Effect of Surface Area Ratios and Bacteria on Electrochemical Behavior of Galvanically Coupled Titanium

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Purpose: This study aimed to investigate the electrochemical behavior of commercially pure titanium (grade II) coupled with type IV gold alloy and nickel-chromium alloy at different surface area ratios in 3 different electrolytes. ***Materials and Methods:*** Titanium was coupled with gold (Ti/Au) and nickel-chromium (Ti/Ni-Cr). For each couple, 9 surface area ratios between titanium and gold or nickel-chromium were prepared. The electrolytes used were 1% lactic acid, tryptic soy broth media, and *Streptococcus mutans* culture supernatant. The corrosion polarization curves were obtained, and average values of corrosion potential and corrosion current density were calculated. ***Results:*** Both Ti/Au and Ti/Ni-Cr were affected by surface area ratios and different electrolytes, showing the least corrosion rate when the ratio was 1:1 and when the lactic acid was used as an electrolyte. ***Conclusions:*** The greater the difference in surface area between titanium and restorative materials, the more corrosive behavior the materials show. The existence of bacteria such as *S mutans* may aggravate corrosive behavior between different metals. *Int J Prosthodont 2008;21:433–436.*

Titanium is the implant material of choice, whereas superstructures are usually fabricated using different dental alloys. This polymetallism leads to a detectable galvanic or coupled corrosion.[1] It was reported that there have been several cases of dental restoration failure due to a lack of understanding of galvanic corrosion properties of restorative materials.[2]

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The intensity of galvanic corrosion is governed by a number of influencing factors. Among these, the ratio of surface area exposed to the electrolyte is claimed to be the most important factor in galvanic corrosion.[3]

Since dental restorations are always exposed in the oral cavity, galvanic corrosion behavior is also influenced by its electrolytic environment. It has been suggested that microbiologic activity influences corrosion in a variety of environments, including the oral cavity.[4]

The purpose of this study was to investigate whether there was a significant influence of each factor on the galvanic corrosion behavior of commercially pure titanium (Ti) coupled with type IV gold alloy (Au) and nickel-chromium alloy (Ni-Cr) with various surface area ratios in different electrolytes. The null hypothesis was that there was no significant influence of each factor on corrosive behavior.

Materials and Methods

Commercially pure titanium (grade II, Biomedical Implant) was coupled with either type IV gold alloy or nickel-chromium alloy (Ticonium). The test coupons of each metal alloy were prepared ($10 \times 3 \times 1$ mm) and,

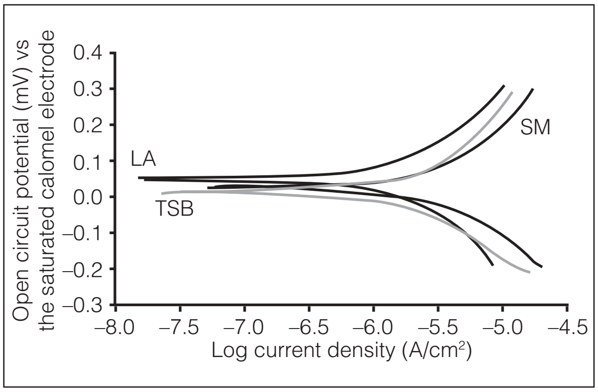

Fig 1 Typical polarization curves of Ti/Au couples with a surface area ratio of 4:0, tested in 1% lactic acid (LA), uninoculated tryptic soy broth media (TSB), and *S mutans* culture supernatant (SM).

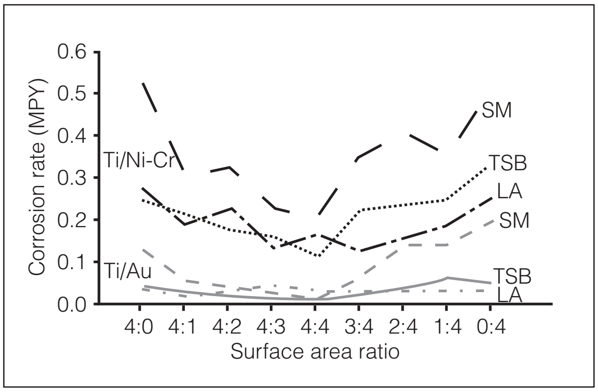

Fig 2 Calculated corrosion rate of Ti/Au and Ti/Ni-Cr couples with all surface area ratios, tested 1% lactic acid (LA), uninoculated tryptic soy broth media (TSB), and *S mutans* culture supernatant (SM).

for galvanic coupling, a mechanical joining method was used. Three identical galvanic couples (Ti/Au, Ti/Ni-Cr) were fabricated, and for each couple, 9 different ratios of surface area were prepared (4:0, 4:1, 4:2, 4:3, 4:4, 3:4, 2:4, 1:4, and 0:4) by applying nail polish vertically on the front surface of the titanium, gold, or nickel-chromium.

The following electrolytes were used: *(1)* 1% lactic acid, *(2)* uninoculated tryptic soy broth media (Becton Dickinson), and *(3) Streptococcus mutans* culture supernatant. The microorganism used in this study was *S mutans* strain A32-2, a colonizer of hard tissues in the oral cavity. The bacteria were taken from a frozen stock culture, plated, and incubated in a 5.0% carbon dioxide incubator at 37°C on plates containing tryptic soy agar (Difco).

For each couple, with 9 different surface area ratios, corrosion tests were conducted at room temperature using a potentiostat (Model 105, Gamry Instruments) under a scanning rate of 0.5 mV/s. First, the open circuit potential, E_{OCP} (mV), was measured compared to the saturated calomel electrode. After the E_{OCP} was stabilized, which normally took 10 to 15 hours, the Stern Geary polarization tests were repeated 3 times on each couple (n = 3). From polarization curves, the corrosion potential (E_{CORR}) and corrosion current density (I_{CORR}) were determined using the computer program installed in the Gamry Corrosion Test system. By determining the I_{CORR}, the corrosion rate was further calculated by the following equation:

$$\text{Corrosion rate (MPY)} = 0.13 \times I_{CORR} \times EW/(d \times A)$$

where MPY is mils per year (1 mil = 1/1,000 inch), d is the density of the corroding element in g/cm^3 (in this study, the mass density value of titanium, 4.51 g/cm^3, was used for the calculation), A is sample area in cm^2, I_{CORR} is the corrosion current in amps, and EW is the equivalent weight of the corroding species. In this study, the equivalent weight of titanium, 47.9/4 = 11.975 g/eq, was used for the calculation.

Statistical Analysis

There were 54 combinations of 3 factors. In all tests, the power was calculated to be at least 0.9 at alternatives that were practically determined. Averaged values of obtained E_{CORR}, I_{CORR}, and corrosion rate were compared using 1-way analysis of variance. When the null hypothesis indicated that there was a statistically significant difference ($P < .05$), further statistical analysis using the Student-Newman Keuls test was conducted to determine which couples were significantly different.

Results

Figure 1 demonstrates typical polarization curves of Ti/Au couples, tested in the 3 electrolytes. Using the software installed in the corrosion testing system, both cathodic and anodic Tafel slopes were determined. The intersection point of these slopes provides 2 important corrosion parameters: E_{CORR} and I_{CORR}.

The calculated corrosion rates are shown in Fig 2. In general, they demonstrate dependency on the surface area ratio, exhibiting a lower corrosion rate around the 1:1 ratio. As the curve moves toward both ends (4:0 and 0:4 ratios), the corrosion rates get higher. This trend was true for both couples and the 3 electrolytes, and was more pronounced for the Ti/Ni-Cr couples, particularly when they were polarized in the bacteria byproducts electrolyte.

Table 1 shows the means and standard deviations of E_{CORR} of coupled Ti/Au and Ti/Ni-Cr, tested in 1% lactic acid, uninoculated tryptic soy broth media, and *S mutans* culture supernatant. The corrosion tendency according to this table and the I_{CORR} table (not shown)

Table 1 Means (SDs) of E_{CORR} of Coupled Ti/Au and Ti/Ni-Cr

	Ti/Au			Ti/Ni-Cr		
Surface area ratio	1% lactic acid	TSB	*S mutans*	1% lactic acid	TSB	*S mutans*
4:0	33.2 (17.9)	−4.9 (3.64)	−14.8 (7.17)	−67.5 (45.0)	−207.8 (13.2)	−162.5 (26.7)
4:1	39.6 (20.0)	0.9 (1.15)	−5.6 (6.17)	−97.9 (14.2)	−189.9 (19.9)	−205.7 (32.6)
4:2	39.1 (9.31)	4.0 (1.45)	−3.5 (1.27)	−128.3 (16.9)	−180.0 (29.5)	−187.9 (16.8)
4:3	23.5 (14.6)	10.9 (9.23)	−16.3 (3.45)	−112.5 (51.0)	−161.5 (27.6)	−198.7 (24.8)
4:4	54.8 (10.3)	2.3 (13.5)	−14.5 (2.30)	−164.4 (17.5)	−170.9 (29.4)	−177.2 (15.0)
3:4	40.3 (11.3)	2.7 (4.10)	−21.5 (1.84)	−153.5 (11.4)	−227.9 (19.2)	−233.9 (24.5)
2:4	46.5 (0.55)	2.6 (6.22)	−7.9 (2.12)	−148.5 (16.4)	−170.4 (33.1)	−210.5 (25.5)
1:4	46.2 (2.75)	−9.3 (7.46)	−15.7 (4.13)	−148.1 (9.70)	−225.6 (46.6)	−396.5 (27.4)
0:4	52.9 (7.36)	−14.7 (8.26)	−16.1 (1.89)	−146.7 (21.9)	−180.3 (21.2)	−394.3 (5.58)

TSB = uninoculated tryptic soy broth media.

is as follows in a descending order: *S mutans* culture supernatant, uninoculated tryptic soy broth media, and 1% lactic acid.

Table 2 summarizes I_{CORR} *P* value comparisons between uncoupled and coupled titanium, gold alloy, and nickel-chromium alloy with full-masked opposing metal. This indicates that the coupling affected the corrosion behavior.

Table 2 I_{CORR} Comparisons (*P* Value) Between Uncoupled and Coupled Titanium, Gold Alloy, and Nickel-Chromium Alloy

	1% lactic acid	TSB	*S mutans*
Ti to Ti/Au (4:0)	.12	.02	.00
Ti to Ti/Ni-Cr (4:0)	.11	.00	.12
Au to Ti/Au (0:4)	.892	.011	.033
Ni-Cr to Ti/Ni-Cr (0:4)	.068	.900	.020

TSB = uninoculated tryptic soy broth media.

Discussion

The surface area ratio was found to be effective on the corrosion behavior of the alloys. All values of the Tafel ratio of 2 couples with 9 different surface area ratios tested in 3 electrolytes were greater than 1, so all of the galvanic reactions were anodic-controlled.

The corrosion behavior of galvanically coupled Ti/Au and Ti/Ni-Cr was found to be significantly influenced by the type of the electrolytes. In general, the bacterial supernatant group demonstrated the most corrosiveness, while the culture media group and the lactic acid group demonstrated moderate resistance and the least corrosiveness, respectively. The byproducts of *S mutans* seemed to influence the galvanic corrosion behavior.

It was suggested that *S mutans,* one of the major microorganisms in the oral cavity, and its byproducts affect electrochemical behavior of the dental alloys.[5] The most important part of the microbiology-related corrosion reaction lies in the thin biofilm under a tubercule on the metal surface. Only the organisms in direct contact with the metal surface influence corrosion.[6] It seems that aerobic and anaerobic bacteria act symbiotically in the process of corrosion.

Galvanic corrosion can accelerate localized corrosion such as crevice or pitting corrosion. A typical example of a crevice corrosion situation in an implant application would be the crevice formed at the area between the implant and the abutment. The interior of the crevice is the anode of the corrosion cell, because its oxygen concentration is lower than that in the surrounding medium, while a cathode forms outside of the crevice.

The Ti/Ni-Cr couple demonstrated less corrosion resistance than the Ti/Au couple regardless of surface area ratio. This is due to the fact that nickel-chromium is less noble than gold. Noble metal is preferred to non-noble metal as a restorative material.[7]

Nonmetallic implant restorations are currently available that eliminate problems associated with galvanic behavior. Although fixed partial dentures or fixed complete dentures often require metallic superstructure, porcelain products for crown restoration are gaining popularity.

It is unknown if metal ions released from restorative materials are enough to induce mechanical failure of the restoration or an unfavorable biologic effect. However, the release of metal ions due to galvanic corrosion can be kept to a minimum in an attempt to maintain good oral hygiene and to provide implant restorations of a similar surface area of the exposed restorative metal to that of the exposed titanium implant.

Conclusions

1. The corrosion behavior of the galvanically coupled alloys is affected by the surface area ratio. The greater the difference in the surface area between 2 coupled alloys, the more corrosive behavior was seen in both Ti/Ni-Cr and Ti/Au couples.
2. The bacterial supernatant was the most corrosive electrolyte, and the existence of bacteria may aggravate corrosive behavior between different metals.
3. The Ti/Ni-Cr couple demonstrated less corrosion resistance than the Ti/Au couple regardless of surface area ratio. This is due to the fact that nickel-chromium is less noble than gold.
4. The coupled titanium, gold, and nickel-chromium had less corrosion resistance than when they are uncoupled. This may be due to the crevice corrosion effect.

Acknowledgments

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Literature Abstract

Vertical ridge augmentation with guided bone regeneration in association with dental implants: An experimental study in dogs

The aim of this study was to evaluate the result of using GBR with titanium-reinforced membranes for augmentation of the alveolar bone in chronic defects with inserted implants. Three dogs were used in this experiment. They were made edentulous in the posterior mandible bilaterally, and the ridge was reduced and left to heal for a period of 4 months before 3 implants were placed in each site. Four sites were randomly allocated to be the test sites and the remaining sites were controls. The implants were placed in such a way to expose about 4 mm of the coronal section of the 10-mm implants. The test sites were treated with a titanium-reinforced membrane stabilized with fixation tacks and the space was filled with venous blood. The control sites, on the other hand, were simply sutured over. The animals were left to heal for 6 months prior to sacrifice. One test site was exposed and the results were discarded. Histomorphometric analysis showed that there was a considerable amount of new bone formation at the test sites compared to the control sites but that the bone was mainly lamellar. Also, the new bone generally was not in direct contact with the implants and in most cases, a band of dense connective tissue was interposed between the implant surface and the bone. This study showed that GBR treatment results in considerable augmentation of the alveolar ridge, but a lack of bone-to-implant contact (BIC) was observed at the grafted sites. The authors recommended further research into factors that are essential for improving BIC.

Simion M, Dahlin C, Rocchietta I, Stavropoulos A, Sanchez R, Karring T. *Clin Oral Implants Res* 2007;18:86-94. **References**: 24 **Reprints**: Prof. Massimo Simion, Reparto di Parodontologia clinica Odontoiatrica, Via della Commenda, 10 20122 Milano, Italy. Tel : +39 02 5799 2881.—*Y L Seetoh, Singapore*