Surface Roughness and Topography of Four Commonly Used Types of Orthodontic Archwire

Jian-Hong Yu, Li-Chun Wu, Jui-Ting Hsu, Yin-Yu Chang, Her-Hsiung Huang, Heng-Li Huang

Abstract

The surface characteristics, such as topography, roughness, and hardness, of orthodontic archwires are important determinants of the effectiveness of archwire-guided tooth movement. They also affect the corrosion potential and the aesthetics of orthodontic components. This study uses a surface profilometer and a hardness tester to evaluate the surface roughness and hardness of four commonly used types of orthodontic archwire: (1) stainless steel (SS) wire, (2) conventional nickel-titanium (NiTi) alloy wire, (3) improved superelastic NiTi-alloy wire (also called low-hysteresis (LH) wire), and (4) titanium molybdenum alloy (TMA) wire. In addition, the surface topography of the four types of archwire is obtained using scanning electron microscopy (SEM). SEM results show that the surface topography of the four types of archwire varies. LH wire and NiTi wire have similar surface topographies, which differ from those of SS wire and TMA wire. SS wire has the smoothest surface (roughness of 0.051 ± 0.023 μm, mean ± SD), followed by TMA wire (0.206 ± 0.007 μm), NiTi wire (0.627 ± 0.072 μm), and LH wire (0.724 ± 0.117 μm). In addition, SS wire has the hardest surface (hardness of 405.4 ± 9.9 kg/mm²), followed by TMA wire (303.3 ± 13.2 kg/mm²), LH wire (215.1 ± 48.5 kg/mm²), and NiTi wire (195.4 ± 17.2 kg/mm²). NiTi wire and LH wire have similar surface topographies, surface roughnesses, and hardnesses. It might therefore be unnecessary for orthodontists to substitute NiTi wires with LH wires.

Keywords: Orthodontic archwires, Surface roughness, Surface topography, Surface hardness

1. Introduction

Tooth movement associated with sliding mechanics occurs as a series of steps involving tooth tipping and uprighting [1-3]. This movement can be resisted by frictional forces between an archwire and brackets. The surface properties, such as roughness, hardness, and topography of orthodontic archwires may affect the sliding mechanics by influencing the coefficient of friction. Surface properties also determine the aesthetics of dental products as well as corrosion potential and biocompatibility.

Stainless steel (SS) archwire is one of the most widely used materials in orthodontics; however, nickel-titanium (NiTi) archwire and titanium molybdenum alloy (TMA) archwire are becoming increasingly popular. Studies have demonstrated that NiTi wire has high spring-back and low friction [4-6], and that TMA wire has low stiffness and high formability [7]. Recently developed superelastic NiTi-alloy wire, also called low-hysteresis (LH) wire, delivers more stable orthodontic forces in an oral environment [8-11]. However, few studies have been conducted on the surface properties of LH archwire.

This study evaluated and compared the surface roughness, hardness, and topography of the four commonly used types of orthodontic archwire (SS, NiTi, TMA, and LH wires).

2. Materials and methods

2.1 Specimen preparation

The following four types of archwire were tested in this study: SS wire (Sin-Yean, Taipei, Taiwan), conventional NiTi wire (Tomy International, Tokyo, Japan), TMA wire (Ormco, Orange, CA, USA), and LH wire (Tomy International, Tokyo, Japan). All the archwires had the same cross-sectional dimensions (0.016 × 0.022 in).
2.2 Measurements of surface topography

High-resolution field-emission scanning electron microscopy (SEM, JSM-7000F; JEOL, Tokyo, Japan) was used to evaluate the surface topography of the samples. The surface was viewed on a monitor at 100× and 1000× magnifications.

2.3 Measurements of surface roughness

The arithmetic mean surface roughness, \( R_a \), of the four types of archwire was measured using a commercial profilometer (Surf-Corder SE-1200, Kosaka Laboratory Ltd., Tokyo, Japan). The scanning distance was 4.0 mm. Vertical movements were measured to an accuracy of ±0.01 μm. The instrument automatically determined the profilometric mean roughness from the surface profile. Eight profilometric scans were performed on different samples of each type of wire; the obtained data are presented as mean ± standard deviation (SD) values.

2.4 Measurements of surface hardness

The surface hardness of the four types of archwire was measured with a digital micro hardness tester (MXT70, Matsuzawa Seiki, Tokyo, Japan) by applying a 100-g force for 20 seconds. The hardness of each archwire was measured eight times. The surface roughness and hardness values of the four types of archwire were initially analyzed using one-way analysis of variance (ANOVA) and Tukey’s test with a 5% level of significance. All statistical analyses were performed using the SAS software package (SAS, Cary, NC, USA).

3. Results

3.1 Surface topography of archwires

The surface topography of the four types of archwire is shown in Fig. 1 (100×) and Fig. 2 (1000×). There are no obvious differences in the surface topographies of the four types of archwire at 100× magnification (Fig. 1).

At 1000× magnification, SS wire has the smoothest surface (Fig. 2a); however, even freshly prepared samples had an irregular surface finish. The surface topographies of NiTi wire and LH wire exhibited a fibrous surface finish (Figs. 2b and 2c). The surface topography of TMA wire differed markedly from those of the other three types of archwire, exhibiting irregular cavities (Fig. 2d).

Figure 2. SEM micrographs of orthodontic archwires at 1000× magnification.

3.2 Surface roughness of archwires

The surface roughness (\( R_a \)) values for LH wire (0.724 ± 0.117 μm) and NiTi wire (0.627 ± 0.072 μm) were much higher than those for TMA wire (0.206 ± 0.007 μm) and SS wire (0.051 ± 0.023 μm) (Table 1). Tukey’s test results show that the roughness does not significantly differ between LH wire and NiTi wire. Figure 3 shows examples of profilometric scans of the four types of archwire, which reflect the typical surface structure of these wires. SS wire, which was the smoothest in this study, had a roughness with a short wavelength and small amplitude. NiTi wire and LH wire exhibited similar, square-wave-like profilometric scans, but those for LH wire exhibited a higher amplitude roughness.

### Table 1. Surface roughness and surface hardness of four types of orthodontic archwire.

<table>
<thead>
<tr>
<th>Archwire type</th>
<th>Surface roughness (( R_a )) (μm)</th>
<th>Hardness (kg/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
</tr>
<tr>
<td>SS</td>
<td>0.051 ± 0.023</td>
<td>405.4 ± 9.9</td>
</tr>
<tr>
<td>NiTi</td>
<td>0.627 ± 0.072</td>
<td>195.4 ± 17.2</td>
</tr>
<tr>
<td>LH</td>
<td>0.724 ± 0.117</td>
<td>215.1 ± 48.5</td>
</tr>
<tr>
<td>TMA</td>
<td>0.206 ± 0.007</td>
<td>303.3 ± 13.2</td>
</tr>
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</table>

3.3 Surface hardness of archwires

The hardness of SS wire was 405.4 ± 9.9 kg/mm² (mean ± SD), making it 2.07, 1.9, and 1.3 times harder than LH, NiTi, and TMA archwires, respectively (195.4 ± 17.2, 215.1 ± 48.5, and 303.3 ± 13.2 kg/mm², respectively) (Table 1). Tukey’s test results show that the hardness does not significantly differ between LH wire and NiTi wire.
4. Discussion

Evaluating the surface of an orthodontic archwire is important due to its influence on the working characteristics and corrosion potential. The conventional gold standard for sliding mechanics has generally been a combination of SS archwire and brackets. SS wire is often used as the reference material in comparisons of the characteristics of other metal types of orthodontic archwire [7]. Besides SS wire, NiTi-alloy and TMA wires are commonly used in clinical trials. However, these two types of archwire have some disadvantages, such as their high spring-back gradually decreasing during the unloading process [12]. LH wire, which delivers more stable orthodontic forces in an oral environment, has recently been developed [8-11]. However, the surface characteristics of LH wire remain unclear. This study therefore evaluated the surface roughness and topography of LH archwire, and compared them with those of the three commonly used types of archwire.

In this study, the surface roughness of NiTi wire was significantly higher than that of TMA wire. SS wire had the lowest surface roughness. These results are consistent with the experimental results of Bourauel et al. [13]. The LH wire used in the present study was developed from conventional NiTi-alloy wire via double heat treatment. It has a damping capacity that buffers force transmission to the periodontal ligament, thereby lessening patient discomfort [8]. Therefore, the similarity in surface roughness between LH wire and NiTi wire is mostly due to their similar compositions. SEM images indicate that these two wire types have similar surface topographies.

The hardness of the archwire affects the degree of wear [14]. In the present study, SS wire had the hardest surface, followed by TMA wire, NiTi wire, and LH wire. This order is inconsistent with the experimental results of Hunt et al. [14], who reported that TMA wire was softer than NiTi wire. This discrepancy might be due to the use of different types of NiTi archwire in the two studies. The hardness of TMA wire measured in this study (303.3 ± 13.2 kg/mm²) is similar to that measured by Hunt et al. (354.9 ± 6.5 kg/mm²), but the hardness of NiTi wire measured in this study (195.4 ± 17.2 kg/mm²) is only around 43% of that measured by Hunt et al. (446.7 ± 22.0 kg/mm²). The TMA wires used in the two studies were obtained from the same company, whereas the NiTi wires were obtained from different companies.

SEM evaluation of the surface characteristics reveals that SS wire had a smooth surface with little irregularity and horizontal wire drawing lines that were probably due to the drawing process during manufacture. In contrast to SS wire, TMA wire had a large number of uniformly distributed pores and exhibited a rough surface, as reported extensively in the literature [15,16].

The surface roughness results and the studies on frictional forces between archwires of various types and brackets suggest complex interactions. The frictional force is higher for TMA wire than for SS and NiTi wires [17-20], which can be attributed to a “cold-welding” feature of TMA wire leading to a repeated stick-slip movement of the bracket relative to the archwire [21]. However, the present study found that the surface roughness of TMA wire was only around one-third those of NiTi wire and LH wire, which indicates that the frictional force between the bracket and archwire cannot directly be predicted from the surface roughness of the archwire.

This study was subject to some limitations. The surface roughness was determined using surface profilometry, in which the topography is scanned along a single line of a preselected area. One of its disadvantages is that surface defects adjacent to the scanning line are not detected and hence do not contribute to the overall measured surface roughness. Although SEM images can show the surface topography, quantifying the actual two-dimensional surface roughness was not possible in this study. Therefore, future studies should use atomic force microscopy or laser specular reflectance to quantify the two-dimensional surface roughness. However, some previous studies [13,22] have demonstrated that profilometry is a useful method for measuring surface roughness.

5. Conclusions

The topography, roughness, and hardness of four types of orthodontic archwire were measured. Experimental results show that NiTi wire and LH wire exhibited similar surface topographies (as assessed using SEM), which differed from those of SS wire and TMA wire. The surface profilometer results indicate that SS wire had the smoothest surface, followed by TMA wire, NiTi wire, and LH wire. The SS wire had the hardest surface, followed by TMA wire, LH wire, and NiTi wire. NiTi wire and LH wire had similar surface topographies, surface roughnesses, and hardnesses. It might therefore be unnecessary for orthodontists to substitute NiTi wires with LH wires.
Acknowledgements

The authors thank Professors Che-Shoa Chang and Yuh-Yuan Shiau for their suggestions during this study.

References