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Research Article

The effect of food simulating liquids on the static frictional forces and corrosion activity of different types of orthodontic wires

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ABSTRACT

Objectives: The purpose of this study was to investigate the effect of some food stimulating liquids (FSLs) on the static frictional forces and corrosion activity of different orthodontic archwire materials.
Methods: Stainless steel (SS), β-titanium (TMA), and nickel titanium (NiTi) archwires were stored in heptane, citric acid, and ethanol each. Every storage combination group consisted of 12 wires. The static frictional forces between the SS brackets and each of the three types of orthodontic wires were measured as received, after 2 weeks and after 4 weeks storage in each FSL. The corrosion activity of the wires in citric acid and ethanol were measured.
Results: For SS wires, citric acid and ethanol 4-week storage showed the highest statistically significant static friction values. For the TMA and NiTi wires, 4-week storage in citric acid showed higher statistically significant static friction values compared with no storage. Citric acid showed the highest corrosion activity for the three types of orthodontic wires. SS showed the highest corrosion activity in both citric acid and ethanol.
Conclusions: Four-week storage in citric acid had the highest deleterious effect, as it significantly increased the static frictional force values of SS, TMA, and NiTi archwires. SS has the highest corrosion activity and thus its frictional force values are affected by 4-week storage in both citric acid and ethanol.

1. Introduction

Orthodontic space closure involves sliding mechanics or friction mechanics as well as loop mechanics or frictionless mechanics. During orthodontic sliding mechanics, the frictional force generated at the bracket/archwire interface tends to hinder the optimal responses to tooth moving forces. Clinically, to have efficient and desired tooth movement with sliding mechanics, the frictional forces generated at the archwire-bracket interface must be overcome and kept to a minimum afterward. The frictional forces generated with orthodontic forces can be categorized as static and kinetic types. The force required to overcome the resistance force and initiate tooth movement is described as static friction and the frictional force experienced with ongoing tooth movement is referred to as kinetic friction. Static frictional forces usually will be higher than those of kinetic friction, which keeps the body in motion [1,2].

Whenever an orthodontic force is applied, tooth movement occurs in an intermittent manner where the tooth undergoes phases of tipping followed by uprighting. The tooth will stop moving until forces resistant to static friction can upright it, once the tipping phase is over. Hence, static friction is considered more important than kinetic friction during orthodontic sliding mechanics of space closure [3]. Friction at the orthodontic archwire-bracket interface is influenced by various factors, such as composition of the archwire and bracket [4], their dimensions [5], the surface roughness and cleanliness of the contacting surfaces [6], the ligation force and type [7,8], and interbracket distances [9]. Apart from this, corrosion can influence frictional forces as the process increases the surface roughness of the affected object, such as orthodontic archwire or bracket [10]. Predisposing factors to corrosion can be either internal factors, such as metal composition and structure, and external factors, which depend on the biological environment (saliva, pH, temperature, and trauma from mastication and brushing) on which the material is made to work [11].

Advances in orthodontic material science has resulted in the development of a variety of wires, such as stainless steel (SS), nickel titanium (NiTi), and β-titanium (TMA), that possess a wide range of properties. Considering the load-deflection properties

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and cross-sections, these alloy archwires assist orthodontists to carry out tooth movement during different phases of treatment mechanics. The varied surface characteristics of these archwires produce different frictional properties with greater frictional resistance exhibited by NiTi archwires followed by TMA alloys and SS wires in their decreasing order [12,13]. Although corrosion resistance is achieved through the development of a passive surface oxide film on these archwire alloys, it is prone to disruption due to mechanical and chemical assaults that it faces in the oral cavity. Among these are acidic conditions created by soft beverages and fluoride-containing products, such as mouthwashes and toothpastes, which can be the main causes of corrosion and deterioration of such alloys [14,15].

The effect of diet on the surface characteristics of orthodontic appliances and their clinical performance is a question that has pondered the specialty for a long time. Foodstuffs vary in composition with respect to the population standards and the region where an individual lives, along with the individual's perception for taste, and, more importantly, foodstuffs are very unstable and deteriorate reasonably quickly. This is the problem by which assessment using actual food regarding its effect on orthodontic appliances becomes very complex and can interfere with the analytical methodology performed. Hence, most of the studies in this regard, in other fields used special extracting liquids, called food simulating liquids (FSLs), in place of actual foodstuffs. Of the FSLs available, heptane, citric acid, and ethanol solutions are commonly used to mimic the wet oral environment provided by fatty foodstuffs, citric fruits, and alcoholic drinks, respectively.

The purpose of this study was to investigate the effect of heptane, citric acid, and ethanol solutions on the static frictional forces of SS, NiTi, and TMA wires after 2 and 4 weeks of storage. The corrosion activity of these wires in citric acid and ethanol solutions was also assessed.

2. Materials and methods

Eighty-four 0.019 × 0.025-inch orthodontic archwire specimens from each alloy group of SS, NiTi, and TMA (Ormco Corp., Glendora, CA), totaling 252 archwire specimens, were used in this study for the friction test. Sample size was calculated using G*Power version 3.1.9.2 for sample size analysis at $\alpha = 0.05$ and 80% power and effect size equal to 0.44, which yields a sample size of 11 samples per group regarding static friction. Twelve samples were performed to account for any dropout. As for the current density and corrosion potential, which yields a sample size of five samples per group was calculated. Six samples were performed to account for any dropout. The FSLs used for storage of orthodontic archwires were heptane, 75% aqueous ethanol solution, and 0.02 M citric acid (Sigma-Aldrich Co., Steinheim am Albuch, Germany) and were chosen according to Food and Drug Administration guidelines [16].

2.1. Frictional characteristics

Standard edgewise SS brackets of 0.022 × 0.028-inch slot size (Ormco Corp.) were obtained for the static friction test. Each of the alloy archwire specimens were divided into three groups of 12 specimens each taking into consideration the period of immersion in the FSLs as received (without storage), after 2 weeks and after 4 weeks of storage. For immersion into three FSLs (heptane, 75% aqueous ethanol solution, and 0.02 M citric acid), the total number of specimens used from each alloy archwire was 108. The archwires were cut into 5-cm-long wire sections and 12 sections of each wire type were placed in a glass container containing 30 mL of one of the FSLs. The container was then placed in an incubator at 37°C for either 2 weeks or 4 weeks. At the end of the storage period, the wires were washed under running water and air-dried before the experiment was performed. Static frictional forces were measured using a universal testing machine (Instron 3365; Instron Co., High Wycombe, UK). A custom-made fixture with two depressions of nearly the same size and shape of the base of the orthodontic bracket were machined on the surface of each half of the metal fixture that was used to perform the static friction test (Fig. 1). The depressions were intended as guides to ensure proper alignment of the brackets so that their slots would be in line with each other and stay parallel to the vertical axis of the testing machine. The depressions were fixed with two orthodontic brackets using cyanoacrylate adhesive. Each archwire for experimental purposes was cleaned with alcohol wipes and a small bend was made at one end of each wire to ensure that the wire slid through one bracket only during the test (Fig. 1B). The wire was ligated to the two brackets using 0.012-inch elastomeric ligatures. Thus, one bracket that remained fixed to the archwire acted as a fixture during testing, while the other bracket allowed sliding of the archwire during the experiment. The friction test was carried out in tensile mode with a crosshead speed of 10 mm/min with 5 N load cell by pulling the two halves of the metal fixture away from each other causing the wire to slide through one of the brackets. Static friction was recorded as the maximum frictional force required to generate initial movement of the wire against the bracket over the 5-mm test distance. After each test, the bracket-wire assembly was removed, and a new assembly was used to eliminate the influence of wear.

2.2. Corrosion behavior

To investigate the corrosion behavior of the three types of orthodontic wires in each of the FSLs, anodic potentiodynamic polarization measurements were performed using a computer-controlled potentiostat (SP-150; Bio-Logic Science Instruments, Seyssinet-Pariset, France). Potentiodynamic testing was performed on six wire segments of 3-cm length for each type of orthodontic wires at a temperature of 37 ± 1°C. Samples for corrosion testing were ultrasonically cleaned with ethyl alcohol solution for 5 minutes then rinsed in distilled water and dried. The working cell was formed of three electrodes, the test specimen was used as a working electrode and immersed in each of the FSLs. A saturated calomel electrode ($Hg/Hg_2Cl_2/KCl$) and platinum sheet were used as the reference electrode and counter-electrode, respectively. Corrosion current density (I_{corr}) and corrosion potential (E_{corr}) were measured. A higher I_{corr} and lower E_{corr} indicate higher corrosion activity.

2.3. Surface topography

The surface topography and roughness of representative samples of SS wires and TMA wires both as received and after 4 weeks of storage in citric acid were evaluated using an atomic force microscopy (Autoprobe cp-research head; Thermomicroscope, Sunnyvale, CA). Atomic force microscopy was operated in contact mode using nonconductive silicon nitride probe (Model MLCT-MT-A; Bruker, Camarillo, CA). Scanning was carried out at a scanning rate of 1 Hz. Measurements was taken over an area of 25 × 25 µm.

2.4. Statistical analysis

Statistical analysis was performed using SPSS version 23.0 (IBM SPSS for Mac OS; IBM Corporation, Chicago, IL). Data were represented as means and standard deviations and analyzed for normality using Kolmogorov-Smirnov and Shapiro-Wilk tests. All tested parameters showed a parametric distribution. One-way analysis of variance (ANOVA) was used to study the effect of