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REVIEW

A study on corrosion behavior of SS316L and Ti-6Al-4V dental implant materials

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This study represents the work carried out on the study of corrosion behavior of SS316L and Ti-6Al-4V that are used as implants in dental applications. This work was carried out to determine the corrosion performance and corrosion resistance of implant materials in physiological conditions of the human body. The results were evaluated through precision measurement of parameters, namely, electrochemical impedance spectroscopy (EIS) and open circuit potential (OCP). The corrosion test was carried out in a three-electrode cell system for a time duration of 3 h at 37°C in Hanks' balanced salt solution that was used as the corrosion testing media. The results showed that the corrosion potential (E_{corr}) is increasing and reached a maximum value of 0.147 and 0.108 for SS316L and Ti-6Al-4V, respectively. Hence, the study revealed that SS316L exhibits better corrosion properties than Ti-6Al-4V to overcome problems encountered with vanadium.

Keywords: SS316L, Ti-6Al-4V, Hanks balanced salt solution, OCP, EIS

1. Introduction

Biomaterial a viable substance that can be used either independently or as part of a system that treats, compliments, or replaces organs, tissues, or human body and performs its function. Such a material may be naturally occurring or synthetic. Biomaterials should possess properties such as biocompatibility, bio inertness, high wear resistance, and corrosion resistance (1).

A dental implant is a substitute for artificial tooth, which replaces the original tooth in the jaw bone (2). Precious metals that were used in dentistry are Ag, Au, steel, and their alloys because of their good resistance to corrosion, ductility, and cast ability. During the early days, the high cost of these materials led to the development of base metal alloys for dentistry applications. These base metals exhibited better aesthetics and mechanical properties in some oral environment applications. As a result, certain base metals were preferred due to their lower density and good mechanical properties. The most commonly used base metals in dentistry are stainless steel, titanium, cobalt-chromium, and nickel-titanium (3).

When a metal is placed in a medium, it results in the release of ions into the microenvironment. This causes deterioration of the metal, and we define this as corrosion. When corrosion takes place in a dental implant, it decreases the fatigue life of the implant and finally affects the strength of the implant, thus resulting in mechanical failure of the implant (4). The implant can also undergo fracture because of fatigue. Inside the human mouth, saliva and salt have the effect of weak electrolytes, resulting in many forms of electrochemical corrosion. The corrosion of dental implants depends on oxidation and reduction reactions and also on certain factors that physically prevent corrosion. Corrosion of metallic implants is given more importance because it may result in affecting of mechanical integrity and biocompatibility of the implant materials. Corrosion can also be influenced by the pH changes occurring in the human body. Implant corrosion can be determined through physical characteristics such as thermodynamic forces in which corrosion can occur through reduction or oxidation reactions and kinetic barriers like surface oxide layer which temporarily avoids corrosion reaction. The corrosion issues occurred are not limited to local problems because the particles that are produced due to corrosion may transfer to other parts of the implant (5).

Stainless steel has been used in dentistry for almost a century. The first stainless steel used in dentistry for implantation consisted of 18wt% Cr and 8wt%Ni which was stronger than steel and corrosion resistant. Later, the properties of stainless steel were improved by the addition of molybdenum (Mo) which was known as type 316. Then, the reduction of carbon (C) content from 0.08wt% to 0.03wt% improved the corrosion resistance of stainless steel which was named type 316L (6).

Titanium alloy (Ti-6Al-4V) has widely been used in dentistry applications due to its good biocompatibility and fatigue strength. However, these alloys are subjected to certain limitations. These alloys release metal ions into the bloodstream which cause tissue sensitivity around the implantation. Studies have shown that the presence of vanadium produces oxides which are dangerous to the human body. Therefore, the toxicity of vanadium had led to studies of other dental biomaterials that can replace Ti-6Al-4V (7).

Most important factor for any biomaterial is evaluated by its corrosion behavior. Hence, the first step in the development of new biomaterials is to evaluate the corrosion parameters and check biocompatibility by in vitro MTT assay or test. The corrosion behavior of the biomaterials mainly depends on a protective passive film. Therefore, for determining passive film composition, in vitro corrosion test is carried out (8).

2. Research elaborations

Both SS316L and titanium alloy (Ti-6Al-4V) dental implant materials were used to evaluate their corrosion behavior by using electrochemical corrosion studies. The composition of the materials was tested by using an optical emission spectrometer BAIRD DV6. The composition of the materials used is depicted in **Table 1**.

TABLE 1 | Composition of the SS316L and Ti-6Al-4V materials.

SS316L	C	Si	Mn	P	S	Cr	Mo	Ni	N	Fe
	0.03	0.408	1.731	0.041	0.030	16.680	2.057	10.311	0.10	Bal
Ti-6Al-4V	**Ti**	**AL**	**V**	**Fe**	**C**	**N**	**H**	**O**	**-**	**-**
	89.765	6	4	0.1	0.01	0.015	0.03	0.08	-	-

The experiment was carried out using a three-electrode cell system. A reference electrode is referred to as saturated calomel electrode and the counter electrode is made of platinum wire. Hanks' balanced salt solution with a pH value of 7.2 was selected as corrosion media to match the physiological human body environmental conditions. The physical composition of Hanks' balance salt solution is given in **Table 2**. The test was carried out for about 3 h at a temperature of 37°C. In this experiment, the open circuit potential (OCP) parameter and electrochemical impedance spectroscopy (EIS) measurement were measured.

3. Results or findings

3.1 Open circuit potential (OCP) measurement method

Open circuit potential is the easiest method to study the corrosion behavior of the materials. The formation of the film on the implants in the solution can be studied and potential can be plotted as a function of time. Increase in potential shows the formation of film and steady-state potential shows that the film is protective, and decrease in potential results shows the dissolution of film or no film formation or break in the film.

Figure 1. Represents the measurements of SS316L and Ti-6Al-4V OCP in HBSS measured for 3 h at 37°C. The performance of corrosion can be evaluated from the analysis of OCP measurements. From the results obtained, graph was plotted for time versus potential for SS316L and Ti-6Al-4V. The curves represent a continuous rise in potential and thus reveal a film formation. It clearly shows that the curves run parallel to each other and are quite similar. The corrosion potential (E_{corr}) is increasing and reached a maximum of 0.147 for SS316L and 0.108 for Ti-6Al-4V. It is seen that the corrosion potential (E_{corr}) is more for SS316L. Hence, it can be evaluated that SS316L exhibits superior corrosion performance than Ti-6Al-4V in Hanks' balanced salt solution.

TABLE 2 | Composition of Hanks' balanced salt solution.

Components	mg/L
Calcium chloride (anhydrous)	140
Magnesium chloride	100
Magnesium sulphate	100
Potassium chloride	400
Potassium phosphate	60
Sodium bicarbonate	350
Sodium chloride	8000
Sodium phosphate (dibasic)	48
D-Glucose (dextrose)	1000

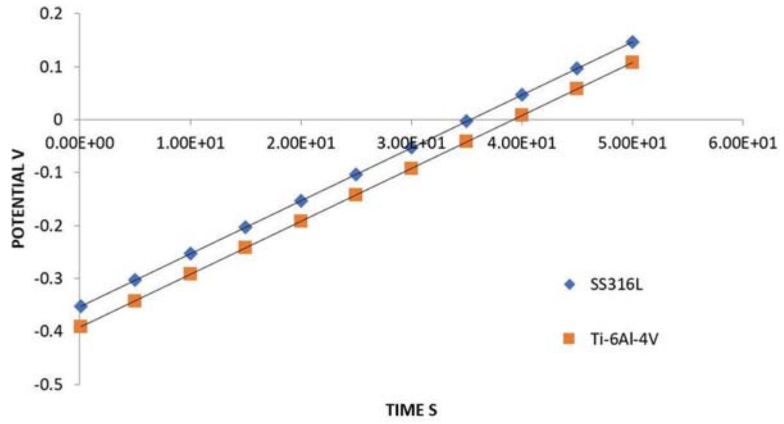

FIGURE 1 | OCP measurements of SS316L and Ti-6Al-4V in HBSS measured for 3 h.

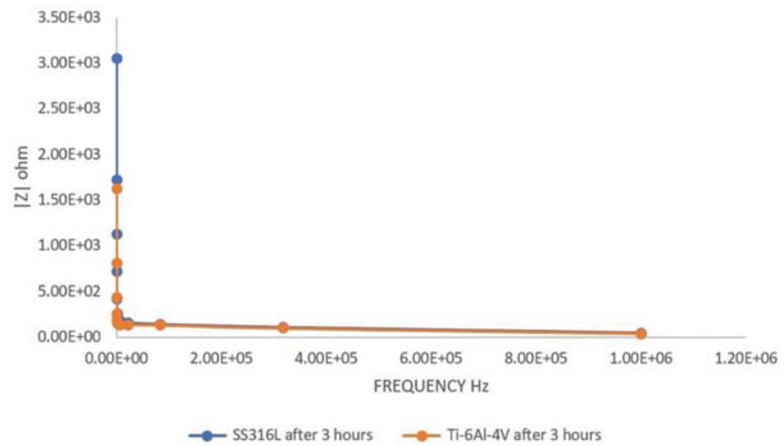

FIGURE 2 | EIS measurements of SS316L and Ti-6Al-4V in HBSS measured for 3 h.

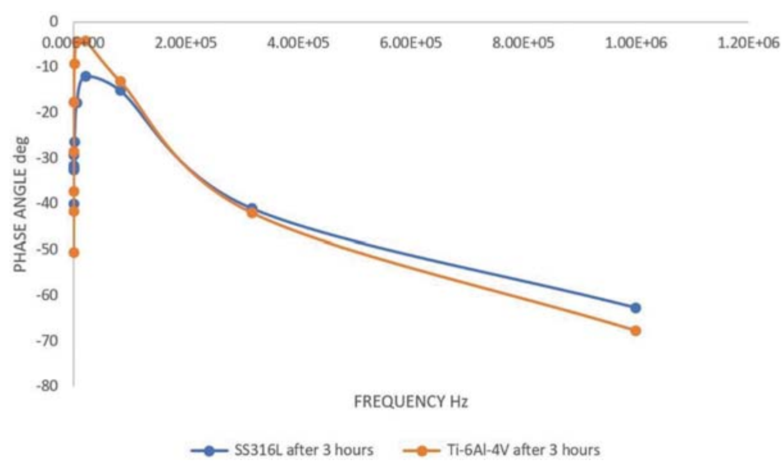

FIGURE 3 | EIS measurements of SS316L and Ti-6Al-4V in HBSS measured for 3 h.

3.2. Electrochemical impedance spectroscopy (EIS) measurement method

The most effective method to study corrosion behavior is the EIS measurement method where the response of the material subjected to corrosion is applied by a small amplitude signal that depends on the frequency of the signal. The behavior of impedance of a specimen can be expressed as Bode plots of impedance modulus |Z| which represents a function of frequency and phase angle.

Figures 2, 3 represent the EIS measurements of SS316L and Ti-6Al-4V in HBSS measured for 3 h at 37°C. Bode plots are plotted for frequency versus current Z and frequency and phase angle for SS316L and Ti-6Al-4V, respectively. From the above graphs, we can observe that the region of higher frequency |Z| tends to be constant as the values of the phase angle decrease to zero for increasing frequencies. The impedance results indicate the formation of a passive layer on both materials SS316L and Ti-6Al-4V which resists corrosion. The film formed consists of a higher impedance inner barrier layer which is responsible for the protection of surface from corrosion and a lower impedance outer porous layer which facilitates osseointegration. The maximum corrosion resistance of SS316L was 3.06E+03 and that of Ti-6Al-4V was 1.63E+03. Hence, it can be evaluated that SS316L exhibited better corrosion resistance than Ti-6Al-4V placed in Hanks' balanced salt solution.

4. Conclusion

The electrochemical corrosion technique used in this study provides the following conclusions. It was evaluated that SS316L exhibited better corrosion performance than Ti-6Al-4V and indicated the presence of film formation. The EIS results exhibited that the film formed is a two-layered oxide which consisted of an inner barrier layer that has a high impedance which is responsible for the protection of surface from corrosion and an outer porous layer that has lower impedance which leads to osseointegration. The results also showed that the corrosion potential (E_{corr}) is increasing and reached a maximum value of 0.147 and 0.108 for SS316L and Ti-6Al-4V, respectively. Hence, the study revealed that the SS316L exhibits better corrosion properties than Ti-6Al-4V to overcome the problems encountered with vanadium.

Author contributions

All authors have carried out this research work and agree to be accountable for the content of the work.

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