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Evaluation of deflection forces of orthodontic wires with different ligation types

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Abstract: The aim of this study was to evaluate deflection forces of orthodontic wires of different alloys engaged into conventional brackets using several ligation types. Stainless steel, conventional superelastic nickel-titanium and thermally activated nickel-titanium archwires tied into conventional brackets by a ring-shaped elastomeric ligature (RSEL), a 8-shaped elastomeric ligature (8SEL) and a metal ligature (ML) were tested. A clinical simulation device was created especially for this study and forces were measured with an Instron Universal Testing Machine. For the testing procedure, the block representing the maxillary right central incisor was moved 0.5 and 1 mm bucco-lingually at a constant speed of 2 mm/min, and the forces released by the wires were recorded, in accordance with the ISO 15841 guidelines. In general, the RSEL showed lighter forces, while 8SEL and ML showed higher values. At the 0.5 mm deflection, the 8SEL presented the greatest force, but at the 1.0 mm deflection the ML had a statistically similar force. Based on our evaluations, to obtain lighter forces, the thermally activated nickel-titanium wire with the RSEL are recommended, while the steel wire with the 8SEL or the ML are recommended when larger forces are desired. The ML exhibited the highest force increase with increased deflections, compared with the elastomeric ligatures.

Keywords: Orthodontic Wires; Alloys; Orthodontics; Friction; Orthodontic Brackets; Elastomers.

Introduction

For a long time, stainless steel was the most used alloy in the manufacturing of orthodontic wires. However, new metal alloys have been introduced recently to better meet the needs of the orthodontist. The particular properties of these alloys allow their application in different stages of the orthodontic treatment, thereby largely replacing the use of classic steel wires.[1] Furthermore, treatment protocols using the new alloys can shorten therapy time.[2]

The importance of light and continuous force for obtaining controlled tooth movement is well known in orthodontics. To meet such requirement, superelastic or pseudoelastic nickel-titanium wires have been created that are able to release constant light forces for a greater period of time compared to stainless steel wires, without the need of bends, and even in arches with severe dental crowding. This is possible due to their elastic properties, low rigidity and good shape memory, making such wires routinely used in the initial stages of the orthodontic treatment.[1,3,4,5,6] Moreover, these properties are enhanced in thermally activated nickel-titanium wires.[7]

The thermally activated nickel-titanium archwire has a shape memory effect that is induced by heat. At room temperature, the wire is malleable and can be easily engaged into brackets bonded to poorly positioned teeth. At body temperature, the proportion of austenite in the wire increases along with its stiffness, causing the wire to recover its original shape. The extent of this effect depends on the TTR (Transformation Temperature Range), which can be specifically defined by modifying the alloy composition or by appropriate heat treatment during manufacture.[8] The produced effect is the release of light and constant forces with greater accuracy, compared to conventional nickel-titanium wires.

The orthodontic wire can be connected to the accessory slot of conventional brackets through different methods, which may result in different forces released to the teeth.[9,10,11,12] The most common are by stainless steel ligatures of different diameters, and elastomeric ligatures.[13]

Metal ligatures allow less accumulation of plaque, but their placement is more laborious. Depending on the degree of pressure that they exert on the wire, the archwire-bracket interaction will display a different amount of friction. The higher the pressure, the greater the friction. Elastomeric ligatures have good properties, such as smooth continuous force, consistent long-lasting seating of the archwire, resistance to water absorption, and shape memory. They are also of easy application. However, elastomeric ligatures allow greater microbial accumulation on the surface of the teeth, compared to the metal ligatures, besides the fact that the archwire may not completely seat during torquing or rotational corrections, and binding may occur with sliding mechanics. Elastomeric ligatures are most commonly placed as ring-shaped ligatures, which promote lower pressure on the wire in the slot, and as 8-shaped ligatures, which promote greater pressure.[13,14,15,16,17,18,19,20] Few studies have evaluated the influence of the ligation type on the force exerted by the wire on the tooth.[11,21,22]

The introduction of new metal alloys for orthodontic wire manufacturing still does not provide all the needed qualities for all stages of the orthodontic treatment. Therefore, a clear understanding of the properties of each wire is necessary when choosing the appropriate one for a particular stage of treatment. Currently, it is possible to accurately measure the forces released by wires manufactured with the new alloys, enabling better understanding of their metallographic and mechanical properties, and the amount of force released during leveling and alignment. Thus, this work aimed to study the forces released by the deflection of orthodontic wires with different ligatures routinely used in the clinic.

Methodology

One set of Edgewise Morelli brackets (Morelli, São Paulo, Brazil) was used for this study. The brackets had a nominal 0.022 × 0.028-inch slot size. Three types of orthodontic 0.016-inch diameter wires were tested: stainless steel, conventional superelastic nickel-titanium and thermally activated nickel-titanium, from three different brands (Dental Morelli, São Paulo, Brazil; GAC, Bohemia, USA; Abzil, São José do Rio Preto, Brazil) (Table 1).

The wires were ligated to the brackets by three different means: ring-shaped elastomeric ligature (RSEL), 8-shaped elastomeric ligature (8SEL) and 0.010-inch diameter metal ligature (ML). All ligatures were from Morelli (São Paulo, Brazil). The wires, brackets and ligatures used belonged to the same

Table 1. Materials tested in this study .

Wire	Diameter	Brand	Ligation Type
Stainless steel		GAC	Ring-shaped elastomeric ligatures (RSEL)
Nickel-titanium	0.016-inch	Abzil	8-shaped elastomeric ligatures (8SEL)
Thermally active nickel-titanium		Morelli	Metal ligature (ML)

manufacturing batch. A needle holder was used for tying both elastomeric and metallic ligatures. The ISO 15841 standard recommends a sample size of 6 specimens per group. However, in this study 10 specimens were included in each group to account for potential technical errors and to increase the reliability of results.

Deflection of the orthodontic wire was performed in a clinical simulation device representing all 14 teeth of the maxillary arch, based on studies that used similar devices.[11,23,24,25,26,27] This device consists of a parabola-shaped acrylic resin plate with acrylic blocks representing the maxillary teeth (Figure 1A). The shape of the parabola was determined by the shape of the wire to be tested to minimize forces other than the deflection applied in the experiment. The brackets were bonded with cyanoacrylate ester gel (Super Bonder, Loctite) on the acrylic blocks, which were fixed to the surface of the acrylic resin plate with screws (Figure 1B). Fixation of the blocks to the plate was performed maintaining a standard interbracket distance of 6 mm.

The test block, corresponding to the maxillary right central incisor, was not fixed to the acrylic base and had a perforation in which a metal cylinder was placed to be used for force application (Figure 1C). During the tests, this block received a 1 mm-movement in the palatal direction, so that later the unloading forces could be recorded (Figure 2). The deflection speed of the testing machine was 2 mm/min.

The force in centinewtons (cN) released by deflecting the wire was obtained after 0.5 mm and 1 mm movements. The deflection tests were performed using the Instron Universal Testing Machine, with a load cell of 10 N, and 0.5% accuracy at 25°C. The load cell was maintained at this temperature. The tip of the activation handle attached to the testing machine had a rounded cut in which the metal cylinder could be fitted (Figure 3).

Parametric tests were performed, since normal distribution of the variables was observed with Kolmogorov Smirnov tests.

Descriptive statistics including means and standard deviation values were calculated for each archwire-bracket combination. ANOVA followed by Tukey's test were used to compare results of the different wires and ligatures.

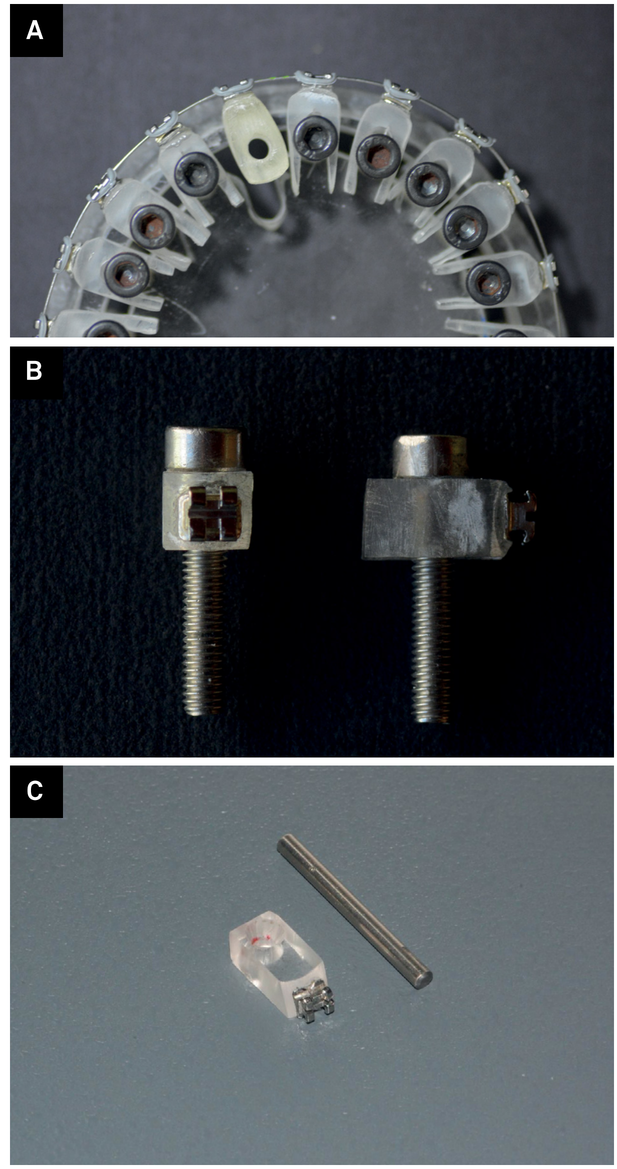

Figure 1. (A) Acrylic resin plate with blocks representing the maxillary teeth. (B) Blocks fixed by screws in the resin plate. (C) Block representing the maxillary right central incisor and the metal cylinder used as anchor.

Results

The results found for the tested alloys are shown in Tables 2 to 4. Comparing the different ligation methods, RSEL showed a smaller force release in most tests, regardless of archwire composition. With 0.5 mm deflections, the 8SEL presented a greater force in most tests; however, with 1.0 mm deflections the ML had statistically similar forces to the 8SEL, and even higher in some cases, as the Abzil 0.016-inch nickel-titanium wire.

The tests showed very similar force release among the brands for all wire alloys.

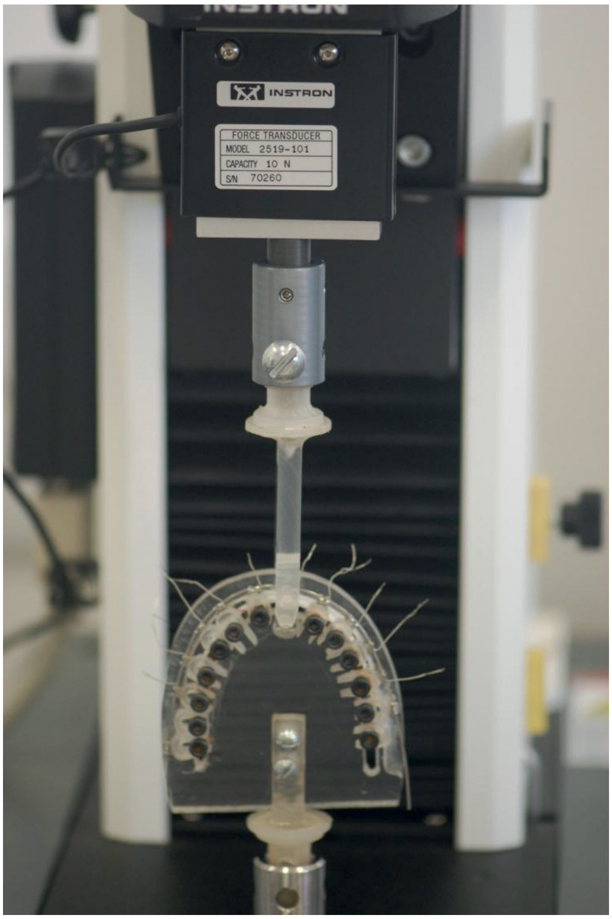

Figure 2. Tip of the Universal testing machine applying a bucco-lingual pressure to the acrylic structure.

Figure 3. Instron Universal Testing Machine used in this study, with 10 N load cell and the activation tip.

Table 2. Mean force (in centinewton) and standard deviation (SD) of stainless steel 0.016-inch diameter wires from Morelli, Abzil and GAC brands with three different ligation types (ANOVA followed by Tukey's tests). n = 10.

Brands	Elastic deflection	0.5 mm				1.0 mm			
		Mean force	Mean (SD)	p	letters	Mean force	Mean (SD)	p	letters
	RSEL	179.46	(33.34)		B,C,E	310.87	(26.47)		B
Morelli	8SEL	230.45	(42.16)		A	388.34	(40.20)		C,D
	ML	163.77	(25.49)		B,E	350.09	(35.30)		B,D,E
	RSEL	134.35	(23.53)		B	218.68	(33.34)		A
Abzil	8SEL	201.03	(27.45)	0.000*	A,D,E	381.47	(28.43)	0.000*	C,E,F
	ML	166.71	(29.41)		B,D	359.90	(38.24)		B,D,F,G
	RSEL	130.42	(12.74)		B	211.82	(17.65)		A
GAC	8SEL	215.74	(45.11)		A,C	396.18	(42.16)		C,E,G
	ML	164.75	(45.11)		B,E	363.82	(55.89)		C,E,G

*Statistically significant at $p < 0.05$; Different letters represent statistically significant differences.

Table 3. Mean force (in centinewtons) and standard deviation (SD) of conventional 0.016-inch diameter Nickel-Titanium wires from Morelli, Abzil and GAC brands with three different ligation types (ANOVA followed by Tukey's tests). n = 10.

Brands	Elastic deflection	0.5 mm				1.0 mm			
		Mean force	Mean (SD)	p	letters	Mean force	Mean (SD)	p	letters
Morelli	RSEL	70.60	(13.72)		A,D	129.44	(15.00)		A,C
	8SEL	107	(17.65)		B,C	158	(20.59)		B,C,D
	ML	78.45	(19.00)		A,C,E	154.94	(27.00)		B,C,E
Abzil	RSEL	79.43	(13.72)		A,C,F	127.48	(17.65)		A,D,E
	8SEL	94.14	(36.28)	0.000*	B,D,E,F,G	126.50	(33.34)	0.000*	A,D,E
	ML	111.79	(15.69)		B	183.38	(22.55)		B
GAC	RSEL	70.60	(14.70)		A,G	132.38	(18.63)		A,D,E
	8SEL	68.64	(22.55)		A,G	144.15	(17.65)		A,D,E
	ML	65.70	(17.65)		A,G	142.19	(20.59)		A,D,E

*Statistically significant at $p < 0.05$; Different letters represent statistically significant differences.

Table 4. Mean force (in centinewtons) and standard deviation (SD) of thermally activated 0.016-inch diameter Nickel-Titanium wires, from Morelli, Abzil and GAC brands with three different ligation types (ANOVA followed by Tukey tests). n = 10.

Brands	Elastic deflection	0.5 mm				1.0 mm			
		Mean force	Mean (SD)	p	letters	Mean force	Mean (SD)	p	letters
Morelli	RSEL	65.70	(14.70)		A	109.83	(12.74)		A,C,F
	8SEL	58.83	(17.65)		A	82.37	(20.59)		A
	ML	80.41	(13.72)		A,C	147.09	(15.69)		B,E
Abzil	RSEL	94.14	(8.82)		B,C,E	144.15	(17.65)		B,E
	8SEL	117.67	(18.63)	0.000*	B	149.06	(21.57)	0.000*	B,E
	ML	70.60	(6.86)		A,E	138.27	(17.65)		B,E,F
GAC	RSEL	78.45	(6.86)		A,E	125.52	(7.84)		C,E
	8SEL	108.85	(38.24)		B	137.29	(45.11)		B,C,E
	ML	81.39	(12.74)		A,E	156.90	(12.74)		B

*Statistically significant at $p < 0.05$; Different letters represent statistically significant differences.

Discussion

The ligation types showed important characteristics for clinical practice. In general, with the smaller deflection, the 8SEL showed higher values, compared to the ML and RSEL. When increasing the deflection, the ML values resembled the values of the 8SEL (Tables 2 to 4). For example, for the 0.016-inch conventional nickel-titanium wire from Abzil in 1 mm deflections, the force released was higher for the ML than the 8SEL (Table 3). These variations demonstrate the difficulty in measuring forces in laboratory settings. In clinical practice, evaluating the amount of force released by the wires is even more difficult. Nevertheless, these data can help choosing the most adequate ligation type for force control in arch leveling and alignment.

The smaller force presented by the RSEL in this study is probably due to the lower pressure promoted by this ligation type on the wire seating in the bracket slot. The higher pressure generated by the 8SEL results in a greater deflection of the wire, increasing the dissipated force.

The same concept applies to the metal ligatures. This study showed that the force exerted by these ligatures increases with a larger deflection, compared with elastomeric ligatures. In smaller activations, the ML showed lower forces than the 8SEL in most tests, but with greater deflections the force was mostly similar or even higher in some cases. This is due to the rigidity (or lack of elasticity) of the ligation system. With increased deflection, there is a trend for the ML to exert higher forces because this ligature maintains the wire pressed into the slot while the elastomeric ligature allows the wire to slightly dislodge.

Moreover, it is not only the rigidity of the ligation system that determines the amount of force. Friction also has an important role in the force released by the archwires. Current studies have shown that the decrease of friction from the ligation system enables the release of greater forces from the wire in arch alignment and leveling.[21] During loading, the presence of friction increases the force, while in unloading it decreases it.[28,29,30]

To maintain light forces in severe dental crowding, the RSEL may be implemented to any of the studied wire brands, especially if combined with conventional or thermally activated nickel-titanium wires. However, a combination of both a ligature and an archwire with low force properties may lead to suboptimal dissipation forces, impairing tooth movement. In this study, the archwire alloys were not statistically compared, but the thermally activated NiTi wire showed values numerically smaller than conventional NiTi and stainless steel wires. Therefore, caution should be exercised when using the combination of this wire with RSEL. This combination might be better suited for severe dental crowding.

On the other hand, since the 8SEL and ML release strong forces, it is preferred that these ligation types be combined with alloys that release low forces, such as thermally-activated NiTi. At the same time, in severe crowding it may be necessary to reduce the archwire diameter so that the force exerted is not too intense, avoiding areas of hyalinization and necrosis of neighboring tissues, and the risk of tooth reabsorption.

Moreover, the orthodontist must pay attention to the relaxation of the elastomer. The elasticity of the ligation reduces with time and consequently changes alignment and leveling forces. One study evaluated the deflection force of orthodontic wires ligated to the brackets with new elastomeric ligatures, "relaxed" elastomeric ligatures and a self-ligating system. Although both elastomeric ligatures were tied with the same shape, the "relaxed" elastic promoted higher forces, approaching the values of self-ligating systems. The authors attributed this result to the reduced friction generated by the relaxation of the elastomeric ligatures.[21] Another study evaluated the load generated by archwires with different ligation types and showed that the elastomeric ligatures exhibited a different behavior in relation to more rigid ligatures, such as metal ligation, altering the superelastic characteristics of the nickel titanium wires.[22] This might have been related to the elastic instability of the elastomeric ligatures.

Conclusions

Regarding the ligation type, the RSEL showed lower force values, whereas the 8SEL and ML showed similar greater forces in most cases;

The ML exhibited higher force increase according to the deflection increase, compared with elastomeric ligatures;

There were very few differences in force liberation among the tested brands.

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