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The effect of heat treatment on sliding mechanics of stainless steel orthodontic wires

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Aim: The aim of this study was to evaluate the effect of heat treatment (tempering) on the sliding mechanics of stainless steel Chrome Nickel (CrNi) orthodontic wires. **Methods:** A universal testing machine EMIC DL 2000 was used at a speed of 10 mm/minute for reading-out the sliding strength and friction between brackets and wires, by simulating the sliding mechanics in a fixed orthodontic appliance. The results were submitted to ANOVA variance test for statistical analysis at the level of 5% ($p<0.05$). **Results:** The results indicated that depending on the type of bracket, wire and type of treatment, the groups without heat treatment showed higher mean static friction values, except for groups with CrNi GAC wire and conventional brackets, which showed no significant difference with and without heat treatment; and the group with self-ligated brackets and CrNi GAC wires that showed the lowest mean static friction values with heat treatment. **Conclusion:** The heat treatment reduced the static friction values on CrNi Morelli wires for any combination of brackets (conventional and self-ligated types) and commercial brands. For the CrNi GAC wires, there was a reduction in friction values only in the combination with In-Ovation R/GAC self-ligated brackets.

Keywords: Orthodontic wires. Chromium alloys. Orthodontic brackets.

Introduction

The effectiveness of orthodontic movement is directly related to the mechanics involved and material used, therefore, the technological evolution of materials used in orthodontics demand the adequate follow-up of a diagnosis and planning required for performing a differentiated orthodontic treatment[1-3].

The trend in Orthodontics is moving in the direction of mechanical systems and materials capable of producing less friction during orthodontic mechanics, leading to more efficient treatments, particularly in sliding mechanics that is strongly influenced by bracket contact with the archwire[4,5].

The friction between the brackets and orthodontic archwires is an important factor to consider with regard to the efficiency of orthodontic treatment in sliding mechanics, as it may reduce the efficacy of orthodontic tooth movement[6]. Therefore, this requires a constant search for strategies to diminish the levels of friction during the application of sliding mechanics, as well as adequate understanding of the phenomena caused by friction between the archwire and orthodontic bracket[2]. Among the outstanding strategies are the use of self-ligating brackets, stainless steel archwires and the caliber of these wires.

There are factors that interfere in friction, such as the method of wire/bracket ligation, type of alloy of wires, presence of saliva and biofilm, and the geometry of the appliance, when the orthodontic archwires slide in the bracket channels[7]. Among the attempts to reduce friction, self-ligating brackets that do not require ligatures to hold the arch wire onto the bracket[1], have presented lower frictional resistance values than those presented by conventional brackets[3,8,9]. Moreover, among the orthodontic archwires, those made of stainless steel show lower frictional force in comparison with those made of chrome-cobalt, nickel-titanium or beta-titanium[10,11].

Different studies have been conducted in the quest for a favorable association of different types of brackets and archwires to diminish the influence of friction in sliding mechanics[1,4] but for this reason it is important to recognize the coefficients of friction of brackets and archwires, so that they can be used without hampering orthodontic treatment[8].

In sliding mechanics, the ideal is to use rectangular stainless steel wires with a maximum caliber of 0.019"x 0.025" in a 0.022" slot, which would facilitate the reduction in friction[12,13]. Stainless steel archwires offer excellent resistance to corrosion, lower friction, greater rigidity[14,15], making their use more advantageous, particularly in conditions in which more rigid wires with lower frictional values are necessary, such as in the stages of space closure[10].

Clinically, when the orthodontist manipulates the steel wires, they are established in a new shape, attaining high internal stress that creates a situation of instability[16] which ranges from reduction in the modulus of resilience and ductility through to reduction in the degree of hardness of the archwires, which may be reverted by means of heat treatment[13,17-19].

Heat treatment was introduced in 1949[20] and may be performed in the orthodontist's dental office, by means of a welding machine; and this is suggested after manipulating all the stainless steel archwires[13].

However, the existent items of information with respect to heat treatment of steel archwires are conflicting, in addition to being insufficient with regard to the changes induced by this procedure in the friction promoted by these archwires. This makes it controversial to use this procedure in the orthodontic medium, especially in view of the small number of publications on this topic[13,21]. The present study aimed to evaluate the effect of heat treatment (tempering) on the sliding mechanics of stainless steel Chrome Nickel (CrNi) orthodontic wires.

Material and Methods

This research was conducted in the laboratory on the premises of Dental Morelli Indústria Ltda., in Sorocaba/SP, and obtained exemption from the Research Ethics Committee of the Dental School and Research Center of São Leopoldo Mandic.

To conduct this research four groups of metal brackets with slot 0.022" were used as follows: Group 1) Conventional stainless steel brackets, Roth Max Morelli® brand, ligated with conventional elastomeric ligatures; Group 2) Conventional stainless steel brackets, Roth Balance GAC® brand, ligated with conventional elastomeric ligatures; Group 3) Self-ligated stainless steel Brackets, Roth SLI (Self Ligating Interactive) System, Morelli® brand; Group 4) Self-ligated stainless steel Brackets, In Ovation R System, Prescription Roth GAC® brand.

For all the groups of brackets, the following were used: rectangular Chrome Nickel (CrNi) stainless steel archwires, in a 0.019"x 0.025" slot; 80 archwires of the Morelli® brand (Lot 1713382/60.02.301); and 80 rectangular Chrome Nickel (CrNi) stainless steel archwires of the GAC® Brand (Lot 082465/10.14.900), with and without heat treatment.

To perform the sliding mechanics tests and readout of frictional force between the brackets and wires, a metal device that allowed five brackets to be bonded to it was used. It was constructed to simulate the sliding movement of a fixed orthodontic appliance; the brackets were all aligned and leveled by means of a centralizer, seeking maximum standardization to avoid factors capable of influencing the veracity of the results. In the simulator, a sequence of brackets was mounted, representing a segment of the maxillary arch, in which brackets were positioned from the central incisor to the second premolar.

Heat treatment (tempered) of the stainless steel wires was performed by means of a welding machine of the Kernit-LTDA brand, micro tip model SMP 3000, power 500W, current 4,0 / 2,0A, frequency 50 / 60Hz (Kernit Indústria Mecatrônica Ltda, Indaiatuba, SP, Brazil - Serial Number 89.114.056).

The power and time of electric current for this heat treatment were determined in tests with five wires of each caliber, identical to the arches of the experiment, until a uniform brown color was obtained by visual exam. Therefore, it was determined that the power would be 02 on a scale of 0 to 10, and the time of 5 seconds, for all the heat treated arches. After obtaining uniformity of color, standardization of the power and time of the appliance, the rectangular stainless steel archwires 0.019"x0.025" were cut into identical lengths (8cm), individually fixated by the operator, on the device of the Kernit machine itself, for the purpose of heat treatment, at all times in the same position.

The wires were randomly tested in the universal test machine (EMIC DL2000, belonging to Dental Morelli Indústria Ltda. Sorocaba/SP, Brazil, at a speed of 10mm/min).

The Tesc software version 3.01, coupled to the universal test machine provided the data studied (static friction) used for statistical analysis.

The data, in kilogram/force (gf) were typed into spreadsheets of the *Microsoft Excel* 2010 program, and later statistical analysis was performed in the SAS software (SAS Institute Inc., Cary, NC, USA, Release 9.2, 2008). An exploratory analysis of the data was made, and the data were found to meet the presuppositions of a parametric analysis. Therefore, the analysis of variance (ANOVA) by the 2 x 2 x 2 factorial scheme (bracket x archwire x treatment) and *Tukey* multiple comparisons tests were applied. For all the analyses, a level of significance of 5% was adopted.

Results

Table 1 presents the data obtained with regard to static friction considering the type of bracket, archwire and type of treatment. Higher mean values ($p<0.05$) were observed in the Groups without heat treatment, with the exception of groups with CrNi GAC wire and conventional brackets, which presented no significant difference with and without heat treatment ($p>0.05$).

As regards the CrNi Morelli archwire, using conventional brackets, significant differences were shown ($p\leq0.05$), with and without heat treatment, for the brands analyzed (Morelli and GAC); that is to say, static friction was statistically higher for the wire without heat treatment. For this same wire, when the self-ligated brackets were tested, only the Morelli brand showed significant differences

Table 1 - Static Friction (standard deviation) considering bracket, archwire and heat treatment

Wire	Bracket	Brand	Heat Treatment	
			Without	With
CrNi Morelli	Conventional	Roth Max Morelli	[$]785.40 (60.44) A	[$#]703.00 (27.04) B
	Conventional	Balance GAC	[$#]830.10 (67.78) A	[$]698.50 (42.66) B
	Self-ligating	Roth SLI Morelli	*590.60 (64.98) A	*449.50 (41.93) B
	Self-ligating	In-Ovation R GAC	446.50 (23.44) A	383.90 (26.18) A
CrNi GAC	Conventional	Roth Max Morelli	*[$]768.40 (51.52) A	*[$]779.90 (41.78) A
	Conventional	Balance GAC	[$]716.40 (72.15) A	[$]682.70 (44.02) A
	Self-ligating	Roth SLI Morelli	*568.10 (33.27) A	*500.00 (43.78) A
	Self-ligating	In-Ovation R GAC	474.20 (49.68) A	375.10 (25.93) B

Means followed by different letters in the horizontal direction differ among them (($p\leq0.05$) *Differs from the GAC bracket on the same wire and with same heat treatment ($p\leq0.05$). [$]Differs from the self-ligating bracket of the same commercial brand, same archwire and same heat treatment ($p\leq0.05$).[#] Differs on the CrNi GAC archwire, for the same type of bracket and heat treatment ($p\leq0.05$).

between the treatments, in which higher static friction (SF) was observed without heat treatment.

As regards the CrNi GAC archwire, there was no significant difference between treatments when the conventional brackets of the Morelli and GAC brands were used; the difference was significant between the treatments only when the self-ligated bracket of the GAC brand was used, which presented lower SF for the wires with heat treatment.

When evaluating the Morelli and GAC archwires for the group without heat treatment there was difference for the use of Conventional GAC brackets, with the GAC wire promoting lower friction. For the group with heat treatment the difference was observed for the Group of conventional Morelli brackets, with the Morelli wire presenting lower friction.

The groups of conventional brackets presented higher static friction values, irrespective of the commercial brand of wire and heat treatment ($p<0.05$) when related to the self-ligated brackets, for both the groups with or without heat treatment.

In the groups with Morelli brackets and wires, heat treatment diminished ST, whereas in the groups with GAC brackets, heat treatment did not influence the SF on the conventional brackets; with only on the self-ligated brackets presenting lower SF. DISCUSSION

The forces generated during orthodontic mechanics are basically applied by the wires, considered components that determine the quality of force and level of stress distributed to the supporting structures of the teeth during the entire active stage of orthodontic therapy[5,8].

Clinically, there is no archwire that has all the essential qualities for the orthodontic control required in the different stages of treatment[3,4,10,22]. However, certain conditions, such as the type of material of the wire, and the type and thickness of the tie may interfere in the friction generated at the bracket/ archwire interface during sliding mechanics[1,23] thus reducing the velocity of tooth movement.

For many years, stainless steel was one of the most important materials for making orthodontic archwires[24,25] , even with the technological evolution and improvement in the alloys used in orthodontics[10,26] stainless steel archwires are those that present the lowest levels of friction, followed by chrome-cobalt, nickel-titanium and beta-titanium archwires[26,27] and are considered the archwires of choice during sliding mechanics[12,13].

Manipulation of stainless steel archwires disorganize the atoms present in the internal structural arrangement of stainless steel, and on account of this disorganization, irregularities are formed making it difficult for them to slide along their main planes[13,16,18,21,28].

The results of the present study, in general, demonstrated that heat treatment led to a reduction in static friction between the wire and bracket for the majority of the combinations.

The Morelli stainless steel archwires were shown to be more susceptible to heat treatment, seeing that for the majority of combinations tested, the result was a reduction in static friction (SF). This may have been influenced by the heat treatment that appears to improve the elastic properties of wires of this brand. For the GAC brand wires, heat treatment was noted to reduce the SF only in the group in which the GAC self-ligating bracket was used, which may be related to the fact that the archwires of this brand presented a smoother morphological aspect and better surface finishing when compared with the archwires of other brands[14,25,29]. The existence of differences in roughness and the production process of stainless steel archwires[2,11,15] may have influenced the reduction in SF on the CrNi Morelli archwires with heat treatment, in comparison with those of the GAC brand.

When comparing conventional and self-ligated brackets of the same brand, the authors observed that in all the groups studied, a higher SF occurred in archwires without heat treatment, and in conventional brackets, this friction was higher. When conventional and self-ligated brackets were compared, the reduction in friction could be from 50 to 70% in self-ligated brackets[1,27,30,31] seeing that their design dispenses with the use of elastic ligatures to ligate the bracket/wire.

Different studies have been conducted in the quest for a favorable association of different types of brackets and archwires[1,4,8] but the important issue is to recognize the coefficients of friction of brackets and archwires, so that they can be used without hampering orthodontic treatment[27].

In the search for ideal conditions for the conduction of orthodontic therapy, one goal is to reduce the friction force created at the bracket / ligature interface[8]. This would imply the use of lighter forces, creating greater biological compatibility and less patient discomfort[5].

When evaluating the self-ligated brackets in this research, they generated significantly lower static friction forces in sliding mechanics than the conventional stainless steel type, when the groups that were or were not submitted to heat treatment were compared in isolation, which may be related to the manner in which the archwire was fixated in the channel of these brackets[1,3,5,8], remaining loose within the slot, even with the system being interactive[5]. This interactive system of the self-ligated bracket presented higher friction values when compared with passive systems of self-ligated brackets, because their clip takes the archwire into contact with the channel of the wire[8,31]. The self-ligated bracket In-Ovation R was observed to present a lower mean static friction value in conditions of wires without heat treatment, and in the present study, it presented an even lower friction value in the presence of the CrNi GAC wire with heat treatment.

Self-bonding brackets produced lower friction values than conventional brackets ligated with conventional elastomeric ligatures; regardless of the mark used, this reduction of friction allows mechanics of reduced forces[7]

Taking into consideration the findings of the present study, the choice of bracket and wire design, in addition to the application of heat treatment, may influence sliding mechanics, allowing the orthodontist to promote tooth movement with lower forces, by overcoming the friction produced by the bracket/wire system.

It can be observed that the heat-treated steel wires presented lower friction, however, it is worth mentioning that the size and design of the brackets, wire diameter, bracket

/ wire bond types, environmental conditions can influence the friction at the bracket / wire interface[7]. It should be noted that all segments of wires subjected to the mechanical tensile tests were seized in the mechanical device always at its end, therefore, near the demarcated site for the measurement of the posterior region.

In the present study, the heat treatment decreased the friction between bracket / wire compared to group without heat treatment. The self-bonding brackets associated with heat-treated wires also presented lower static friction. However, additional studies on these factors are necessary in order to achieve standardization in the methodology and especially a faithful reproduction of what is observed in the oral cavity.

In conclusion, heat treatment reduced the static friction values on CrNi Morelli wires for any combination of brackets (conventional and self-ligated types) and commercial brands. For the CrNi GAC wires, there was a reduction in friction values only in the combination with In-Ovation R/GAC self-ligated brackets.

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