Comparison of the Load Deflection Characteristics of Esthetic and Metal Orthodontic Wires on Ceramic Brackets using Three Point Bending Test

Umal Hiralal Doshi, Rajan K Mahindra

ABSTRACT

Objectives: To compare the load deflection of orthodontic wires with round section of 0016" made of stainless steel (SS), nickel-titanium (NiTi) and glass fiber-reinforced polymer composite (GFRPC).

Materials and methods: A total of 60 specimens were obtained from the posterior arches of 30 precontoured trademark TP Orthodontics (La Porte, Indiana) wires and were divided into three groups of 20 according to each type of material and length of 50 mm. The methodology consisted of a 3-point bending test using esthetic ceramic brackets (INVU-TP Orthodontics, Standard Edgewise, 0.022" × 0.025") as points of support. The tensile tests were performed on a mechanical test machine, EMIC model DL500 (São José dos/SP), at a speed of 10 mm/min, deflection of 1, 2 and 3 mm.

Results: GFRPC wires had lower strength values among all groups evaluated (statistically significant, p < 0.05). The NiTi wire presented smaller load/deflection compared with SS. 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: Steel wires showed highest strength values, requiring the incorporation of loops and folds to reduce the load/deflection. NiTi and GFRPC wires produced more deflection at low levels of force, however the esthetic wire was shown to fracture and break.

Keywords: Orthodontic wires, Esthetic wires, Load/deflection.

INTRODUCTION

Orthodontic mechanics uses forces of various intensities in various directions, which result in an expected tissue response for tooth movement. According to Halderson and Reitan, the ideal orthodontic wire should develop light, continuous forces during deactivation to avoid hylalination, anoxia and even necrosis of the periodontal ligament. When selecting orthodontic wire, one must bear in mind the basic knowledge of their elastic properties, and should bear in mind that the ideal wire must transmit the lightest possible force. To do this, the wire must have a low modulus of elasticity, high resilience and low deflection load.

Over the course of years, the esthetic appearance of fixed orthodontic devices during treatment has become a concern, particularly to adult patients and due to their growing number there has been an increasing demand for esthetic orthodontic appliances. To guarantee the esthetic appearance, as well as the biomechanical needs of metal wires during orthodontic treatment, manufacturers have developed highly esthetic wires.

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 transluscent composite using a polymer for a matrix and glass fibers for reinforcement [glass fiber-reinforced polymer composite (GFRPC)]. 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).

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
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released by stainless steel (SS), NiTi and GFRPC wires, as well as the maximum deformation presented by these wires when ligated to polycrystalline ceramic brackets.

MATERIALS AND METHODS

Three types of orthodontic wires were evaluated: SS (Shiny Bright™-TP Orthodontics), NiTi (Reflex™ nickel-titanium-TP Orthodontics, La Porte, IN) (0.016") and GFRPC (OPTIS™-TP Orthodontics). All the wires had a round section of 0.016” 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” × 0.025”) were fixed (Fig. 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. The straight line posterior segments of each precontoured archwire were measured with a digital pachymeter to a length of 50 mm and sectioned, thus obtaining 60 segments, totaling 60 test specimens which were divided into three 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 Super Slick ligatures (TP Orthodontics, La Porte, IN).

The test method selected was the three-point bending test and 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 2 kgf (20 N) 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, 2 and 3 mm were attained. Deflections in a graded order were used due to the possibility of plastic deformation or fracture of the test specimens when submitted to large deflections. 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, using the software Tesic, version 3.04.

The values obtained were analyzed with the purpose of comparing:
- The load/deflection properties at the deflections of 1, 2 and 3 mm irrespective of the wire;
- The load/deflection properties among groups: steel, NiTi and GFRPC at the flexions of 1, 2 and 3 mm.

Statistical analyses were performed with the licensed program SPSS 13.0 (SPSS Inc, Chicago, Illinois, USA). Descriptive statistical analysis including mean, median and standard deviation was calculated for the groups evaluated. The Shapiro-Wilk test was used to evaluate the distribution of the samples. The nonparametric Kruskal-Wallis test and Friedman’s nonparametric multiple comparisons test were also applied, at the level of significance of 0.05 to analyze differences among the groups.

RESULTS

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. The measurements are presented in gram-force (gf).

In Table 2, Friedman’s nonparametric multiple comparisons are shown, at the level of significance of 0.05 to analyze differences between the deflection value of each group.

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

<table>
<thead>
<tr>
<th>Wire × Flexion</th>
<th>n</th>
<th>Mean (gf)</th>
<th>Median (gf)</th>
<th>Standard</th>
<th>CV (%)</th>
<th>Interval of confidence (95%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>LI</td>
<td>LS</td>
<td></td>
<td></td>
<td>LLI</td>
</tr>
<tr>
<td>Steel</td>
<td>1 mm</td>
<td>20</td>
<td>1.005</td>
<td>0.979</td>
<td>0.067</td>
<td>6.675</td>
</tr>
<tr>
<td></td>
<td>2 mm</td>
<td>20</td>
<td>1.254</td>
<td>1.221</td>
<td>0.078</td>
<td>6.239</td>
</tr>
<tr>
<td></td>
<td>3 mm</td>
<td>20</td>
<td>1.316</td>
<td>1.285</td>
<td>0.079</td>
<td>6.068</td>
</tr>
<tr>
<td>NiTi</td>
<td>1 mm</td>
<td>20</td>
<td>0.289</td>
<td>0.288</td>
<td>0.008</td>
<td>2.850</td>
</tr>
<tr>
<td></td>
<td>2 mm</td>
<td>20</td>
<td>0.372</td>
<td>0.372</td>
<td>0.006</td>
<td>1.775</td>
</tr>
<tr>
<td></td>
<td>3 mm</td>
<td>20</td>
<td>0.409</td>
<td>0.407</td>
<td>0.011</td>
<td>2.897</td>
</tr>
<tr>
<td>GFRPC</td>
<td>1 mm</td>
<td>20</td>
<td>0.227</td>
<td>0.228</td>
<td>0.021</td>
<td>8.872</td>
</tr>
<tr>
<td></td>
<td>2 mm</td>
<td>18</td>
<td>0.300</td>
<td>0.315</td>
<td>0.075</td>
<td>27.89</td>
</tr>
<tr>
<td></td>
<td>3 mm</td>
<td>08</td>
<td>0.332</td>
<td>0.340</td>
<td>0.058</td>
<td>26.73</td>
</tr>
</tbody>
</table>
Table 2: Friedman’s nonparametric multiple comparisons for the variable force according to the type of wire

<table>
<thead>
<tr>
<th>Set of observation</th>
<th>Steel</th>
<th>NiTi</th>
<th>GFRPC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force at 1 × 2 mm</td>
<td>7.74 × 10^{-6}</td>
<td>7.74 × 10^{-6}</td>
<td>X</td>
</tr>
<tr>
<td>Force at 3 × 2 mm</td>
<td>5.69 × 10^{-5}</td>
<td>7.74 × 10^{-6}</td>
<td>X</td>
</tr>
</tbody>
</table>

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

Table 3: Friedman’s nonparametric multiple comparisons for the variable deflection at 1, 2 and 3 mm

<table>
<thead>
<tr>
<th>Groups</th>
<th>1 mm</th>
<th>2 mm</th>
<th>3 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>GFRPC vs NiTi</td>
<td>7.74 × 10^{-6}</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>GFRPC vs steel</td>
<td>7.74 × 10^{-6}</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>NiTi vs steel</td>
<td>7.74 × 10^{-6}</td>
<td>6.30 × 10^{-8}</td>
<td>6.30 × 10^{-8}</td>
</tr>
</tbody>
</table>

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

Table 4: Descriptive statistics of the variable maximum deformation according to the types of wires

<table>
<thead>
<tr>
<th>Wire x Flexion</th>
<th>n</th>
<th>Mean (mm)</th>
<th>Median (mm)</th>
<th>Standard deviation</th>
<th>CV (%)</th>
<th>Interval of confidence (95%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NiTi</td>
<td>20</td>
<td>3.108</td>
<td>3.132</td>
<td>0.03748</td>
<td>1.206</td>
<td>3.007 3.137</td>
</tr>
<tr>
<td>GFRPC</td>
<td>20</td>
<td>2.612</td>
<td>2.787</td>
<td>0.4920</td>
<td>18.83</td>
<td>1.722 3.089</td>
</tr>
</tbody>
</table>

Table 3 presents the nonparametric 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 SS having presented permanent deformation after deflection at 3 mm, this group was excluded from the statistical analysis when maximum deformation was evaluated.

In Table 4, 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 = 0.0004).

**DISCUSSION**

The present study sought to use the three-point bending test methodology as it offers reproducibility, thus facilitating comparison among studies available in the literature. Four ceramic brackets were used as points of support so that the wire would slide through the bracket slots instead of becoming deformed at the extremities.

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. In the present trial, elastic ligatures of the Super Slick (TP Orthodontics, La Porte, IN) brand were used, because researches conducted by the manufacturer revealed a reduction of over 70% in the friction between the orthodontic wire and this ligature. Due to its good elastic recovery, the original shape is maintained, as shown in the study conducted by Haim et al.

Analysis of the results of this study demonstrated that the mean force generated by the orthodontic wires ranges from 227 to 1.316 gf, 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. 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 Waters et al who affirmed that among the disadvantages of using SS arches at the beginning of treatment is that these tend to apply excessive forces to the teeth.

This study demonstrated that the SS wire presented a mean force of 1.005 gf in the deflection at 1 mm; 1.254 gf in the deflection at 2 mm and 1.316 gf in the deflection at 3 mm. These values are comparable with the results of Andreasen and Hilleman who tested steel and NiTi wires.

In the studies of Miura et al, in three point bending or angular bending tests, they indicated that the SS wires required a statistically significant force for the same activations, in comparison with NiTi wires.

In comparison with steel, the NiTi wires exert much lighter and more constant forces and in the present research, promoted forces of 289 to 409 gf. The mean force at a deflection of 3 mm in NiTi wires was 409 gf. This value is comparable with the results of Iijima et al.

Berger, Byloff and Waram analyzing the NiTi superelastic, round section with a thickness of 0.016” recorded forces of 259, 211 and 187 gf 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 Strike Industries). These data are in agreement with the observations of Hemingway et al who simulated a clinical environment, using a mannequin, and performed bending tests on NiTi 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 aesthetic appearance of orthodontic appliances. 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.

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 (TP Orthodontics, La Porte, IN), a translucent wire composed of fiber glass-reinforced polymer resin. According to the company, this esthetic wire has a performance equivalent to that of NiTi.

In the results presented in this study, the forces of the GFRPC wire were statistically lower than those of NiTi in the deflection interval of 1 mm. At this deflection the esthetic wire exerted a mean force of 227 gf. However, as some of the test specimens fractured after the deflection at 1 or 2 mm, comparisons were not made between the groups at the deflections of 2 and 3 mm. The mean force of the test specimens that did not fracture at the deflection of 2 mm was 300 gf, and 332 gf at 3 mm of deflection.

The results obtained by the esthetic wire evaluated could not be compared with those of other commercial wires with the same composition, because the only similar wire sold was OptiFlex™ and there are no reports on this wire in the literature for the purposes of comparison.

As regards the maximum deformation, the SS wires presented permanent deformation after a deflection of 3 mm. The wires in the group NiTi tested demonstrated resistance to deformation, proving the memory effect of NiTi and this is in agreement with Andreasen and Brady who indicated that the NiTi wires could be stretched up to approximately 7 to 8% of their length and show complete recovery.

The maximum deflection 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 Jancar et al who affirmed that the possible factors that contraindicate 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.

Clinical Implications

1. Ceramic brackets with esthetic wires can be a best possible option as regards to patient’s appearance during treatment.
2. But as shown in the present study the load deflection characteristics of GFRPC wires showed fracture of wires at 2 and 3 mm deflection. Hence, in severely crowded cases these wires can get fractured very easily.
3. Effect of oral environment especially saliva during treatment with GFRPC wires is still unclear.
4. Technological innovations in terms of orthodontic wires should not give precedence to their esthetic advantages to the detriment of their biological and mechanical functions. All orthodontic treatment must be for the purpose of correcting malocclusion and obtaining a stable occlusion without causing damage to tissues.

CONCLUSION

1. At similar deflections, the SS wire produces higher mean force values than the NiTi wire, whose values in turn are higher than those of the GFRPC wire.
2. As regards the maximum deformation presented by the wires: the NiTi wire presented a shape memory effect; the SS wire presented permanent deformation after a deflection of 3 mm, and the glass fiber-reinforced polymer wire presented fracture without rupture with a mean deformation of 2.61 mm.
3. Future studies are needed to evaluate in vivo response of GFRPC wires especially with ceramic brackets.

REFERENCES


