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ELECTROCHEMICAL CORROSION OF STAINLESS STEELS IN COMMERCIALLY AVAILABLE SOFT DRINKS

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ABSTRACT

In recent years, there has been a developing trend towards the use of advanced materials in the dental replacement industry. Corrosion mechanisms of 316L Stainless Steel in electrolyte containing common household soft drinks have been studied through investigating the corrosion performance by using electrochemical methods to measure the in-situ corrosion current during the immersion in four commercially available soft drinks. The objective of this research work was to evaluate the effect of electrochemical behavior on the corrosion performance of the material. 316L Stainless Steel was selected because it is commonly used as a dental replacement material. This is an important area of work as the use of steel retainers as well as other stainless steel dental replacements are still widespread and the effectiveness of these devices will be determined by their corrosion resistance performances.

KEYWORDS: stainless steel, soft drinks, electrochemical corrosion

1. Introduction

One of the goals of the implantology research is to design devices that induce controlled, guided, and rapid integration into surrounding tissues. Austenitic stainless steels as 316 L are the materials chosen for many load bearing surgical implants because they combine mechanical strength, excellent corrosion resistance and good biocompatibility [1]. AISI 316 L stainless steel has been successfully applied in medicine due to its biocompatibility and relatively low cost [2, 4]. Different surface engineering techniques can be performed to increase the corrosion resistance of the base metal, in particular when exposed to electrolytes simulating a body and oral fluid, which leads to diverse applications as biomaterial [1]. There is always concern about the corrosion resistance of the 316 L stainless steel in physiological fluids. For this reason, the development of the biomedical implants requires the improvement of their corrosion resistance [3].

There are different procedures established for the surface treatment of biomaterials, some of which depend on the particular application, like orthopedic surgery. The biofunctional behavior of these implant materials are generally governed by volume properties but the interaction with the biologic medium is determined by the characteristics of the surface films [4]. 316L Stainless steel has been employed to fabricate joint screws, prostheses, brackets for a long time due to its excellent mechanical and biomedical properties. However, it has some bioactivity and biocompatibility issues [5]. The corrosion resistance and mechanical properties of stainless steels make them a suitable material for use in medical applications, including dental purposes and orthopedic treatments. The main quality of stainless steel is its resistance to corrosion, which can vary depending on the grade of stainless steel used, where the formation of a passive chromium oxide film (passivation) can protect the material [6].

Most orthodontic appliances are made of a stainless-steel alloy, containing approximately 6% to 12% nickel and 15% to 22% chromium, and, because they are continuously exposed to saliva, the metals must exhibit corrosion resistance. All metals and alloys are subject to corrosion. The alloy ability to be biocompatible appears to be related to its pattern and mode of corrosion [7].

Increased consumption of soft drinks in the population led to the emergence of a new enemy for metallic materials used in orthodontic implants. The fluoride present in commercially available soft drinks is a factor that leads to corrosion of biomedical materials used in dentistry [8].

Fluoride ion concentrations present in soft drinks range from 0.02 to 2.80 parts per million, in part because of variations in fluoride concentrations of water used in production [9].

In dentistry, orthodontics is the branch in which the problem of biocompatibility is most felt, since patients are young and, therefore, more susceptible to develop inflammatory reactions; also, alloys might have toxic effects. It is important to evaluate the biocompatibility and the corrosion resistance of materials used in orthodontic mini-implants and temporary anchorage devices, because their materials are directly inserted to the periodontal tissues and alveolar bones. Metallic ions released from orthodontic mini-implants and temporary anchorage devices might cause a reaction (inflammation or necrosis) in adjacent tissues, such as the oral mucosa and gingival, or alveolar bone [10].

A reason to conduct research in biomedical steel corrosion is given by the fact that some metallic biomaterials such as nitinol alloy releases toxic ions during corrosion causing allergic reactions, local anaphylaxis, and inflammation [11].

For the purpose of hygienic health of the oral cavity, especially for the prevention of tooth decay, fluorides are widely introduced into the oral environment by means of toothpastes, mouth rinses, orthodontic gels and other therapeutic dental products. Additionally, systemic fluorides may be ingested orally through tea, soft drinks, and fluoridated bottled water. Therefore, orthodontic wires, mini implants, and anchorage device, are readily exposed to fluoride medium. [12], an environment that favors the appearance of degradation processes, in particular corrosion of biomedical material. Numerous aggressive anions have been reported for various alloys. Out of these aggressive anions, halides are the most important group which provoke localized corrosion for a lot of metals and alloys such as stainless steel [13].

The principal aim of this research work attempts to evaluate the behaviour and effect of corrosion resistance properties of stainless steel SS 316 L in some commercially available soft drinks solutions and to make a comparison between the specific corrosive characteristics. In this experimental research work it is investigated comparatively the corrosion resistance of 316L stainless steel. All samples have been subjected to corrosion in commercially available soft drinks. The corrosion properties were studied using electrochemical methods such as: open circuit potential (OCP), polarization resistance (Rp) and potentiodynamic polarization (PD).

2. Experimental set-up

The corrosion experiments were performed on stainless steel 316 L. For corrosion measurements, all the samples were cut to the dimensions of 25 x 25 x 2 mm.

Samples used in the experimental protocol have been bonded with copper wire and insulated with epoxy resin to obtain a well determined active measurable surface area. The stainless steel (SS) 316 L samples were degreased with alcohol and acetone.

The chemical composition of SS 316 L can be found in the Table 1.

Table 1. *Chemical composition of 316 L stainless steel, in %*

Grade		C	Mn	Si	P	S	Cr	Mo	Ni	N
SS316L	Min	-	-	-	-	-	16.0	2.00	10.0	-
	Max	0.03	2.0	0.75	0.045	0.03	18.0	3.00	14.0	0.10

In order to perform the corrosion experiments it was used a standard three-electrode cell consisting of the tested samples as working electrode, a Pt-Rh grid used as auxiliary electrode and saturated calomel electrode (SCE) (saturated KCl solution, E = -244 mV vs. normal hydrogen electrode (NHE)) as reference electrode.

Table 2. *Characteristic of soft drinks*

Type of soft drink	pH	Conductivity [mS]	Salinity [ppt]	TDS [mg/L]	E [mV]
Energizing soft drink	3.63	1.82	0.9	0.11	89
Orange Juice	2.87	0.84	0.4	446	110
Cola Soft drink	2.85	1.16	0.6	0.61	108
Orange soda	2.87	0.738	0.4	394	109

As the electrolytes were used four commercially available soft drinks. In Table 2 are shown the characteristics of soft drinks.

The experiments were done using a Potentiostat / Galvanostat PGZ 100 and the data were recorded with VoltaMaster 4 software and edited with graphical software.

3. Results and discussion

3.1. Open circuit potential (OCP)

The potential-time measurements of the stainless steel 316 L surface studied in four different commercially available soft drinks are shown in Fig. 1. The evolution of OCP was monitored for 1 hour of immersion for each sample.

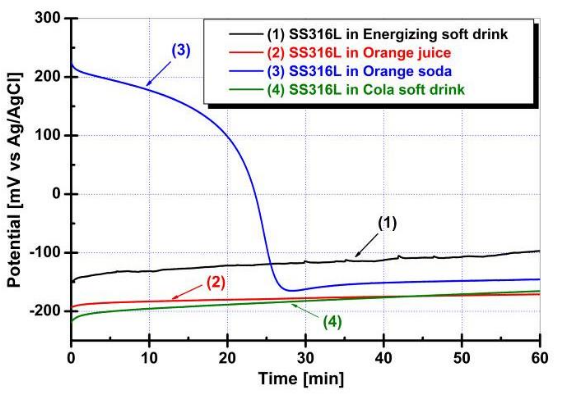

***Fig. 1.** Variation of open circuit potential with time: (1) SS 316L immersed in energizing soft drink solution, (2) SS 316L immersed in orange juice solution, (3) SS 316L immersed in orange soda solution and (4) SS 316L immersed in cola soft drink solution*

For the samples immersed in energizing soft drink solution, the OCP increases slightly and reaches a steady-state around -115 mV vs. Ag/AgCl. The increasing trend of potential reveals the increase of protective layer and improvement of corrosion resistance. The same growth trend can be seen in the case of SS 316 L immersed in orange juice and cola soft drink. The potential of SS 316 immersed in orange juice is stabilized at a value around -197 mV vs. Ag/AgCl, and in the case of SS 316 L immersed in cola soft drink the potential value is stabilized around -175 mV vs. Ag/AgCl. This is associated with an improved behavior of corrosion resistance.

The OCP of SS 316 L immersed in orange soda decreases gradually from the noble value of +226 mV vs. Ag/AgCl to a more active value of -145 mV vs. Ag/AgCl during about 30 minutes of the immersion time. After 30 minutes the free potential value is stabilized in this solution at a mean value of -145 mV vs. Ag/AgCl.

3.2. Evolution of polarization resistance during immersion time

Linear polarization resistance (R_p) is the only corrosion monitoring method that allows corrosion rates to be measured directly, in real time.

The evolution of polarization resistance was performed by linear polarization method around free potential value with a very small overvoltage value of (± 40 mV) in order to keep the steady state of the surface.

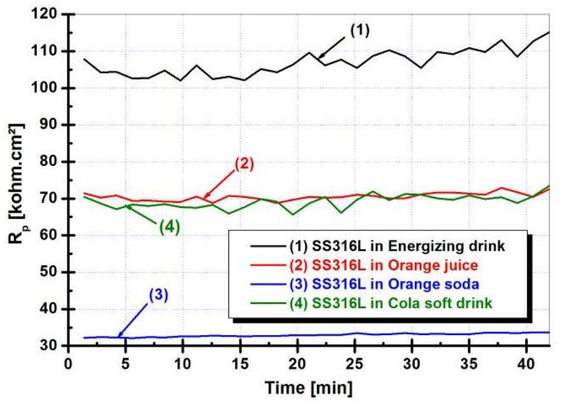

***Fig. 2.** The evolution of R_p values during immersion time of: (1) SS 316L immersed in energizing soft drink solution, (2) SS 316L immersed in orange juice solution, (3) SS 316L immersed in orange soda solution and (4) SS 316L immersed in cola soft drink solution*

The polarization resistance values of the 316L stainless steel surfaces studied in four different commercially soft drinks are presented in Fig. 2. In Fig. 2 it can be seen that the higher polarization resistance value is attained by the SS 316 L immersed in energizing soft drink solution, being equal to 115 kohm·cm^2, this value increasing slowly during the immersion time.

In Fig. 2. it can be seen that the lowest polarization resistance (R_p) value is attained by the SS 316 L immersed in orange soda being equal to 33 kohm·cm^2. In the case of stainless steel SS 316 L immersed in orange juice, R_p reaches a mean value of 72 kohm·cm^2 and for stainless steel 316 L immersed in cola soft drink the free potential mean value is similar to 72 kohm·cm^2.

According to the data presented in Fig. 3 it can be seen that the higher corrosion rate corresponds to SS 316 L immersed in orange soda. From the corrosion rate evolution shown in Fig. 3 it can be also seen a good stability of SS 316L immersed in energizing soft drink having a very low value of corrosion rate.

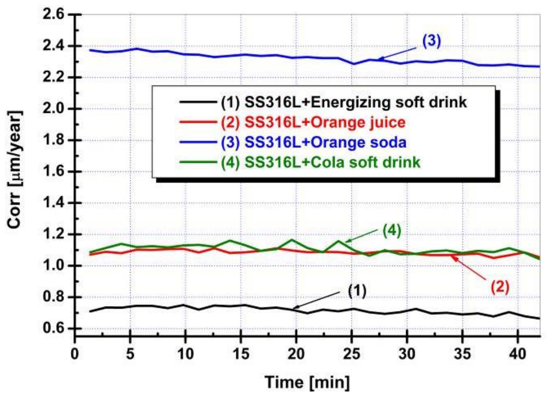

Fig. 3. *Evolution of corrosion rate during immersion period for: (1) SS 316L immersed in energizing soft drink solution, (2) SS 316L immersed in orange juice solution, (3) SS 316L immersed in orange soda solution and (4) SS 316L immersed in cola soft drink solution*

An increased value of polarization resistance means a lower corrosion current density and therefore a lower corrosion rate, as it can be seen in Figs. 2 and 3.

In the case of SS 316 L immersed in orange juice and cola soft drink solutions the corrosion rate values obtained are almost equal for both drinks.

3.3. Potentiodynamic polarization

The diagrams I = f(E) (current density-potential curves) were recorded in a range of potentials starting from -1500 mV vs. Ag/AgCl to +1500 mV vs. Ag/AgCl at a scan rate of 5 mV/s. Potentiodynamic polarization diagrams were performed to assess the polarization domains of stainless steel 316 L, immersed in four commercially soft drinks. The passive state is usually studied with respect to corrosion protection. If the passive state covers a higher potential domain and the passivation current value is smaller, then the metal or alloy shows a high corrosion resistance in this environment.

In Fig. 4 are presented the potentiodynamic polarization diagrams of these four surfaces which were studied in four commercially available soft drinks. It can be observed a higher current density values for 316 L Stainless Steel in cathodic domains for all solutions and a large passive domain only for three solutions. The higher current in the anodic domain for 316 SS immersed in orange soda suggests a general dissolution with a high corrosion rate. The passive current densities of SS 316 L immersed in energizing soft drinks, orange juice and cola are very low, being close to zero, revealing a better corrosion resistance compared with SS 316 L immersed in orange soda. In the zoom of Fig. 4, which is presented in Fig. 5, it can easily be observed the differences revealed for SS 316 L immersed in the four commercially available soft drinks. Practically, the stainless steel immersed in orange soda drink solution did not present a passive domain, having a continuous dissolution behaving as if the passive film was dissolved by this solution.

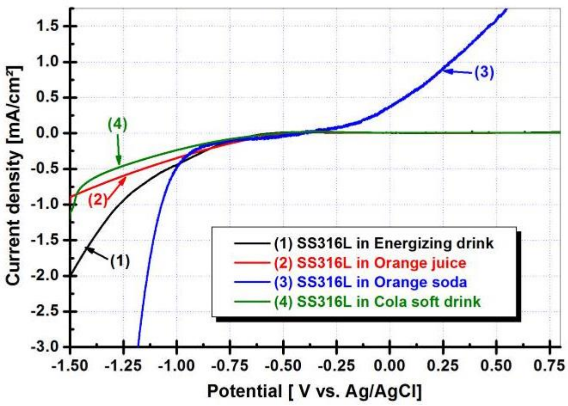

Fig. 4*. Potentiodynamic polarization curves of: (1) SS 316L immersed in energizing soft drink solution, (2) SS 316L immersed in orange juice solution, (3) SS 316L immersed in orange soda solution and (4) SS 316L immersed in cola soft drink solution*

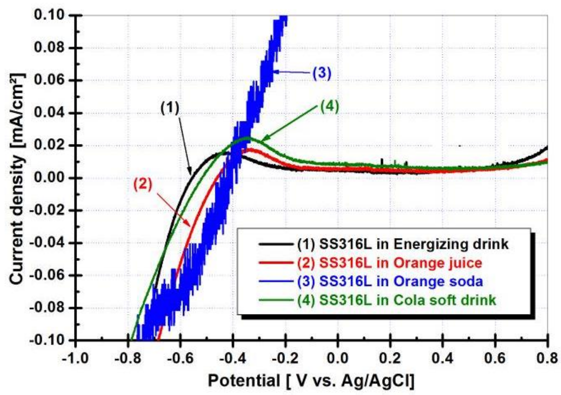

Fig. 5. *Zoom at lower passivation current density of potentiodynamic polarization curves of: (1) SS 316L immersed in energizing soft drink solution, (2) SS 316L immersed in orange juice solution, (3) SS 316L immersed in orange soda solution and (4) SS 316L immersed in cola soft drink solution*

In Fig. 4 in the monitored potential interval, there were identified three different potential domains for SS 316 L immersed in orange soda drink solution: cathodic domain, passive domain and transpassive domain. In the cathodic domain, the passive film is destroyed by the hydrogen reduction reaction, while in passive domain the passive film is formed by the oxidation process. In transpassive domain the passive film is damaged and the dissolution occurs through passive film.

For the stainless steel immersed in orange juice, energizing, and cola drinks solutions, in the monitored potential interval it can be identified only a cathodic and the passive domain which is comprised in very large potential range. Also, these three types of solution show very low passive current densities values compared with SS 316 L immersed in orange soda drink, fact which reveals a good corrosion performances SS 316 L immersed in energizing soft drinks, orange juice and cola, as it is shown in Fig. 5. The lowest passive current density values are almost equal for stainless steel immersed in the three commercially available solutions of orange juice, cola and energizing drink.

4. Conclusions

The corrosion behavior of SS 316 L immersed in four commercially available soft drinks solutions - energizing soft drink, orange juice, orange soda and cola soft drink - was investigated in this work. The following conclusions can be drawn.

- The evolution of open circuit potentials during immersion time in the four commercially available drink solutions show the nobler value for stainless steel immersed in energizing drink. The orange soda affects the surface of stainless steel by dissolving the natural oxide passive film and making the free potential to shift down to more active values. The other two drinks like orange juice and cola have about the same corrosive effect on 316 stainless steel, which shows about the same free potential values at immersion in these solutions.

- The SS 316 L immersed in energizing soft drink solution presents the highest polarization resistance in comparison with other solutions, suggesting an increased corrosion resistance.

- The higher corrosion rate corresponds to SS 316 L stainless steel immersed in orange soda juice compared with other three types of soft drinks solution.

- The passive states cover a higher potential domain and the passivation current values are smaller for 316 L stainless steel immersed in energizing soft drink, orange juice and cola soft drink than those values of SS 316 L immersed in orange soda drink, proving once again a high corrosion resistance, and good behavior of SS 316 L immersed only in three drinks.

- By using stainless steel 316 L in dental implantology as it is recommended by its good behavior in corrosion environments of soft drinks, much attention must be paid to consuming orange soda.

- The long lifetime of the stainless steels in dental replacements have to be under recommendations concerning some forbidden commercially available drinks.

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