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Original Research Article

Comparative assessment of the corrosion process of orthodontic archwires made of stainless steel, titanium–molybdenum and nickel–titanium alloys

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ABSTRACT

The phenomenon of corrosion of orthodontic appliances is of interest to both clinicians and researchers dealing with the issue of biocompatibility of medical materials. The oral cavity, due to its temperature fluctuations, changing pH, high humidity, action of mechanical forces and the presence of microorganisms is a favorable environment for degradation of dental materials. This article presents the comparative assessment of the intensity of corrosion of orthodontic archwires made of alloy steel, nickel–titanium and titanium–molybdenum alloys in laboratory conditions. Corrosion resistance examinations were carried out by means of the impedance and the potentiodynamic methods using an Autolab PGSTAT100 potentiostat/galwanostat (Eco Chemie B.V., Holand) with FRA2 module, in non-deaerated artificial saliva solution at 37 °C. An analysis of the impendence method's data showing that the highest corrosion resistance is observed for NiTi arches (3M, USA), while the lowest resistance for SS arches (3M, USA). These observations were confirmed by the data obtained from potentiodynamic tests; it was observed that the average corrosion current density [I_{cor}] was the lowest for nickel–titanium archwires (3M, USA) and averaged 2.50×10^{-3} μA/cm^2. The highest I_{cor} corrosion current was observed in the case of steel wires from the same manufacturer and averaged 4.96×10^{-2} μA/cm^2.

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1. Introduction

The use of fixed appliances for the treatment of malocclusion is a common therapeutic method in modern orthodontics.

The basic elements that make up thin-arch fixed appliances are brackets attached to the teeth, rings embracing molar teeth and arches connecting the individual parts of the appliance.

Orthodontic brackets can be made of ceramics, composite materials or metal alloys. The commonly used metal brackets are produced with the use of iron alloys with chromium, cobalt, nickel and manganese [1–3]. For the sake of better biocompatibility, manufacturers also provide brackets with lower content of nickel or products made from titanium alloys.

Orthodontic archwires, which are extremely diverse as far as material is concerned, are elements generating forces that allow movement of teeth as well as provide the base along which they move, for example when the so-called slip mechanics is applied.

The main material used in production of orthodontic archwires is austenitic alloy steel grade X5CrNi18-10 (ASTM304) containing about 18% chromium and 8% nickel [4].

Archwires are also made from cobalt-chromium-nickel alloy (CoCrNi), containing about 40% of cobalt, 20% of chromium, 15% of nickel, 16% of iron, and an addition of molybdenum and manganese [4].

In the 1980s orthodontic archwires made of titanium–molybdenum alloys/TMA, also called β-titanium, were introduced. They were composed mainly of titanium, constituting about 70% of their mass, and molybdenum – about 11% of the weight of the product [4,5].

Nickel–titanium archwires, which are becoming more and more common in orthodontic practice, contain about 55% of nickel and 45% of titanium [6]. Their variants are enriched with copper and chromium additions, and often their composition is a manufacturer's secret, due to unique mechanical properties of modified wires, so desirable in the process of orthodontic treatment.

Orthodontic brackets remain in the oral cavity for the whole period of treatment, which is about two years. Metal alloy based archwires are components of fixed appliances for a period of one to several months, depending on therapeutic needs. The same is true for steel or polyurethane ligatures used to fix archwires to brackets.

During that time metal alloys are exposed to constant humidity, variable temperatures and pH fluctuations. Saliva, in which metal elements are immersed, is an electrolyte, and the material variety of the used elements makes the orthodontic appliance a kind of a cell in the oral cavity environment, being subjected to continuous electrochemical processes.

The phenomenon of corrosion of fixed orthodontic braces is of interest to both clinicians and researchers dealing with the issue of biocompatibility of medical materials. The oral cavity, due to its temperature fluctuations, changing pH, high humidity, action of mechanical forces and the presence of microorganisms [7,8], is a favorable environment for degradation of dental materials. It should also be mentioned that individual elements forming the orthodontic appliance are not made of the same type of alloy, but of materials of different electrochemical reactivity that could potentially create a corrosion center [9–11]. The degradation process may be intensified by presence of bacterial plaque [7], whose effective removal may be hampered when the appliance's parts adhere to the surface of teeth.

Destruction of dental materials in the oral cavity is often macroscopically unnoticeable. Small centers of degradation appear on their surface, and, with time, such centers join together. Constant changes in physical and chemical parameters in the oral cavity support and intensify the course of certain processes. These processes lead to very serious weakening of the structure of restorative reconstructions, prostheses, orthodontic archwires and brackets as well as other elements of fixed appliances. As a result of corrosion, dental materials based on metal alloys undergo gradual degradation, not only losing their mechanical characteristics or visual qualities, but also releasing potentially harmful metal ions into the external environment [10–12]. These include first of all nickel, cobalt or chromium, which are generally recognized as biologically harmful [12,13].

Although it is assumed that the amount of metal ions released from dental materials into the oral environment is not sufficient to produce acute symptoms of intoxication, their extended supply can cause both localized and systemic adverse effects. Corrosion affecting dental materials may result in unesthetic discoloration around amalgam fillings or orthodontic brackets, whereas metal ions released into the external environment may increase or induce the formation of pre-malignant lesions in the structure of oral mucosa [14]. In the mechanism typical for type IV allergic reactions, nickel ions released from archwires of orthodontic appliances may cause ulceration of the lips, mucous membrane or tongue, localized swelling or taste disorders [15,16].

In the light of the above, it seems very important to continuously monitor the biological characteristics of commercially available medical materials in the context of the safety of their use.

The **aim** of the study was a comparative *in vitro* assessment of corrosion susceptibility of six different types of orthodontic archwires (made of alloy steel, nickel–titanium and titanium–molybdenum alloys) in artificial saliva solution with the use of both impedance and potentiodynamic methods.

2. Material and methods

The study material were orthodontic archwires with a cross-section of 0.017 by 0.025 in. (0.04×0.06 cm) from two different manufacturers: 3M (USA) and Rocky Mountain Orthodontic [RMO] (USA), made of alloy steel /ASTM304-labeled SS/, beta-titanium alloys /β-TMA/ and nickel–titanium alloys /NiTi/.

From the orthodontic archwires mentioned above, six specimens of 2 cm length were prepared, five for each type of arch. The surface of the tested materials was 0.4 cm^2.

Electrochemical tests were performed in artificial saliva [17], whose composition is shown in Table 1.

Corrosion resistance examinations were carried out by means of the impedance and the potentiodynamic methods

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