;24:309–317.
4. Cacciafesta V, Sfondrini MF, Ricciardi A, Scribante A, Klersy C, Auricchio F. Evaluation of friction of stainless steel and esthetic self-ligating brackets in various bracket-archwire combinations. *Am J Orthod Dentofacial Orthop*. 2003;124: 395–402.
5. Sims APT, Waters NE, Birnie DJ, Pethybridget RJ. A comparison of the forces required to produce tooth movement in vitro using two self-ligating brackets and a pre-adjusted bracket employing two types of ligation. *Eur J Orthod*. 1993;15:377–385.
6. Angolkar PV, Kapila S, Duncanson MG Jr, Nanda RS. Evaluation of friction between ceramic brackets and orthodontic wires of four alloys. *Am J Orthod Dentofacial Orthop*. 1990;98:499–506.
7. Saunders CR, Kusy RP. Surface topography and frictional characteristics of ceramic brackets. *Am J Orthod Dentofacial Orthop*. 1994;106:76–87.
8. 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;107:20–27.
9. Ogata RH, Nanda RS, Duncanson MG, Sinha PK, Currier GF. Frictional resistances in stainless steel bracket-wire combinations with effects of vertical defections. *Am J Orthod Dentofacial Orthop*. 1996;109:535–542.
10. Eliades T, Eliades G, Athanasiou AE, Bradley TG. Surface characterization of retrieved NiTi orthodontic archwires. *Eur J Orthod*. 2000;22:317–326.
11. Husmann P, Bourael C, Wessinger M, Jager A. The frictional behavior of coated guiding archwires [Das Reibungsverhalten beschichteter Fuhrungsbogen]. *J Orofac Orthop [Fortschr Kieferorthop]*. 2002;63:199–211.
12. Quintão CCA, Brunharo IHVP. Fios ortodônticos: conhecer para otimizar a aplicação clínica. *R Dent Press Ortodon Ortop Facial Maringá*. 2009;14:144–157.
13. Martins CCR. *Propriedades mecânicas de fios estéticos obtidas em ensaios de tração* [dissertação]. Rio de Janeiro, Brazil: Faculdade de Odontologia, Universidade do Estado do Rio de Janeiro; 2007.
14. Bhushan B. *Handbook of Micro/Nanotribology*. Boca Raton, Fla: CRC Press; 1995.
15. Bhushan B. *Principles and Applications of Tribology*. New York, NY: John Wiley and Sons; 1999.
16. Bandeira AMB. *Avaliação da força de atrito de fios ortodônticos recobertos com resina epoxídica* [dissertação]. Rio de Janeiro, Brazil: Universidade Federal do Rio de Janeiro; 2004.

17. Keith O, Kusy RP, Whitley JQ. Zirconia brackets: an evaluation of morphology and coefficients of friction. *Am J Orthod Dentofacial Orthop*. 1994;106:605–614.
18. Proffit WR. *Contemporary Orthodontics*. St Louis, Mo: Mosby Company; 2000.
19. Kusy RP. A review of contemporary archwires: their properties and characteristics. *Angle Orthod*. 1997;3: 197–207.
20. Kapila S, Angolkar PV, Duncanson MG Jr, Nanda RS. Evaluation of friction between edgewise stainless steel brackets and orthodontic wires of four alloys. *Am J Orthod Dentofacial Orthod*. 1990;98:117–126.
21. Gurgel JA, Ramos AL, Kerr SD. Fios ortodônticos. *R Dental Press Ortodon Ortop Facial*. 2001;6:103–114.
22. Imai T, Watari F, Yamagata S, Kobayashi M, Nagayama K, Toyoizumi Y, Nakamura S. Mechanical properties and aesthetics of FRP orthodontic wire fabricated by hot drawing. *Biomaterials*. 1998;19:2195–2200.
23. Ramakrishna S. Development of a fiber-reinforced polymer orthodontic bracket and arch wire. Available at: http://www.bioeng.nus.edu.sg/nanobio/nanobio.html. Accessed October 25, 2010.
24. Sadique SE, Ramakrishna S, Batchelor AW, Bing CH. In vitro frictional behavior and wear patterns between contemporary and aesthetic composite orthodontic brackets and archwires. *Wear*. 2006;261:1121–1139.
25. Pratten DH, Popli K, Germane N, Gunsolley JC. Frictional resistance of ceramic and stainless steel orthodontic brackets. *Am J Orthod Dentofacial Orthop*. 1990;98: 398–403.
26. Fortini A, Lupoli M, Cacciafesta V. A new low-friction ligation system. *J Clin Orthod*. 2005;39:464–470.
27. Tecco S, Tetè S, Festa F. Friction between archwires of different sizes, cross-section and alloy and bracket ligated with low-friction or conventional ligatures. *Angle Orthod*. 2009;79:111–116.
28. Bortoly TG, Guerrero AP, Rached RN, Tanaka O, Guariza-Filho O, Rosa EAR. Sliding resistance with esthetic ligatures: an in-vitro study. *Am J Orthod Dentofacial Orthop*. 2008;133:340.e1–340.e7.