Comparative study of frictional forces generated by NiTi archwire deformation in different orthodontic brackets: *In vitro* evaluation

Gilberto Vilanova Queiroz[1], Rafael Yagüe Ballester[2], João Batista De Paiva[3], José Rino Neto[3], Giselle Mara Galon[4]

Introduction: The purpose of this study was to compare the frictional forces between 0.014-in NiTi wires (Aditek) with 4 mm horizontal deflection and brackets with different archwire ligation systems.

Methods: Four types of self-ligating brackets (Damon MX, Easy Clip, Smart Clip and In-Ovation), a triple bracket (Synergy) and a twin bracket with 8-shaped ligature (Tecnident) were tested. Twin brackets with conventional elastomeric ligatures (Morelli) were used as control group. Tests were repeated 10 times for each bracket/archwire combination. Frictional forces were measured in an Instron universal tensile machine at 3 mm/minute speed and a total displacement of 6 mm. Statistical analysis comprised ANOVA and Dunnett's multiple comparison post hoc test.

Results: Deflection-induced frictional (DIF) forces increased in the following order: Synergy, Damon, 8-shaped Ligature, Easy Clip, In-Ovation, Smart-Clip and conventional ligatures. The differences among groups were significant, with the exception of the 8-shaped ligature groups which was equal to the Damon and Easy Clip groups.

Conclusions: Compared to conventional ligatures, all ligation systems tested reduced frictional forces. However, such reduction varied according to the ligation system employed.

Keywords: Orthodontic brackets. Friction. Corrective Orthodontics.

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Estudo comparativo da força de atrito produzida pela deformação de arco NiTi em diferentes braquetes ortodônticos: avaliação *in vitro*

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Objetivo: o objetivo desse trabalho foi comparar as forças de atrito entre fios NiTi 0,014" (Aditek) com deformações horizontais de 4mm, e braquetes com diferentes sistemas de ligação dos arcos.

Métodos: foram testados 4 tipos de braquetes autoligáveis (Damon MX, Easy Clip, Smart Clip e In-Ovation), um braquete triplo (Synergy) e um braquete gêmeo com amarrilho 8 (Tecnident). Como grupo controle, foi utilizado braquete gêmeo com ligadura elástica convencional (Morelli). Foram executadas 10 repetições em cada combinação arco/braquete. As forças de atrito foram medidas em máquina de tração universal Instron, com velocidade de 3mm/minuto e deslocamento total de 6mm. Para análise estatística, usou-se a ANOVA e o Teste de Comparações Múltiplas de Dunnett.

Resultados: as forças de atrito por deformação do fio se mostraram crescentes na seguinte ordem: Synergy, Damon, amarrilho 8, Easy Clip, In-Ovation, Smart-Clip e ligadura convencional. As diferenças entre todos os grupos foram estatisticamente significantes, com exceção do Amarrilho 8 em relação aos grupos Damon e Easy Clip.

Conclusão: em relação à ligadura convencional, todos os sistemas de fechamento das canaletas testados são eficientes em reduzir a força de atrito, porém, tal redução varia significativamente de acordo com o sistema de fechamento da canaleta selecionado.

Palavras-chave: Braquetes ortodônticos. Fricção. Ortodontia Corretiva.

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INTRODUCTION

Straight wire technique is the most widely used in contemporary orthodontic treatments and its effectiveness depends on two basic factors: Archwire/bracket sliding and the amount of orthodontic forces effectively delivered to the periodontium.[1] The frictional forces present in the archwire/bracket interface play an important role in this context because it opposes archwire/bracket sliding, thereby decreasing the amount of force delivered to the periodontium for tooth movement.[6,7,12]

Determining the approximate magnitude of friction in different clinical situations can assist in identifying the actual force employed in moving teeth, thus enabling professionals to apply light forces to the periodontium while stimulating maximal biological forces in the tooth being moved and minimal bone remodeling in the anchorage tooth.[2]

Two basic types of friction that restrict orthodontic sliding mechanics can be found at the archwire/bracket interface: The ligation friction produced by elastomeric or steel ligatures when the archwire is compressed against the bottom of the slot, and the deflection-induced friction (DIF) generated by compressing the deflected archwire against the bracket slot.

By eliminating ligation friction in the stage of tooth alignment one can optimize the action of superelastic archwires and produce sliding mechanics with light, continuous forces with the purpose of moving teeth. Self-ligating brackets, Slide unconventional elastomeric ligatures (Leone) and 8-shaped ligatures (Tecnident) as well as the special Synergy (Rocky Mountain) and Delta Force (Ortho Organizers) brackets are effective and equivalent options for the control of friction in the phase of dental leveling and alignment.[1,3,4,5]

Archwire deflection-induced friction usually takes place in the initial phase of orthodontic treatment when the orthodontic slots are in different planes. Archwire deflection creates the forces responsible for correcting malpositioned teeth and simultaneously exerts pressure on anchorage teeth, generating deflection-induced friction, which undermines tooth movement effectiveness. The magnitude of archwire deflection-induced friction, also called binding, depends on the intensity of force with which the archwire presses against the walls of the anchorage brackets and is influenced by interbracket distance, diameter and type of orthodontic wire alloy.

In malocclusions displaying deviations in the horizontal plane (lingual or buccal), the archwires are deflected and compress the bracket slot closing system. In light of the differences in bracket design and friction coefficient of the materials employed in the manufacture of slot closing systems, it is important to assess whether the magnitude of the friction generated through archwire deflection is similar between brackets with different slot closing systems.

The purpose of this study was to compare frictional forces generated by 0.014-in NiTi wires subjected to 4 mm horizontal deflection in brackets featuring different slot closing systems.

MATERIAL AND METHODS

A test device with 5 brackets, representing the central and lateral incisors, canine, first and second premolars of the upper left quadrant, was used to compare the frictional forces produced by different archwire ligation systems: Four types of self-ligating brackets were tested, Damon MX (Ormco), Easy Clip (Aditek), In-Ovation (GAC) and Smart Clip (3M/Unitek), as well as the Synergy triple bracket (Rocky Mountain Orthodontics) and twin brackets (Morelli) tied to the archwires with 8-shaped ligatures (Tecnident). Twin brackets (Morelli) tied conventionally with elastomeric ligatures (Morelli) were used as control group. Five bracket sets with 0.022 x 0.028-in slots were employed for each ligation system tested.

The test device had 5 sliding cylinders which acted as support for bonding the brackets, and two 0.022 x 0.028-in guiding slots located at the ends of the area designed for the brackets (Fig 1). Direct bonding of the brackets was performed individually and followed this sequence: Seating of straight 0.021 x 0.025-in steel archwire in the guiding slots; insertion of a standard 0.022-in thick ruler in the guiding slots while compressing the 0.021 x 0.025-in archwire; application of primer to the bracket base and initial placement of support cylinder; sliding of support cylinder until the 0.021 x 0.025-in archwire was seated in the bottom of the slot throughout the wire's mesiodistal extent, thereby

determining the final bonding position (Fig 2); Direct bonding with cyanoacrylate (Superbonder, Henckel/Brazil) proved strong enough to stabilize the brackets during the mechanical tests, even in the specimens where there was no full contact between bonding surface and bracket (Fig 2). The distance between the bracket centers' was 7.5 mm.

A straight superelastic NiTi wire (Aditek) with 0.014" cross-section and 12 cm length was employed in the tests in an active configuration. The wire was stabilized inside the slot through the various self-ligating brackets, through 8-shaped ligatures on the Morelli brackets, throughconventional elastomeric ligatures on Morelli brackets and through the center tie-wings of Synergy brackets.

To simulate a scenario of linguoversion, the cylinder where the upper canine bracket was positioned was loosened and shifted horizontally by 4 mm, producing elastic deflection in the 0.014-in NiTi wire as well as deflection-induced friction (Fig 3).

The wire was pulled until it slid inside the bracket slot and the deflection-induced friction forces were recorded. A model 5565 Instron universal mechanical testing machine was used with a load cell of 500 Newtons and a speed of 3 mm/minute. Parallelism between the testing device and the latch on the Instron machine was achieved by inserting the tip of a standard 0.022-in thick ruler in the guiding slots while the opposite tip contacted the right wall of the latch, which remained stationary. The closing and opening of the latch was carried out by laterally displacing the left movable wall (Fig 4).The machine was calibrated prior to the experiment. Starting from the initial movement of the archwire the forces were recorded at

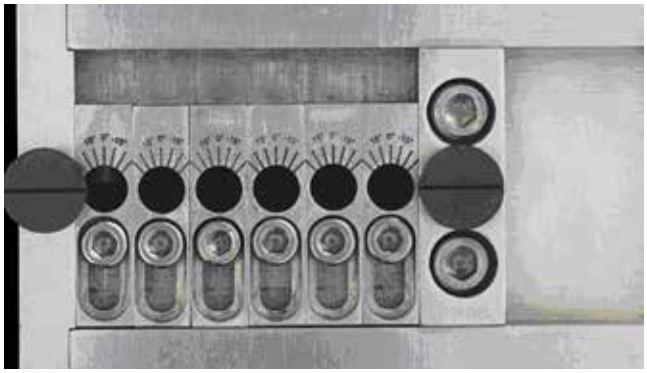

Figure 1 - Device with guiding slots at both ends.

Figure 2 - Brackets positioned in a passive configuration.

Figure 3 - Brackets positioned in an active configuration.

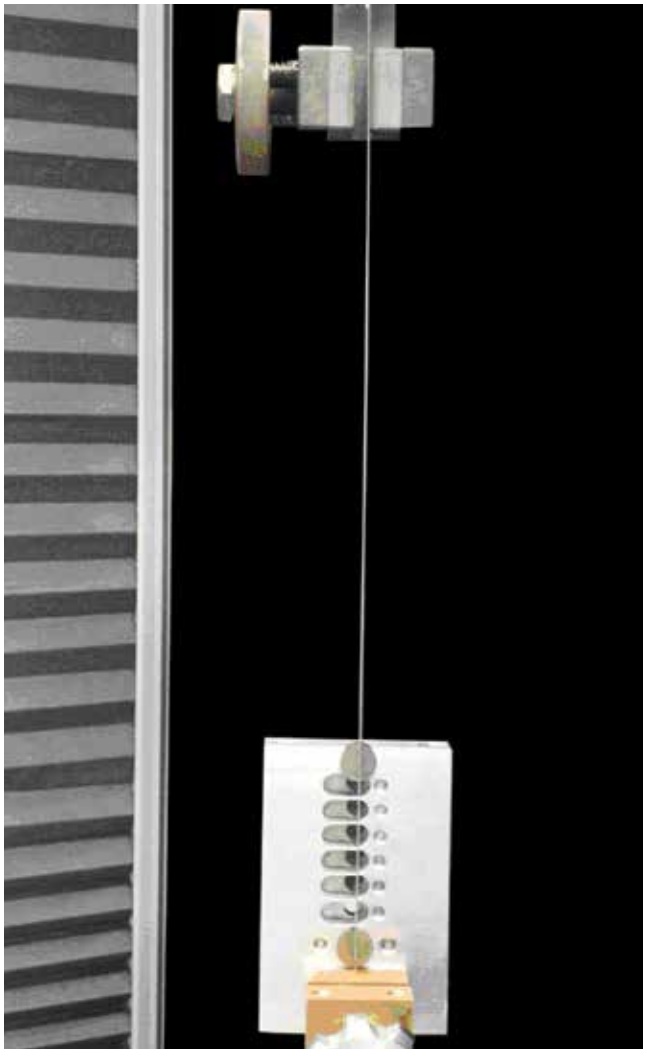

Figure 4 - Device positioned in the Instron machine.

every 0.1 mm up to a total wire displacement of 6 mm.

Each test was repeated 10 times. The brackets were replaced every other test and the wires and ligatures at every test to prevent changes in the friction magnitude resulting from wear of the contacting surfaces. The elastomeric ligatures were inserted immediately before each test. The tests were performed in a dry environment at a temperature between 24 and 26° C.

STATISTICAL ANALYSIS

Means and standard deviations were calculated and normality tests applied for each orthodontic archwire/bracket combination. The differences between the 7 archwire ligation methods were analyzed by ANOVA. In order to identify which groups were different, Dunnett's multiple comparison test for groups with unequal variances was employed.

A 5% significance level was set for all tests ($p<0.05$).

RESULTS

Table 1 depicts the descriptive analysis of friction forces with the 0.014" NiTi wire in an active configuration and the direct comparisons between ligation methods using Dunnett's test. The lowest mean magnitude of friction was 222 gf (gram/force), achieved by Synergy brackets. Archwire ligation with 8-shaped ligatures also produced a low magnitude of friction, of about 279 gf. Damon, Easy Clip, In-Ovation and Smart Clip self-ligating brackets exhibited wide variations in friction forces, yielding the following respective values: 270 gf, 317 gf, 405 gf and 543 gf. Conventional Morelli brackets with conventional ligatures reached higher values, which averaged 770 gf.

The last column of Table 1 indicates the ligation methods whose results were similar according to Dunnett's multiple comparison test ($p<0.05$). In general, there were significant differences between the groups, with the exception of the 8-shaped ligatures used with Damon and Easy Clip brackets.

Figure 5 shows the percentage differences in friction magnitude using as a horizontal reference line the value of 270 gf obtained by Damon brackets. This reference line was determined because this bracket is very widely used in orthodontic practice. Synergy brackets exhibited a 17% lower friction force and 8-shaped ligatures only 3% higher than Damon. Easy Clip, In-Ovation, Smart Clip and conventional Morelli brackets showed increments in friction forces equivalent to 17%, 50%, 100% and 185%, respectively.

DISCUSSION

In sliding mechanics, the force applied to a tooth is not fully delivered to the periodontium because the friction force at the archwire/bracket interface opposes the sliding archwire and thereby dissipates part of the force designed to move teeth.[6,7,12] Therefore, orthodontic forces must first overcome friction while the remaining force promotes bone remodeling, causing teeth to move.[1,5,7]

Damon MX, Easy Clip, In-Ovation, Smart Clip self-ligating brackets, special Synergy brackets, and conventional Morelli brackets with 8-shaped ligatures are effective in eliminating ligation friction when the archwire is flat and undeflected. The purpose of this study was to investigate whether or not the different slot closing methods described above produce similar friction magnitudes when the archwire is subjected to deflection. Twin brackets

Table 1 - Descriptive statistics in grams-force. Similar methods based on friction magnitudes with no differences according to Dunnett's multiple comparison test ($p<0.05$).

Ligation Method	Mean	SD	Similar methods
Synergy	222	15	-
Damon	270	14	8-shaped ligatures
8-shaped ligatures	279	32	Damon, Easy Clip
Easy Clip	317	37	8-shaped ligatures
In-Ovation	406	30	-
Smart Clip	543	35	-
Conven. Lig.	771	73	-

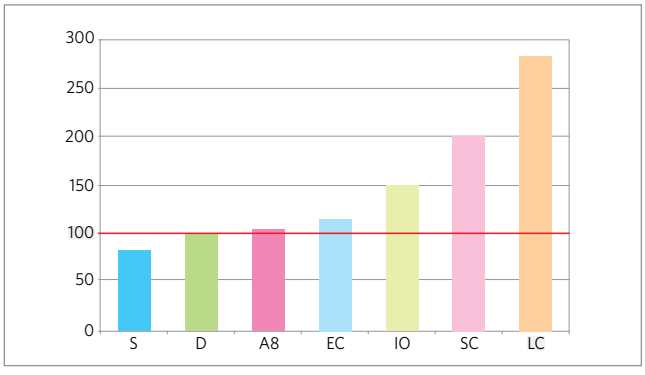

Figure 5 - Percentage changes in friction force between the brackets evaluated using Damon brackets as reference (Fati = 270gf).

with conventional elastomeric ligatures (Morelli) were used as control group.

Nickel titanium wires were used because the authors were interested in examining friction magnitude in the initial phase of orthodontic treatment when archwires with a low modulus of elasticity are indicated. Horizontal deflections of 0.014-in NiTi wires were standardized at 4 mm with the purpose of enabling them to reach full superelastic regime, since NiTi archwire deflections around 2 mm may be insufficient to bring out the superelastic properties of archwires.[11,9]

In order to assess the actual orthodontic forces and friction applied to teeth, in vitro studies using an active configuration must reproduce the actual interbracket distances.[11] A 15 mm distance was adopted between bracket centers that act as support for deflection in the canine region because this corresponds to the average distance between lateral incisor and maxillary first premolars.

In this study, self-ligating brackets, Synergy brackets and 8-shaped ligatures produced frictional forces significantly lower than conventional brackets tied to the archwires with conventional elastomeric ligatures, corroborating the findings of Kim et al.[7] This was expected as there was no sum of ligation friction plus archwire deflection-induced friction.

Although the same archwire diameter, alloy and deflection were used in all slot closing systems tested, the magnitude of the deflection-induced friction forces produced by the archwires were not uniform. Frictional forces gradually increased in the following order: Synergy, Damon, 8-shaped Ligature, Easy Clip, In-Ovation and Smart-Clip. With the exception of the 8-shaped ligatures in relation to the Damon and Easy Clip brackets, all other groups showed significant differences. Such differences are probably related to the influence exerted by bracket design on wire stiffness.

Archwire deflection can be mechanically described as a beam supported by brackets at both ends. The activation force (Facti) deflect the wire at the midline, generating symmetric reactions at the left and right points of support. Reaction forces can be represented by a normal force (FN) perpendicular to the archwire at the point of contact with the slot, the friction force (Ffric) that opposes the direction of the sliding archwire and opposite moments (M) inside each support bracket10 (Fig 6).

Normal force (FN) intensity at the archwire/bracket interface depends on archwire stiffness. Since the (a) archwire diameter, (b) type of alloy, (c) 4 mm deflection and (d) average distance of 15 mm between the centers of the cylinders used as support for bonding the brackets were all standardized, the variables that influence archwire stiffness are the bracket width and the material used to manufacture the slot closing system.

Bracket width affects archwire stiffness because it modifies the effective interbracket distance. According to Whitley and Kusy,[13] the total interbracket distance (IBD) should be measured between the centers of the support brackets (Fig 7). The effective interbracket distance (IBDe) equals the IBD minus half the width of the right support bracket (L1), the width of the interposed bracket (L2) and half the width of the left support bracket (L3). Therefore, the greater the width of the bracket, the shorter the effective length of the interbracket archwire, causing increased stiffness, increased archwire/slot normal compression force (NF) and increased archwire

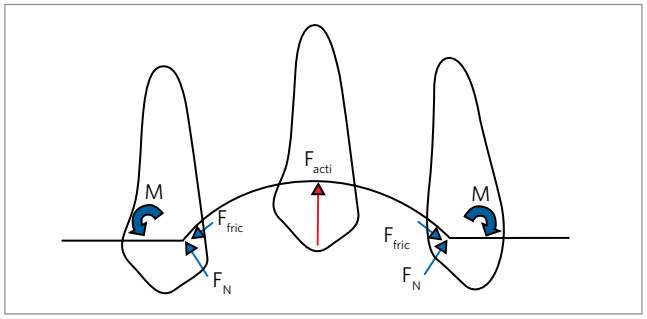

Figure 6 - Free body diagram during archwire activation. Adapted from Nikolay[10].

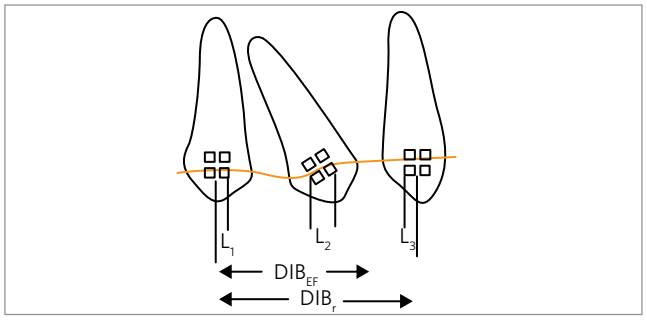

Figure 7 - Parameters for determining the effective interbracket distance. Adapted from Whitley and Kusy[13].

deflection-induced friction force. Given that the stiffness of a round cross-section beam is inversely proportional to the third power of its length,[10] the influence exerted by bracket width on archwire stiffness becomes clear.

Table 2 shows the widths of the brackets assessed in this study. The widths of the slot closing system or elastomeric ligatures placed on the tie-wings of canines are clearly marked because in these brackets first-order deflections occurred at the archwire/closing system or archwire/ligature interface. Therefore, the closing systems and ligatures reflect the effective bracket widths.

The material employed in the bracket slot closing system can influence the force of the archwire deflection-induced friction according to its flexibility and friction coefficient. When the slot closing system is resilient it may be somewhat deflected, which results in decreased horizontal deflection of the archwire inside the slot, thus reducing the normal force intensity at the wire/bracket interface. This may be one of the reasons underlying the good performance of systems that use elastomeric ligatures for bracket ligation. In addition, the horizontal deflection of a 0.014" NiTi wire causes it to contact the slot closing system. Moreover, the portion of normal force (FN) converted into deflection-induced friction forces varies according to the friction coefficient of the different materials used in the manufacture of the slot closing systems. Thus, friction coefficients also contribute to the differences found in the magnitude of archwire deflection-induced friction.

Table 2 - Bracket widths.

	Central incisor	Lateral incisor	Canine	Premolar
Damon	2.7	2.7	2.1	2.7
Easy Clip	3.2	3.2	2	3.2
In-Ovation	2.9	2.6	2.9	2.9
Smart Clip	3.7	3.2	3.5	3.4
Synergy	2.6	2.5	2.6	2.6
Morelli	3.6	2.4	3.4	3.4

It should also be emphasized that frictional forces interfere with orthodontic movement as they reduce the forces delivered to the periodontium. Thus, the results found in this study suggest that archwires with similar activations, seated in brackets with different slot closing systems can deliver significantly different forces to the teeth.

CONCLUSIONS

1) Compared to conventional ligatures, all closing systems tested were effective in reducing friction forces.
2) The frictional force produced by deflection of NiTi archwires varies significantly according to the closing system selected.

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