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Mechanical properties of orthodontic wires on ceramic brackets associated with low friction ligatures

Propriedades mecânicas de fios ortodônticos em bráquetes cerâmicos associados com ligaduras de baixa fricção

Fernando KOIKE[a], Hiroshi MARUO[a], Rogério LACERDA-SANTOS[b*], Matheus Melo PITHON[c], Orlando Motohiro TANAKA[a]

[a]PUCPR – Pontifícia Universidade Católica do Paraná, Curitiba, PR, Brasil
[b]UFJF – Universidade Federal de Juiz de Fora, Governador Valadares, MG, Brasil
[c]UESB – Universidade Estadual do Sudoeste da Bahia, Jéquie, BA, Brasil

Resumo

Introdução: Poucos estudos investigaram as propriedades mecânicas dos fios ortodônticos em bráquetes cerâmicos associados às ligaduras. **Objetivo:** O objetivo deste estudo foi comparar a carga-deflexão de fios ortodônticos com seção redonda de 0,016” de aço inoxidável (AI), níquel-titânio (NiTi) e composto de polímero reforçado com fibra de vidro (CPRFV). **Material e método:** Sessenta espécimes obtidos a partir de 10 arcos pré-contornos seccionados (TP Orthodontics), foram divididos em 3 grupos de 20 de acordo com cada tipo de material (1 fio estético e 2 não estético) e comprimento de 50 mm. A metodologia consistiu de um teste de flexão de 3 pontos usando bráquetes estéticos cerâmicos (INVU, TP Orthodontics, Edgewise, 0,022 “x 0,025”) como pontos de suporte. Os ensaios de tração foram realizados em uma máquina de ensaios mecânicos, a uma velocidade de 10 mm / min, deflexão de 1 mm, 2 mm e 3 mm. Utilizou-se o teste não-paramétrico de comparações múltiplas de Friedman (P <0,05). **Resultado:** O fio de níquel-titânio apresentou menor carga / deflexão em relação ao aço inoxidável. Os fios CPRFV tiveram valores de resistência mais baixos entre todos os grupos avaliados (P <0,05). O fio de aço mostrou deformação permanente após deflexão de 3 mm, fio NiTi demonstrou efeito de memória e o tipo estético teve fraturas com perda de força. **Conclusão:** Pode-se concluir que os fios de aço têm valores de resistência elevados, exigindo a incorporação de alças e dobras para reduzir a carga / deflexão. Os fios NiTi e CPRFV produziram baixos níveis de força, porém o fio estético mostrou-se fraturado e quebrado.

Descritores: Fios ortodônticos; elastômeros; materiais odontológicos.

Abstract

Introduction: Few studies investigated the mechanical properties of orthodontic wires on ceramic brackets associated the ligatures. **Objective:** This study aimed to compare the load-deflection of orthodontic wires with round section of 0.016” made of stainless steel (SS), nickel-titanium (NiTi) and glass fiber-reinforced polymer composite (GFRPC). **Material and method:** Sixty specimens obtained from 10 sectioned pre-contoured arches (TP Orthodontics), were divided into 3 groups of 20 according to each type of material (1 esthetic-type wire and 2 not esthetic) and length of 50 mm. The methodology consisted of a 3-point bending test using esthetic ceramic brackets (INVU, TP Orthodontics, Edgewise, 0.022”x 0.025”) as points of support. The tensile tests were performed on a mechanical test machine, at a speed of 10 mm/min, deflection of 1 mm, 2 mm and 3 mm. Friedman’s Non Parametric Multiple comparisons test was used ($P<0.05$). **Result:** The nickel-titanium wire presented smaller load/ deflection compared with stainless steel. GFRPC wires had lower strength values among all groups evaluated ($P<.05$). The steel wire showed permanent deformation after 3 mm deflection, NiTi wire demonstrated memory effect and the esthetic type had fractures with loss of strength. **Conclusion:** It can be concluded that steel wires have high strength values, requiring the incorporation of loops and folds to reduce the load / deflection. NiTi and GFRPC wires produced low levels of force, however the esthetic wire was shown to fracture and break.

Descriptors: Orthodontic wires; elastomers; dental materials.

INTRODUCTION

Over the course of the years, the esthetic appearance of fixed orthodontic devices during treatment has become a concern, particularly to adult patients[1] and, due to their growing number, there has been an increasing demand for esthetic orthodontic appliances[2,3]. Orthodontic patients, including a growing population of adults, not only want and improved smile, but also demand better esthetics during treatment[3].

To guarantee the esthetic appearance, as well as the biomechanical needs of metal wires during orthodontic treatment, manufacturers have developed esthetic wires[4,5]. Two types of orthodontic wires have been idealized to improve the esthetic aspect: one of these is a metal wire with white colored Teflon (polytetrafluorethylene) or epoxy resin on its surface, the other type is manufactured from a translucent composite using a polymer for a matrix and glass fibers for reinforcement (GFRPC)[5]. The latter wire is made with a glass fiber-reinforced polymer resin for an exceptionally translucent appearance, virtually invisible and performance equivalent to that of nickel titanium (NiTi)[5,6].

As the esthetic advantages must not surpass those of mechanical functions, it has become relevant to prove whether the GFRPC wires really confirm the qualities claimed. Therefore, the aim of this study was to make a comparative evaluation, by means of the load/deflection ratio, of the force released by stainless steel, nickel-titanium and glass fiber-reinforced polymer composite wires, as well as the maximum deformation presented by these wires.

MATERIAL AND METHOD

Three types of orthodontic wires were evaluated: stainless steel (CrNi) (Shiny Bright™ - TP Orthodontics, main composition: Ni 8%, Cr 18%, Fe 74%), nickel titanium (NiTi) (Reflex™ nickel titanium - TP Orthodontics, main composition: Ni 55%, Ti 45%) and glass fiber-reinforced polymeric composite (GFRPC) (OPTIS™ - TP Orthodontics, main composition: Fiberglass 59%, Epoxy resin 41%). All the wires had a round section of 0.016" (0.40 mm) and were of the Straight Form - Maxillary type.

Before the mechanical tests, a simulation device was developed. It consisted of a horizontal metal base with two vertical, changeable steel rods that had two bases on the top part, to which four esthetic ceramic brackets (INVU - TP Orthodontics, Edgewise Standard, 0.022" x 0.025") were fixed (Figure 1). The distance between the centers of the two central brackets was 14 mm, corresponding to the interbracket distance from the maxillary lateral incisor to the maxillary first premolar. Between the centers of the central and peripheral brackets there was a distance of 8 mm, corresponding to the interbracket distance between the maxillary premolars.

A sample size calculation based on a pilot study showed that the minimal difference between the mean force values (Kgf) for a load/deflection ratio between the stainless steel wire with the other wires, was of 0.70 Kgf ($\alpha = 0.01$, $\beta = 0.30$), and considering a power of 90%, a minimum of 8 specimens per group was required. For greater safety in the study and due to fracture risks in the GFRPC group presented in the pilot study, 20 specimens were used for each group.

The straight line posterior segments of each pre-contoured arch wire were measured with a digital pachymeter (Mitutoyo, Santo Amaro, Brazil) to a length of 50 mm and sectioned, thus obtaining 60 segments, totaling 60 test specimens which were divided into 3 groups according to the type of wire: Group Arch (n=20); Group NiTi (n=20) and Group GFRPC (n=20).

Each test specimen was fastened to the brackets of the device by means of transparent elastic ligatures[7,8] (Mini Stix Ligature Ties Non-Coated - TP Orthodontics), that was changed in every trial. The test method selected was the three-point bending test[5,9] and

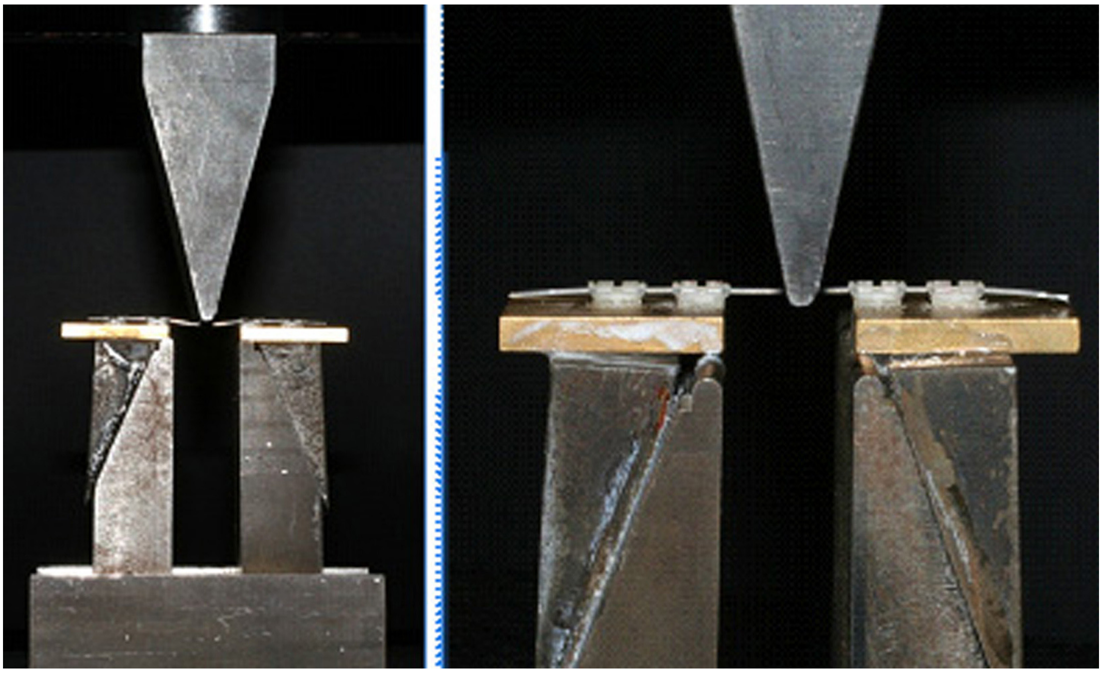

Figure 1. Application of force deflection in the specimen.

consisted of bending the test specimen supported on two points at a distance of 14 mm from each other. Four brackets were used as supports to allow the wire to slide into the bracket slot, not causing deformation at the extremities of the wires.

By means of a 2kgf (20N) load cell, at the speed of 10 mm/min., a bending force was applied on the test specimen center, which was at a distance of 7 mm from each support, until deflections of 1 mm, 2 mm and 3 mm were attained. The pre-established load/deflection or fracture force was measured during the test. Thus, during deactivation a value of force corresponding to the deflection was obtained and recorded on a computer coupled to the Test Machine (EMIC DL 500, São José dos Pinhais, Brazil), using the software Tesc version 3.04.

The values obtained were analyzed with the purpose of comparing: a) The load /deflection properties at the deflections of 1, 2 and 3 mm irrespective of the wire, and b) The load/deflection properties among Groups Steel, NiTi and GFRPC at the flexions of 1, 2 and 3 mm. Statistical analysis was performed with SPSS software (version 16.0; SPSS, Chicago, Ill). Descriptive statistics were calculated for each group tested. A multi-factor analysis of variance (ANOVA) was applied to determine whether there were significant differences among the various groups. Friedman's Non Parametric Multiple comparisons test was used ($P<0.05$).

RESULT

Table 1 shows the mean force values for the wires analyzed in the three-point bending test, with the respective displacement and number of test specimens of each sample (n), as well as the bottom and top limit of each deflection for the type of wire analyzed.

Friedman's non parametric multiple comparisons showed statistical difference ($P<0.05$) for the differences between the deflection values of each group. In observation of force at 1 mm × 2 mm, force at 2 mm × 3 mm and force at 1 mm × 2 mm the Group Steel demonstrated the values of $7.74.10^{-6}$, $5.69.10^{-5}$ and $7.74.10^{-6}$ respectively. For all set of observation of forces demonstrated the value of $7.74.10^{-6}$ for the Group NiTi. The Group GFRPC was not considered due to the occurrence of fractures.

Table 2 presents the non parametric multiple comparisons by means of Friedman's test, in which it may be observed that the Groups differ among them in the deflection at 1, 2 and 3 mm. Due to the occurrence of test specimen fractures in Group GFRPC, this was not considered in the comparisons between the groups at deflections of 2 and 3 mm.

Due to stainless steel having presented permanent deformation after deflection at 3 mm, this group was excluded from the statistical analysis when maximum deformation was evaluated.

In Table 3 the maximum deformation values are shown in millimeters for the NiTi and GFRPC wires.

As the sample did not present normality in the Shapiro Wilk test, the Mann Whitney U test was performed for comparison of the maximum deformation between the Groups NiTi and GFRPC, which accepted the hypothesis that there were statistically significant differences between the two wires (p=0.004).

DISCUSSION

The present study used the three-point bending test methodology as it offers reproducibility, thus facilitating comparison among studies available in the literature[5,9,10].

The orthodontic wires were fixed to the brackets by means of elastic ligatures. Although some authors have demonstrated that metal ligatures (ties) produce less friction than the elastomeric ligatures, the force generated during the placement of the metal ligature is subjective, and could vary according to the orthodontist[7,8,11]. In this trial, elastic ligatures of the Super Slick (TP Orthodontics) brand were used, because researches conducted by the manufacturer revealed a reduction of over 70% in the friction between the metallic orthodontic wire and this ligature. Due to its good elastic recovery, the original shape is maintained, as shown in study[12] which the forces of friction of common modulus's elasticity and those of super-slick with loose metal ties were compared.

Table 1. Descriptive statistics of the variable force according to the types of wires and flexions

Wire x Flexion		n	Mean (Kgf)	Median (Kgf)	Standard Deviation	C.V (%)	Confidence Interval (95%)	
							BL	TL
Steel	1 mm	20	1.00	0.97	0.06	6.67	0.95	1.14
	2 mm	20	1.25	1.22	0.07	6.23	1.19	1.41
	3 mm	20	1.31	1.28	0.07	6.06	1.25	1.51
NiTi	1 mm	20	0.28	0.28	0.00	2.85	0.27	0.31
	2 mm	20	0.37	0.37	0.00	1.77	0.36	0.39
	3 mm	20	0.40	0.40	0.01	2.89	0.39	0.44
GFRPC	1 mm	20	0.22	0.22	0.02	8.87	0.19	0.25
	2 mm	18	0.30	0.31	0.07	27.89	0.13	0.40
	3 mm	08	0.33	0.34	0.05	26.73	0.25	0.44

n= number of test specimens; CV= Coefficient of variance; BL=Bottom limit; TL= Top limit.

Table 2. Friedman's non parametric multiple comparisons test for the variable deflection at 1, 2 and 3 mm

Groups	1 mm	2 mm	3 mm
GFRPC vs. NiTi	$7.74.10^{-6*}$	X	X
GFRPC vs. Steel	$7.74.10^{-6*}$	X	X
NiTi vs. Steel	$7.74.10^{-6*}$	$6.30.10^{-8*}$	$6.30.10^{-8*}$

*Indicate statistically significant difference between the two groups ($p<0.05$).

Table 3. Descriptive statistics of the variable maximum deformation according to the types of wires

Wire × Flection	n	Mean (mm)	Median (mm)	Standard Deviation	C.V (%)	Interval of Confidence (95%)	
						BL	TL
NiTi	20	3.10	3.13	0.03	1.20	3.00	3.13
GFRPC	20	2.61	2.78	0.49	18.83	1.72	3.08

Analysis of the results of this study demonstrated that the mean force generated by the orthodontic wires ranges from 0.227 Kgf to 1.316 Kgf, the lightest forces being found in the esthetic orthodontic wires GFRPC and the highest forces in the steel wires. According to the values obtained, the forces exerted by the wires are higher than those considered ideal, around 200 gf to 550 gf, considering the force distribution for two incisors and two molar, respectively[13]. Nevertheless, it must be pointed out that laboratory conditions do not correspond faithfully to clinical conditions.

In all the parameters evaluated the Group Steel of 0.016" presented much higher values than Group GFRPC and NiTi, which is in agreement with authors[14] who affirmed that among the disadvantages of using stainless steel arches at the beginning of treatment is that these tend to apply excessive forces to the teeth.

This study demonstrated that the stainless steel wire presented a mean force of 1.005 Kgf in the deflection at 1 mm; 1.254 Kgf in the deflection at 2 mm and 1.316 Kgf in the deflection at 3 mm. These values are comparable with the results of authors[15] who tested steel and nickel-titanium wires.

Studies, in three point bending or angular bending tests[16], they indicated that the stainless steel wires required a statistically significant force for the same activations, in comparison with nickel titanium wires. The behaviors of these wires are connected to their composition and structure. The stainless steel alloy consisting of chromium, iron and small amounts of nickel and their face-centered cubic structure known as austenite phase express higher rigidity compared to titanium nickel wires, which have high amounts of nickel and titanium and its microstructure that provides high resilience for this wire[15,17,18].

In comparison with steel, the nickel titanium wires exert much lighter and more constant forces due to the resilience and the "memory of form" and in the present research, promoted forces of 289 gf to 409 gf. The mean force at a deflection of 3 mm in nickel titanium wires was 409 gf. This value is comparable with the results of other authors[19].

The "shape memory effect" of nickel titanium wire, consisting in the capacity of return to original shape after deformation. Is attributed to the cause of this capability the free energy difference between the structures involved in the process, which induces changes in the chemical ligation and in the crystallographic nature of alloy. These changes present as main characteristics the temperature dependence and the property of reversibility[20,21].

Authors[22], analyzing the nickel titanium superelastic, round section with a thickness of 0.016" recorded forces of 259gf, 211gf, and 187gf for the deflections of 3, 2 and 1 mm, respectively. These values are lower than those found in the present research. However, it is difficult to make a comparison of the values obtained due to the difference between bracket systems used. This study was developed with conventional ceramic brackets, whereas the above mentioned authors used self-ligating brackets (Speed – Speed system Strite Industries). These data are in agreement with the observations of authors[23] who simulated a clinical environment, using a mannequin, and performed bending tests on nickel titanium wires of 0.014" with brackets of different materials, and concluded that the force varies according to the type of bracket, being higher in ceramic brackets, followed by ceramic brackets with metal slots, and metal brackets, without differences among them, and with significantly lower values in the self-ligating type.

The use of esthetic ceramic brackets in this study was due to the growing demand by patients, particularly adults, who are concerned about the esthetic appearance of orthodontic appliances[24,25]. The use of esthetic brackets, whether they are ceramic or plastic, is becoming increasingly popular and their quality has been enhanced by the manufacturing companies by clinical and laboratory studies. However, in clinical practice, normally the orthodontic wires used with these brackets are composed of metal alloys, harming the final esthetics of the set. The stainless steel wires have become traditional for clinical use because of the versatility of wire, its physical properties, among them, the formability which allows the execution of folds easily and accurately. In addition to presenting excellent weldability, low coefficient of friction and corrosion resistance[15,17,18].

So, with the constant concern about developing a wire to complement the esthetic brackets, but with a mechanical performance similar to those made of metal alloys, TP Orthodontics released OPTIS™ Preformed Archwire, a translucent wire composed of fiber glass-reinforced polymer resin. According to the company, this esthetic wire has a performance equivalent to that of nickel titanium (NiTi).

The maximum deformation level showed that the GFRPC wires presented fracture without rupture of the orthodontic wire evaluated. The mean deformation was 2.61 mm. The determination of this characteristic is interesting from the point of view of force exerted on orthodontic arches during mastication, or even while fitting the orthodontic wire into the bracket slot.

All the GFRPC wire test specimens showed signs of whitening and beginning of cracks. The appearance of cracks is the sign of plastic deformation of the wire and later loss of force. This result is in agreement with authors[5] who affirmed that the possible factors that contra-indicate the use of polymer and fiber based esthetic wires are in the transverse fractures, fractures due to stress with detachment of the fibers, fractures at the polymer-fiber bond surface, compressive fracture arising from bends located in the fibers, and fractures close to the surface.

Technological innovations in terms of orthodontic wires should not give precedence to their esthetic advantages[26] to the detriment of their biological[27] and mechanical functions[28]. All orthodontic treatment must be for the purpose of correcting malocclusion and obtaining a stable occlusion without causing damage to tissues[29]. Considering the clinical applicability of these wires, it can be observed that the stainless steel wire presented a greater force of deflection because it is less resilient than the other evaluated wires. This can create a greater risk of discomfort for patients with significant dental crowding. Titanium nickel wires and GFRPC are more resilient, however the GFRPC wire is not indicated for malocclusion with large dental crowding because they can fracture when are submitted to deflection above 2 mm.

CONCLUSION

The stainless steel wire produces higher mean force values in the load/deflection ratio than the nickel titanium wire, followed by GFRPC wire. In the maximum deformation, the nickel titanium wire presented a shape memory effect, the stainless steel wire presented permanent deformation and the GFRPC wire presented fracture without rupture.

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CONFLICTS OF INTERESTS

The authors declare no conflicts of interest.

*AUTOR PARA CORRESPONDÊNCIA

Rogério Lacerda-Santos, Departamento de Ortodontia, Faculdade de Odontologia, UFJF – Universidade Federal de Juiz de Fora, Av. Doutor Raimundo Monteiro Rezende, 330, Centro, 35010-177 Governador Valadares - MG, Brasil, e-mail: lacerdaorto@hotmail.com; lacerdaorto@gmail.com

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