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# Corrosion Behavior between Dental Implant Abutment and Cast Gold Alloy

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Two types of HL hexed abutments of a Steri-Oss system, gold/plastic coping and gold coping, were compared in terms of corrosion behavior. The anodic polarization behavior and the galvanic corrosion between abutments and Type III gold alloys, before and after casting, were analyzed. In addition, the crevice corrosion of the casting samples was analyzed with cyclic potentiodynamic polarization tests using the $|E_r\text{-}E_{corr}|$ value and scanning electron microscopy. Before casting, gold/plastic coping and gold coping were shown to have similar corrosion patterns in the anodic polarization test. Type III casting gold alloy was shown to have a lower corrosion potential and passivation film. The corrosion potential of the gold/plastic coping after casting was higher than that of gold coping, but the passive region for the gold/plastic coping was smaller than that of gold coping. The contact current density between the cast gold alloys and gold/plastic before casting was higher than that between gold coping and cast gold alloy. The contact current density of the samples after casting was shown to be similar to that before casting. The crevice corrosion resistance of cast samples using gold coping was lower than that of cast samples using gold/plastic coping, and severe corrosion was observed by SEM at the abutment-casting gold alloy interface.

**Keywords:** abutments, gold/plastic coping and gold coping, crevice corrosion, galvanic corrosion

## 1. INTRODUCTION

Recently, the field of dentistry has witnessed remarkable developments in the study of implant systems for various restorative purposes. Ever increasing demand by patients for more retentive, yet, superior quality prostheses has driven this trend, while also fueling active research into implant materials. Consequently, dentists have seen rapid introduction of new materials for implant fixtures and abutments, adding to their variety and ease of use.

Along with this positive evolution, however, many implant failures have also been reported. These unfortunate situations arrive when compromises occur during a procedure, since the success of an implant system depends on steadfast attention to each procedure involved from pre-surgery evaluation to maintenance. Thus, individual assessments must focus on achieving proper and stable position of implant fixtures, screws, abutments, and suprastructure [1,2]. In addition, solid bonding between the implant abutment and its suprastructure is critical in attaining dental implant prosthesis. Failures within the interface bonding have been shown to induce microbial colonization and corrosion, ultimately resulting in dislodgment of an entire implant prosthesis.

Due to the paramount importance of strong interface bonding, there have been many studies regarding this topic [3-7]. Yoshitaka [8] *et al.* pointed out the risks involved in screw retained implant prostheses, as mechanical failures may occur when the casting alloy interfaces with a premachined abutment coping. If incomplete adhesion occurs between the alloy and the abutment coping during casting, microbial colonization within the crevice is often initiated, causing crevice corrosion.

In addition to crevice corrosion, galvanic corrosion can also endanger the success of an implant system [6,9-12]. Galvanic corrosion is a direct result of current flow between dissimilar metals in contact, such as those used for an implant abutment and a suprastructure.

Despite this recent awareness of corrosion-induced implant failures, however, a paucity of information exists regarding the exact nature and extent of corrosion for single implant systems. Many recent articles failed to address the role of

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crevice and galvanic corrosion in inducing implant failures, as many studies concentrate only on the issue of osseointegration as a primary measure of a successful implant system.

Therefore, the purpose of our study was to ascertain the extent of galvanic and crevice corrosion on a Steri-Oss implant system by using various electrochemical techniques.

## 2. EXPERIMENTAL PROCEDURE

For implant abutments, two types of HL hexed abutment for the Steri-Oss system, gold coping, and gold/plastic coping, were chosen in this study. The two types of abutment are illustrated in Fig. 1. These copings have been widely used in single implant systems. The accurate compositions of the implant abutments and type III gold alloy are listed in Table 1. To cast the gold alloy onto the gold and gold/plastic copings, respectively, premolar wax-ups were completed on the coping samples, and invested with Denti Vest (phosphate-bonded investment, Sinji, Korea). A casting ring containing the invested pattern was preheated slowly in a furnace to the temperature at which adequate thermal expansion of the investment was obtained, generally 685 °C. A gas-oxygen torch was used to melt the metal alloy quickly and the molten metal was forced in the mold by centrifugal force. To simulate an oral environment, the cast samples were polished and subsequently exposed to artificial saliva (Modified Fusayama's Artificial Saliva). The exact composition of the modified Fusayama's artificial saliva is listed in Table 2.

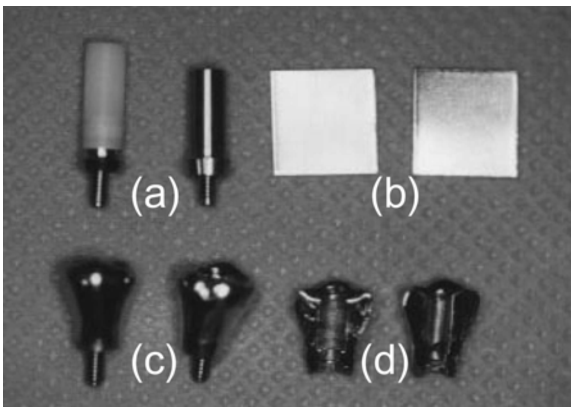



**Fig. 1.** Samples for this study: (a) Steri-Oss HL-Hexed abutment (gold/plastic coping & gold coping); (b) Type III casting gold alloy; (c) casting samples; and (d) sectioned samples.

**Table 1.** Chemical composition of abutments and casting gold alloy

| Samples | Composition | Melting point |
|---|---|---|
| Steri-Oss gold alloy* Abutment & coping | Au 60 %<br>Pt 25 %<br>Pd 15 % | 1400-1460 °C |
| Type III gold alloy** | Au 46 %<br>Pd 4.5 %<br>Ag 40 % | 877-963 °C |

*Steri-Oss: Steri-Oss Yorba, Linda,USA
**Type III gold alloy: We Deng Myung Dental Alloy Co., LTD

**Table 2.** Constituents in modified Fusayama's artificial saliva

| | |
|---|---|
| KCl | 0.4 gm/l |
| NaCl | 0.4 gm/l |
| $NaH_2PO_4 \cdot H_20$ | 0.6 gm/l |
| $Na_2S \cdot 5H_2O$ | 0.0016 gm/l |
| Urea | 0 gm/l |

**Table 3.** Electrode and scanning conditions in this study

| | |
|---|---|
| Counter electrode | : High density Carbon (C) |
| Reference electrode | : Saturated calomel electrode (SCE) |
| Working electrode | : sample |
| Scanning range | : −1500 mV~ +1500 mV |
| Scan rate | : 100 mV/min |
| Electrolyte | : modified Fusayama's artificial saliva |
| Temperature | : 37±1 °C |

The galvanic corrosion test was carried out as shown in Fig. 1(b). The anodic polarization test and crevice corrosion test were preformed as shown in Fig. 1(d). A saturated calomel electrode (SCE) and high-density carbon electrodes were set as a reference electrode and as a counter electrode, respectively, according to ASTM G5-87 [13]. For implementation of the potentiodynamic method, the potentials were controlled at a scan rate of 100 mV/min. by a potentiostat (EG&G Instruments Model 273A) connected to a computer system (Table 3). The various electrochemical methods included the use of artificial saliva deaerated by pure Ar gas. After each electrochemical measurement, the corrosion morphology of each sample was investigated by scanning electron microscopy (SEM).

For the galvanic corrosion, gold/plastic coping and gold coping were set as shown in Fig. 2. The contact current density was measured for 24 hr and mass loss was calculated by a potentiostat connected to a computer system.

For the crevice corrosion assessment, samples were placed under the artificial saliva. The potential of the crevice corro-

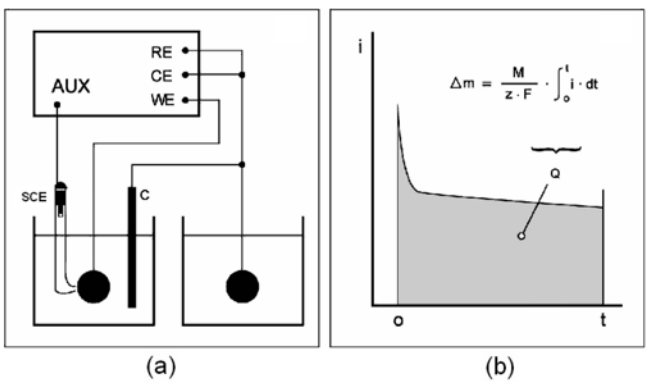



**Fig. 2.** (a) Schematic representation of the galvanic corrosion test set-up and (b) calculation of mass loss according to Faradays law.

sion was measured using CPPT (cyclic potentiodynamic polarization test). In short, CPPT utilizes a forward and reverse application of the electric potential on the sample to obtain $E_{corr}$ (corrosion potential) and $E_r$ (repassivation potential; i.e., the potential below which the metals protective layer is reformed, resisting the conduction of any current). The absolute difference between $|E_r\text{-}E_{corr}|$ is measured to obtain the potential of the crevice corrosion. A greater absolute difference indicates a larger resistance potential against the crevice corrosion. The cast copings were sectioned into metal discs and polished with 0.1 μm $Al_2O_3$ powder after the corrosion test. The sectioned segments were studied under a scanning electron microscope to determine the extent and location of crevice corrosion.

## 3. RESULTS

### 3.1. Anodic polarization behavior of implant abutment and casting gold alloy

3.1.1. Anodic polarization behavior before casting

A similar pattern was observed between the two samples, i.e., the gold coping and gold/plastic coping before casting, in terms of anodic polarization behavior, as shown in Fig. 3. With regard to the actual values along the x-axis (current density) or y-axis (potential), however, the polarization curve of the gold coping abutment exhibited a right-sided shift, indicating increasing current density for a given applied potential. A larger surface area of gold, compared with gold coping, contributes to this phenomenon as more current is allowed to flow through the gold coping than the gold/plastic coping, where only the bottom half is composed of high noble gold. For the type III gold alloy, the graph shows a marked reduction in the area of the passivation potential, as well as corrosion potential, suggesting an inherent deficiency in its resistance against corrosion.

3.1.2. Anodic polarization behavior after casting

After casting, the anodic polarization behavior was again compared between the gold/plastic coping and gold coping. As seen in Fig. 4, the corrosion potential of the gold/plastic coping was –347.9 mV. This is higher than that of gold coping, which was –475.5 mV, indicating that a greater electric potential was required to induce corrosion in the gold/plastic coping. However, the gold/plastic coping showed a smaller area of passivation, as well as increased current density for a given potential. These results suggest that the corrosion resistance of the gold/plastic coping is actually lower than that of gold coping. In the former, more metal may dissolve, as shown by the greater current density, and the gold/plastic coping has a decreased amount of protective metal oxide layer, as indicated by the decrease in the area of passivation.

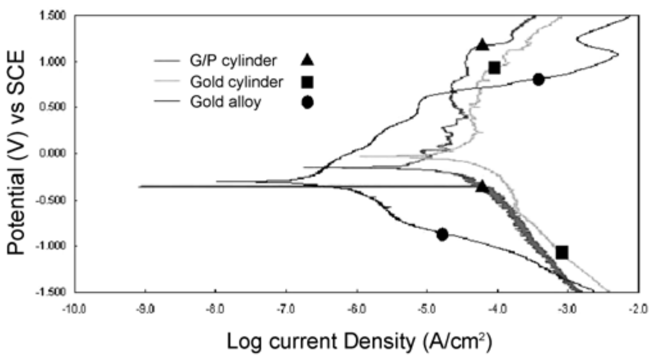



**Fig. 3.** Anodic polarization curves of samples (gold/plastic coping, gold coping, and type III casting gold alloy) in artificial saliva before casting.

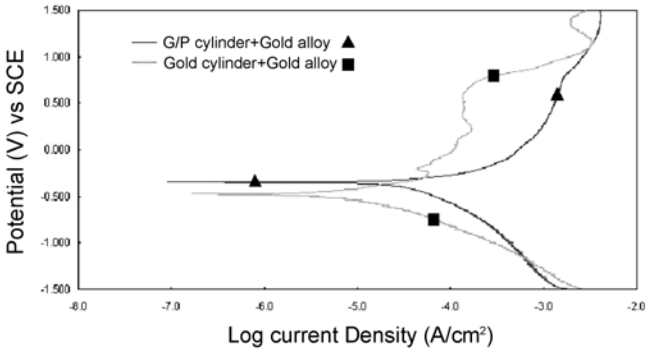



**Fig. 4**. Anodic polarization curves of samples (gold/plastic coping and gold coping) in artificial saliva after casting.

### 3.2. Galvanic corrosion behavior of implant abutment and casting gold alloy

3.2.1. Galvanic corrosion behavior before casting

The galvanic corrosion between the coping samples and the type III gold alloy was assessed by measuring the amount of current flow between the two materials for a given period of time (Coulomb as a unit). Before casting, the current flow between the gold/plastic coping and the type III gold alloy was $3.578\times10^{-3}$ C/cm$^2$. This is higher than that between the gold/plastic coping and gold coping, which was measured to be $3.208\times10^{-4}$ C/cm$^2$, suggesting that the gold coping suffered less galvanic corrosion. Regarding the location of the corrosion, most of the corrosion for gold coping was observed around the type III gold alloy, while the gold/plastic coping exhibited more corrosion around the coping itself (Figs. 5(a) and (b)).

3.2.2. Galvanic corrosion behavior after casting

The galvanic corrosion between the coping samples and type III gold alloy was measured 24 hr after casting. The gold coping showed a higher value of current flow, and thus galvanic corrosion resistance of gold coping (7.940 C/cm$^2$) is lower than that in the gold/plastic coping (5.725 C/cm$^2$). However, the difference between the values was not statistically significant (Figs. 6(a) and (b)). Both samples exhibited

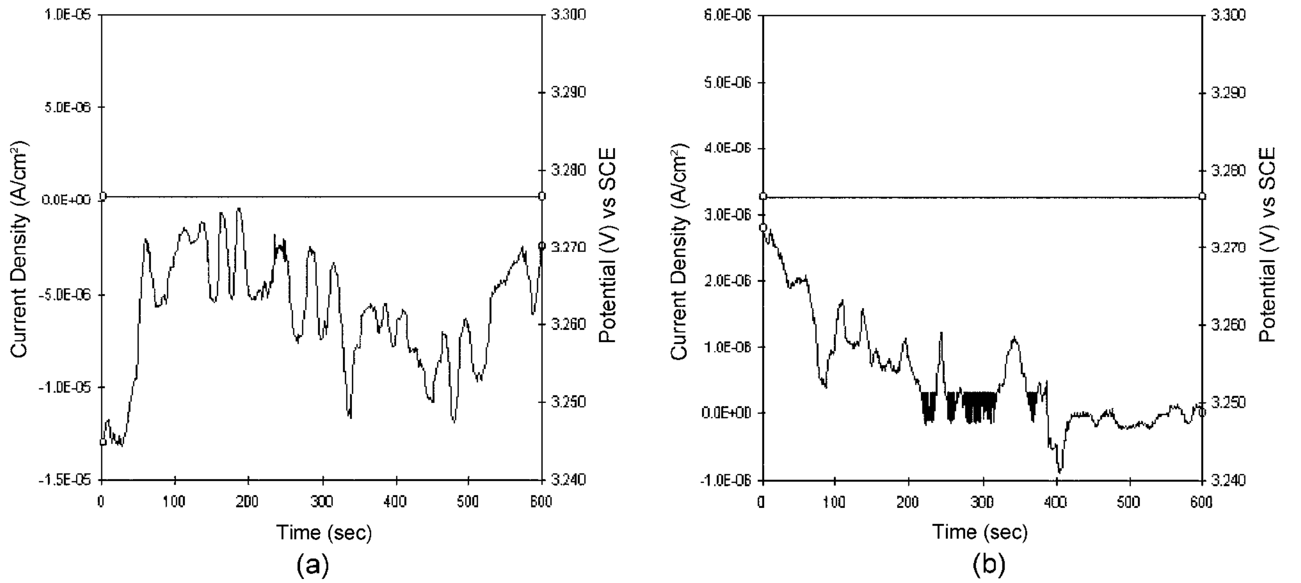



**Fig. 5.** Galvanic corrosion behaviors of samples in artificial saliva before casting: (a) between gold/plastic coping and casting gold alloy and (b) between gold coping and casting gold alloy.

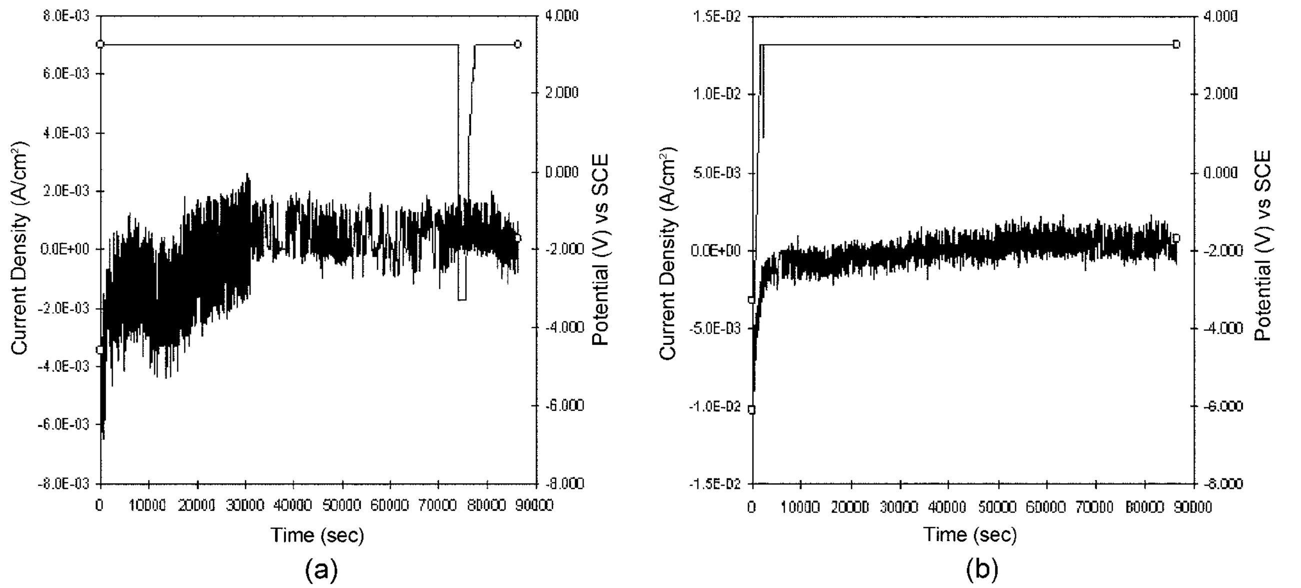



**Fig. 6.** Galvanic corrosion behaviors of samples in artificial saliva after casting: (a) between gold/plastic coping and casting gold alloy and (b) between gold coping and casting gold alloy.

most corrosion around the coping.

### 3.3. Crevice corrosion behavior of implant abutment and casting gold alloy

3.3.1. Cyclic potentiodynamic polatization test results

The premolar implant crowns were set and subjected to CPPT tests as noted previously. By calculating $|E_r-E_{corr}|$ ($E_r$: repassivation potential, $E_{corr}$: corrosion potential) [13], we were able to compare the corrosion resistance between the two sample groups. Briefly, $|E_r-E_{corr}|$ indicates an area of passivation, the range of electric potential where relatively constant current density is maintained because of the effective role of the metal oxide layer. $|E_r-E_{corr}|$ of the gold/plastic coping was 605.6 mV, higher than that of gold coping, which was 465.5 mV. Hence, the crevice corrosion resistance of the gold/plastic coping was higher than the gold coping (Fig. 7).

3.3.2. Observation of crevice corrosion with scanning electron microscope

After casting, the samples were sectioned and observed with a scanning electron microscope for the presence of crevice corrosion. For both gold/plastic and gold coping,

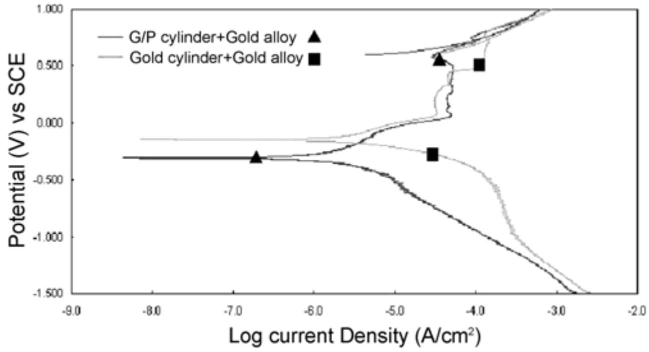



**Fig. 7.** Cyclic polarization curves of samples (gold/plastic coping and gold coping) in artificial saliva before casting.

most of the severe crevice corrosion was evident in and around the interface between the abutment coping and the gold alloy (Figs. 8(a)-(d)). These findings suggested that the apparent crevice must have been due to contraction that occurred toward the gold alloy during cooling. The higher concentration of non-noble metals, and hence the higher contraction coefficient within the gold alloy, caused the shrinkage process to concentrate at the bottom of the interface where a sudden change in the gold content was present. (Figs. 9(a)-(d)). Casting of the gold coping also revealed additional porosities within the gold alloy. These small porosities can potentially serve as housings for microbial colonization, thus increasing the risk of crevice corrosion.

## 4. DISCUSSION

Recently, there have been several reports on possible galvanic corrosion between an implant fixture and its abutment. Some researchers have suggested that galvanic coupling may contribute to defective osseointegration of an implant, as well as bone loss around the implant fixture, which may ultimately dislodge the prosthesis [14-16]. In contrast to these reports, however, a lack of information exists concerning galvanic and crevice corrosion between an implant abutment and its suprastructure, and how certain types of materials may increase predisposition to such phenomena.

Generally, the study of corrosion has been conducted using the potentio dynamic polarization method. This method consists of applying a range of electrical potentials to induce oxidation of metals, and subsequently measuring the density of current flow. By graphing the change in the current density in relation to the electrical potential applied, the corrosion resistance of a material, the rapidity of corrosion formation, the range of passivation potential, and even the pitting tendency can be observed. These data can then be compared among numerous different samples. As such, this type of study offers many features important to scientific experiments: comparability, repeatability, accuracy, and rapid experimental set-up. It is not, however, without faults. For example, to date, the results cannot be extrapolated to clinical situations. The study is often short in duration, simulating clinical situations in an accelerated experimental set-up. Thus, it is incapable of explaining clinical outcomes that are the results of months to years in duration [17].

With respect to corrosion that occurs in dental materials, many studies have emphasized the role of $Cl^-$ ions in inducing breakdown of the protective metal oxide layer [18,19]. Thus, our study used artificial saliva that contained an ample amount of $Cl^-$ ions to observe corrosion patterns in two different implant abutment samples, gold coping, and gold/plastic coping, as well as in type III gold alloy used in implant suprastructures. As shown in Fig. 3, the corrosion patterns between the two abutment samples were found to be similar. The type III gold alloy, however, exhibited a

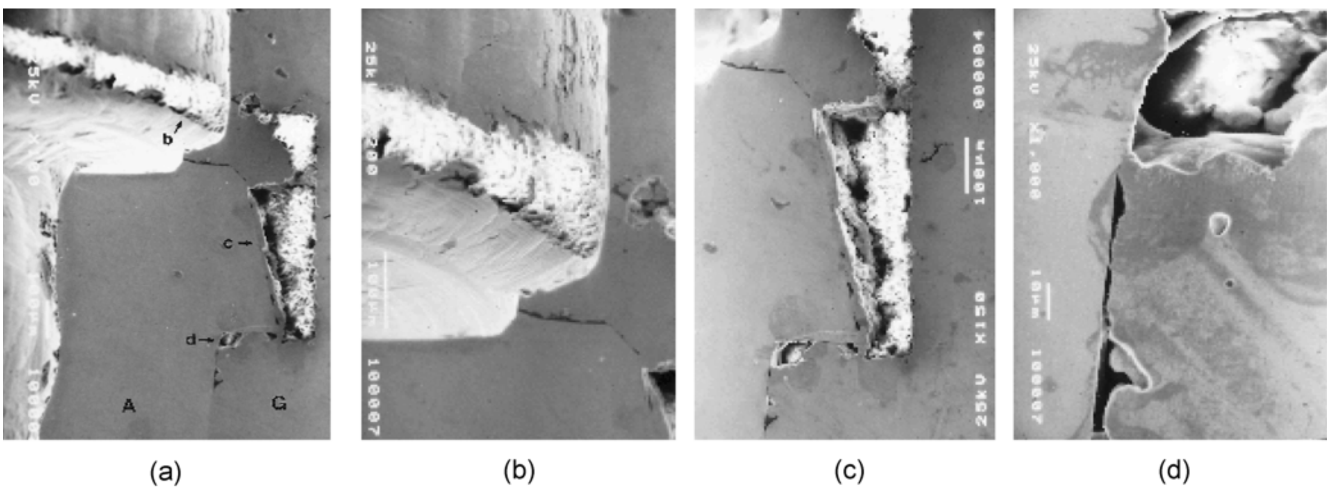
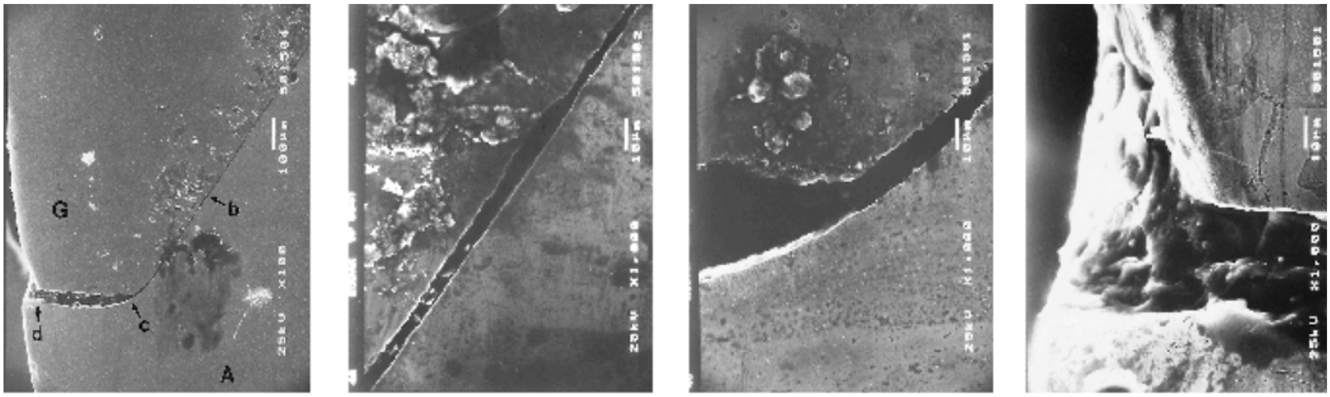



**Fig. 8.** SEM micrographs showing crevice corrosion behavior of cast samples using gold/plastic coping after CPPT in artificial saliva: (a) interface between abutment and gold alloy (G: gold, A: abutment); (b) corrosion morphology at **b** point of (a); (c) corrosion morphology at **c** point of (a); and (d) corrosion morphology at **d** point of (a).




(a) (b) (c) (d)

**Fig. 9.** SEM micrographs showing crevice corrosion behavior of cast samples using gold coping after CPPT in artificial saliva: (a) interface between abutment and gold alloy (G: gold, A: abutment); (b) corrosion morphology at **b** point of (a); (c) corrosion morphology at **c** point of (a); and (d) corrosion morphology at **d** point of (a).

decreased range of passivation and corrosion potential, indicating that the material had a reduced corrosion resistance compared to that of the abutment. These findings correspond with [19] the relative composition of high noble gold within dental materials, which is directly proportionate to the corrosion resistance of the material. Thus, a lower gold content of type III gold alloy would result in decreased resistance against corrosion. This is also apparent in the corrosion resistance of the two abutment samples following casting. As expected, the gold/plastic coping exhibited lower corrosion resistance as the plastic component transforms into type III gold alloy during casting.

The implant abutment and suprastructure samples were also studied in terms of the extent of galvanic corrosion. Comparing the corrosive behavior before casting, the gold coping showed better resistance against galvanic corrosion. This is due to current that concentrates within the smaller area, thus increasing the current density as measured by galvanic corrosion for the gold/plastic coping. In the case of the gold coping, however, the surface area of gold and the type III alloy in contact are comparable, and thus the difference in high noble gold content between the contacting metals is of greater significance in inducing corrosion. Consequently, the galvanic corrosion occurred more around the alloy, where the lower concentration of the high noble gold caused the alloy to retain greater oxidation potential. After casting, however, both abutment samples displayed comparable galvanic corrosion. This suggests that the casting process created a uniform transition between the two different metals, thus reducing the effect of galvanic corrosion, which depends on actual contact between different metals.

Yoshitaka *et al.* [8] have also reported findings regarding another source of corrosion, referred to as crevice corrosion. Such corrosion is derived from incomplete adhesion between the coping and the alloy during casting, thus creating a gap. Though considerable time is required to produce clinically significant corrosion in most cases, the extent of corrosion broadens rapidly once it is initiated, provided sufficient $Cl^-$ ions are present to displace the metal oxide layer [20].

In a comparison of crevice corrosion among our samples, gold coping showed lower resistance against this form of corrosion. The increased surface area of contact between the gold coping and alloy served to produce more areas where small porosities and gaps could form, thus inducing greater crevice corrosion. With regard to the location of such crevice corrosion, the interface between the coping and the alloy was observed to be the area of most corrosion. As was noted previously, this pattern can be explained by the sudden contraction that occurs following casting. The higher contraction coefficient of the alloy caused the material to shrink to a greater degree, which is most apparent at the interface between the two different metals.

It is our hope that the findings reported here will serve as an initiative toward understanding the behavior of different metals, and how they affect the final outcome of an implant prosthesis. We cannot ignore the fact that the materials composing an implant system are not of inert nature, and as such are capable of significantly influencing the stability of a given system by undergoing various electrochemical reactions. Thus, further research is required to fully comprehend various electrochemical behaviors in order to develop materials that are biocompatible and resistant against corrosive reactions.

## 5. CONCLUSIONS

1. Before casting, both gold/plastic coping and gold coping displayed similar anodic polarization behavior. Type III gold alloy, however, exhibited a lower range of passivation, indicating a lesser degree of inherent resistance against cor-

rosion. Following casting, gold/plastic coping showed reduced area of passivation compared to that of gold coping, suggesting that the larger amount of type III gold alloy negatively affects the inherent resistance against corrosion.

2. Before casting, the extent of galvanic corrosion was significantly higher for gold/plastic coping. However, the extent of such corrosion was comparable between the two samples after casting.

3. In the segments sectioned for scanning electron microscopy, gold coping showed a greater extent of crevice corrosion. Also, the crevice corrosion was observed to be concentrated at the interface between the coping and the suprastructure.

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