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Original Article

Mechanical and frictional properties of aesthetic orthodontic wires obtained by hard chrome carbide plating

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KEYWORDS
orthodontic wires;
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Abstract *Background/purpose:* Although aesthetic wire coating has been increasing in demand, it has problems that changes in mechanical properties and increase in frictional force. The aim of this study was to evaluate the coating of the wire, as characterized by aesthetics, in terms of low and constant friction and mechanical properties.
Materials and methods: Hard chrome carbide-plated (HCCP) wires (HCCP group), commercially available polymer-coated wires (P group), rhodium-coated wires (R group), and uncoated wires (control group) were used. For all wire types, a stainless steel wire of dimensions 0.017 inch × 0.025 inch was used. They were evaluated by three-point bending, friction testing, surface observation, and colorimetric testing.
Results: The HCCP group was not significantly different from the control group in terms of flexural strength (σ) and flexural modulus (E) (σ: $p = 0.90$, E: $p = 0.35$). However, it was significantly inferior compared to the three other groups in terms of the maximum static and kinetic frictional forces under both dry and wet conditions ($p < 0.05$). In the surface observation, scratches were observed on the wire after the friction test. In the colorimetric test, no significant difference was observed between the HCCP group and the R group ($p > 0.05$).
Conclusion: The mechanical properties of the HCCP wire were not significantly different compared to the control group. The frictional force of the HCCP wire was significantly lower than the other group. Therefore, the HCCP wire was suggested to increase the efficiency of tooth movement in clinics.
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Introduction

The use of aesthetic wires has increased in orthodontic treatment because of the increased number of patients who require good aesthetics as a prerequisite of their treatment. Here, "good aesthetics" refers to wires matching the tooth color. In order to obtain better aesthetics, orthodontic wires of colors similar to tooth colors have been introduced. However, because of the coating on the wire surface, it is necessary to consider how the coating may influence the orthodontic treatment.

Several problems involving the coatings of these coated wires have been identified. Kim and Cha reported that the friction coefficients of these coated wires are higher than those of uncoated wires.[1] Frictional forces between the brackets and the wire affect tooth movement. Reducing the coefficient of friction shortens the treatment period, reduces patient pain, and prevents anchorage loss.[2–6]

It has been reported that the mechanical properties of some coated wires were significantly worse than those of uncoated wires.[7] Deterioration in the physical properties of the wire adversely affects the orthodontic treatment. The load–deflection characteristics determine the nature of the wire and affect tooth movement. Deterioration of the mechanical properties of the wire also negatively affects the orthodontic treatment. When wires are subjected to deflection, the load–deflection properties determine the nature of tooth movement. These properties of the wire may be altered upon coating, because the diameter of the wire must be smaller than that of uncoated wires to compensate for the coating thickness.[8]

Some research has suggested that using surface treatments could reduce the friction between the brackets and the wire.[9–11] Diamond-like carbon (DLC) is one coating that can reduce the frictional force between brackets and wire. However, the color of the DLC coating is black. Hard chrome carbide plating (HCCP) has been introduced in industrial applications because it offers properties like low friction, chemical inertness, high surface hardness, high wear resistance, and thin coating.[12]

The ionization potential of Cr is between those of Zn and Fe; Cr has basic properties compared to Ni, Sn, Pb, and Cu. Thus, Cr can easily form oxides in the atmosphere, depositing a dense oxide film primarily composed of Cr_2O_3 on the metal surface. Because the solubility of the oxide film is very low in the aqueous phase (pH 7), the chrome interior is protected and the metallic luster is maintained. When the metal Cr surface slides on other materials, the Cr_2O_3 of the coating surface becomes slightly worn. The wear particles act as a lubricant, making Cr a low-friction material.[13] The aim of this study is to achieve the following objectives using HCCP processing of the wire: 1. good aesthetics, 2. immutable physical characteristics, and 3. low friction. Here, "immutable physical characteristics" means that the aesthetic wire does not differ in mechanical strength (flexural strength, flexural modulus) compared with the uncoated wire. Low friction means that the aesthetic wire has low friction as compared to the uncoated wire.

Materials and methods

Materials preparation

The base material of HCCP was a stainless steel wire of dimensions 0.017 inch (0.432 mm) × 0.025 inch (0.635 mm) (Stainless steel wire®, CDB corporation, U.S.A.), which was subjected to electroplating. The metal was used as the cathode and the material for plating was used as the anode. For the plating bath, 250 g/L chromic anhydride was used (Fig. 1). First, the wire for HCCP was degreased to remove surface filth. Next, the wire was mounted on the jig. After anodic oxidation, electrodeposition of Cr is performed for 10 min. After electrodeposition, the hydrogen is removed and the wire is polished. A detailed description of the plating procedure was reported by Amifune and Fujiwara.[14] For comparison, we obtained three commercial orthodontic wires from the market.

Uncoated wires (VIM STAINLESS STEEL Wire®, ACME MONACO, U.S.A.) were used as the control group. As experimental groups, polymer-coated wires comprising epoxy resin (micro-coated stainless steel wire®, G&H Wire Company, U.S.A.), Rh-coated wires (White stainless wire®, Tomy International, Tokyo, Japan), and HCCP wires were used (Fig. 2a–d). Recently, various kinds of coatings have been developed; among these, polymer-coated and Rh-coated wires have been reported in various articles.[1,15–17] Thus, there were 4 groups: uncoated wires (control group); polymer-coated wires (P group); Rh-coated wires (R group); and HCCP wires (HCCP group) (Table 1).

Three-point bending test

The three-point bending test was performed using a universal testing machine (AG-100N, Shimadzu, Kyoto, Japan). The crosshead speed for loading was 1.0 mm/min with a span length of 16 mm (Fig. 3). The flexural strength (σ) was calculated using the equation

$$\sigma = 3FL/2bh^2, \quad (1)$$

where L, b, h, and F are the span size, wire width, wire thickness, and maximum load, respectively. The flexural modulus E was calculated using the equation

$$E = (L^3/4bh^3) \times (\Delta F/\Delta S), \quad (2)$$

where ΔF is the variation of load, ΔS is variation of flexure, L is the span length, b is the specimen width, h is

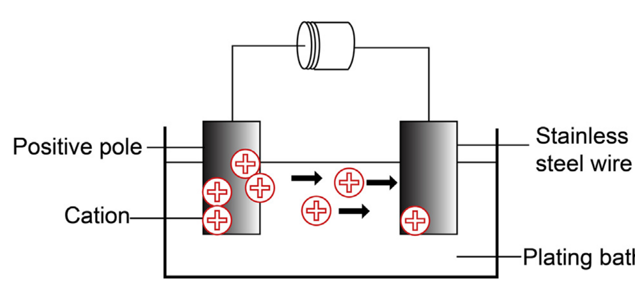

Figure 1 The electroplating method. The metal cations are attracted to the surface of the base material of the cathode.

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