EFFECT OF THE pH OF ARTIFICIAL SALIVA ON ION RELEASE FROM COMMERCIALY PURE TITANIUM

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Due to their excellent characteristics, such as chemical inertness, mechanical resistance, low Young’s modulus, high corrosion resistance, and outstanding biocompatibility, titanium and its alloys are the most used metallic materials for biomedical applications. In dental practice, these materials have demonstrated success as biomedical devices which are used for repairing and replacing failed hard tissue. However, the oral cavity is constantly subjected to the changes in the pH value changes and such an environment is strongly corrosive for titanium dental implants. The objective of this study was to examine ion release from commercially pure titanium (cpTi) in artificial saliva with different pH values (4.0, 5.5 and 7.5). The concentrations of released titanium ions were determined after 1, 3 and 6 weeks using Inductively Coupled Plasma - Mass Spectrometry. The results indicate that the ion release from commercially pure titanium in the artificial saliva is dependent both on the pH of artificial saliva and duration of immersion.

KEY WORDS: cpTi, ion release, artificial saliva, pH value, immersion time, ICP-MS

INTRODUCTION

In both medical and dental practice, metallic biomaterials are mainly used for the damaged hard tissue replacements (1). Metallic biomaterials used for the manufacture of the implants must possess the following properties: non-toxicity, considerable biocompatibility, high corrosion resistance, good wear resistance, high strength and toughness, and low Young’s modulus (2). Stainless steels, commercially pure titanium (cpTi), titanium- and cobalt-based alloys are the main metallic materials used in biomedicine (3). In dental practice, titanium and its alloys have demonstrated success as biomedical devices such as implants, crowns, bridges, overdentures and dental implant prosthesis components (screw and abutment). Also, titanium and its alloys are widely used for manufacturing different implant devices, such as artificial hip joints, artificial knee joints, bone plates, fracture fi-
screws, cardiac valve prosthesis, and pacemakers. Compared with stainless steels and cobalt-based alloys, titanium is superior in specific strength (strength-to-density ratio), but inferior in tribological properties. In addition, the Young’s modulus of titanium is about 50% lower compared to that of stainless steels and cobalt-based alloys (4). In fact, in most cases, titanium has been the first choice for dental implants due to its extraordinary specific strength, low Young’s modulus, outstanding biocompatibility and excellent corrosion resistance, both in air and biological fluids (5-8). The main physical properties of titanium responsible for its biocompatibility are: low level of electric conductivity, thermodynamic state at the physiological pH values and low ion-formation tendency in aqueous environments (9). Furthermore, under atmospheric conditions or in solutions titanium reacts quickly with moisture or water molecules, and a very stable passive oxide layer is formed on its surface. These titanium oxide surfaces are well tolerated in contact with bones (10). Actually, titanium favors osseointegration with the surrounding bone tissue and this capability is responsible for its success in dental implant applications (11).

According to the ASTM F67-13, unalloyed cpTi is represented by four grades marked with numbers from 1 to 4 due to small, but strictly defined differences in composition and mechanical properties (12). Larger grade numbers indicate higher ultimate tensile and yield strength values, but lower percentage of elongation. It should be noted that the production of pure titanium is extremely difficult due to its high reactivity. In fact, cpTi is an alloy of titanium and oxygen. However, titanium high reactivity is one of its advantages because the thin, adherent and impermeable TiO₂ oxide layer formed on the surface is extremely stable and has a passivating effect on the titanium surface. Passivation does not mean that the metallic material will not corrode in the human body environment, but corrosion resistance is significantly increased in the presence of such a stable oxide layer (13). Additionally, any surface damage can be self-repaired quickly, as illustrated in Fig. 1. Furthermore, the composition of surface oxide layer is changing in accordance with biological surroundings, even though the oxide layer is macroscopically stable, as illustrated in Fig. 2. (13,14).

![Figure 1. Regeneration of the surface oxide layer (13)](image)

Corrosion resistance of titanium must be sufficiently high since the contact between titanium dental implants and human saliva results in corrosion appearance (15). In fact, corrosion occurs when the passive oxide layer is damaged by friction and micro-movements. The release and transport of metallic ions as a direct consequence of corrosion of implant materials were the objective of many studies (16-19). The available literature data show that the oral cavity is constantly subjected to changes in the pH and that such an environment is strongly corrosive for dental implants. Therefore, the aim of this study
was to examine ion release from cpTi in artificial saliva with different pH values over different immersion periods.

**EXPERIMENTAL**

Since the objective of the present study was to investigate ion release from cpTi in artificial saliva with different pH values, the cpTi grade 2 was chosen for this purpose, as the most commonly used cpTi grade for dental implant manufacture. The examined material was supplied by Fiko Ltd, Ukraine. Its chemical composition and mechanical properties, defined by the manufacturer in accordance with ASTM F67–13 standard (12), are given in Table 1 and Table 2, respectively.

**Table 1. Chemical composition of cpTi grade 2 according to the ASTM F67-13 standard (12)**

<table>
<thead>
<tr>
<th>Element</th>
<th>C max</th>
<th>Fe max</th>
<th>H max</th>
<th>N max</th>
<th>O max</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal weight, %</td>
<td>0.10</td>
<td>0.30</td>
<td>0.015</td>
<td>0.03</td>
<td>0.25</td>
<td>Balance</td>
</tr>
</tbody>
</table>

**Table 2. Mechanical properties of cpTi grade 2 according to the ASTM F67-13 standard (12)**

<table>
<thead>
<tr>
<th>Property</th>
<th>Yield Strength, min. MPa</th>
<th>Ultimate Tensile Strength, min. MPa</th>
<th>Elongation, %</th>
<th>Elastic Modulus, GPa</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>275</td>
<td>345</td>
<td>20</td>
<td>103-107</td>
</tr>
</tbody>
</table>
CpTi was cut into the disc-shaped samples (8.0 mm in diameter and 3.2 mm in thickness) and metallographically ground and polished. In order to remove impurities present on the surface, the samples were subjected to ultrasonic cleaning in ethanol. After washing with distilled water and drying with sterile gauze, each sample was placed in a separate hermetically closed glass test tube with 5 ml of testing solution. Afterwards, the test tubes were placed in a thermostat at 37°C in order to simulate temperature of the oral cavity.

The testing solution used in this study was artificial saliva made in the laboratory and its composition is shown in Table 3. The initial pH value of artificial saliva was 6.8. In order to analyze the effects of the pH of the artificial saliva on metallic ion release from cpTi, the pH value was lowered to the level of 5.5 and 4.0 by adding hydrochloric acid and increased to the level of 7.5 by adding sodium hydroxide solution.

The concentrations of released titanium ions were quantified after 1, 3 and 6 weeks using Inductively Coupled Plasma - Mass Spectrophotometer (Agilent ICP MS 7500ce).

Table 3. Composition of the artificial saliva with the initial pH value of 6.8

<table>
<thead>
<tr>
<th>Component</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl</td>
<td>0.0856</td>
</tr>
<tr>
<td>KCl</td>
<td>0.1200</td>
</tr>
<tr>
<td>MgCl₂ x 6H₂O</td>
<td>0.0052</td>
</tr>
<tr>
<td>CaCl₂ x 2H₂O</td>
<td>0.0148</td>
</tr>
<tr>
<td>Mannitol</td>
<td>0.2000</td>
</tr>
<tr>
<td>KH₂PO₄</td>
<td>0.0272</td>
</tr>
<tr>
<td>K₂HPO₄</td>
<td>0.0456</td>
</tr>
<tr>
<td>Carbomer 974P</td>
<td>0.1000</td>
</tr>
<tr>
<td>NaOH 10%</td>
<td>0.4000</td>
</tr>
<tr>
<td>Purified water</td>
<td>96.9016</td>
</tr>
</tbody>
</table>

RESULTS AND DISCUSSION

The concentrations of titanium ions released from cpTi grade 2 in the artificial saliva with different pH values (4.0, 5.5 and 7.5) after 1, 3 and 6 weeks are presented in Fig. 3.

As can be seen in Fig. 3, the ion release from cpTi in the artificial saliva is dependent both on the pH of artificial saliva and the duration of immersion. The pH of human body fluids is usually within the range of 7.0 - 7.35, while human saliva is slightly acidic (pH ~ 5.8). In the oral cavity, extremely low pH values (2.0 - 3.0) can occur in the case of its pathological diseases (20-22). In healthy population, low pH values cannot be maintained for a long period because of the buffering action of the human saliva and such a low pH value was not considered in this study. The decrease of the pH value lead to the increase of the concentrations of released titanium ions.
Figure 3. Concentrations of released titanium ions in artificial saliva after: a) one week, b) three weeks and c) six weeks.
With increasing immersion time, the concentrations of released titanium ions were increased, as is shown in Fig. 4. The relation between the concentrations of released ions and the immersion time is in accordance with the literature data (23).

![Figure 4. Dependence of the released titanium ion concentration on the immersion time](image)

Generally, the metallic ion release from the dental implant material depends on numerous factors, such as material composition, sample dimensions, type, composition, temperature, pH value, volume of testing solution, etc. (24-26). Hirayama et al. (27) analyzed ion release from cpTi in mixed solutions of organic acids normally present in human saliva. They concluded that there were significantly larger amounts of released titanium ions in the mixed organic acid solutions than in the lactic acid solution. In the presence of chloride and fluoride ions, the corrosion rate is increased being higher in fluoride media (28). As a matter of fact, dental implants are subjected to whole human saliva, which contains various substances, such as plaque constituents, gingival crevice fluid, proteins, microorganisms and organic acids, so further analysis will include different testing solutions in order to determine influence of composition of testing solution on the metallic ion release. Generally, cpTi is considered the best biocompatible metallic material for dental application because its surface properties result in the spontaneous formation of a stable passive oxide layer.

**CONCLUSION**

The results of the study of the ion release from cpTi grade 2 in artificial saliva of different pH values indicate that the concentrations of released titanium ions increased with increasing immersion time. Also, the decrease of the pH value led to the increase of the concentrations of released titanium ions. Mechanical resistance, chemical inertness, absence of toxicity, extraordinary specific strength, low Young’s modulus, and outstanding biocompatibility of titanium, combined with low ion-release tendency, confirmed in this study, recommend the usage of cpTi as a biomaterial for dental implants.
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REFERENCES


УТИЦАЈ рН ВРЕДНОСТИ ВЕШТАЧКЕ ПЉУВАЧКЕ НА ОТПУШТАЊЕ ЈОНА ИЗ КОМЕРЦИЈАЛНО ЧИСТОГ ТИТАНА

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Титан и његове легуре су најчешће коришћени метални материјали за биомедицинску примену због њихових одличних карактеристика, као што су хемијска инертност, механичка отпорност, низак Јунгов модул, висока отпорност на корозију и изванредна биокомпатибилност. У стоматолошкој пракси, титан и његове легуре су показали успех као биомедицински уређаји, који се користе за поправку или замену оштећених чврстих ткива. Међутим, усна дупља је стално изложена променама рН вредности и таква средина је изузетно корозионога за денталне им-
плантате израђене од титана. Циљ овог рада је био да се испита отпуштање јона из комерцијално чистог титана (срТи) у вештачкој пљувачи различите рН вредности (4.0, 5.5 и 7.5). Концентрације отпуштених јона титана су одређене после 1, 3 и 6 недеља коришћењем индуктивно спрегнуте плазме са масеном спектрометријом (ICP-MS). Резултати показују да отпуштање јона из комерцијално чистог титана зависи и од рН вредности вештачке пљувачке и од дужине трајања потапања.

Кључне речи: срТи, отпуштање јона, вештачка пљувачка, рН вредност, време потапања, ICP-MS

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