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Corrosion by galvanic coupling between amalgam and different chromium-based alloys

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ABSTRACT

Objectives. In recent years there has been an increase in the use of dental casting alloys in prosthodontic treatment. Many patients have metals or alloys, as well as amalgam fillings, in their mouth, and will have them for many years. The aim of this study was to evaluate and compare, in vitro, the galvanic corrosion behavior of chromium–cobalt alloy (Remanium GM 380) and chromium–nickel alloy (Remanium CS) when bound together or coupled with silver-based amalgam (Amalcap plus).

Methods. An electrochemical characterization of the alloys was performed by potentiostatic and potentiodynamic methods, i.e. the open circuit potential (OCP), the corrosion potential (E_{CORR}), corrosion current density (i_{CORR}) and corrosion resistance (R_p). The electromotive force (EMF) of the bimetallic cells was also tested. Electroanalytical techniques were used to estimate the release of any respective element from the dental alloys under study into the artificial saliva solution.

Results. It was found that a bimetallic cell consisting of Remanium CS and Remanium GM 380 alloys has a very low EMF (a few mV) and is not a potential source of galvanic currents in the oral cavity. However, galvanic cells prepared from Amalcap plus and Remanium CS or Remanium GM 380 showed a much greater EMF: 104 and 109 mV, respectively. This clearly indicates that in these latter cases it is possible to expect some metal ions in the saliva solution as a result of the work of galvanic currents. It was found, by adsorptive stripping voltammetry analysis, that nickel or cobalt, depending on the alloy used, appeared in the saliva solution and increased in concentration over time.

Significance. The results indicate that the correct design and use of dental alloys are important when determining the appropriate treatment for a specific patient.

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1. Introduction

It is well known that dental cast alloys have been used in the manufacture of fixed dental appliances for many years. These devices have to display not only optimal castability, hardness and strength but must also exhibit an excellent resistance to tarnishing and corrosion [1–4].

The corrosive characteristics of dental alloys are of both fundamental and applied interest because corrosion not only affects the functionality of the dental constructions but may also cause pathological phenomena [5,6]. It has long been established that during the corrosion of dental alloys over the long-term, ions of the constituent elements are released into the body [7–11]. The speed of this ionic release is a function

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of the corrosion rate of the alloy and the solubility of the initial corrosion products. The higher the corrosion rate of an alloy, the greater the ionic release and the greater the risk of unwanted reactions in the mouth. These reactions may include unpleasant metallic tastes, allergy, irritation or another reaction.

Corrosion presents the greatest problem in the specification of materials for dental applications. The corrosion of metallic materials implies the reaction of a material with its environment causing a measurable change in the material and properties possibly leading to corrosion damage. This is usually an electrochemical process, but it may be related to a chemical or physical process.

The oral environment is particularly favorable for corrosion. The corrosive process is mainly of an electrochemical nature and natural saliva presents a good electrolyte. Fluctuations in temperature (hot and cold meals), changes in pH because of diet (milk products or acid dressings), and decomposition of food all contribute to the process.

One of the problems associated with the use of metallic materials in dentistry is the possibility of the phenomena of galvanic-type corrosion [12–18]. Galvanic corrosion occurs when dissimilar alloys or metals are placed in direct contact within the oral cavity or within tissue matter. Their interaction may lead to the creation of a galvanic cell, possibly enhancing the amount of ions released. For example, a restoration or prosthesis in physical contact with amalgam in an adjacent tooth may develop galvanic corrosion problems. This process is similar to the corrosion observed from a one Euro coin, consisting of two different nickel alloys, in the perspiring or clammy hand. Nickel ions released here are a result of galvanic corrosion.

The aim of this article is to compare the corrosion behavior of three dental alloys in an artificial saliva solution. The nickel–chromium-based alloy (Remanium CS), the cobalt–chromium-based alloy (Remanium GM 380), and the silver-based alloy (Amalcap plus) were selected for the reported study. An electrochemical characterization of the alloys examined was performed by potentiostatic and potentiodynamic methods. The main parameters determined for all alloys studied were the open circuit potential (OCP), the corrosion potential (E_{CORR}), the corrosion current density (i_{CORR}) and polarization resistance (R_p).

The electromotive force (EMF) of bimetallic cells of two different chromium dental casting alloys when bound together and when coupled with silver-based amalgam was also tested. Galvanic current–time transients were typically characterized by an immediate and rapid rise to a peak current, followed by an exponential decay to a much lower values at 15 and 5000 s.

2. Materials and methods

Two chromium-based alloys (Remanium GM 380, Remanium CS) and amalgam (Amalcap plus) were selected for the study. The compositions of these alloys are listed in Table 1. All electrochemical measurements focusing on corrosive characteristics were carried out on alloy cylinders of 3 mm diameter and 10 mm length. The cylindrical specimens were mounted in a chemically inert plastic shrinking tube and one end

Table 1 – Commercial alloys studied

Alloy	Composition	Manufacturer
Remanium GM 380 (GM-380)	Co 64.6%, Cr 29%, Mo 4.5% + Mn, Si, C	Dentaurum (Germany)
Remanium CS (CS)	Ni 61%, Cr 26%, Mo 5% + Si, C	Dentaurum (Germany)
Amalcap Plus (Am)	Ag 70%, Sn 18%, Cu 12% + Hg	Ivoclar-Vivadent (Lichtenstein)

of each cylinder was polished with a standard metallurgical polishing technique. An electrical contact was established through a 10 cm long copper wire, fixed at the other end of the alloy cylinder and kept in place by the shrinking tube.

A conventional double-wall Pyrex glass electrolysis cell with a three electrode compartment was used. All electrochemical experiments were carried out using a μ Autolab electrochemical analyzer (Eco Chemie, The Netherlands) connected to a PC for control and data storage. The working electrodes (alloy cylinders) were firstly polished with emery paper of a gradually decreasing grade (down to 600 grade), followed by alumina paste (1 μ m). After polishing, each specimen was ultrasonically cleaned in both ethanol and distilled water for 5 min, respectively. The counter electrode was a large-area platinum sheet. All potentials reported in this paper are referenced to a saturated calomel electrode without regard for the liquid junction potential. The measurement cell was thermostatically held at 37 °C and contained an artificial saliva solution according to Fusayama data [19] (concentrations in grams per liter): NaCl, 0.400; KCl, 0.400; CaCl₂·2H₂O, 0.795; NaH₂PO₄·2H₂O, 0.780; Na₂S·9H₂O, 0.005; NH₂CONH₂, 1.000, with a pH of 5.6. The solutions were not deaerated.

Traditional electrochemical measurement techniques were used to obtain information on: open circuit potential (OPC)—potential of an electrode measured with respect to a reference electrode when no current flows to or from the material; E_{CORR} (corrosion potential)—the potential calculated at the intersection of the cathodic and anodic polarization curve where the total oxidation rate is equal to the total reduction rate; i_{CORR} (corrosion current density)—current divided by the surface of the electrode at E_{CORR} ; R_p (polarization resistance)—the slope dE/di at E_{CORR} .

The electrochemical characteristic for each specimen consisted of a number of stages. Firstly, the OCP of each studied alloy was monitored for 6 h. This measurement was performed: (1) starting from -1.0 V (OCP1) and (2) starting from $+1.0$ V (OCP2). Following the OPC measurement two potentiodynamic tests were carried out in order to determine the E_{CORR} and i_{CORR} of each alloy. The first test involved the specimen being maintained at -1.0 V for 2 min to remove surface oxide films and then a cyclic polarization scan was performed from -1.0 V to $+1.0$ V and back to -1.0 V at a scan rate of 1 mV/s. The second test consisted of a Tafel scan (± 300 mV versus OCP at 0.5 mV/s). Additionally, the R_p for each alloy was determined using Electrochemical Impedance Spectroscopy (EIS). The galvanic voltage (EMF) and the galvanic current density

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