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The effect of surface treatment and clinical use on friction in NiTi orthodontic wires

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Summary *Objectives*: Since the low friction of NiTi wires allows a rapid and efficient orthodontic tooth movement, the aim of this research was to investigate the friction and surface roughness of different commercially available superelastic NiTi wires before and after clinical use. The surface of all of the wires had been pre-treated by the manufacturer.
Materials: Forty superelastic wires (Titanol Low Force, Titanol Low Force River Finish Gold, Neo Sentalloy, Neo Sentalloy Ionguard™) of diameter 0.016×0.022 in. were tested. The friction for each type of NiTi archwire ligated into a commercial stainless steel bracket was determined with a universal testing machine. Having ligated the wire into the bracket, it could then be moved forward and backwards along a fixed archwire whilst a torquing moment was applied. The surface roughness was investigated using a profilometric measuring device on defined areas of the wire. Statistical data analysis was conducted by means of the Wilcoxon test.
Results: The results showed that initially, the surface treated wires demonstrated significantly ($p<0.01$) less friction than the non-treated wires. The surface roughness showed no significant difference between the treated and the non-treated surfaces of the wires. All 40 wires however showed a significant increase in friction and surface roughness during clinical use.
Significance: Whilst the Titanol Low Force River Finish Gold (Forestadent, Pforzheim, Germany) wires showed the least friction of all the samples and consequently should be more conservative on anchorage, the increase in friction of all the surface treated wires during orthodontic treatment almost cancels out this initial effect on friction. It is therefore recommended that surface treated NiTi orthodontic archwires should only be used once.

Introduction

Today's treatment of choice for malocclusion are fixed orthodontic appliances. The clinician can

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choose from a large variety of different bracket systems and also from a wide range of alloys from which to select an arch wire for straight wire mechanics. During orthodontic treatment, teeth move intermittently along the archwire undergoing phases of tipping followed by uprighting in addition to rotational movements. The archwire lies in and is in contact with the bracket slot which leads to problems with friction and wear of the archwire. The amount the arch wire is deformed is dependent on the applied force and elasticity of the wire [1,23]. Some of the applied force is used to overcome the friction between the two surfaces in contact, i.e. the bracket and archwire. If static friction occurs, movement of the tooth is inhibited until the tooth is uprighted by the elastically deformed superelastic wire; tooth movement then occurs as the friction is reduced as the tooth slides along the archwire. Uprighting of the tooth requires an applied force from the archwire which has also unwanted side effects on the adjacent teeth and can strain the anchorage. The force necessary to bring about orthodontic tooth movement must clearly overcome the friction as well as move the tooth. This applied force has a reactive force on the molars which moves them in a mesial direction. This is frequently not a desired clinical response and can be considered as anchorage loss. It is clear therefore that the development of materials with low coefficients of friction for straight wire mechanics are highly desirable because they can reduce the strain on anchorage.

Friction between the bracket and archwire can cause up to 50% loss of force [5,9,11,18,21]. As a result the desired tooth movement is slowed down or even inhibited. It is therefore desirable that orthodontic wires and brackets show the lowest possible friction coefficients. Numerous factors have an impact on friction and it is very difficult to isolate individual factors. Besides the alloy composition of the archwire [2,13], the wire size [2,13], the elasticity [1,17,19] and the surface structure including surface treatments also play an important role. Studies have shown that the surface characteristics influence both the friction and the biocompatibility of orthodontic arch wires in situ [4,6,11,14,16,20,21,23]. Plaque accumulation is affected by the surface roughness and this in turn affects the properties described above.

When describing friction in orthodontics we have to consider a system consisting of three variables which are relevant: the bracket as a friction counterpart, the wire as a friction solid and the surrounding medium. In the present study, the effect clinical use of the wires has on the frictional forces was analysed using a laboratory friction test system which measures the friction between the stainless steel surface of the bracket and a torqued NiTi arch wire in dry conditions. Measurements of the surface roughness were also carried out before and after use of the wires.

Superelastic NiTi wire shows a martensitic transformation between the austenite and the martensite phases during loading and unloading as well as during cooling and heating. This transformation leads to large amounts of reversible strain occurring either during heating (shape memory effect) or during loading (superelastic effect) [10]. In orthodontics both effects are important, although the key effect is the superelasticity, which produces reversible strains of up to 8% [23]. Understanding the physics of these effects is of importance for both fracture mechanics as well as friction and wear because the phase transformation in shape memory alloys dissipates large amounts of elastic energy. Consequently, NiTi shape memory alloys are known for being surprisingly resistant to wear despite their relatively low surface hardness. Also with respect to this study, it is important to appreciate that the implementation of conventional hardening mechanisms to increase the wear resistance such as dislocations, precipitations or particles in NiTinol is very limited. This is due to the fact that the functional properties of NiTinol are very sensitive to almost any of the aforementioned hardening mechanisms. Therefore, most mechanisms and treatments which may be applied to increase the hardness of NiTinol are typically related to a decrease of functional properties, such as the length of the lower pseudoelastic plateau, the transformation temperature of the alloy or the shape of the plateau.

Besides conventional mechanical polishing techniques there are other surface treatments which can be carried out during manufacturing such as ion implantation, a technique in which the metallic substrate is hardened by the implantation of high energy ions in a very thin surface layer. The increase in hardness is due to the mechanical stresses induced by the mismatch of the implanted ions in the crystal structure of the substrate [5].

The manufacturers claim that pre-treated wires reduce friction during orthodontic fixed appliance mechanics. The aim of this research was to investigate whether the friction of different commercially available superelastic NiTi wires was indeed constant before and after 4 weeks of clinical use and also whether there was any change in surface roughness and how this was related to any change in friction. The wires under investigation