In Vitro Evaluation of the Corrosion Resistance and Biocompatibility of Different Dental Implant Metals

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Abstract: Objective: To evaluate the corrosion resistance and biocompatibility of different dental implant metals in vitro.
METHODS: Six dental implant metals (titanium, titanium alloy, stainless steel, cobalt-chromium alloy, nickel-titanium alloy, and zirconium) were evaluated for corrosion resistance using electrochemical impedance spectroscopy and potentiodynamic polarization tests. Biocompatibility was assessed using cell culture tests with human osteoblast-like cells.
RESULTS: Titanium and titanium alloy showed the highest corrosion resistance (10.2 ± 0.5 Ω/cm² and 9.5 ± 0.4 Ω/cm², respectively) and biocompatibility (95.2 ± 2.1% and 92.1 ± 2.5% cell viability, respectively). Zirconium also showed high corrosion resistance (8.1 ± 0.4 Ω/cm²) and biocompatibility (90.5 ± 2.8% cell viability). Stainless steel, cobalt-chromium alloy, and nickel-titanium alloy had lower corrosion resistance and biocompatibility.
CONCLUSION: This study suggests that titanium and titanium alloy are suitable materials for dental implants due to their high corrosion resistance and biocompatibility. Zirconium may also be a suitable alternative.

Keywords: Titanium, nickel-titanium alloy, biocompatibility, Corrosion

1. Introduction

Dental implants have become a widely accepted treatment option for replacing missing teeth(1). The success of dental implants depends on various factors, including the material used for the implant, the design of the implant, the surgical technique, and the patient's overall health(2).
Metals are commonly used for dental implants due to their high strength, corrosion resistance, and biocompatibility(3). However, the choice of metal for dental implants is critical, as it can affect the long-term success of the implant(4).
Titanium and its alloys are widely used for dental implants due to their high corrosion resistance, biocompatibility, and mechanical properties(5). However, other metals such as stainless steel, cobalt-chromium alloy, and nickel-titanium alloy are also used for dental implants(6).
Despite their widespread use, there is limited information available on the corrosion resistance and biocompatibility of these metals in the oral environment. Therefore, this study aimed to evaluate the corrosion resistance and biocompatibility of different dental implant metals in vitro.
Dental implants are designed to withstand the harsh conditions of the oral environment, including exposure to saliva, bacteria, and mechanical forces(7). However, the oral environment can also lead to corrosion of the implant material, which can result in the release of ions and the degradation of the implant(8).

Corrosion resistance is an important property of dental implant materials, as it can affect the long-term success of the implant(9). Biocompatibility is also critical, as it can affect the tissue response to the implant and the overall health of the patient(10).
The rationale for this study is to provide a comprehensive evaluation of the corrosion resistance and biocompatibility of different dental implant metals. The findings of this study can help guide the selection of dental implant materials for optimal clinical outcomes.
The objectives of this study are:
To evaluate the corrosion resistance of different dental implant metals in vitro.To evaluate the biocompatibility of different dental implant metals in vitro.To compare the corrosion resistance and biocompatibility of different dental implant metals.

2. Materials and Methods

Dental implant metals:Six different dental implant metals were evaluated in this study: Titanium(Ti),Titanium alloy(Ti-6Al-4V) Stainless steel (SS) Cobalt-chromium alloy (Co-Cr) Nickel-titanium alloy (Ni-Ti) Zirconium (Zr) ,Specimen preparation:Disc-shaped specimens (10 mm in diameter and 2 mm in thickness) were prepared from each metal using a CNC machining center. Corrosion testing: The specimens were immersed in a corrosion testing solution (artificial saliva) at 37°C for 30 days. Cell culture: Human osteoblast-like cells (MG-63) were used for the cell culture tests.Cell culture medium: The cell culture medium consisted of Dulbecco's Modified Eagle's Medium (DMEM) supplemented with 10% fetal bovine serum (FBS) and 1% penicillin-streptomycin. CorrosionTesting: Electrochemical impedance spectroscopy (EIS):EIS tests were performed using a potentiostat (VersaSTAT 4, Princeton Applied Research) to evaluate the corrosion resistance of each metal.Potentiodynamic polarization (PDP):PDP tests were performed using the same potentiostat to evaluate the corrosion behavior of each metal.Corrosion rate calculation:corrosion rate was calculated using the Tafel extrapolation method.Cell Culture Tests: Cell seeding: MG-63 cells were seeded onto the metal specimens at a density of 1 × 10^4 cells/cm^2.Incubation:The cells were incubated at 37°C in a humidified atmosphere of 5% CO2 for 24, 48, and 72 hours. Cell viability:Cell viability was evaluated using the MTT assay. Cell morphology:Cell morphology was evaluated using scanning electron microscopy (SEM).
STATISTICAL ANALYSIS:
Data analysis:The data were analyzed using one-way ANOVA and Tukey's post-hoc test to compare the corrosion resistance and biocompatibility of the different metals. Significance level:The significance level was set at $p < 0.05$.
EXPERIMENTAL DESIGN:
The experimental design consisted of six groups, each representing a different dental implant metal. Each group consisted of five specimens for the corrosion testing and five specimens for the cell culture tests. The corrosion testing and cell culture tests were performed in triplicate.

3. Statistical Results:

Corrosion Resistance:
The corrosion resistance of the different metals was evaluated using EIS and PDP tests. The results are presented in Table 1.

Table 1: Corrosion Resistance Results

Metal	EIS (ù/cm²)	PDP (V)	Corrosion Rate (mm/year)
Ti	10.2 ± 0.5	0.5 ± 0.1	0.01 ± 0.001
Ti-6Al-4V	9.5 ± 0.4	0.4 ± 0.1	0.02 ± 0.002
SS	5.1 ± 0.3	0.8 ± 0.2	0.05 ± 0.005
Co-Cr	4.2 ± 0.2	1.1 ± 0.3	0.10 ± 0.010
Ni-Ti	3.5 ± 0.2	1.4 ± 0.4	0.15 ± 0.015
Zr	8.1 ± 0.4	0.6 ± 0.2	0.03 ± 0.003

The results show that titanium (Ti) had the highest corrosion resistance, followed by titanium alloy (Ti-6Al-4V) and zirconium (Zr). Stainless steel (SS), cobalt-chromium alloy (Co-Cr), and nickel-titanium alloy (Ni-Ti) had lower corrosion resistance.

Biocompatibility:
The biocompatibility of the different metals was evaluated using cell culture tests. The results are presented in Table 2.

Table 2: Biocompatibility Results

Metal	Cell Viability (%)	Cell Proliferation (%)
Ti	95.2 ± 2.1	120.5 ± 5.2
Ti-6Al-4V	92.1 ± 2.5	115.2 ± 4.9
SS	80.5 ± 3.2	90.2 ± 4.2
Co-Cr	75.2 ± 3.5	80.1 ± 4.5
Ni-Ti	70.1 ± 3.9	75.2 ± 4.9
Zr	90.5 ± 2.8	110.2 ± 5.1

The results show that titanium (Ti) had the highest biocompatibility, followed by titanium alloy (Ti-6Al-4V) and zirconium (Zr). Stainless steel (SS), cobalt-chromium alloy (Co-Cr), and nickel-titanium alloy (Ni-Ti) had lower biocompatibility.

Statistical Analysis:
The data were analyzed using one-way ANOVA and Tukey's post-hoc test to compare the corrosion resistance and biocompatibility of the different metals. The results are presented in Table 3.

Table 3: Statistical Analysis Results

Metal	Corrosion Resistance (p-value)	Biocompatibility (p-value)
Ti	< 0.001	< 0.001
Ti-6Al-4V	< 0.01	< 0.01
SS	0.05	0.05
Co-Cr	0.05	0.05
Ni-Ti	0.05	0.05
Zr	< 0.05	< 0.05

The results show that titanium (Ti) had significantly higher corrosion resistance and biocompatibility than the other metals ($p < 0.001$). Titanium alloy (Ti-6Al-4V) and zirconium (Zr) also had significantly higher corrosion resistance and biocompatibility than stainless steel (SS), cobalt-chromium alloy (Co-Cr), and nickel-titanium alloy (Ni-Ti) ($p < 0.05$).

4. Discussion:

The results of this study demonstrate that titanium (Ti) and titanium alloy (Ti-6Al-4V) had the highest corrosion resistance and biocompatibility among the six metals evaluated. The corrosion resistance of Ti and Ti-6Al-4V was significantly higher than that of stainless steel (SS), cobalt-chromium alloy (Co-Cr), and nickel-titanium alloy (Ni-Ti). This is consistent with previous studies that have shown Ti and Ti-6Al-4V to have high corrosion resistance due to their naturally occurring oxide layers(11).The biocompatibility of Ti and Ti-6Al-4V was also significantly higher than that of SS, Co-Cr, and Ni-Ti. This is consistent with previous studies that have shown Ti and Ti-6Al-4V to be biocompatible and non-toxic(12). The high biocompatibility of Ti and Ti-6Al-4V can be attributed to their ability to support cell growth and differentiation(13).Zirconium (Zr) also showed high corrosion resistance and biocompatibility, although slightly lower than that of Ti and Ti-6Al-4V. This is consistent with previous studies that have shown Zr to have high corrosion resistance and biocompatibility(14). The high corrosion resistance of Zr can be attributed to its naturally occurring oxide layer, while its biocompatibility can be attributed to its ability to support cell growth and differentiation(15).In contrast, SS, Co-Cr, and Ni-Ti had lower corrosion resistance and biocompatibility. The low corrosion resistance of these metals can be attributed to their lack of a naturally occurring oxide layer, while their low biocompatibility can be attributed to their ability to release ions that are toxic to cells(16).The results of this study have important implications for the selection of metals for dental implants. Ti and Ti-6Al-4V are widely used for dental implants due to their high corrosion resistance and biocompatibility. However, Zr may also be a suitable alternative, particularly for patients with Ti allergies or sensitivities. SS, Co-Cr, and Ni-Ti may not be suitable for dental implants due to their low corrosion resistance and biocompatibility. The corrosion resistance of the metals evaluated in this study can be attributed to their naturally occurring oxide layers. Ti and Ti-6Al-4V have a naturally occurring oxide layer that provides a barrier against corrosion(11,12). Zr also has a naturally occurring oxide layer that provides a barrier against corrosion(14). In contrast, SS, Co-Cr, and Ni-Ti do not have a naturally occurring oxide layer, making them more susceptible to corrosion(16).The biocompatibility of the metals evaluated in this study can be attributed to their ability to support cell growth and differentiation. Ti and Ti-6Al-4V have been shown to support cell growth and differentiation, making them biocompatible(13). Zr has also been shown to support cell growth and differentiation, making it biocompatible(15). In contrast, SS, Co-Cr, and Ni-Ti have been shown to release ions that are toxic to cells, making them less biocompatible(16).

Clinical Implications:

The results of this study have important implications for the selection of metals for dental implants. Ti and Ti-6Al-4V are widely used for dental implants due to their high corrosion resistance and biocompatibility(11,13). However, Zr may also be a suitable alternative, particularly for patients with Ti allergies or sensitivities(15). SS, Co-Cr, and Ni-Ti may not be suitable for dental implants due to their low corrosion resistance and biocompatibility(16).

Future Directions:

Future studies should aim to evaluate the corrosion resistance and biocompatibility of other metals used for dental implants. Additionally, in vivo studies should be conducted to evaluate the performance of these metals in a clinical setting.

5. Conclusion:

This in vitro study evaluated the corrosion resistance and biocompatibility of six different dental implant metals. The results showed that titanium (Ti) and titanium alloy (Ti-6Al-4V) had the highest corrosion resistance and biocompatibility, followed by zirconium (Zr). Stainless steel (SS), cobalt-chromium alloy (Co-Cr), and nickel-titanium alloy (Ni-Ti) had lower corrosion resistance and biocompatibility

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