

A Novel Method of Coating Orthodontic Archwires with Nanoparticles

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Abstract:

Background: The major hazard to the orthodontic tooth movement is the friction developing at the bracket wire interface. In the past, there have been various attempts to reduce this friction. We believe that coating the commercially available orthodontic wires with nanoparticles can result in a successful reduction of this friction. The objective of this study is to develop a novel method of coating orthodontic archwires with nanoparticles.

Materials and Methods: Stainless steel (Ormco, CA, USA), titanium molybdenum alloy (Ormco, CA, USA) and nickel-titanium (G and H Wire Company, USA) orthodontic wires with a rectangular cross-section dimension of 0.019"× 0.025", were selected. The wires were later coated with a uniform and smooth nanoparticle film using 100 ml nanocremsics. The coating procedure described in this article is a sol-gel thin film dip coating method.

Results: The coating procedure was verified by comparing the surface topography of nanocoated archwires with the commercially available archwires in an environmental scanning electron microscope (ESEM). The ESEM images prove that the surface topography of the coated wires was found to be smoother with less surface deteriorations as compared to the commercially available wires.

Conclusion: Commercially available orthodontic wires can be successfully coated using a novel method of sol-gel thin film dip coating method.

Key Words: Nanocremsics, nickel-titanium, stainless steel, titanium molybdenum alloy

Introduction

In the past few decades, a number of wire alloys with a wide spectrum of mechanical properties have been introduced, adding versatility to orthodontic treatment. Selecting the appropriate archwire requires a thorough knowledge of the

biomechanical properties of it. In the past, there have been attempts to improve the mechanical properties of orthodontic wires using different types of alloys and surface treatment of wires. These attempts were successful to some extent. Coating the orthodontic wires with nanoparticles is one such attempt that is still under research. In the current study, we shall discuss the novel method of coating orthodontic wires with nanoparticles.¹

The nanoparticle used in our study is nanocremsics (Figure 1a) which is commercially available nanoparticle coating precursor solution. This was the solution of choice in our study as it was readily available commercially in India. Secondly the laboratory procedure for coating of the same could be easily carried out in India. The nanocremsics solution coating procedure described here is the sol-gel thin film dip coating method. In order to evaluate the adherence of the coating on to the orthodontic wire, the coated orthodontic wires were analyzed by scanning electron microscope (SEM).^{1,2}

Materials and Methods

1. Commercially available straight length orthodontic wires of stainless steel (SS), nickel-titanium (NiTi) and titanium molybdenum alloy (TMA) were first cleaned under running water to discard any dust particles which will interfere with our coating procedure.
2. The orthodontic wires were inserted into the bathtub containing nanoparticle solution for 30 min (Figure 1b).
3. Later the wires were removed from the tub and kept in a hanger where they further painted with nanoparticle solution (Figure 1c).
4. The wires were then air dried with the help of drier for 2 min (Figure 1d).
5. The wire with the hanger was then placed in the hot air oven at 160°C for 3 min. In this way, the commercially available orthodontic wires were coated with nanoparticles (Figure 2a-c).

Results

The coated wires were analyzed by a SEM (Figure 3) to check for the surface topography.

SEM was used to assess the surface topography of the archwires. The SEM used for our study was based on the technology of environmental SEM (ESEM).

The ESEM gives us microscopic images of both wet and dry sample specimen. With the help of ESEM, we can examine the



Figure 1: (a) Nanocreemics – commercially available nanoparticle coating precursor solution. (b) Commercially available orthodontic wires inserted into the bathtub containing nanoparticle solution. (c) Wires kept in a hanger where they are further painted with nanoparticle solution. (d) Wires were then air dried with the help of drier.

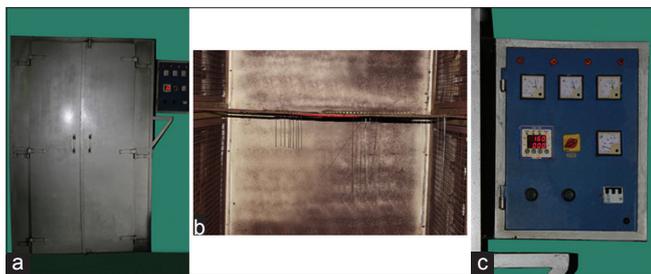


Figure 2: (a-c) The wire with the hanger were then placed in the hot air oven at 160°C.



Figure 3: Scanning electron microscope machine.

specimen in a faster and easy way. Another advantage of ESEM is that there is no need to modify the surface of the original specimen. In order to procure the ESEM images of coated and uncoated archwires; 20 mm length of straight archwires were taken. They were cleaned with distilled water to remove any precipitates. Later the specimen were mounted in a machine holder and observed under field-emission ESEM. The images were recorded at $\times 500$ magnification. Figure 4a-f shows SEM

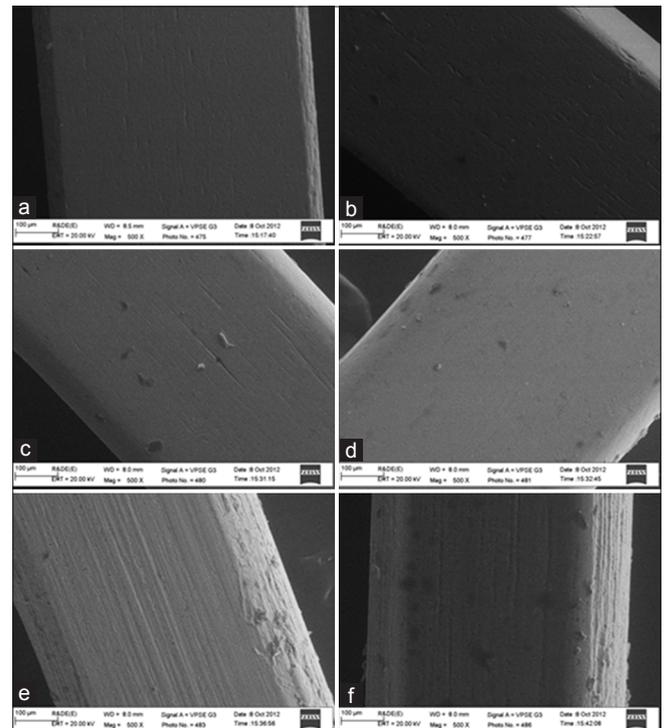


Figure 4: (a) Scanning electron microscope (SEM) image for commercially available uncoated stainless steel (SS) wire (0.019" \times 0.025"). (b) SEM image for nanoparticle coated SS wire (0.019" \times 0.025"). (c) SEM image for commercially available uncoated nickel-titanium (NiTi) wire (0.019" \times 0.025"). (d) SEM image for nanoparticle coated NiTi wire (0.019" \times 0.025"). (e) SEM image for commercially available uncoated titanium molybdenum alloy (TMA) wire (0.019" \times 0.025"). (f) SEM image for nanoparticle coated TMA wire (0.019" \times 0.025").

pictures of the uncoated and coated (straight) wire with the nanoparticles with $\times 500$ magnification. The SEM study reveals that the orthodontic wires coated with nanoparticles has fewer surface irregularities than the commercially available uncoated wires. Thus, the surface topography of the coated wires was found to be smoother with less surface deteriorations as compared to the uncoated wires.

Discussion

The main motto of this study is to develop the novel method of coating the orthodontic archwires with nanoparticles. Once the surface treatment of wire is done thoroughly with this novel method; in the next series of articles we will be discussing about the physical properties of this nanocoated wires and how is it beneficial to us for clinical use.

One of the most important benefits of coating the archwires with nanoparticles would be the significant reduction in the frictional resistance at the bracket wire interface.

In orthodontics, many studies have evaluated factors that influence frictional resistance between the bracket and

archwire using experimental testing models that included one and three brackets.³⁻⁶ These studies have shown that the most important factors involved in the determination of the level of friction are: The bracket and wire material, the surface condition of the archwire and bracket slot, the wire section, the torque at the wire-bracket interface, the type and force of ligation, use of self-ligating bracket, inter bracket distance, and oral functions.⁷⁻⁹

Consequently, the above factors are important when considering the clinical application of sliding mechanics, as they could influence friction. Such a reduction in friction can help shorten overall treatment time, especially in patients undergoing extractions where tooth translation is achieved by sliding mechanics.³

Frictional forces measured in this study were comparable in magnitude and range with those reported by other investigators, great care was taken to ensure the methodology was comparable with previously published work.¹⁰

Our study is an extension of the research by Redlich *et al.* on orthodontic SS wires coated with nanoparticles. These nanoparticles consist of inorganic fullerene impregnated in the electroless nickel phosphorus film. It was found in this study that the nanocoating of archwires reduces the friction considerably. Additional tests were carried out to test the biocompatibility of the nanoparticles.¹

In the research study, they have used inorganic fullerene-like tungsten disulfide (IF-WS₂) nanoparticles. The inorganic fullerene-like tungsten disulfide (IF-WS₂) nanoparticles were described first in 1992. It was shown that under certain reducing and sulfidizing conditions, at elevated temperatures, tungsten oxide (WO₃) nanoparticles could form nested WS₂ fullerene-like nanostructures creating layers that resemble an onion or a nanotube. These nanoparticles are constructed of multiple layers that can be represented as a sandwich of covalently bonded S-W-S moieties within the plane. The layers are weakly connected through van der Waals forces only. The size of these nanoparticles ranges from 20 to 200 nm depending on the WO₃ precursor size. It is known that WS₂ and MoS₂ particles with a layered structure (platelets) provide good lubricity. Synthesis of fullerene-like WS₂ nanoparticles has allowed remarkable improvement of friction and wear properties under different contact conditions. Low friction and wear are associated with the penetration of solid lubricant WS₂ nanoparticles into the interface between rubbed surfaces. As the load between the bodies increases, the nanoparticles gradually deform and exfoliate, leaving nanoplatelets of the sandwiched material to coat the asperities at the interface. The weak forces, between the thin sheets of the exfoliated nanoparticles, allow a very low shear force sliding motion between the two contacting bodies.

The nanoparticle used in our study is nanocremsics that is commercially available nanoparticle coating precursor solution. This was the solution of choice in our study as it was readily

available commercially in India. Secondly the laboratory procedure for coating of the same could be easily carried out in India.

The WS₂ nanoparticle used in the research work of Redlich *et al.* (2008) was coated by the following procedure. Orthodontic SS wires (Ormco, CA, USA) with a rectangular cross-section (0.019" × 0.025") shape, were coated with a uniform and smooth Ni-P film using 100 ml solution (ENPLATE Ni-425, Enthron Inc.). The orthodontic wires were inserted into the electroless Ni-P bath (88°C, pH 4.8, magnetic stirring) for 30 min. The plating resulted in a shiny, smooth Ni-P layer 1-2 μm thick. Subsequently, the wires were submerged into another electroless solution with 200 mg IF-WS₂ powder having an average particle size of 120 nm. A cationic surfactant (cetyltrimethylammonium bromide) was added to minimize the agglomeration of the nanoparticles. A short (1 min) sonication (Sonifaier 150, Branson - 30 w) was used to disperse the agglomerates and ensure the stability of the suspension. Excessive sonication time (>2 min) is known to damage the IF nanoparticles. To ensure the deposition of a uniform and relatively smooth composite Ni-P + IF film and secure its adequate adherence to the underlying archwire the following procedure was developed. First the wires were etched with HF (20%) solution. Subsequently, thin Ni coating (50 nm) was applied using e-beam evaporation. On top of this film, a pure Ni-P electroless film was deposited, and only at the final stage of the process electroless Ni-P + IF film was deposited on the etched wires. The total thickness of the coated film was 3-5 μm. The wires were annealed at 400°C for 1h under nitrogen gas flow. The annealing led to the formation of a multi-crystalline Ni₃P film that adhered very well to the underlying substrate.

The nanocremsics solution used in our study was coated with sol-gel thin film dip coating method as discussed earlier in materials in method. In order to evaluate the adherence of the coating on to the orthodontic wire, the coated orthodontic wires were analyzed by SEM. Also, the slot of the bracket that was used for sliding the coated orthodontic wires and was checked for remnants of coated material.

On the basis of our study we found that commercially available orthodontic wires can be successfully coated using a novel method of sol-gel thin film dip coating method and that coating commercially available SS, NiTi and TMA orthodontic wires with nanoparticles improves their surface topography.

With further studies, this nanoparticle coated wires may represent a valid alternative to commercially available wires when minimal amount of friction is desired. The coatings can also be used for brackets, flexible archwires, and self-ligating systems.

We assume that the friction can further be reduced significantly by coating both the bracket as well as archwire as the corrosion factors would be eliminated this way.

Limitations of this research are that it was carried out *in vitro*, in a passive configuration. Tipping, torquing forces and the functional forces of the stomatognathic muscles can also affect the frictional resistance during space closure; however, these factors need to be studied.

It should be stressed out that an *in vitro* study can't replicate exactly the same physiologic changes that occur in the oral cavity during an orthodontic tooth movement. Thus, another drawback of this study can be the changes in the friction at the bracket wire interface caused during various oral activities.

Preliminary toxicology tests of the IF-WS₂ revealed that the material showed no apparent toxic reaction after an oral administration test in rats and no sensitization in lymph nodes following a topical dermal application.^{11,12} More recent inhalation tests have shown that the material has no toxic effect in rats.¹³ Nonetheless, the composite coating needs to be further tested. More toxicity and sensitivity tests, evaluating the effect of the nanoparticles on various body organs, and especially oral tissues are necessary. Various tests for the biocompatibility issues of nanocremsics need to be undertaken.

Thirdly, since a certain amount of the nanoparticles was likely to be released from the coating, or exfoliate during motion, it was very important to examine the coated wires after sliding, to assure the adhesion properties of the nanocremsics in the matrix layer. The presence of nanoparticle is a prerequisite for proper lubrication during motion.

With further improvements in the coating method and its approval for use in the oral cavity, the problem of friction during orthodontic treatment could be minimized consequently, enhancing anchorage control, reducing duration of treatment and decreasing the risk of root resorption.

Conclusion

From the above study it can be concluded that:

1. Commercially available orthodontic wires can be successfully coated using a novel method of sol-gel thin film dip coating method.
2. Coating commercially available SS, NiTi and TMA orthodontic wires with nanoparticles improves their surface topography.

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