Effect of Esthetic Coating on the Load Deflection and Surface Characteristics of the NiTi Orthodontic Archwires

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The aim of the present study was to evaluate and to compare the mechanical properties and force levels of as-received and retrieved coated and regular NiTi archwires. The surface characteristics and coating stability after intraoral exposure were also analyzed. Twenty regular (Lowland NiTi) and twenty epoxy coated (Spectra Aesthetic NiTi) NiTi wires of the same shape and dimension, around 0.016 inch, from a single manufacturer (GAC Company) were investigated. Ten as received regular and ten coated wires were subject to tensile tests and three point bending tests. Twenty archwires, from the same type and diameter were used in vivo for a period of 4-6 weeks and then subject to the same testing protocol. Optical and scanning electron microscopes were used to assess surface topography of the wires. Compared with the as received regular wire, the as received coated archwires showed highly significant differences for the ultimate tensile strength (p=0.001) and modulus of elasticity (p=0.017). The yield strength also showed lower values, but these are not statistically significant. There were no differences between as received and retrieved archwires of the same type. Significantly lower loading and unloading forces were obtained for the coated archwires compared with the as received regular wires. SEM images of the as received coated NiTi wires showed small delamination and irregularities of the coating over some points. The retrieved coated wires have an inhomogeneous surface with more irregularities and loss of surface materials. The as received regular NiTi wires surface exhibited specific irregularities due to the manufacture process, while the retrieved wires had corrosion signs with numerous pitting and cracks patterns.

Key words: surface characteristics, esthetic archwires, nickel-titanium (NiTi)

Tooth movement for achieving dental alignment and functional occlusion is clinically obtained through the application of orthodontic forces developed by a system composed by archwires and brackets [1]. The esthetic appearance of the archwire-bracket system is rated by patients, especially adults, as a significant factor [2]. While the introduction of transparent ceramic and composite brackets partially solved the problem, the archwires are still made of metals such as nickel-titanium, stainless steel or beta titanium [3]. Coating technology for metallic archwires based on plastic resin materials has been recently developed and it is intended for improving esthetics. The materials used in the coating process are teflon™ and epoxy resin [3,4].

From a chemical point of view, the teflon is a polytetrafluoroethylene, applied on the wire surface using clean compressed air as a transport medium. The wires are then heat treated in a chamber furnace [5]. The epoxy resins, also known as polyepoxides are a class of reactive prepolymers and polymers which contain epoxide groups. Epoxies have excellent adhesion, chemical and heat resistance, good-to-excellent mechanical properties and very good electrical insulating properties [3].

Little information is available in the orthodontic literature regarding the mechanical properties and surface characteristics of the coated archwires after intraoral use. Although, some authors found the coating undurable [4], the same plastic coating decrease friction between archwires and brackets, according to Hussman [5]. Other authors have also observed disadvantages of these archwires, claiming that the coating splits during use in the mouth and it tends to change colour with time [6-8].

The mechanical properties of an orthodontic archwire evaluated by tensile and bending tests are a very good indicator of the wires clinical performances. Hence, from a biomechanical point of view, the biologic nature of tooth movement might be predicted by the load-deflection curves and the stress-strain diagrams of an orthodontic archwires [7]. At the same time, the surface quality of the archwires influences the corrosion behaviour, the plaque retention and biocompatibility [9]. The friction coefficient could also be increased by the surface roughness of the archwire [8].

The aim of the present study was to evaluate and to compare the mechanical properties and force levels of as-received and retrieved coated and regular NiTi archwires. The surface characteristics and coating stability after intraoral exposure were also analyzed.

Experimental part
Materials and methods

Twenty regular (Lowland NiTi) and twenty epoxy coated (Spectra Aesthetic NiTi) NiTi wires of the same shape and dimension around 0.016 inch from a single manufacturer were purchased. Ten archwires of each type were used...
during fixed orthodontic treatment of 10 patients. The inclusion criteria of the patients were:
- good general medical status (no medication or diseases interfering with normal salivary secretion);
- similar age;
- similar malocclusions, no extractions or congenitally missing teeth;
- upper and lower fixed appliance inserted.

The archwires were used intraorally from 4 to 6 weeks and ligated with elastomeric ligatures. Retrieval protocol of the archwires included: rinsing with distilled water to remove any precipitations and placing the archwires in a self-closed plastic bag. The bags were labelled, recording the date of placement and retrieval, name of patient and type of archwire.

The wires were subject to tensile and bending tests. The distal straight segments of each preformed arches were tested.

An Instron Universal Testing Machine type 3366, 10kN was used to perform the tests. The measured values were recorded for each specimen by the testing machine software InstronBluehill 2. The collected data was exported in spreadsheet file format (Microsoft Excel).

Tensile stress at yield (0.2%), tensile stress at maximum load and modulus of elasticity were determined using a standard tensile test for each group of the wire. Five wires were tested individually. The span of the wire between crossheads was 40 mm and the crosshead speed of the machine was set to 1 mm/min for all tests. The load-displacement data obtained from the tensile test were used to get the stress-strain diagrams.

The retrieved coated NiTi wires could not be subject to tensile stress due to technical difficulties. During the test, the coating of the wires tend to exfoliate and the wires slipped from the jaws of the machine. The as received coated wires have a distal, uncoated portion, which offers necessary retention during tensile testing.

In order to determine the load-deflection characteristics of the wires, each specimen was subject to a three-point bending test (Miura et al. modified by Krishnan and Kumar [10]). The specimens were ligated with elastomeric ligatures in the slots of four edgewise brackets (3B STD Edgewise). These brackets were glued to an aluminum base, such a way that a 14 mm span was created between the internal sides of two adjacent brackets. The base was attached to the lower jaw of the machine. A metal blade, with a curvature of 1 mm of its extremity, was fixed to the upper jaw of the machine, to deflect the mid portion of each sample. Each Ni-Ti wire was deflected 4 mm, at a deflection speed of 1 mm/min and then returned to its starting point at the same speed. The loading forces were reported at 2 and 4 mm and unloading forces at 2 mm.

All the data obtained from the 2 tests described above were statistically analyzed. Descriptive analysis was made to determine the mean and standard deviation values. Student t test was performed in order to compare the results. Statistically significant differences (p<.05) were evaluated for all measurements. Statistical analysis was performed using Microsoft Excel.

Four regular and four coated archwires (4 as received and 4 retrieved) were randomly selected and subject to microscopy analysis (Olympus GX 51 and Quanta 3D FEI). Surface morphology of each wire was studied.

### Results and discussions

#### Tensile test

The results of the tensile test for both as received and retrieved regular and coated wires are shown in table 1. It can be seen (table2) that, compared with the as received regular wire, the as received coated archwires have registered lower values for all the three properties, and the differences were highly significant for the ultimate tensile strength (p=0.001) and modulus of elasticity (p= 0.017). The yield strength also showed lower values, but these were not statistically significant.

In table 3 the yield strength, ultimate tensile strength and modulus of elasticity for the as received and retrieved regular archwires are compared. Although the exhibited values (excepting the yield strength) are lower, the differences are not statistically significant.

#### Bending test

The loading and unloading forces of the tested wires are shown in table 4.

There were no differences between as received and retrieved archwires of the same type. Significantly lower loading and unloading forces were obtained for the coated archwires compared with the as received regular wires. Moreover, the value of coated wires unloading force was very close to 0. Examination of the set-up after bending test of the coated archwires showed that the archwires did not slide back through the ligated brackets, the archwire remained bended, although the load was released (fig. 1).

### Table 1

VALUES OBTAINED THROUGH TENSILE TESTING OF THE REGULAR AND COATED AS RECEIVED AND COATED ARCHWIRES

<table>
<thead>
<tr>
<th>Archwire material / Mechanical property</th>
<th>Regular Ni-Ti Mean value (Std. dev.)</th>
<th>Coated NiTi Mean value (Std. dev.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield Stress [MPa]</td>
<td>646.19 (32.6)</td>
<td>463.7 (360.4)</td>
</tr>
<tr>
<td>Ultimate Tensile Stress [MPa]</td>
<td>1257.3 (25.3)</td>
<td>649.9 (98.0)</td>
</tr>
<tr>
<td>Modulus of elasticity [MPa]</td>
<td>30187 (1932)</td>
<td>23291 (2410)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mechanical property</th>
<th>Coated-NiTi</th>
<th>NiTi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield Strength</td>
<td>463.74±360.49</td>
<td>0.016</td>
</tr>
<tr>
<td>Ultimate tensile strength</td>
<td>1257.3±25.34</td>
<td>0.0015</td>
</tr>
<tr>
<td>E-modulus</td>
<td>30187±1932.17</td>
<td>0.0176</td>
</tr>
</tbody>
</table>

### Table 2

COMPARISON OF THE MECHANICAL PROPERTIES OF THE COATED AND REGULAR NiTi Wires

<table>
<thead>
<tr>
<th>Mechanical property</th>
<th>Niti as received</th>
<th>NiTi retrieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield Strength</td>
<td>646.19±532.69</td>
<td>976.99±470.52</td>
</tr>
<tr>
<td>Ultimate tensile strength</td>
<td>1257.3±25.34</td>
<td>1210.9±470.15</td>
</tr>
<tr>
<td>E-modulus</td>
<td>30187±1932.17</td>
<td>27069±2410.53</td>
</tr>
</tbody>
</table>

### Table 3

COMPARISON OF THE MECHANICAL PROPERTIES OF AS RECEIVED AND RETRIEVED REGULAR NiTi Wires
Microscopic analysis

Figure 2-5 represents the microscopic images of both as received and retrieved archwires. The SEM images of the same wire types are shown in figure 6-9. SEM images of the as received coated NiTi wires show small delamination and irregularities of the coating over some points. The retrieved coated wires have an inhomogeneous surface with more irregularities and loss of surface materials. The light microscope images confirm the anterior aspects.

The as received regular NiTi wires surface exhibited specific irregularities due to the manufacture process. The retrieved wires had corrosion signs with numerous pitting patterns and cracks.

A comprehensive knowledge of orthodontic archwires allows the orthodontist to make an informed and better choice, on the basis of biomechanical requirement of the clinical situation. The mechanical properties of regular NiTi archwires were intensively studied in numerous works [2,5, 9-19], although the great majority of the authors focused their attention on the characteristics of the as received wires. Eliades et al [8] emphasized the importance of the retrieval studies, as the complex conditions present in the oral cavity, including plaque accumulation and biofilm formation alter the surface properties and structural conformation of the archwires.

The tensile tests offer information about the yield strength, ultimate tensile strength and elastic modulus of a wire [7]. In our study, these parameters showed lower values for the coated archwires, compared with the regular ones. A possible explanation could be the decreased size of the NiTi wires occupying the inner core of the coated wires [20].

No significant differences were recorded between the as received and retrieved regular archwires, regarding the tensile properties, showing that a mean one month intraoral exposure could not relevantly affect the yield strength, ultimate tensile strength or elastic modulus. However, corrosion signs were found on the surface topography of the retrieved wires, while the as received wires exhibited numerous irregularities, specific to the manufacture process.

Eliades et al. [8] stated that the retrieved NiTi wires are coated by intra-orally formed proteinaceous integuments. The intraoral exposure period and the individual oral circumstances of the patients determine the extent of that specific coating. Crevice and pitting corrosion pattern has also been documented on NiTi wires in vitro [21], although no effects on physical and mechanical properties of the wires have been identified [8].

In the present study, the load deflection characteristics of the wires were evaluated by means of the three point bending test. The three-point bending test has numerous advantages: it simulates application of wire pressure on the teeth in the oral cavity, differentiate wires with superelastic properties and offers reproducible results [10]. From the load-deflection diagram, produced by the three-point bending test, loading and unloading force values can be determined. While, the clinical importance of the loading forces is reduced (it represents the force needed to engage the wire to the brackets), the unloading forces represents the forces delivered to the periodontal structures [20]. The esthetic coated archwires produced lower forces than the regular wires, in both loading and unloading at 4 mm deflection. In fact, the unloading forces of the coated wires were very close to 0 (0.09 for as received and 0.10 for retrieved specimens). This indicates that efficiency of the coated wires to generate tooth movement is reduced. Furthermore, the deflected specimens were unable to slide back after the load was released. This could be due to the increased friction between the archwire-bracket system.

Our results are in accordance with the results of Elavyan’s study [21] regarding the coated NiTi wires with conventional and self-ligating bracket system. Kaphor[20]
also observed lower force values of the coated archwires from 4 different manufacturers.

Literature findings stated that the surface treatment in aesthetic wires contributes to a reduction in the frictional properties of the archwires [17-19,23]. Moreover, the best results were reported for Teflon coated wires [23]. After intraoral use, the surface modified wires become rougher with time, the plaque accumulation and colour instability being encouraged by this rough surface [8,17]. In our study, SEM images of the retrieved coated archwires revealed variable amounts of deterioration. The coating remained intact in some areas, while in others delamination and discoloured were observed. Hence, esthetic value of the archwires are clearly affected.

Conclusions
As received coated archwires have significantly lower values of ultimate tensile strength and modulus of elasticity when compared to the as received regular NiTi wires.

Surface corrosion signs of the retrieved regular NiTi archwires were observed.
The esthetic coating of the archwires suffered variable amounts of deterioration.
Both as received and retrieved coated archwires produced significantly lower unloading force values than regular NiTi archwires.

References

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