Three-point bending test comparison of fiber-reinforced composite archwires to nickel-titanium archwires

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Aim: Various alternatives to metal orthodontic archwires have produced varied successes over the years. This study sought to evaluate the bending properties of fiber-reinforced polymeric composite (FRC) archwires compared with similarly sized nickel-titanium (Ni-Ti) archwires. Methods: Two different 0.018-inch translucent FRC orthodontic wires (Translucent Archwire I and Translucent Archwire II) were tested against 0.014-, 0.016-, and 0.018-inch nonsuperelastic nickel titanium orthodontic wires. The wires in each group (n = 10) were evaluated with three-point bending using a universal testing machine. Wire segments were deflected at midspan to 3.1 mm at a rate of 2 mm/min. Loading and unloading slope and modulus were calculated, as were force values during activation and deactivation and elastic recovery. Results: It was found that the 0.018-inch Ni-Ti archwire demonstrated the highest force values at different deflection distances followed by Translucent Archwire II, 0.016-inch Ni-Ti, Translucent Archwire I, and finally 0.014-inch Ni-Ti. 0.016-inch Ni-Ti exhibited the highest modulus value, followed by 0.018-inch Ni-Ti, 0.014-inch Ni-Ti, Translucent Archwire II, and finally Translucent Archwire I. During deactivation, the elastic recovery of 0.014-inch Ni-Ti and 0.016-inch Ni-Ti was significantly greater than Translucent Archwire II. Conclusion: The bending properties of BioMer’s FRC archwires were found to be comparable to Ni-Ti, as advertised by the manufacturer. ORTHODONTICS (CHIC) 2012;13:46–51.

Key words: archwire properties, composite archwires, three-point bending tests

Since its introduction to orthodontics in 1971, nickel-titanium (Ni-Ti) has gained widespread use because of its mechanical properties and availability in various archwire sizes.¹ The alloy possesses a low elastic modulus, a high resiliency, a high yield strength, and a high springback (maximum elastic deflection). These properties produce an archwire that generates relatively low but near constant forces over a wide working range. Its high springback makes it particularly suitable for situations of poorly aligned teeth that require large deflections of the archwire, situations often addressed in the initial stages of treatment.² One drawback to Ni-Ti is that it is normally gray in color and therefore noticeable against the enamel.
Adults account for approximately 20% to 50% of all orthodontic patients. With the change in the treatment population comes a rising demand for esthetics. A majority of adult patients surveyed stated that even though they wanted correction of their occlusions, they would not undergo treatment with visible appliances. Various alternatives to the metal appearance of orthodontic appliances have been introduced. Plastic brackets, ceramic brackets, clear elastic modules, polytetrafluoroethylene-coated archwires and ligatures, lingual brackets, and clear aligners have been developed and used to meet esthetic demands. Some have proven more successful than others. Therefore, the clinician is often forced to use an unesthetic wire with esthetic appliances to achieve the desired orthodontic outcome.

More recent attempts to meet esthetic demands have focused in the area of fiber-reinforced polymeric composite (FRC) archwires. These composite archwires can be made with varying properties by altering the composition of its reinforcement material. The use of a composite resin material allows for the production of an archwire that is esthetically similar to enamel and would not discolor like coated archwires. It has even been stated that “FRCs have the potential to replace metals in clinical orthodontics.” The mechanical properties of various FRC prototype archwires have been tested and their results have shown promise for clinical use, especially during the initial stage of orthodontic treatment.

BioMers Products recently introduced a polymer resin archwire that is reinforced with glass fibers (Fig 1). This wire's mechanical properties are available from the manufacturer. Based on these properties the manufacturer claims “the performance is equivalent to nickel titanium (Ni-Ti).” A PubMed search found no independent studies comparing the properties of this archwire with Ni-Ti. The objective of this independent study was to characterize the bending properties of this FRC archwire.

METHODS

All wires were tested in as-received condition and are listed in Table 1. The only two commercially available translucent FRC orthodontic wires were selected for study. The wires are both 0.018-inch diameter but are of differing stiffness. The low force wire is known as Translucent Archwire I, and the intermediate force wire is Translucent Archwire II (BioMers Products). For comparison, 0.014-inch, 0.016-inch, and 0.018-inch nonsuperelastic or martensitic-stabilized Ni-Ti wires (3M Unitek) were tested. These comparison wires were selected based on the manufacturer's claim that Translucent Archwire I has a stiffness similar to 0.016-inch Ni-Ti and Translucent Archwire II has a stiffness similar to 0.018-inch Ni-Ti.
From each wire (n = 10 per group), one 25-mm segment was sectioned from the distal end to allow testing on a relatively linear section. The wires were evaluated with three-point bending to determine their bending force and deflection properties. ADA Specification no. 32 was used as a guide, with the exception that the distance between bottom supports was increased from 12 to 14 mm because of a limitation with the fixture design causing impingement of the top and bottom supports when a distance of 12 mm was used. Other studies have also used a similar bottom support distance. Wire segments were deflected at midspan to 3.1 mm at a rate of 2 mm/min using a universal testing machine (Instron) with the force continuously monitored during loading and unloading (Fig 2). Measurements for all wires were conducted in air at 37±1°C.

Loading and unloading slope and modulus were calculated from the activation and deactivation curves, respectively. Additionally, the force values at 1.0, 2.0, and 3.0 mm during activation and deactivation were also compared, as was the elastic recovery. The data were analyzed with SPSS 17.0 (IBM) using analysis of variance (ANOVA) and a post hoc Tukey test (α = .05) when indicated.

RESULTS

Figure 3 is a typical illustration of the force vs deflection curves of the five wires tested. For each wire during activation, force increases linearly up to approximately 1 mm of deflection and then gradually lessens in slope with greater deflections. During deactivation, force decreases with less deflection until it approaches zero at the original point of activation. The deactivation curve does not follow the activation curve. The force at any deflection during activation is higher than the corresponding force during deactivation. The hysteresis

<table>
<thead>
<tr>
<th>Archwire</th>
<th>Force</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.018-inch Translucent Archwire I</td>
<td>Low</td>
<td>Maxillary arch form, BioMers Products</td>
</tr>
<tr>
<td>0.018-inch Translucent Archwire II</td>
<td>Intermediate</td>
<td>Maxillary arch form, BioMers Products</td>
</tr>
<tr>
<td>0.014-inch Ni-Ti</td>
<td>Low</td>
<td>Orthoform II maxillary arch form, 3M Unitek</td>
</tr>
<tr>
<td>0.016-inch Ni-Ti</td>
<td>Intermediate</td>
<td>Orthoform II maxillary arch form, 3M Unitek</td>
</tr>
<tr>
<td>0.018-inch Ni-Ti</td>
<td>High</td>
<td>Orthoform II maxillary arch form, 3M Unitek</td>
</tr>
</tbody>
</table>

Fig 1 Comparison of FRC and Ni-Ti archwires. Note the contrast in appearance.

Fig 2 Equipment used to execute the three-point bending test.
The loop seen for each wire is a reflection of the nonreversible nature of the force deflection characteristics of each wire. All wires were able to withstand substantial deflection without breakage.

Various parameters related to the bending characteristics of each wire were calculated from data presented in Fig 3 and shown in Tables 2 and 3. It is apparent from these tables that the values related to these parameters are different for different wires. The slopes of the activation and deactivation curves along with the force values at 1, 2, and 3 mm followed the same pattern of

**Table 2  Bending values during activation**

<table>
<thead>
<tr>
<th>Archwire</th>
<th>Activation</th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Slope (g/mm)</td>
<td>Modulus (GPa)</td>
<td>Force at 1 mm (g)</td>
<td>Force at 2 mm (g)</td>
<td>Force at 3 mm (g)</td>
</tr>
<tr>
<td>0.018-inch Translucent Archwire I</td>
<td>117 ± 10C</td>
<td>30.5 ± 2.6D</td>
<td>115 ± 10C</td>
<td>210 ± 19C</td>
<td>245 ± 21C</td>
</tr>
<tr>
<td>0.018-inch Translucent Archwire II</td>
<td>155 ± 1B</td>
<td>40.5 ± 4.2C</td>
<td>152 ± 16B</td>
<td>279 ± 29B</td>
<td>323 ± 31B</td>
</tr>
<tr>
<td>0.014-inch Ni-Ti</td>
<td>77 ± 1D</td>
<td>54.7 ± 0.8B</td>
<td>76 ± 1D</td>
<td>141 ± 2D</td>
<td>163 ± 2D</td>
</tr>
<tr>
<td>0.016-inch Ni-Ti</td>
<td>144 ± 2B</td>
<td>60.3 ± 0.9A</td>
<td>142 ± 2B</td>
<td>267 ± 5B</td>
<td>321 ± 6B</td>
</tr>
<tr>
<td>0.018-inch Ni-Ti</td>
<td>217 ± 2A</td>
<td>56.8 ± 0.5B</td>
<td>213 ± 2A</td>
<td>389 ± 6A</td>
<td>489 ± 11A</td>
</tr>
</tbody>
</table>

Within each parameter, different letters denote significant differences (*P* < .05) between the wires.

**Table 3  Bending values during deactivation and elastic recovery**

<table>
<thead>
<tr>
<th>Archwire</th>
<th>Deactivation</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Slope (g/mm)</td>
<td>Modulus (GPa)</td>
<td>Force at 3 mm (g)</td>
<td>Force at 2 mm (g)</td>
<td>Force at 1 mm (g)</td>
<td>Elastic recovery (%)</td>
</tr>
<tr>
<td>0.018-inch Translucent Archwire I</td>
<td>104 ± 9C</td>
<td>27.3 ± 2.3D</td>
<td>226 ± 18C</td>
<td>178 ± 15C</td>
<td>99 ± 9C</td>
<td>99.2 ± 0.6AB</td>
</tr>
<tr>
<td>0.018-inch Translucent Archwire II</td>
<td>135 ± 24B</td>
<td>35.1 ± 6.2C</td>
<td>296 ± 36B</td>
<td>231 ± 37B</td>
<td>128 ± 24B</td>
<td>99.1 ± 1.0B</td>
</tr>
<tr>
<td>0.014-inch Ni-Ti</td>
<td>68 ± 2D</td>
<td>48.7 ± 1.6B</td>
<td>142 ± 2D</td>
<td>109 ± 3D</td>
<td>67 ± 2D</td>
<td>99.9 ± 0.2A</td>
</tr>
<tr>
<td>0.016-inch Ni-Ti</td>
<td>133 ± 2B</td>
<td>55.6 ± 0.9A</td>
<td>300 ± 4B</td>
<td>209 ± 3B</td>
<td>127 ± 1B</td>
<td>99.8 ± 0.3A</td>
</tr>
<tr>
<td>0.018-inch Ni-Ti</td>
<td>192 ± 4A</td>
<td>50.3 ± 1.0B</td>
<td>464 ± 11A</td>
<td>301 ± 7A</td>
<td>181 ± 2A</td>
<td>99.3 ± 0.4AB</td>
</tr>
</tbody>
</table>

Within each parameter, different letters denote significant differences (*P* < .05) between the wires.
0.018-inch Ni-Ti > Translucent Archwire II and 0.016-inch Ni-Ti > Translucent Archwire I > 0.014-inch (P < .05). For activation and deactivation modulus, the pattern was 0.016-inch Ni-Ti > 0.018-inch Ni-Ti and 0.014-inch Ni-Ti > Translucent Archwire II > Translucent Archwire I (P < .05). Note that this ranking is different from that seen when ranking slope and force values. Elastic recovery was greater than 99.0% for all five wires. Thus, the amount of permanent deformation was less than 1%. The wires returned to essentially their original shape despite the substantial deflection.

DISCUSSION

The results obtained in this study are in general agreement with the data provided by the manufacturer in that the BioMers, fiber-reinforced composite wires, deliver forces within the range of that available with Ni-Ti, a material with a long history of performance. A caveat, however, is that for wires of the same dimension, the FRC wires are less stiff and delivered less force for a given deflection compared with martensitic-stabilized Ni-Ti. For instance, the 0.018-inch Translucent Archwire II archwire delivered less force than the 0.018-inch Ni-Ti, but it was statistically equivalent to the 0.016-inch Ni-Ti wire. The 0.018-inch Translucent Archwire I provided forces between that of 0.016-inch Ni-Ti and 0.014-inch Ni-Ti. Thus, simply substituting an FRC wire for a Ni-Ti of the same size would result in lower force values. This is not surprising given the greater flexural modulus values for Ni-Ti compared with FRC (see Tables 2 and 3). Flexural modulus is a material property, whereas the other bending parameters listed (force and slope) will depend upon both the material and size of the wire. The small differences among the modulus values for Ni-Ti wires of different dimensions may be attributed to variations in the manufacturing process (degree of cold-working, etc) to obtain a given size. It is also obvious from the modulus values that Translucent Archwires I and II do indeed differ in flexural modulus, which explains their different bending values. Although proprietary information, variations in the quantity and/or length of the fibers used for reinforcing the polymer matrix may be responsible for the different modulus values.

The manufacturer’s packaging includes information concerning indications and precautions for use of the FRC archwires. It recommends the use of these FRC archwires for only leveling and aligning. Because of the archwires’ composition, the manufacturer advises against the use of serrated or sharp-edged instruments, as well as deflecting the wire beyond an angle of 60 degrees. When deflected beyond the wire’s limits, the manufacturer states that crazing or whitening of the wire will be seen. When cutting these wires, a loss of translucency occurs in the area of the cut. To the naked eye, the wire appears to be cut cleanly, but some raggedness is observed microscopically. The wire is “not recommended for brackets with metal slots and certain self-ligating brackets.” The wire is preformed and cannot be bent into shape, nor can the wire withstand the placement of loops or bends.

Whether the clinical performance of the BioMers’ FRC archwires is equivalent to the Ni-Ti archwires cannot be ascertained from the results of the present study. The mechanical properties of the wires are dependent on the nature of the materials as well as on the environment in which they are tested. In the present study, the properties were evaluated in air, which is quite different from the aqueous oral environment in which they function. Considering the nature of the two materials—one metallic and the other polymeric—there is reason to believe that the two materials will behave differently in an aqueous environment. To clarify, Ni-Ti is a fairly corrosive resistant material; it would stand to reason that its deflection properties would not be adversely affected in a simu-
lated oral environment.\textsuperscript{21} The FRC, on the other hand, may be susceptible to degradation resulting from water sorption and the hydrolysis of the fiber-resin interface. An evaluation of the FRC archwires in a medium similar to the oral environment must be carried out before recommending its clinical use. Such a study is in progress in our laboratory.

CONCLUSION

In this study, it was found that the bending properties of BioMer’s FRC archwires are comparable with Ni-Ti archwires, as advertised by the manufacturer.

ACKNOWLEDGMENTS

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REFERENCES