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Electron-microscopic study on structural changes of mini-implants following fixed orthodontic treatment

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ABSTRACT

In today's society, patients who turn to the orthodontist want final results in the shortest possible time, with maximum emphasis on smile aesthetics, dental alignment and facial harmony. In this regard, some procedures have emerged to accelerate the movement of teeth through the alveolar bone, thus shortening the duration of active treatment: corticotomy, application of mini-implants, etc. Of these methods, bone anchorage on mini-implants is increasingly popular among adult patients, as it is a versatile technique that ensures a stable, bony anchorage and more predictable final results.

Compared to implantology in prosthodontics, which has a long history, mini- orthodontic implants emerged later in medical practice. In 1998, Shapiro and Kokich described for the first time the possibility of using dental implants for anchorage in orthodontic therapy. Odman J et al. (Upsala University, Sweden) applied implants to patients with partial edentulousness. The results were favorable, leading the authors to recommend the technique for adult partial edentulousness. Kanomi (1997) showed that a 1.2 mm diameter titanium mini- implant provides anchorage for the intrusion of the lower front teeth. After 4 months, the mandibular incisors were intruded by 6 mm without root resorption.

Birte Melsen et al. (1998) introduced the use of zygomatic ligatures as anchorage in patients with partial edentulousness. To this they attached nickel-titanium springs for intrusion and retraction of maxillary incisors. Hugo de Clerk (2008) used 4 mini-implants (Bollard type) inserted into the infra-zygomatic crest in patients with Angle class III anomalies. He used 2 mini-implants with hooks in the chin area, and patients wore Class III 150 grams elastics on each side. This direct anchorage also has orthopedic effects, with clinicians achieving upper jaw advancement and correction of mandibular prognathism.

Keywords: mini-implants, fixed therapy, electron microscopy, structural defects

INTRODUCTION

Mini-implants have recently been widely used as anchoring aids in orthodontics. Their clinical effectiveness lies in their ability to maintain contact with the bone, thus resisting reactive orthodontic forces. Mini-implants are made of stainless steel, commercially pure titanium, or titanium alloy with a diameter of 1 to 2 mm and a length of 8 to 20 mm. They

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usually do not induce osseointegration due to their small size, short-term presence in the oralcavity and the fact that they do not protrude beyond the cortex [1,2].

Using implants as temporary anchorage devices (TAD) revolutionized the biomechanical planning of orthodontic treatment and eliminated the problem of anchorage loss. The results obtained are more predictable and the time of treatment is reduced.

Orthodontic mini-implants are not affected during insertion [3,4], due to the higher hardness of titanium and higher strength compared to bone. Despite numerous attempts to modify the chemical characteristics of titanium surfaces, degradation is time-dependent, i.e., chemical properties are substantially affected, as osseointegration is reduced on Ti surfaces [5,6].

The metals (alloys) used in the construction of mini-implants form a double dielectric layer in electrolyte solution. Non-noble metals have a greater tendency to release ions into solution, which have an increased „solubility voltage“ [7,8,9]. Thus, the corrosion process of orthodontic springs occurs as a result of the interaction of the spring with the oral environment and is accelerated by manufacturing defects. Corrosion and biocompatibility of orthodontic archwires are closely related. Satomi K [10,11] stated in 1988 that the corrosion resistance of an alloy determines its biocompatibility.

Another modern method of reducing the corrosion of dental mini-implants and improving their mechanical properties is the PIII technique (namely Plasma Immersion Ion Implantation) [12]. This method consists of coating the spring surface with a nitrogen layer that significantly inhibits the release of Ni ions from NiTi alloys. SEM studies compared to conventional springs reveal a significantly smoother surface [13]. The degree and type of corrosion depends both on the loco-regional factors present in the oral cavity and on the typeof alloy and the method of manufacturing and finishing the spring itself.

The aim of this study is to evaluate the structural variations and corrosion behavior of two types of orthodontic mini-implants made of commercially pure alpha-titanium (CP).

MATERIAL AND METHOD

In this study, we used scanning electron microscopy (SEM) to evaluate structural variations of orthodontic implants sampled after treatment as well as mechanical properties that would adversely affect the stability of orthodontic implants. For the analysis, we used 10 self-tapping mini-implants, sampled after orthodontic treatment, made of commercially pure alpha-titanium (CP) and Cr-Ni -Mo (SS) with different length and diameter the shape of the thread is radius or angle. (Picture 1 a, b, Table 1)

a

b

FIGURE 1. a – Titanium implant, b – Cr-Ni-Mo implant

The mini-implants were inserted in the jaw and kept in the oral cavity for 3 months. These were anchorage aids, with which only dental displacements were performed: mesialization, distalization and intrusion. The mini-implants were stored in sterile saline solution for 5 days at room temperature. After storage, they were analyzed under a scanning electron microscope, represented by a LEO 1450VP + Inca 2000EDS, (Phenom ProX, manufacturer PhenomWorld) (Figure 2).

FIGURE 2. Scanning Electron Microscope – SEM, Phenom ProX

We measured some characteristics of the implant: the length of the implant joint; thread length of the turns. We analyzed the structural variations according to the degree of morphological deformation of the head, transmucosal neck, threaded body and implant tip up to a magnification of 10,000x (Figure 3, 4).

TABLE 1. Mini-implant characteristics

Mini-implant	Dimensional characteristics	The shape of the fillet
A1.1 Titanium	Diameter = 1,8 mm, Length = 8 mm	radius
A1.2 Titanium	Diameter = 1,6 mm, Length = 8 mm	angle
A2.1 Cr-Co-Mo	Diameter = 1,6 mm, Length = 7 mm	radius
A2.2 Cr-Co_Mo	Diameter = 1,8 mm, Length = 7 mm	angle

We used EDX X-ray scattering spectroscopy, PANalytical B.V. Netherlands for surface and material

FIGURE 3. Removed implant (optical microscopy 25X)

FIGURE 4. Removed implant (optical microscopy 50x)

composition analysis of the mini-implants. EDX is a technique used for elemental analysis the corrosion. It is based on the interaction of X-ray excitation sources and a sample.

RESULTS

No significant traces resulting from themanufacturing process were observed (Figure 5,6). X-ray energy dispersive spectroscopy confirmed that the alloy is Ti6Al4V, also known as commercially pure titanium alloy. (CP) is chemically homogeneous.

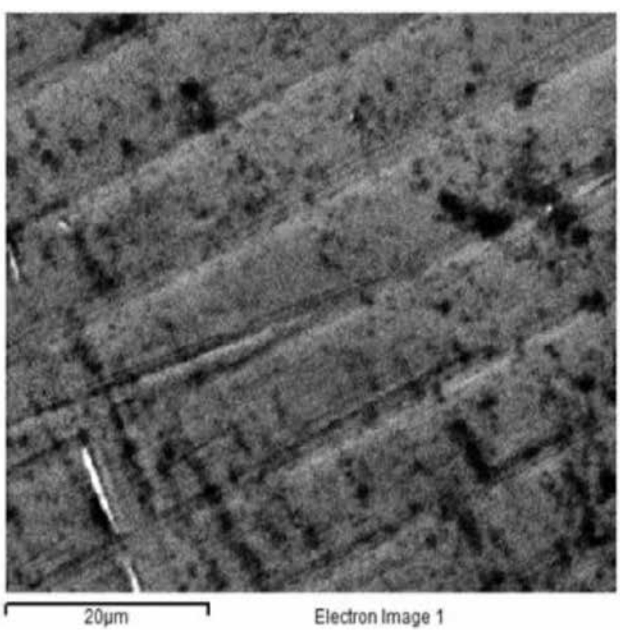


FIGURE 5. Implant coil EDX image

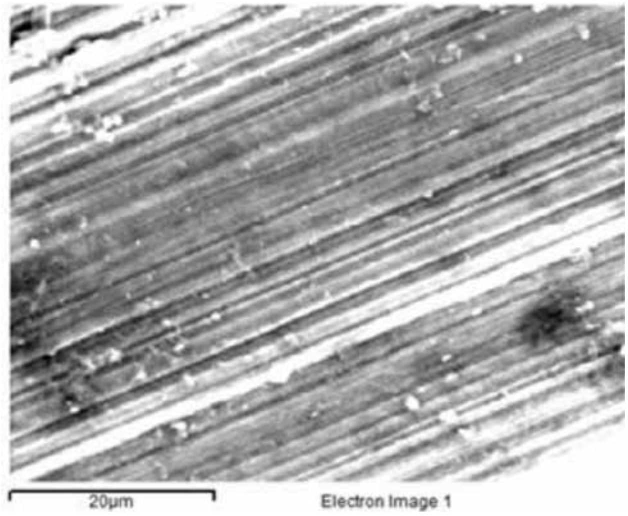


FIGURE 6. Implant removal EDX image

The coils and threads of the mini-implants underwent minor changes during orthodontic treatment, changes directly proportional to the duration and intensity of the force, in a proportion of 50%. (Table 2, 3). These changes do not affect primary stability or orthodontic biomechanics, being visible only in electron microscopy. No statistically significant differences were observed between the two manufacturing companies.

TABLE 2. Titanium implants analysis

Implant Ti	Implant Tip	Implant coils	Implant Collar	Implant head	Implant Str.
Implant A 1.1	-	-	-	-	X
Implant A 1.2	X	X	-	X	-
Implant 2.1	-	-	X	-	-
Implant 2.2	X	-	-	-	X

TABLE 3. Cr-Ni-Mo implant analysis

Implant SS	Implant Tip	Implant coils	Implant Collar	Implant head	Implant Str.
Implant A 1.1	X	X	-	X	X
Implant A 1.2	-	-		X	X
Implant A 2.1	X	-	X	-	-
Implant A 2.2	X	X	-	-	-

All mini-implants showed obvious signs of corrosion, (100%), the longer the duration of insertion in the oral cavity (Figure 7, 8; Table 4), the more pronounced.

Corrosion of metals is an inevitable and uncontrollable process, as they tend to return to their original state of oxides or sulphides as found in nature, which is also their stable state. The presence of orthodontic mini-implants in the oral cavity is short-term (3-6 months), so this effect has no negative repercussions on periodontal tissues.

The corrosion phenomenon is dependent on the electrolyte in which the metal is introduced and es-

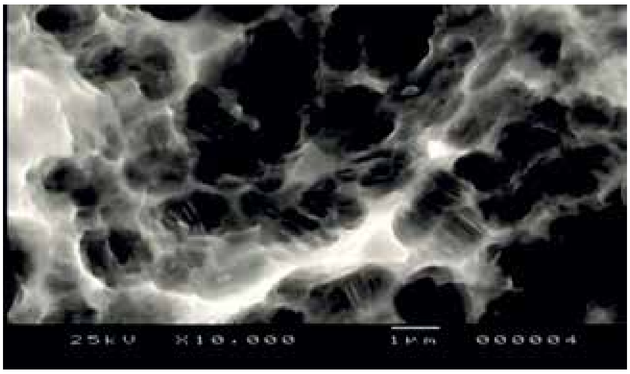


FIGURE 7. 10,000X structural SEM image

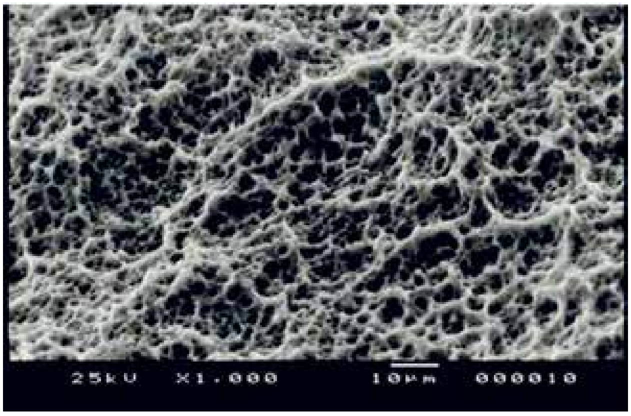


FIGURE 8. SEM 1000X structural SEM image

pecially on the pH of the medium, the concentration of oxygen, chlorine ions the temperature of the medium or the gradients of all these factors. (Figure 9, 10)

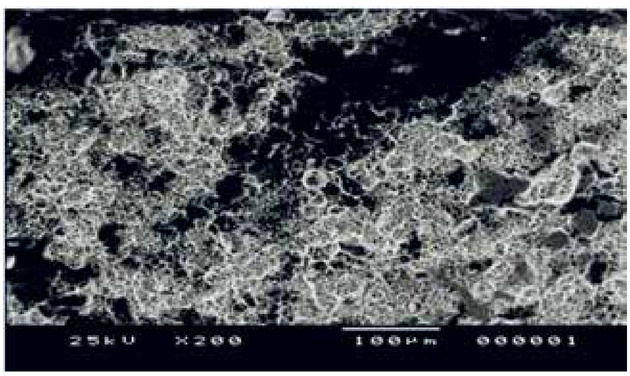


FIGURE 9. 200X structural SEM image

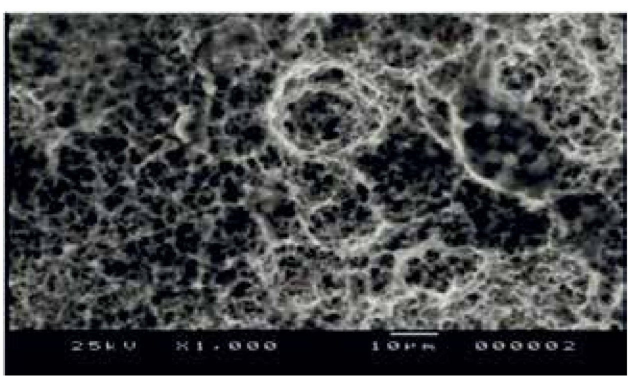


FIGURE 10. 1000X structural SEM image (traces of corrosion)

The surface passivity of the materials is very effective against corrosion, creating a protective layer of stable oxides on the metal surface. This is the case for pure titanium, whichcan be coated with a layer of stable chromium oxides. Polishing of the corroded surface leads in the first stage to a decrease in corrosion by reducing the metal-medium contact area and byremoving impurities from the polished surface. When polishing is too intense, various inclusions may appear on the polished surface, including from the polishing cutter, which will provide more intense corrosion. This is one reason why it is contraindicated to sand the mini- implant posts in the oral cavity after fitting.

On all recovered mini-implants we observed deposited debris: carbon, calcium, phosphorus obvious at high magnifications (Figure 11, 12, 13, 14; Table 4).

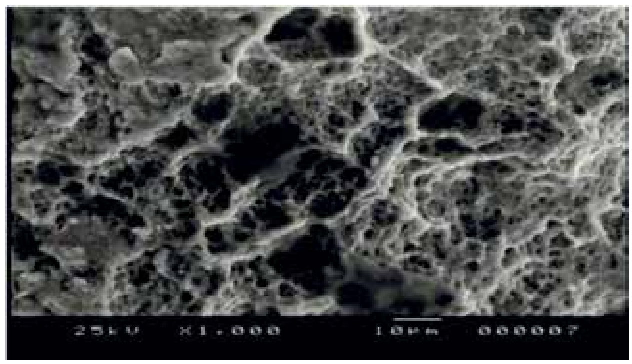


FIGURE 11. Deposited debris Magnification 500x

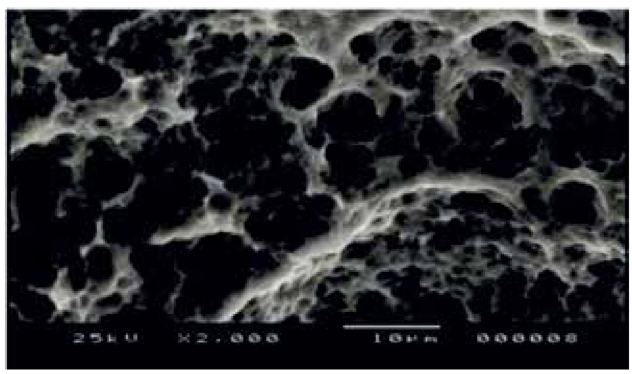


FIGURE 12. Deposited debris Magnification 1000x

TABLE 4. Ti and Cr-Co-Mo implant results

Implant	Carbon	Phosp-horus	Cal-cium	Cocci bacteria	Filiform Bacteria
Implant A 1.1	X	X	X	X	X
Implant A1.2	X	X	X	X	X
Implant A 2.1	X	X	X	X	X
Implant A 2.2	X	X	X	X	X

High amounts of bacteria (cocci and Filiform bacteria), were present in 100% of cases (Figure 13, 14; Table 4), regardless of the patients' hygiene status. These bacterial deposits are also responsible for

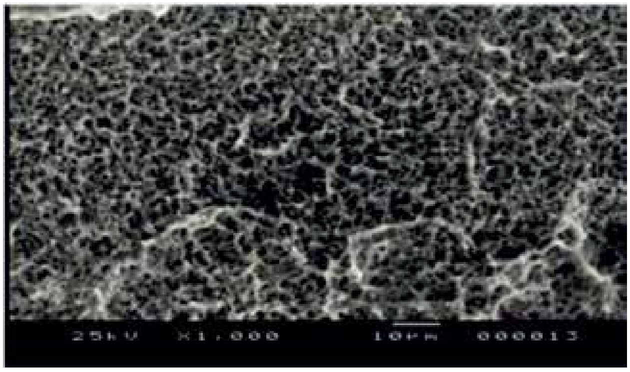


FIGURE 13. Deposited bacteria. Magnification 500x

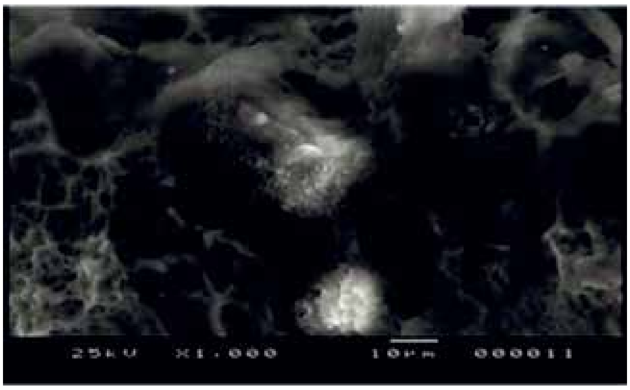


FIGURE 14. Deposited bacteria. Magnification 1000x

the initiation of an inflammatory peri-implantitis process.

Images of the distribution of the main substances used in the composition of the alloys can also be found in Figures 15 a, b, c (for the Ti sample) and Figure 16 a, b, c (for the Cr-Co-Ti sample) The EDS spectrum is presented in Figure 17 a (Titanium) and 17 b (Cr-Co-Mo)

Images of the analyzed surface, elemental distribution images and EDS spectrum for the SSsample

No corrosion was found on the surface of the Ti mini-implants (Figure 18 a). A few corrosion signs are observed on the Cr-Ni-Mo mini-implants. (Figure 18 b.) However, as in the case of implants immersed in SA show (to a lesser extent) surface formations/deposits due to the test agent.

DISCUSSIONS

The advantages and disadvantages of titanium have been the subject of much research in the specialized literature. In general, the massive use of titanium in implantology in recent years can be explained by its numerous advantages compared to other metal alloys used in dentistry: excellent corrosion resistance, superior to any other alloy used in prosthetics or orthodontics;absolute biocompatibility and lack of any toxicity, being perfectly tolerated by the body [12]. The possibility of using a single material for implants and superstructures or any other prosthetic restorations in the same patient, in order to avoid physico-chemical reactions that may be generated by the use of different metals.

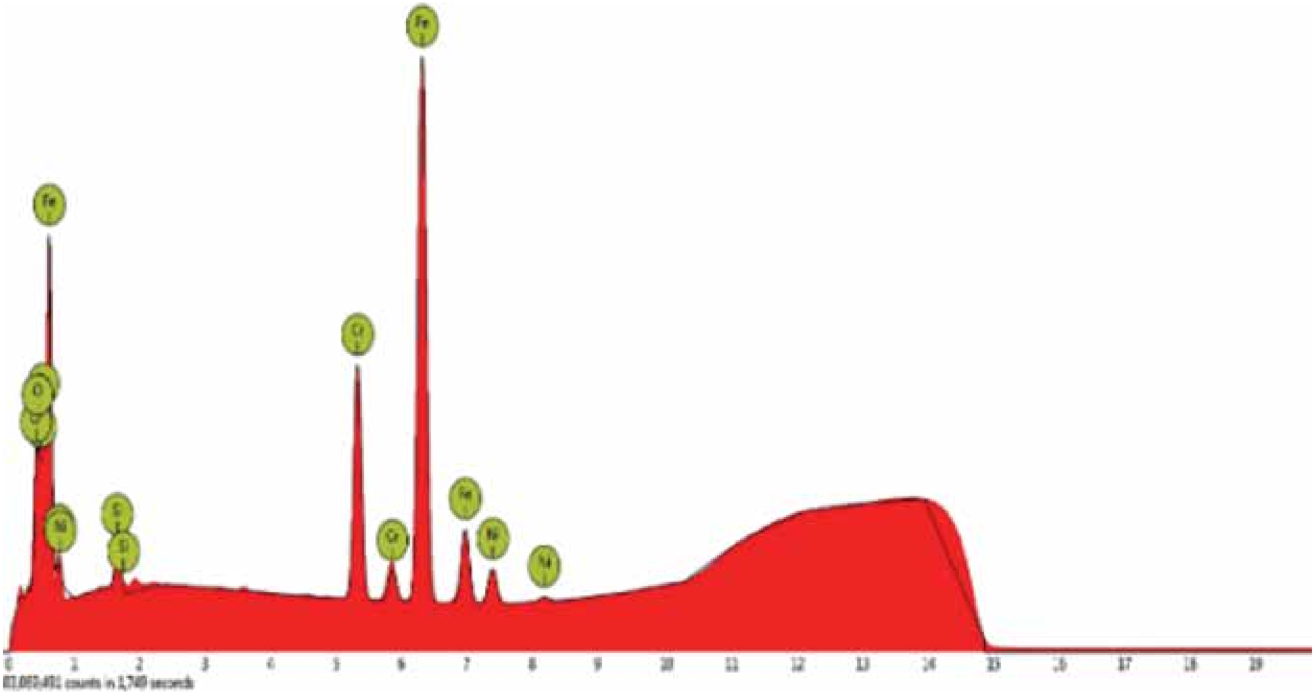
The purity of the metal and the biological environment lead to less corrosion. After corrosion, the resulting products pass into the surrounding biological environment in the form of cations, which are then found in the body at certain levels. As a rule, metal ions react with compounds in the biological environment such as: water, organic compounds, inorganic compounds, tissues. Some of these ions remain free and move through the diffusion gradient, and the rest will combine with organic molecules

a. Ti b. Fe c. Cr

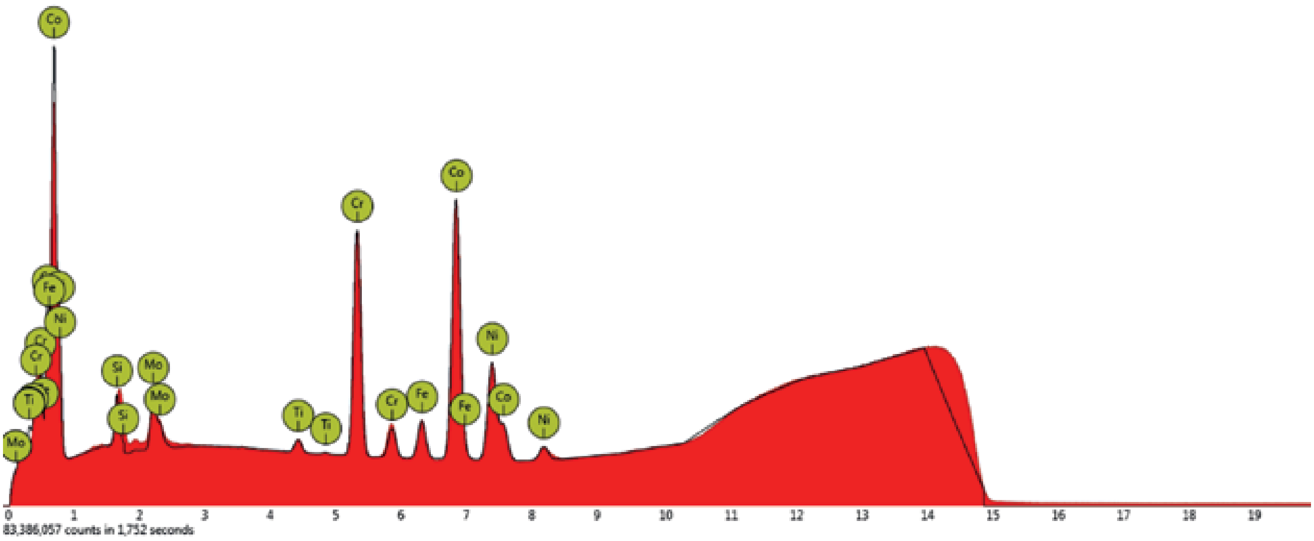
FIGURE 15. Analyzed surface, 1000x

a. Co b. Ti c. Cr

FIGURE 16. Analyzed surface

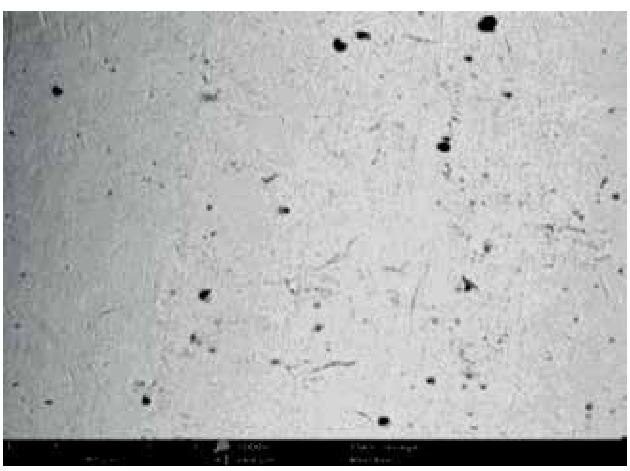


a

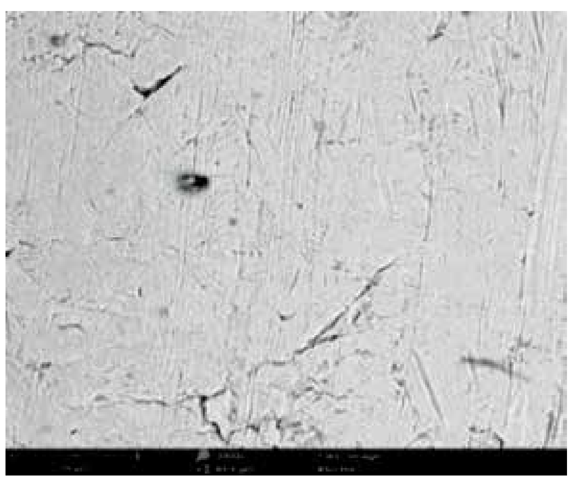


b

FIGURE 17. a. EDS Spectrum (Ti); b. EDS Spectrum (Cr -Co-Mo)



a



b

FIGURE 18. a. Aspects of corrosion Ti; b. Aspects of corrosion Cr-Ni-Mo

and tissues. The amount of the diffused ionsdepends on: their local concentration, their diffusion coefficient, the type of medium surrounding the material. After corrosion, titanium is in the form of trivalent Ti^{3+} ions and binds rapidly with stable organic molecules, thus concentrating mainly at the tissue insertion site [14]. So far, no allergic forms generated by titanium are known. In the presence of other metals, however, it induces a hypersensitivity reaction, which makes it necessary to use titanium in its pure form and without the presence of other metals nearby.

Noble metals have a higher corrosion potential than non-noble materials, which generally corrode more easily and therefore have greater stability. When two materials are placed in an electrolyte solution, such as saliva, the material with the lower corrosion potentialwill definitely corrode. The corrosion phenomenon is dependent on the electrolyte in which the metal is introduced and especially on the environment pH, the concentration of oxygen, chlorine ions, ambient temperature or the sum of all these factors.

All these factors allow us to understand the high negative effects of bimetallism frequently found in the oral cavity and manifesting through metal corrosion and metallosis in biological tissues [15]. After corrosion, the resulting products pass into the surrounding biological environment in the form of cations, which will then be found in the body at certain levels [16]. As a rule, metal ions react with compounds of the biological environment such as water, organic compounds, and inorganic compounds.

Currently, materials used in orthodontic and implant prosthetic therapy are tested in fourtests: urine test, in which the material is inserted into the patient's urine and the corrosion and toxicity phenomenon is monitored; saliva test, in which the corrosion and toxicity phenomenon of a material in the patient's saliva can be analyzed; the skin test, in which patches containing oxides of various materials are applied to the skin of the arm and the local toxicity reaction in the form of local allergic manifestations is monitored; the Helisa test, in which certain corrosion products of various materials are analyzed using isotopes present in the patient's blood.

Regarding the biological environment that surrounds the biomaterial and influences corrosion, the following aspects are mentioned: differential aeration, environmental composition, pH variations, and temperature gradient. At variable aeration the more oxygenated site becomes cathodic and the less oxygenated site anodic. This occurs in areas that are difficult to access for cleaning or in areas covered with tartar or soft tissue. Electrolyte, by its composition, greatly influences the degree of corrosion, especially through chloride ions which sensitize the metal to corrosion.

Chlorine causes variations in Ph, which in the oral cavity is close to 7, and in gum and bone tissue it can reach up to 4.5. Thus, electrochemical corrosion reactions are sensitive to pH changes, with corrosion being more intense in acidic environments [17]. The temperature gradient can also lead to thermopiles that trigger and/or accentuate corrosion. The types of corrosion are closely related to the electrolyte surrounding them, the metals used and the conditions of use of these materials, and different forms of corrosion can occur [18]: uniform corrosion, intergranular corrosion, pitting corrosion, cavernous corrosion, and stress corrosion.

Most researchers [19,20,21], state that metals subject to corrosion process generate anacute tissue reaction with rejection of the inserted material, but the lowest corrosion effect is in titanium. Studies similar to ours have found large amounts of microorganism on the surfaces of mini-implants, establishing a causal relationship with the occurrence of various complications: periimplantitis. The specific responses depend very much on the allergenic and antigenic properties of each individual metal and thediffusion dynamics of each type of ion. Thus, the soft tissue response to stainless steel can be assessed in vivo and in vitro. In vivo, stainless steel is subject to corrosion. In the short-term, stainless steel does not cause toxic reactions, but after 8 months a fibrous capsule appears surrounding the metal, of variable thickness. After one year the phenomenon of metallosis appears, with obvious inflammatory reactions, these reactions favouring with time an advanced degree of corrosion [22].

Several recent studies have attempted to investigate methods of decontamination of mini-implants recovered for reuse. Some authors [23,24] states that regardless of the sterilization method used, the micro-implant surface cannot be considered identical to the original in terms of surface morphological properties, ion release and histological cell response.

The specific biocompatibility of the alloys used in the fabrication of mini-implants has been little studied in biomaterial testing, mainly limited to general cytotoxicity tests. Several procedures are available for in vitro testing, using different cell families, and can test biomaterials and corrosion products to some extent. [25,26]. There are several testing methods, but the most widely used is the low-density seeding method.

The low-density seeding method is the most sensitive method for determining toxicity levels of corrosion products in biomaterials. The agar-agar diffusion method uses mouse fibroblasts, human skin fibroblasts or mouse neuroblasts. This method gives the best results as the cells are easy to culture, with excellent reproducibility and optimal sensitivity. Insertion of an implant leads to tissue injury, with successful healing closely linked to the tissue response around the implant. This response is related to the tissue response to the foreign body and the quality of regeneration of the damaged tissues [27].

Reusing orthodontic mini-screws in the same patient would reduce treatment costs and could lead to longer mini-screw use and improved orthodontic treatment. But the chemical breakdown products and microbial load on the surface make this unlikely. Reuse of medical instruments has a long history and can only be performed when after use they do not undergo any change in surface and clinical characteristics [28].

Over the past two decades, much research has been done to achieve skeletal anchorage using a variety of titanium mini-implants (micro-screws), palatal implants and plates or mini- plates with screws, which did not require osseointegration [29,30,31].

Many authors [32,33,34,35], showed that microimplants with thread diameter less than 1.5 mm do not resist torsion. They maintain their stability after insertion by mechanical anchorage in the bone. The anchorage capacity depends on the surface of the microimplant, its length and diameter. The diameter determines the optimal retention in the bone. The mini-implants used in our study fall within the sizes recommended by most studies.

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CONCLUSIONS

The mini-implants analyzed by SEM show no major structural defects, but there are small deformations of the coils or thread tip. There are no statistically significant differences between the two types of mini-implants titanium and Cr-Co-Mo both showing the same type of deformation and corrosion.

There is not significant difference between the shape (angle or radius) of the orthodontic implants concerning the defects.

These defects do not influence the primary stability rate, especially since mini-orthodontic implants are used for a limited period of time (3 - 6 months). In all cases, there were obvious signs of corrosion and microorganism deposits, which contraindicate the sterilization and reuse of orthodontic anchorage implants.

Titanium is the material of choice for orthodontic anchorage mini-implants due to its multiple qualities, in particular biocompatibility and lower corrosion rate.

The most reliable types of mini-orthodontic implants are the cylindrical-conical, screw-type, 0.5 thread pitch, radius thread form, screw-retained, which cause the least damage to periodontal tissues.

Mini-implants retrieved after primary insertion may show deformation of the tip structure as well as surface contamination, which also requires strict bacterial plaque control.

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