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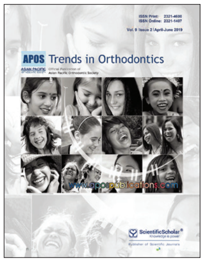

Original Article

Friction evaluation of an elastic chain positioned under or over the wire in self-ligating brackets

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Received : 19 February 2021
Accepted : 26 June 2021
Published : 05 October 2021

DOI
10.25259/APOS_26_2021

Quick Response Code:

ABSTRACT

Objectives: This study aimed to evaluate the frictional resistance produced by active and passive self-ligating brackets on stainless steel archwires in the absence or presence of elastomeric chains under or over the wire.

Materials and Methods: Four types of self-ligating brackets were used: Two active and two passive. For each commercial brand, five brackets were bonded to an acrylic plate and the frictional resistance was evaluated with 0.018” and 0.019” × 0.025” stainless steel wires in three situations: Without elastomeric chain, with elastomeric chain placed under and over the wire.

Results: The bracket type, cross-section of the wire, and type of ligation had significant interactions with each other; the frictional resistance was significantly lower with the use of passive self-ligated brackets, while no difference was found when a 0.018” wire was tested. Moreover, the frictional resistance in the absence of an elastomeric chain, or when the chain was under the wire, was significantly lower in comparison with the values obtained when the chain was placed on the wire.

Conclusion: Frictional resistance of passive and active self-ligated brackets is influenced by the ligation methods and the cross-sectioning of archwires.

Keywords: Orthodontic friction, Elastomeric ligatures, Orthodontic archwire, Active self-ligating bracket, Passive self-ligating bracket

INTRODUCTION

Several factors can influence the friction resistance for sliding mechanics, such as cross-sectioning and alloy composition of the wire,[1-7] composition and design of the bracket,[8-10] connection type from bracket to wire,[4,11-13] and elastomeric ligatures or chains.[14,15]

Among these factors, orthodontists can routinely select brackets, wires, and types of connections that can lead to smaller friction with better biological responses, allowing for benefits in orthodontic tooth movement within a shorter period.[16,17] Self-ligating brackets have demonstrated low friction resistance during sliding mechanics when compared to conventional brackets,[2,5,18,19] although there is no consensus in the available literature.[20,21] In addition, the type of orthodontic wire used throughout treatment, as well as the thickness, should be taken into consideration,[17] considering that the thicker the wire, the more the slot of the bracket is filled and thus the greater the amount of force for orthodontic tooth movement.[22]

Another important factor that produces frictional resistance, although necessary during orthodontic mechanics, is the elastomeric chain used for space closure.[15] Elastomeric chains can cause great friction and are widely used in closing spaces, as they are compatible with oral tissues, ease of installation, and removal, and do not require patient compliance.[23] Elastomeric chains, when used with self-ligating brackets, can be installed over[24] or under[25] the bracket; however, there are no studies that have evaluated the interaction between the three factors of brackets, wire, and position of the elastomeric chain; and just a few studies that analyzed the elastomeric chain under the wire.[25]

Due to the possibilities of the combination of brackets (conventional and self-ligating brackets), types of wires, and ligation methods (over and under) interfering with the resistance during the sliding or arch wire-guided mechanics, the objective of this research was to provide an *in vitro* evaluation of the static frictional resistance of active or passive self-ligating brackets, when using elastomeric chains positioned over and under the wire, using 0.018” and 0.019 × 0.025” stainless steel archwires.

MATERIALS AND METHODS

The experimental units were constituted by active and passive self-ligating bracket segments (from the upper right second premolar to upper right central incisor), evaluated with a round cross-sectional 0.018” stainless steel archwire (ref.55.01.018, Morelli, Sorocaba, São Paulo, Brazil) and a 0.019” × 0.025” rectangular cross-section stainless steel archwire (ref.55.04.014, Morelli, Sorocaba, São Paulo, Brazil), subjected to friction in three situations: A. without elastomeric chain (none), B. with medium linked elastomeric chain (ref.34-023-68, GAC, Bohemia, New York, USA) positioned under the archwire (under), and C. with elastomeric chain positioned above the archwire (over) [Figure 1]. The materials and their respective characteristics are shown in [Table 1].

Cylindrical acrylic devices were developed, with dimensions of 14 mm in diameter and 50 mm in length, with one of its ends adapted to an acrylic. In this plate, five brackets of each trademark, corresponding to the teeth: Right maxillary second premolar, right maxillary first premolar, right maxillary canine, right maxillary lateral incisor, and right maxillary central incisor were aligned parallel to the long axis of the plate, in the most central region, with the first bracket (corresponding to the premolar) positioned at a distance of 3 mm from the upper end of the plate. This alignment represented the right maxilla hemi-arcade with an inter-bracket distance of 8 mm, corresponding to the average inter-bracket distance, which is usually found in clinical situations. The inter-bracket distance was measured from the center of the bracket to the center of the adjacent bracket [Figure 2a-g].

To fix the brackets on the plate, the slots were aligned, in a parallel position, with a guide made with 0.021” × 0.025” steel wire. The brackets were attached to the acrylic plate with a resinous resin bonding system (Transbond XT, 3M Unitek, CA, USA). The photoactivation was performed for 40 s on each bracket, using anLED curing light (radii-cal, SDI, Bayswater, Victoria, Australia). Next, the guidewire was removed for testing on the universal test machine [Figure 2h and i].

Mechanical tests were performed using a universal testing machine (Emic DL 2000, São José dos Pinhais, Paraná, Brazil). The device with fixed brackets was positioned at the base of the universal test machine so that their slots were parallel to the traction of the wire. For this, a 0.019” × 0.025” steel wire was used and positioned on the hook, and the parallelism of these with the slots of the brackets was verified.

Each set of brackets under the three different elastomeric chain positions was tested 5 times in each situation ($n = 5$). The tests were randomly drawn by lot. Before each test, the wires were cleaned with gauze soaked in 70% alcohol and dried with absorbent paper, thus avoiding the presence of any undesirable debris that could influence the slide. At each test, the clips were opened, the wire was positioned on the traction hook and in the slots of the brackets, and the clips were then closed. The slots were lubricated with 0.10 μl artificial saliva (0.4 g/L KCl, 0.4 g/L NaCl, 0.6 g/L NaH_2PO_4, 0.0016 g/L Na_2S, 1.0 g/L urea, and 3900 mg/L of mucin)[25] for each test. For the groups, where the elastomeric chain was tested, segments of six links were cut. According to the group, the chain was positioned under or above the wire in all five brackets.

The universal test machine has been programmed to move the wire by traction with a speed of 3 mm/min, using a load

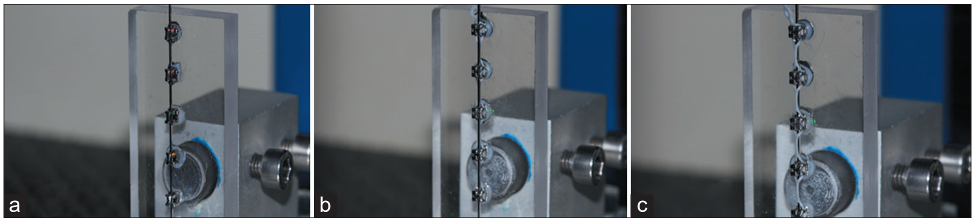

Figure 1: Frictional resistance test carried out for the groups: (a) without elastomeric chain; (b) elastomeric chain under the wire; (c) elastomeric chain over the wire.

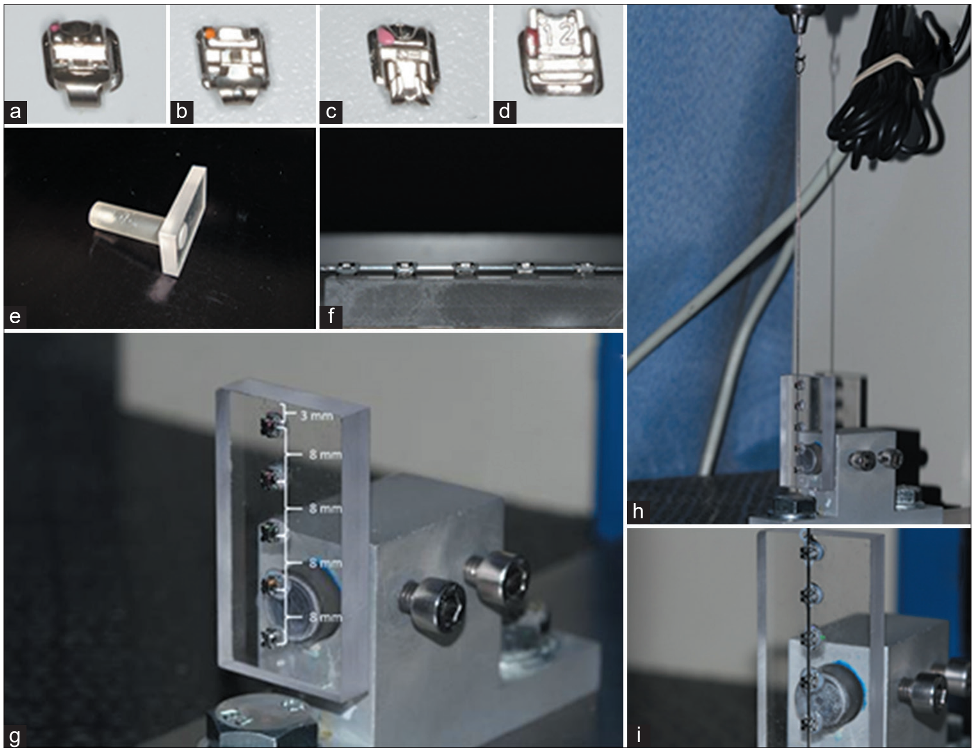

Figure 2: (a) In-Ovation R. (b) SLI. (c) Damon MX. (d) Tellus EX. (e) Cylindrical device adapted to acrylic plate. (f) Bonding the brackets with the parallel guide to the acrylic base. (g) Brackets positioned on the acrylic plate at a distance of 8 mm inter-brackets. (h) Wire positioned for the test. (i) Frictional resistance test being carried out *n* = 5.

Table 1: Brackets, characteristics, and connection method used for the elastomeric chain in the experiment.

Bracket (manufacturer) City, state, country, Characteristics	Type	Characteristics	Connection method
In-Ovation R (GAC) - Bohemia, New York, United States Slot 0.022" ×0.025"	Maxillary second premolar R ref.87-142-90	Torque: −7°; angulation: 0°	Active self-ligating
	Maxillary first premolar R ref. 87-142-90	Torque: −7°; angulation: 0°	
	Maxillary canine R ref. 89-132-10	Torque: −2°; angulation: 13°	
	Maxillary lateral incisor R ref. 89-122-00	Torque: 8°; angulation: 9°	
	Maxillary central incisor R ref. 89-112-00	Torque: +11°; angulation: 5°	
SLI (Morelli) - Sorocaba, São Paulo, Brasil Slot 0.022" × 0.025"	Maxillary second premolar R ref. 10.14.007	Torque: −7°; angulation: 0°	
	Maxillary first premolar R ref. 10.14.007	Torque: −7°; angulation: 0°	
	Maxillary canine R ref.10.14.005	Torque: −2°; angulation: 9°	
	Maxillary lateral incisor R ref.10.14.003	Torque: 8°; angulation: 9°	
	Maxillary central incisor R ref.10.14.001	Torque: +11°; angulation: 5°	
Damon MX (Ormco) - Glendora, Califórnia, Estados Unidos da América Slot 0.021" × 0.025"	Maxillary second premolar R ref. 494-4492	Torque: −7°; angulation: 2°	Passive self-ligating
	Maxillary first premolar R ref. 494-4490	Torque: −7°; angulation: 2°	
	Maxillary canine R ref. 494-4480	Torque: 0°; angulation: 6°	
	Maxillary lateral incisor R ref. 494-4470	Torque: 8°; angulation: 9°	
	Maxillary central incisor R ref. 494-4460	Torque: 12°; angulation: 5°	
Tellus EX (Eurodonto) - Curitiba, Paraná, Brazil Slot 0.021" × 0.025"	Maxillary second premolar R ref. 1027-15G	Torque: −7°; angulation: 0	
	Maxillary first premolar R ref. 1027-14G	Torque: −7°; angulation: 0	
	Maxillary canine R ref. 1027-13G	Torque: 0; angulation:8°	
	Maxillary lateral incisor R ref. 1027-12	Torque: 10°; angulation:8°	
	Maxillary central incisor R ref. 1027-11	Torque: 17°; angulation: 4°	

cell of 20N. The resistance to static friction was measured in gf. The record of the friction resistance was performed in a specific computer program (São José dos Pinhais, Paraná, Brazil). The mechanical tests were performed at room temperature (approximately 23°C). For each test, the wires and the elastomeric chain (when present) were removed. The brackets were cleaned by gauze soaked in 70% alcohol and dried with absorbent paper. The process was then repeated using a new wire and new chain, according to the drawn set.

Results were expressed as mean ± standard deviation of the mean, considering that data sets presented a non-normal distribution (Kolmogorov–Smirnov test). A three-way ANOVA test was used to analyze differences among the three criteria: Brackets, chain, and wire. Tukey tests were used for multiple comparisons. Statistical calculations were performed using the SPSS 20 program (SPSS Inc., Chicago, IL, USA), with a significance level of 5%.

RESULTS

The analysis of variance with three criteria showed that there was no significant interaction among the three factors under study: Bracket, wire, and elastomeric chain ($P = 0.083$).

Frictional resistance depends on the type of bracket design and wire section ($P < 0.001$). Regardless of the use or not of an elastomeric chain, when the 0.018” steel wire was used frictional resistance proved to be statistically similar between the brackets. As for the 0.019” × 0.025” wire, using an elastomeric chain or not, a significantly less frictional force was observed with the use of the passive self-ligating Damon MX and Tellus EX brackets, which did not differ between them [Table 2 and Figure 3]. The frictional forces provided by the active self-ligating In-Ovation R and SLI brackets in the presence of the 0.019” × 0.025” wire were significantly greater than for the passive Damon MX and Tellus EX brackets, either in the presence or absence of the elastomeric chain [Table 2]. Regardless of the bracket brand and the elastomeric chain, significantly higher frictional forces were presented by the 0.019” × 0.025” wire [Table 2].

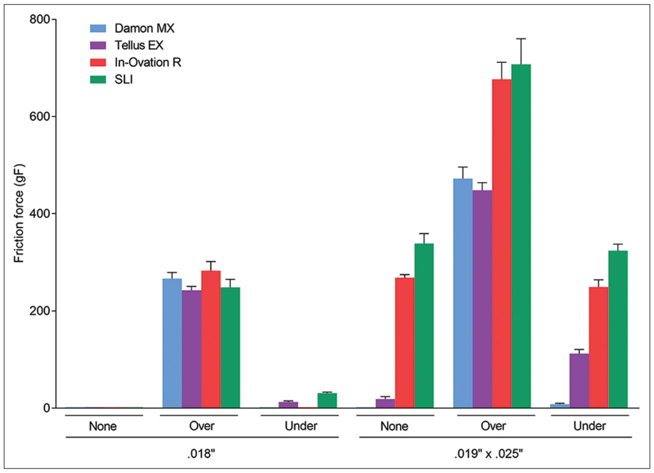

Figure 3: Column diagram of the average values±standard deviation of frictional force (gF) according to the bracket brand, the wire, and the use or not of an elastomeric chain.

The bracket design and elastomeric position influences the frictional resistance ($P = 0.003$). Regardless of both the ligating method of the elastomeric chain and the type of wire, the passive self-ligating Damon MX and Tellus EX brackets, which did not demonstrate significant differences between them, provided lower values of frictional resistance compared to the active brackets [Figure 3]. In the absence of elastomeric chains, although SLI brackets showed increased frictional resistance compared to In-Ovation R, no statistical difference was verified between them [Table 3]. No significant difference was observed between the active self-ligating In-Ovation R and SLI brackets when it was positioned over the wire. Nonetheless, when the elastomeric chain was under the wire, the greatest frictional force was revealed with the use of the SLI bracket [Table 3].

Even considering the position of the elastomeric chain, the SLI brackets demonstrated the higher values and the frictional force gradually decreased with the use of the In-Ovation R, Tellus EX, and Damon MX brackets, all of which differed significantly among them [Table 3]. For the Damon MX, In-Ovation R, and SLI brackets, regardless of the wire

Table 2: Average and standard deviation of the frictional force values (gF) according to the bracket and the wire, regardless of the connection method of the elastomeric chain. Capital letters indicate a significant difference between brackets within same wire thickness. Lower case letters indicate a significant difference between 0.018” and 0.19” × 0.025” wires. *n*=5. Tukey test. *P*<0.05.

Bracket	Wire	
	0.018”	**0.019” × 0.025”**
Damon MX	90.26 (129.99) Aa	160.96 (229.86) Ab
Tellus EX	85.74 (115.21) Aa	193.23 (192.20) Ab
In-Ovation R	95.73 (138.92) Aa	398.36 (209.12) Bb
SLI	93.95 (115.59) Aa	456.89 (196.32) Bb

Table 3: Mean and standard deviation of the frictional force values (gF) according to the bracket and the elastomeric chain connection, regardless of the wire thickness. Capital letters indicate a significant difference between brackets within the same elastomeric chain. Lower case letters indicate a significant difference between the connection methods. *n*=5. Tukey test. *P*<0.05.

Bracket	Elastomeric chain		
	None	**Over**	**Under**
Damon MX	2.05 (0.00) Aa	369.64 (115.60) Ab	5.13 (4.13) Aa
Tellus EX	10.46 (11.42) Aa	345.43 (111.71) Ac	62.57 (54.14) Bb
In-Ovation R	135.38 (140.83) Ba	480.00 (215.76) Bb	125.74 (132.20) Ca
SLI	170.46 (180.08) Ba	478.15 (255.53) Bb	177.64 (155.74) Da

Table 4: Mean and standard deviation of the friction force values (gF) according to the wire and the elastomeric chain method, regardless of the bracket brand. Capital letters indicate a significant difference between wires within same elastomeric chain condition. Lower case letters indicate a significant difference between the connection methods. *n*=5. Tukey test. *P*<0.05.

Wire	Elastomeric chain		
	None	Over	Under
0.018"	2.05 (0.00) Aa	260.20 (33.90) Ab	12.00 (12.56) Aa
0.019" × 0.025"	157.13 (154.35) Ba	576.41 (139.22) Bb	173.54 (127.11) Ba

type, significantly lower values of frictional resistance were verified when the elastomeric chain was not used or when it was positioned under the wire [Table 3]. For the Tellus EX bracket, the lowest values of frictional resistance were observed in the absence of the elastomeric chain [Table 3]. For all brackets brands, the position of the elastomeric chain over the wire generated significantly higher values of frictional resistance than those found in the absence of chain, but lower when the chain was under the wire [Table 3].

The wire and ligation methods interfere with the frictional resistance ($P < 0.001$). The frictional force for both 0.018" and 0.019" × 0.025" wires, in the absence of the elastomeric chain or when it was under the wire, was significantly lower compared to the values obtained when the chain was over the wire, regardless of the bracket design [Table 4]. For all bracket types, regardless of the ligating method of the elastomeric chains, the frictional force was significantly greater with the use of the 0.019" × 0.025", as compared to the 0.018," wire [Table 4].

DISCUSSION

During sliding mechanics, the friction between the wire and the bracket can be influenced by the type of material and section of the wire, composition, and design of the bracket, angulation, and inclination of the wire/bracket, type and bond strength, and the topographic surface of the materials.[1,4,17,26,27] Among these factors, the influence of the connective method of the wire to the bracket is the most commonly studied, observing that the self-ligating brackets have presented less friction than conventional brackets.[1,5,7,16,17] This study thus highlights, in an *in vitro* model, which the frictional resistance depends on the type of bracket design, wire section, and position of the elastomeric chain.

Friction is a complex phenomenon and many factors may affect the frictional resistance.[14,15] With this regard, the resistance to sliding can also be explained by three factors: binding, notching, and classic friction.[28] The friction is caused by the direct contact of wire with the bracket, while the binding may begin after tooth movement and the wire flexes, touching the ridges of the brackets causing the moment delay.[28] Notching is a permanent alteration of the structure of the wire and/or bracket.[28,29] Furthermore, the type of mechanics used (sliding vs. loop) may affect the frictional resistance.[29,30] The application of a loop during the orthodontic treatment may nullify the resistance to sliding.[30] To better comprehend the effects of the resistance to sliding during sliding mechanics, this study used different ligation methods to evaluate the classical friction.

In a critical analysis of the *in vitro* friction studies published in the literature, it has been stated that the self-ligating brackets produced less friction than conventional brackets when used with smaller caliber round wires with aligned and torque-free brackets.[31] The ligating method for self-ligating brackets occurs without the need for elastic or metal ligature but through clips or doors present in the brackets which, when closed, provide the sliding of the round section wire with minimal or no interaction to the linkage system.[2,6,24,32,33]

In the current study, passive and active self-ligating brackets showed no statistically significant differences when using a 0.018"gauge steel wire, regardless of whether the elastomeric chain is used or not, corroborating with studies in which passive and active self-ligating brackets showed low or no resistance to friction in round section wires.[13,17,25,27,32] Depending on the gauge, section, and position of the wire in the slot, the clips of the active brackets work passively, without interaction with the wire, similar to the doors of the passive self-ligating brackets, showing similar friction results.[7,12,24,27] Our results also demonstrated that passive self-ligating brackets showed less resistance to friction than did active brackets when using rectangular 0.019" × 0.025" stainless steel wires. These results corroborate with studies that compared the sliding of passive and active self-ligating brackets on rectangular stainless steel wires.[1,9,12,17,24] This fact can also be explained by the characteristic of the clip that, in the active self-alloys, interact with the larger gauge wires, acting as a spring, pushing them against the bottom of the slot which generates friction. On the other hand, in passive self-ligating, the bracket has a rigid door that, when closed, acts as a fourth wall, giving the bracket the appearance of a tube providing less friction.[12,24,27,32]

Regarding the wire gauge, in general, the rectangular wires produced significantly greater friction than did the round wires for all evaluated brackets, corroborating with several studies, despite the different methodologies employed.[2,3,27] In corroboration with other studies,[10,34-36] the absence of the elastomeric chain in the Damon MX bracket with 0.019" × 0.025" wire produced the lower friction and had similar results when compared to the 0.018" wire.

To better understand the effects of the presence or absence of the elastomeric chain, a clinical condition, with perfect alignment of the brackets and using elastomeric chain in a hemiarcade, was simulated *in vitro*. The option of placing the chain over or under the wire relates to the possibility of using the elastomeric chain in the sliding mechanics in self-connected appliances with the least possible friction.[11] In mechanics with conventional brackets, elastomeric chains are usually used over the wire; in self-ligating brackets, for reasons of clinical convenience, elastomeric chains have also been positioned under the wire.[25] Shivapuja and Berger[25] observed that active and passive self-ligating brackets demonstrated different profiles when the elastomeric chain was positioned under the wire. The passive self-ligating brackets did not differ when tested with the chain positioned under the wire concerning the tests carried out without the chain, while the active bracket showed greater friction,[25] which is in accordance with our results.

The literature has demonstrated that passive self-ligating brackets have less frictional resistance to sliding compared to active self-ligating brackets depending on the archwire alloy used during the treatment.[37-39] Despite active self-ligating brackets, the depth of the wire has a larger role in the frictional resistance than its height.[37] An analogy can be made between the archwire alloy and the position of the ligation method and a possible explanation might be explained because the design of the bracket rod of the active brackets allows for the contact of the elastomer with the wire, increasing the friction even with the chain positioned under the wire.[37-39]

Regarding the elastomeric chain, regardless of the wire, the passive self-ligating Damon MX and Tellus EX brackets without chains showed lower friction averages when compared to the active brackets, which showed similar results. The passive self-ligating bracket system is more efficient in providing less friction when compared to the active brackets due to the clip acting on the passive systems that do not interact with the wire and causing reduced friction.[10,37,39]

Greater friction resistance was exhibited for all brackets tested with the elastomeric chain used over the wire, regardless of the wire, with friction being significantly higher in active brackets than in passive brackets. The chain positioned over the brackets caused intimate contact of the elastomeric chain with the wire, generating greater friction, which may clinically cause inefficiency due to the dissipation of force, which is not desired in sliding mechanics.[25] The SLI brackets showed greater friction, followed by In-Ovation R, Tellus EX, and Damon MX brackets. For the Damon MX, In-Ovation R, and SLI brackets, similar frictional resistance was shown without the elastomeric chain or its position under the wire, which might be explained due to the possibility of the elastomeric chain being positioned behind the lever arm, thus distancing itself from the wire without causing an increase in friction.[25] The Tellus EX bracket showed greater friction in tests with the chain under the wire compared to the use of no elastomeric chain, demonstrating that, even under the wire, this bracket allowed for a relative contact of the chain with the wire.[25] However, it must be reported that the friction produced in these brackets with the chain under the wire was significantly less than the friction produced when the elastomeric chain was tested over the wire and was also significantly less when compared to the active brackets tested in this same situation. Thus, the passive self-ligating Tellus EX bracket was less efficient than the passive Damon bracket and more efficient than the active Inovation R and SLI brackets concerning friction when the chain was positioned under the wire.

It was also found that in both 0.018” and 0.019” × 0.025” wires, the presence of the chain positioned over the wire generated greater friction when compared to the use of no elastomeric chain or when it was positioned under the wire regardless of which bracket was used. In this case, even with the difference between the closing system of passive and active brackets, when using elastomeric chains over the bracket/wire set, the elastomeric chain comes into contact with the wire, causing greater friction during sliding, and regardless of the wire.[5,6,12,17,25] In all situations tested in this study, the resistance to friction was significantly higher with the use of the 0.019” × 0.025” wire. These results can be explained by the decreased area inside the slot of the bracket in the rectangular 0.019” × 0.025” wires, as they are larger in the vertical direction when compared to the round 0.018” wires, causing greater friction due to the increased surface contact of the wire corners with the inner walls of the bracket slot.[1,2,17]

Clinically, the use of a bracket system does not require an elastomer, since the bracket/wire connection favors sliding due to reduced friction, allowing the orthodontist to use light forces, thus reducing the undesirable effects of orthodontic mechanics.[27,33,36] During orthodontic treatments, especially with the use of the self-ligating system, the appearance of diastema in the arcades is common and, usually, orthodontists use elastomeric chains in the treatment. In conventional systems, the elastomeric chains are positioned over the wire,[34,35] which for convenience sake, can also lead the orthodontist to use the chain over the wire when using self-ligating brackets.[25] Our results suggest that when considering sliding mechanics in passive and active self-ligating brackets when using 0.018” or 0.019” × 0.025” steel gauge wires, a viable alternative to avoid the production of a heavy frictional resistance is to use the elastomeric chain in the sliding mechanics under the wire.

CONCLUSION

Regardless of the use of elastomeric chains, when 0.018" stainless steel wire was used, the resistance to friction was similar between the passive and the active self-ligating brackets. For the 0.019" × 0.025" wire, the resistance to friction was lower for the passive self-ligating brackets. In the absence of the elastomeric chain, or when it was positioned over the wire, regardless of the wire, the passive self-ligating brackets showed less resistance to friction than did the active self-ligating. The resistance to friction, in the absence of an elastomeric chain or when it was under the wire, was lower regardless of the bracket.

Declaration of patient consent

Patient's consent not required as there are no patients in this study.

Financial support and sponsorship

Nil.

Conflict of interest

There are no conflict of interest.

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How to cite this article: da Silva RR, Pereira GO, Macari S, Barbosa JA, Basting RT. Friction evaluation of an elastic chain positioned under or over the wire in self-ligating brackets. APOS Trends Orthod 2021;11:183-90.