Corrosion Behaviour and Surface Modification of Intra-orally Engaged Orthodontic Ni-Ti Wires

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Almost all orthodontic wires suffer from corrosion as they are intra-orally engaged. This chemical structure alteration appears on the surface of these wires, surface topography can be easily visualised with scanning electron microscope method. The aim of our study was to assess the intraoral corrosion of the retrieved orthodontic Ni-Ti archwires. Archwire retrieval procedure yielded approximately 30 retrieved wires, placed intra-orally for 1-5 months. SEM analysis was performed and surface changes were interpreted. Our SEM results showed, that surface corrosion and pitting can be seen on the surface of retrieved Ni-Ti wires, the depth of corrosion depends on the time wires have been engaged in the oral cavity. With regards of metal liberation consequently surface corrosion, practitioners should be avare of these chemical changes which can affect the resistence of the orthodontic appliance and patient health.

Keywords: Ni-Ti wires, corrosion, scanning electron microscop, orthodontic

Orthodontic fixed appliance technique involves the use of different types of alloys through well defined elements, which all are in long term contact with oral environment.

During fixed therapy, brackets and tubes are bonded and banded directly on the labial surface of the teeth. These attachments are made usually of stainless steel (SS) alloys, in their slot arches are ligated using elastic or SS ligatures. Selection of orthodontic wires depends on the phase of the treatment: during alignment and levelling phase, superelastic and shape memory capable nickel-titanium (Ni-Ti) wires are used, during the active phase of treatment mainly the use of SS alloy made wires dominate. Although there is still no perfect alloy or arch for all the demands of orthodontic tooth movement, all the alloys we use have to obey in biocompatibility.

The average treatment duration in orthodontic fixed therapy is around 24 month, which means that the above mentioned alloys will certainly be exposed to oral environment for a long time. Since metals suffer some changes in increased humidity and acidic environment, appearance of chemical and structural changes can be expected.

The aim of our study was to evaluate the intraoral aging of Ni-Ti orthodontic wires by studying the surface corrosion they develop by scanning electron microscope and to evaluate their behaviour depending on the time they were worn.

Experimental part

One type of uncoated, work hardened, preformed superelastic Ni-Ti orthodontic archwire, 0.016x0.022-inch, Lowland (Dentsply GAC Int., Islandia, NY) was investigated. For SEM study purpose, twenty orthodontic patients were selected from those referred for orthodontic treatment to the Department of Orthodontics, Faculty of Dentistry, University of Medicine and Pharmacy of Tirgu Mures and Timisoara. A written informed consent was obtained from the patient or he's legal representative. Research protocol was reviewed and approved by the Ethical Committee of Scientific Research of the University of Medicine and Pharmacy of Tirgu Mures, decision nr. 117/21.11.2013.

Patients included in this study had similar age (14.1±1.2), were in good general health, without long term drug consumption, good oral hygiene and salivary pH around 7 (7.08±0.09), non-smokers. In every case the same bracket system was used (0.018 slot size Roth Omni, Dentsply GAC Int., Islandia, NY) and elastic ligatures were used. Arches were retrieved only from non-extraction cases.

Name of the patients, insertion and retrieval appointments were noted on the plastic bag in which wires were individually collected. Archwire retrieval procedure yielded approximately 30 retrieved wires, placed intra-orally for 1-5 months.

The retrieved archwires were rinsed with distilled water to detach precipitations, specimens of 15 mm length were prepared from molar region of each archwire. Sectioned arch-segments were chosen to be the segment of the arch inserted in bicuspids brackets and first molar tube. For control specimen an unused archwire of the identical cross-section and size and same manufacturer was used.

Scanning electron microscopy (SEM) was used to assess micromorphological changes induced on wire surfaces after intra-oral exposure. For this purpose a Philips XL30 type SEM machine was used, examinations were performed at 20kV accelerating voltage, 5.0 nm resolution, secondary electrode detection mode and 9.3 mm focus range. 21x, 100x and 1000x magnification was used for each specimen (fig.1).

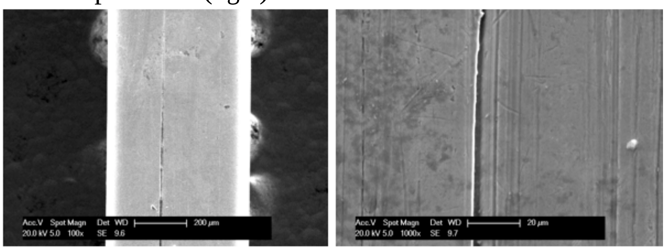

Fig.1. Control specimen Ni-Ti wire with linear scratch due to manufacture procedure

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Results and discussions

SEM analysis of control and retrieved Ni-Ti arches showed altered surface from intra-orally engaged arches. Shallow longitudinal scratches were observed on the surface of control arches as well, probably due to pliers which were used for wire placement or to the manufacturing procedure of drawing (fig. 2).

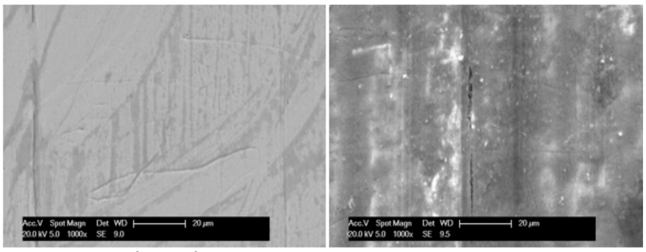

Fig. 2. Surface of control and intra-orally engaged Ni-Ti arch

The depth of these scratches increased for retrieved arches, where intraoral exposure was prolonged. Transversal and anarchical exposed scratches were observed also on arches kept intra-orally for a longer time (fig. 3). Surface corrosion appears on retrieved arches kept intra-orally for more than two months. Dark areas representing (fig. 4) the corrosion can be seen at ×100 magnification, at x1000 magnification, these patches become more intense and debris can also be identified.

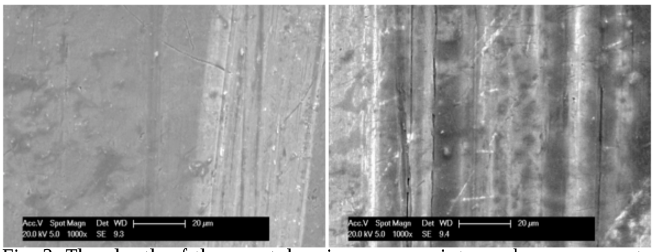

Fig. 3. The depth of the scratches increase as intraoral engagement time is longer. Surface topography of 1 month and 4 month used Ni-Ti wires

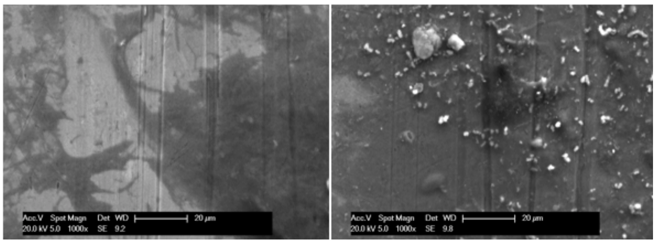

Fig. 4. SEM aspect of surface corrosion and debris on 4 month intra-orally engaged Ni-Ti wires

Linear and grouped granular structures can also be observed on wire surface, pitting corrosion is present on wires with prolonged intraoral existence (fig. 5). No crevice corrosion or erosion was noticed on any examined wire.

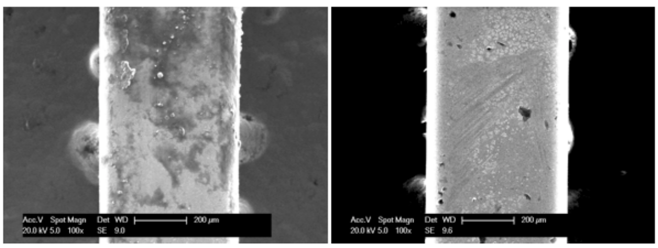

Fig. 5. Granular structures and pitting corrosion due to prolonged intraoral existence

Although prior to the examination, retrieved arches were rinsed in distilled water, plaque deposition could be identified in some cases arch surface.

There are many tests available to assess the mechanical and physical properties of orthodontic archwires. Load deflection properties is measured using three-point wire bending tests provides information on the behaviour of the wires to horizontal and vertical deflections.

The surface topography of orthodontic archwires can be studied with high resolution microscopy. Scanning Electron Microscopy (SEM) is a type of electron microscope that images a sample by scanning it with a beam of electrons in a raster scan pattern. Surface roughness measured by profilometry indicates *the roughness* of the surface and is defined as *the arithmetic mean deviation of the roughness profile from the mean lin*e.

Durability of coating can be calibrated with photography method or analysed with SEM [1]. SEM method is a reliable way to analyse surface changes, this is the reason we have chosen it. It may not emphasise subsurface structural changes, it may not show ion release, but allows the topographic study of the wire surface. Bishara et al studied biodegradation of orthodontic appliances in vitro and showed that nickel ions released from orthodontic appliances of nickel - titanium and stainless steel increased over the first week then diminished over time [2].

Biodegradation of metals and alloys in contact with increased humidity is well-known. The wires we have studied were engaged in the oral cavity for a period of time, surface modification can be considered both mechanical and chemical ones. The SEM images of all wires before and after intraoral use showed some mechanically induced scratches which may be due to manufacturing process in the as received wires and due to various factors in retrieved wires like manipulation by pliers, mastication stresses etc. [3].

The specimens we examined became from posterior region, where engaging the wires in the buccal tube means plier usage and more difficult plaque removal. No difference was noted between the incisor and molar regions with respect to the extent of the changes induced; similarly, an identical ageing pattern was observed for round, square, and rectangular archwires from different manufacturers.

The wire surfaces engaged in the bracket slots demonstrated material loss and various modes of corrosion such as delamination, crevices, and pitting. The sites of the retrieved wires engaged to the brackets exhibited a much smaller grain size compared with the etched reference wires [4]. Because of the posterior position and difficult cleaning, increased plaque deposition is expected. Underneath plaque, the corrosion is possible, which will increase the friction in the bracket-wire-ligature system. The specific region of the buccal inter-bracket archwire segment used to analyze frictional resistance was scanned for surface debris. SEM revealed surface deposits on the archwires after intraoral exposure which was scored accordingly. A debris score of 0 was obtained for as-received wires, but the scores were significantly higher for clinically used archwires [5].

By definition, corrosion, the graded degradation of materials by electrochemical attack, is of concern particularly when orthodontic appliances are placed in the hostile electrolytic environment provided by human mouth. Factors such as temperature, quantity and quality of saliva, plaque, pH, proteins, physical/chemical properties of solids/liquids food and oral conditions may influence corrosion processes [6]. Corrosion of metals in general can be pitting, crevice or filiform corrosion, orthodontic wires can present uniform, pitting, crevice corrosion, fretting, erosion-corrosion, intergranular corrosion due to galvanism, stress and microbial attack suffered in the oral cavity. Potentiodynamic polarization experiments and scanning electron microscopic observations of archwires composed of stainless steel, CoCr, NiCr, Ni-Ti and Beta-Ti exposed to electrochemical corrosion in artificial saliva have shown evidence of pitting corrosion formed on the wire surfaces [6, 7]. With regard to chemical composition, Ni-Ti wires present predominance of Ni and Ti with a small percentage of Al, Ca, and Si. The superelastic Ni-Ti wires present the lowest wire-surface roughness, in comparison with superelastic and heat-activated Ni-Ti and Cu-Ni-Ti wires, the size of the microcavities found for superelastic Ni-Ti wires was larger than that found for heat-activated Ni-Ti wires [8].

Corrosion can lead to roughening of the surface, weakening of the appliances, and liberation of elements from the metal or alloy. Breakage of orthodontic wires has frequently been found in clinical studies and subjected to degradation caused by corrosion in the oral environment [6].

Debris accumulation, surface roughness and frictional force of orthodontic wires will change after exposure to the intraoral environment. Archwire cleaning before wire replacement can influence that, Normando et al. concluded that steel wool sponge and ultrasound cleaning can effectively eliminate these changes [9].

The anticorrosive behaviour of Ni-Ti-based wires has been evaluated in several works [10, 11]. Corrosion of the SS and Ni-Ti alloys depend on a combination among saliva *p*H, the exposition time, and the concentration of F– ions. The critical condition was observed for Ni-Ti wires at *p*H = 3.0, and high concentration of F– ions, causing an increase in Ni dissolution and corrosion current density [12]. It is a proven fact that corrosion of orthodontic devices occurs, but the impact of corrosion on orthodontic treatment and on patient's health is still not fully understood. Ni-Ti alloys can have >50% of nickel content and, consequently, release sufficient nickel ions to cause allergic reactions.

The corrosion and deterioration of certain metals and alloys have been related with the acidic environment of the buccal cavity and with the presence of fluoride ions in several toothpastes and mouthwash solutions [13]. Some studies have shown that Ni-Ti alloy exhibits excellent resistance against corrosion in physiological media, others have shown that it exhibits poor resistance. Diet will also influence salivary *p*H and corrosion also. The consumption of soft drinks cannot be acknowledged as one possible reason for the degradation of the physical and chemical properties of heat activated nickel titanium orthodontic wires in patients undergoing fixed orthodontic treatment [14].

Analysing the topographic alterations of different coated Ni-Ti archwires and comparing the SEM aspect of these with uncoated ones, Rongo et al. concluded that the clinical use of wires altered their surface properties and increased surface roughness and level of friction. The SEM images confirmed the heterogeneous surface of the coated wires after clinical use, a certain degree of corrosion and a large amount of debris were present on the non-coated wires [15].

Uncoated Ni-Ti and N Ni-Ti wires had similar surface composition prior to and after corrosion tests. SEM images showed surface irregularities in the form of dark spots, with the largest dark areas visible on Rh Ni-Ti. After corrosion testing, surface irregularities on rhodium-coated Ni-Ti wires were more prominent and larger in number when compared with smoother surfaces of Ni-Ti and nitrified Ni-Ti. Coatings slightly increase surface roughness, rhodium coating more than nitrification.

Nitrification of wire surface improves corrosion resistance [16]. Surface modified Ni-Ti arch wires showed significant improvement in corrosion resistance compared with conventional Ni-Ti. Similarly, surface roughness values also underwent considerable modification with coating [17]. Comparing the surface characteristic of as-received aesthetic coated rectangular archwires with the surface of SS and Ni-Ti wires after 21 days of oral exposure, Lopes da Silva et al. concluded that coated archwires had low aesthetic value as they presented a nondurable coating. The remaining coating showed a severe deterioration and a greater surface roughness than conventional SS and Ni-Ti wires [18].

Analysing the ultrastructure (surface roughness) and mechanical properties (load-deflection curve) of three as-received, white-coated superelastic nickel-titanium (Ni-Ti) archwires Ryu et al. found reverse nanostructural changes in the surface roughness in the uncoated metallic areas. The results suggested that the load-deflection properties and the surface roughness of superelastic Ni-Ti archwires were affected directly by the coating materials [19]. SEM micrograph revealed that the uniform oxidation occurred on Ni-TiNb alloy after corrosion test in tomato juice, and did not show an obvious tendency of deterioration, selective corrosion at the surface of Ni-Ti orthodontic wires was observed [17].

Analysing the effect of passivation using periodate solution was expected to modify the surface properties of Ni-Ti alloy. Mechanism of electropolishing and passivation and their in vitro corrosion resistance and biocompatibility have been analyzed and compared to those of mechanically polished Ni-Ti alloy. Scratches and grooves due to mechanical polishing were seen clearly in bare Ni-Ti. After electropolishing at 20V, the surface appeared smoother and the polishing marks were completely eliminated. Surface of the passivated sample appeared dull compared to electropolished sample possibly due to the formation of oxide layer [20].

PTFE coating provide a more effective barrier against metallic substrate dissolution [21]. Coated orthodontic wires presented good electrochemical corrosion resistance [22].

Conclusions

The originality of this topic consists in the analysis of the surface changing of retrieved archwires after intraoral exposure and compare them with unexposed control specimens. Even if intraoral exposure was of different time duration, the difference among wearing period was not significant, as these wires are used in the early phase of orthodontic treatment. The specimens we observed were retrieved form posterior regions, this explains the debris we found on labial surface of the arches.

Our results showed, that Ni-Ti wires suffer corrosion after intraoral engagement. Since these structural changes will alter saliva composition by metal-ion liberation, practitioners should be aware of this jeopardy.

Corrosion of the Ni-Ti wires we examined were surface modifications, pitting corrosion was the most severe form of it. The depth of pits and scratches increase with wearing time duration and seems to be more severe where debris deposit is found.

The limitation of this study consist in lack of further chemical examinations, for measurements of the released Ni ions further studies will be conducted.

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Manuscript received: 15.12.2016