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Comparative analysis of plastic deformation of NiTi and CuNiTi wires submitted to mechanical cycling

Análise da deformação plástica em fios ortodônticos de NiTi e CuNiTi submetidos à ciclagem mecânica

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ABSTRACT

Objetivo: The aim of this study was to evaluate the plastic deformation of NiTi and CuNiTi archwires submitted to mechanical cycling. **Material and Methods:** Orthodontic archwires made of CuNiTi of five commercial brands (n=10) were used: RMO, Orthometric, Ormco, Aditek and Eurodonto; and a Control Group of NiTi archwire: Aditek thermoactivated. All the archwires, with caliber 0.016", were fitted into the slots of four conventional brackets, aligned and fixed to an acrylic plate. The test was performed by applying a load of 3 N and frequency of 2 Hz between the most central brackets, limited to 10,000 cycles. After cycling, the presence or absence of archwire fracture was observed. When there was no fracture, the archwires were analyzed relative to plastic deformation with the use of a transferer, measuring the angulation of the deformed archwire. **Results:** The results showed that there was no fracture in any of the wires analyzed. The Kruskal-Wallis test showed differences among the angulations of the orthodontic archwires (p=0.0009). With exception of the Ormco wires, the other types presented plastic deformation. The highest median of the angulation value was observed for the Aditek Copper NiTi archwire. The lowest median values were observed for the RMO, Eurodonto and Ormco archwires. The Aditek thermoactivated and Orthometric archwires presented intermediate angulation. **Conclusion:** None of the archwires analyzed presented fracture. These archwires presented differences in plastic deformation, irrespective of the presence of copper in their chemical composition. The Ormco archwire was the only type that presented no deformation whatever.

KEYWORDS

Mechanical cycling; Copper; Deformation; Orthodontic wires; Fracture.

RESUMO

Objective: O objetivo deste trabalho foi avaliar a deformação plástica em fios NiTi e CuNiTi submetidos à ciclagem mecânica. **Material e Métodos:** Utilizaram-se fios ortodônticos de CuNITi de cinco marcas comerciais (n=10): RMO, Orthometric, Ormco, Aditek e Eurodonto; e um grupo controle de fio NiTi: Aditek termoativado. Todos os fios, com calibre 0.016", foram encaixados em slots de quatro bráquetes convencionais alinhados e fixados a uma placa de acrílico. O teste foi realizado com aplicação de carga de 3 N e frequência de 2 Hz entre os dois bráquetes mais centrais, limitando-se à 10.000 ciclos. Após a ciclagem, observou-se a presença ou ausência de fratura dos fios. Não havendo fratura, os fios foram analisados quanto à deformação plástica com uso de transferidor, medindo-se a angulação do fio deformado. **Resultados:** Os resultados mostraram que não houve fratura de nenhum dos fios analisados. O teste de Kruskal-Wallis mostrou diferenças entre as angulações dos fios ortodônticos (p=0.0009). Com exceção dos fios da Ormco, os demais apresentaram deformação plástica. A maior mediana do valor de angulação foi observada para o fio Aditek Cuper NiTi. Observou-se que as menores medianas foram observadas para os fios RMO, Eurodonto e Ormco. Os fios Aditek termoativado e Orthometric apresentaram angulação intermediária. **Conclusão:** Nenhum dos fios analisados apresentou fratura. Houve diferenças quanto à deformação plástica sofrida pelos fios avaliados, independentemente da presença de cobre na sua composição química, sendo que o fio Ormco foi o único que não apresentou qualquer deformação.

PALAVRAS-CHAVE

Ciclagem mecânica; Cobre; Deformação; Fios ortodônticos; Fratura.

INTRODUCTION

Effective orthodontic movement involves adequate interaction of factors related to the patient, mechanics applied to the teeth and their supporting structures, and these are particularly dependent on the action of the orthodontic archwires [1]. These archwires must generate the biomechanical force necessary for promoting tooth movement with maximum efficiency and lowest biological cost, presuming the use of a light and continuous system of forces (optimal forces) to preserve the integrity of the periodontium and physiological bone remodeling [1-3].

In 1986, the CuNiTi archwires appeared; these were thermoactivated (tensoactive) and superelastic, containing approximately 6% copper [4]. These archwires generate lower forces on the teeth, have greater mechanical strength and a lower percentage of deformation [5,6]. They can be used in cases of excessive crowding and in periodontally compromised patients [7]. Thus, by means of light continuous force, these archwires help with the movement of teeth in the most biological manner, avoiding the area of hyalinization, necrosis and loss of anchorage, diminishing the probability of root resorption [5,8,9].

The fatigue resistance of orthodontic archwires is a most important factor in orthodontic therapy, because should a fracture occur, the result of treatment may be compromised. Some orthodontic archwires, such as those with the addition of copper, are more resistant than other types (without copper in their composition) relative to the application of forces [10]. They also maintain their physico-chemical properties over the course of time in which they remain in the oral cavity, and when removed from the mouth, they have practically the same characteristics as those of a virgin archwire [5].

Hysteresis, as a negative factor for orthodontic archwires, is lower in CuNiTi archwires because these exhibit greater capacity for loading/unloading of force, however, without losing their capacity to return to their original form [11,12]. They are more resistant to permanent deformation and promote more consistent tooth movement, because they have optimal force throughout the entire time in activity. These archwires develop around 20% less load force, therefore, generate less trauma and discomfort to the patient. Close to the position of rest, the reduction in force generated in these archwires is less than it is in the nickel titanium alloys, thus explaining the clinical efficiency of CuNiTi archwires to continue working even in teeth placed close to their ideal position [13]. Due to the fact that Copper NiTi alloys generate more constant forces, they are more resistant to permanent deformations and exhibit better elastic characteristics [11,12].

The CuNiTi 27ºC archwires have superior mechanical properties to the superelastic NiTi types, releasing a lower deactivation load [12]. They also have smaller microcavities in the fracture region when this occurs [4].

Therefore, these archwires appear to exhibit greater fracture strength and resistance to permanent deformation than the other conventional types of NiTi archwires, but up to now, no study has been conducted to evaluate this characteristic. Thus, the aim of the present study was to evaluate the *in vitro* plastic deformation of orthodontic archwires with or without copper in their composition, after performing mechanical cycling.

MATERIAL AND METHODS

Experimental Design

The experimental units consisted of orthodontic archwires of six different commercial brands (n=10) fitted into the slots of conventional brackets fixed to an acrylic device. The factor under study was the type of wire, at five experimental levels of CuNiTi archwires: RMO (FLI CuNiTi 27ºC, 0.016”), Orthometric

(FLEXY NiTi Copper, 0.016"), Ormco (Damon Cu NiTi, 0.016"), Aditek (Copper NiTi 35ºC, 0.016") and Eurodonto (Copper NiTi 27ºC, 0.016"); and a Control Level of NiTi archwire: Aditek (NiTi thermoactivated 0.016"). The 0.016" gauge was chosen because it is an archwire used in the initial phases of the treatment, and because it remains in the oral cavity for a considerable length of time. For each experimental group, ten repetitions were performed.

The response variables were as follows: the presence or absence of fracture of the archwire after performing mechanical cycling; deformation of the archwire, measured qualitatively by the angulation present in the archwire.

Materials used

The materials used in the experiment, their respective characteristics and manufacturers are presented in Table 1.

Table I - Materials evaluated and their specifications.

Materials Used	Characteristics, References and Lot	MANUFACTURER
NiTi (Control Group)	NiTi 0.016" Reference 5110116 Lot 160687	Aditek (Cravinhos, SP, Brazil)
Copper NiTi 35ºC	CuNiTi 0.016" Reference 09020913 Lot 247687	Aditek (Cravinhos, SP, Brazil)
FLI CuNiTi 27ºC	CuNiTi 0.016" Reference E07032-1 Lot S1401410	RMO (Denver, CO, USA)
Copper NiTi 27ºC plus	Copper NiTi 0.016" Reference 772 Lot F1408578	Eurodonto (Curitiba, PR, Brazil)
DAMON Copper NiTi	CuNiTi 0.016" Reference 205-1902 Lot 15F342F	Ormco (Orange CA, USA)
FLEXY NiTi Copper	CuNiTi 0.016" Reference 51472016 Lot 02235001	Orthometric (Marília, SP, Brazil)
VECTOR Roth	Conventional metal bracket for maxillary central incisors Roth 0.022" X 0.028" Reference 12.32.421 Lot 174725	Aditek (Cravinhos, SP, Brazil)

Preparation of test specimens and mechanical test

Segments 4 cm long were used, obtained from the straightest posterior portion of the archwires [14].

In total 30 acrylic plates were fabricated, measuring 40 mm long, 40 mm high and 6 mm thick, for fixation of the brackets and placement of the archwires. After this, four conventional metal brackets (Aditek, slot 0.022" x 0.028") were bonded to both surfaces of the plate with cyanoacrylate-based adhesive (Super Bonder gel, Henkel, Itapevi, São Paulo, Brazil) at an interbracket distance of 7 mm [10,15]. To guarantee that the brackets were bonded in an aligned manner, a steel wire (0.021" x 0.025" Morelli, reference 5062005) was inserted into the slot of the brackets during the bonding process. After bonding, this wire was removed.

For each set of four brackets, clinical universal tweezers 317 Duflex (SSWhite, Rio de Janeiro, Rio de Janeiro, Brazil), were used to take a segment of archwire that was carefully bonded into the slots, so that 2 mm at each extremity of archwire remained outside of the brackets. These orthodontic archwires were fixed into the bracket slots with 0.25 mm metal ties pinched with a Mathieu 11 cm needle carrier (Zatty, Iacanga, São Paulo, Brazil) and afterwards locked with an orthodontic stop that was pressed with 139 orthodontic pliers (Quinelato, reference QO.064.00, Schobell Industrial Ltda, Rio Claro, São (Figure 1).

The plates were fixed with Araldite adhesive (Brascola Indústria Química, Joinville, Santa Catarina, Brazil) in a vertical position on a horizontal support made of polyvinyl chloride (PVC), which fitted into the perforation existent at the base of the mechanical cycling machine (Equipment for Simulating Fatigue due to Mastication ("Equipamento para Simulação de Fadiga por Mastigação", Elquip, São Carlos, São Paulo, Brazil). Subsequently the test specimens were positioned in the machine to perform the cycles.

Figure 1 - Brackets bonded on one of the surfaces of the acrylic plate with orthodontic archwire in place.

For cycling, a vertical force (parallel to the plate) of 3 N and frequency of 2 Hz was applied between the two central brackets (that represented the maxillary central incisors) with a point denominated "counter-part" on which a steel wire 1.6 mm in diameter was fixed, associated with a spring that would generate the previously described force. In total 10,000 cycles were applied to each test specimen, which would clinically correspond to 10,000 bites, totaling 4.38 uninterrupted hours of use of the machine, at a speed of 80 mm/minute simulating approximately 38 bites per minute (Figure 2) or until fracture of the wire occurred.

After performing cycling, the archwires were analyzed while still fixed on the test specimens, to measure the plastic deformation caused by fatigue. Plastic deformation was measured with the use of a plastic transferer (Acrimet 180º ref. 551.0 crystal, São Bernardo do Campo, São Paulo, Brazil). A transparent glass plate was used, on which a sheet of black cardboard paper was placed, with a square (4 x 4 cm) cut out of the center. Under this set, a light emitting diode (LED) type white light source was placed. Each test specimen was carefully put into the cut out square. Then, a tracing of the archwire fragment was made on a sheet of ultraphan paper, by using 0.7 mm graphite. After this the degree of angulation (=deformation) was obtained in steps of 0.5 to 0.5 degrees.

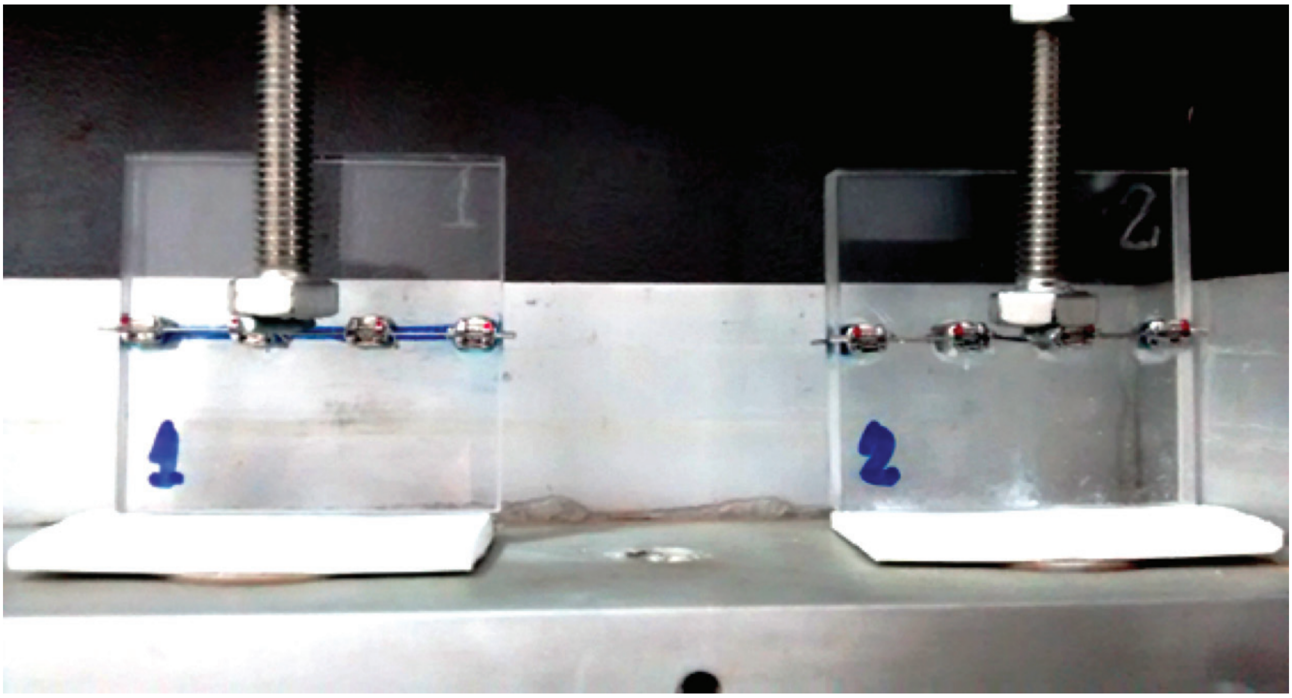

Figure 2 - Test specimens in the mechanical cycling machine.

The value obtained was approximate, that is, when it was below 0.25º, the lower value was considered, and when above 0.26º the upper limit was considered. For the purpose of obtaining calibration of the measurement, each segment was analyzed at three different time intervals, with an interval of four days between evaluations. As no different result was observed between measurements, this made excellent intra-examiner calibration possible.

Statistical Analysis

The data did not meet the suppositions of a parametric analysis, and were analyzed by the Kruskal-Wallis and Dunn tests. Analyses were performed in the Bioestat 5.0 statistical program (Mamirauá Maintainable Development Institute, Belém, Pará, Brazil, 2009) and in R Core Team (R: A Language and Environment for Statistical Analysis, R Foundation for Statistical Computing 2016), considering the level of significance of 5%.

RESULTS

There was no fracture of any of the orthodontic arch wires after performing mechanical cycling in the different groups analyzed.

The Kruskal-Wallis test showed differences among the angulations of the orthodontic archwires analyzed (p = 0.0009). By means of multiple comparisons (Table II and Graph I) the highest median of the angulation value was observed for the orthodontic archwire Aditek (NiTi Copper NiTi 35°C 0.016”). The lowest medians were observed for the archwires RMO (FLI CuNiTi 27ºC 0.016”), Eurodonto (Copper NiTi 27ºC 0.016”) and Ormco (Damon CuTiNi 0.016”). The archwires Aditek (NiTi thermo-activated 0.016”) and Orthometic (Flexy NiTi Copper 0.016”) presented intermediate angulation, not differing significantly from the other types.

Table II - Test specimens in the mechanical cycling machine.

Commercial Brand	Degree of angulation
RMO (FLI CuNiTi 27º 0.016”)	0.00 (0.00; 1.00) b
Orthometric (Flexy NiTi Copper 0.016”)	1.00 (0.00; 3.00) ab
Aditek (NiTi thermoactivated 0.016”)	0.25 (0.00; 3.00) ab
Aditek (NiTi Copper NiTi 35ºC 0.016”)	2.00 (0.00; 4.00) a
Eurodonto (Copper NiTi 27ºC 0.016”)	0.00 (0.00; 1.00) b
Ormco (Damon CuTiNi 0.016”)	0.00 (0.00; 0.00) b

Medians followed by different letters differed among them ($p<0.05$)

DISCUSSION

After the tests performed with the archwires under study, the authors observed there was no fracture of any of the archwires, even for those of the control group that contained no copper in their composition. The presence of copper in the chemical composition of the orthodontic archwire improved their mechanical properties and their resistance to deformation and/or fracture [5,10], because this chemical element is an efficient heat conductor, and when it is incorporated into nickel and titanium, it promotes more defined transition temperatures, guaranteeing the generation of more homogeneous loads [4],

However, the absence of fracture in the archwires may have been related to the number of cycles to which the archwires were submitted (10,000 cycles) and force applied (3 N), which may not have been sufficient to promote their rupture, and a larger number of cycles and higher force applied may be necessary for this phenomenon to occur. The above-mentioned force [16] was compatible with periodontal tissues and sufficient for tooth movement. On the other hand, in the *in vitro* study [10], which was used as a basis for the methodology of the present study, there was fracture of all the archwires tested, which may be justified because forces above those of the ideal value had been used. Hernández et al. also verified that the Ormco archwires presented greater elasticity when compared with those of GAC and 3M, because they withstood a higher number of cycles until their rupture occurred.

It must be considered that the fracture of an orthodontic archwire is not a great clinical concern during orthodontic treatment, because orthodontic archwires do not normally remain in the mouth for a long time, and when any deformation is detected, they are soon replaced by others of equal shape and caliber, thereby avoiding a possible fracture. Nevertheless, this may occasionally be found, especially in uncooperative patients [17], who do not follow the rules suggested by the orthodontist; thus they bite on extremely hard foods, as well as objects and their nails. Thus debonding of the appliance (brackets) occurs, and they do not go to the dental office immediately to have them rebonded, consequently generating a vulnerable point for this type of occurrence.

Moreover, the limits of *in vitro* simulation of the way in which force falls on the orthodontic archwires in a clinical situation must be considered. *In vitro*, factors are established that impede the exact reproduction of the situation that occurs clinically, because clinically, the load and sites of force application when the archwire is in the intraoral environment occur in a multidirectional manner with varied loads over the course of time, due to the foods present in the mouth, brushing, presence of possible parafunctional habits such as bruxism, biting hard objects (pencils, pens and other similar types), onichophagia (nail biting) and the influence of oral fluids. Therefore, in the present study there was no possibility of faithfully simulating these intraoral conditions, as the tests were performed in a dry medium, without the action of electrolytic chemical phenomena (saliva, acid present in the oral cavity, mouth wash solutions), which may contribute to greater degeneration of these archwires [18,19]. Moreover, the force applied always fell on the same site (between the brackets of two maxillary central incisors) in a unidirectional manner, with a load of 3N, which is biologically compatible with the periodontal tissues, causing minimal possible aggression necessary for tooth movement. Otherwise, with elevated forces, the blood vessels in the periodontium may collapse, leading to hypoxia and consequent chemotaxis of clasts that could generate root resorptions [20].

The forces mechanically applied in Orthodontics are not used to produce a mechanical movement, but rather to produce biological stimuli that trigger tooth movement, which is a biological phenomenon and not a physical event. Further to the foregoing discussion, the mean length of time that the archwire remains in the oral cavity - this could be for around 3 to 5 months [21] - is not sufficient to receive the number of cycles capable of generating orthodontic archwire fracture [22], thus, as the force applied to the archwire (under normal treatment conditions) does not exceed the 3 Newtons, and the occlusal forces transferred to a considerably deflected arch are not capable of producing fatigue in the release of force generated by the archwire [17,23]. During this period, they receive a large number of light forces during mastication, and are not capable of presenting extra fatigue and/or fracture [23]. Therefore, the authors verified that the addition of copper to the composition of orthodontic archwires, irrespective of the commercial brand, did not influence the fracture strength of the archwires.

On the other hand, the archwires studied behaved in a different manner in relation to the deformations (in increasing order), some with more (Aditek thermo, Orthometric, Aditek Copper), others with less (Rock Mountain and Eurodonto), and there was one commercial brand without any deformation whatever (Ormco). It is important to point out that after mechanical cycling, the test specimens were carefully analyzed and no movement of the stops was noted; not in the sense of having become loose, or of having entered into the slots of the brackets. The fragments of archwires were also analyzed after the fatigue test and the authors observed that they maintained their original length, which could be explained due to the ductibility presented by the orthodontic archwires. Therefore, the authors suggest that the differential between the wires would be the quality of the manufacturing process, and not only the presence or absence of copper in their composition.

Within the range of archwires existent on the market, the NiTi type are those that release lighter forces when compared with the other archwires [4, 9], and may be presented in the conventional superelastic [6,24,25] or thermoactivated [20,26,27] form, with 55% nickel and 45% titanium [28]. Whereas, the CuNiTi archwires that may also be classified as being thermoactivated (tensoactive) and superelastic, are basically composed of nickel, titanium and copper, on an average, presenting, 50%, 44% and 6%,respectively, of these chemical elements [2,4,29]. Due to the incorporation of copper, they present more defined thermoactive properties than the superelastic NiTi archwires, and allow an optimum system of forces to be obtained, with more accentuated control of tooth movement. There may be a reduced possibility of permanent deformation because they present greater mechanical strength [5,11,16]. Therefore, hysteresis is lower in CuNiTi archwires, because they exhibit a greater capacity for activation/deactivation, and do not lose their capacity to return to their original shape [11,12].

The CuNiTi archwires are more resistant to permanent deformation and promote more consistent tooth movement because they have optimal force throughout the entire time in activity. They were introduced onto the market with three transition temperatures (27ºC, 35ºC e 40ºC); develop approximately 20% less load force [8], therefore, generate less trauma and discomfort to the patient, and because they contain copper, the release fewer nickel ions due to their greater resistance to corrosion [29]. They also allow quantification and application of load levels suited to the objectives of orthodontic treatment, and consequently, lower potential for tooth resorptions [7].

According to the deformation results, the authors observed that the archwire that presented no changes in shape whatever was that of the Ormco brand (Damon CuNiTi), which demonstrated greater dimensional elastic capacity and lower level of force [30] capable of clinically providing greater stability to orthodontic treatment. Even when using a slightly different methodology, some authors [10] also corroborated the finding that archwires of the ORMCO brand (Damon CuNiTi) were the most resistant to fracture. Some authors [15,31] described the greater resistance to deformation of the CuNiTi and NiTi (Ormco) archwires, and did not mention any type of fracture of these on application of forces by means of the three point bending test, which would probably be related to the manufacturing process of these archwires. When fractures occurred [32] (and not very frequently), they were localized in the posterior region of the archwire, without any relationship to the composition of the orthodontic wire, but rather related to excessive masticatory load. On the other hand, the archwire of the Aditek commercial brand (Copper NiTi) presented the largest deformations when compared with the other samples studied, and the authors presumed that their manufacturing process probably needed to be submitted to some type of improvement. The other archwires studied (RMO: FLI CuNiTi, Orthometric: Flexy NiTi Copper, Aditek: NiTi thermoactivated, Eurodonto: Copper NiTi) that presented an intermediate degree of deformation probably went through an improved manufacturing process, but not to the extent of that of Ormco.

With the present study, the authors perceived that not all CuNiTi archwires analyzed presented the same resistance to deformation, and that even when they had an equal percentage of copper in their compositions, some brands presented a considerable degree of deformation. Therefore, the authors could infer that it would not be only the copper that could provide the materials with mechanical resistance, but also the manufacturing process of this archwire, which varies from one commercial brand to another. This process is not completely known, and the orthodontic archwire manufacturers do not generally disclose the exact composition and manufacturing processes of the orthodontic archwires [33]. Therefore, future studies must be conducted with the purpose of investigating the number of cycles after which the archwires begin to present plastic deformation, and to evaluate the manufacturing process of these archwires related to their clinical performance.

CONCLUSION

The authors could conclude that none of the archwires analyzed presented fracture as a result of performing mechanical cycling. These archwires presented differences in plastic deformation, irrespective of the presence of copper in their chemical composition. The CuNiTi Damon (ORMCO) archwire was the only type that presented no deformation whatever.

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