

Original Article

The effect of electrical potential on the penetration of metal ions through radicular dentin

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Purpose: Electrical potential may facilitate the moving of corroded metal ions across radicular dentin to cause allergic reaction. This study was to investigate the effect of electrical potentials on the penetration of silver and copper ions through radicular dentin.

Materials and Methods: Eighty-eight dentin discs were prepared from intact premolar teeth and placed between two containers of the model. One container was filled with copper and/or silver solution. Another container was filled with 0.9% sodium chloride solution. Five levels of electrical potential were applied to the model at 37°C for 1 and 24 hrs. Then silver and copper ions in sodium chloride solution were measured by ICP-ES. The data was analyzed by one-way ANOVA with Tukey comparison test and student's t-test ($P < 0.05$).

Results: The concentrations of metal ions significantly increased as the electrical potentials increased when above 250 mV were applied after 1 hr. The concentrations of silver ions were signifi-

cantly greater than those of copper ions. Low concentrations of silver and copper ions were detected after 24 hrs at 125 mV level.

Conclusions: These results suggest that the penetration of corroded silver and copper ions through radicular dentin caused by intraoral potential might be minimal.

Key words: metal ions, penetration, electrical potential, radicular dentin

Introduction

Corroded metal ions from intraoral restorations are believed to be one of the substances that could stimulate metal allergic responses¹. In dentistry, metal allergy is usually found to be associated with type IV reaction in which antigen presenting cells might play an important role in activating the allergic reaction. Dendritic cell is one of antigen presenting cells, locating in the periodontal ligament as well as the tissues throughout the body². It has been reported that 20-50 ppm of nickel could induce maturation of dendritic cells³. Therefore, the patients might be suffering from metal allergy if corroded metal ions originated from cast posts, even if that would not be exposed to the oral cavity, would be able to penetrate through radicular

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dentin into periodontal ligament and activate immune responses.

Clinically, electrical current is used to facilitate the rate of permeation of ionic substances through dentin which is known as iontophoresis⁴. Previous study has actually shown that metal ions could be distributed into coronal dentin and deposited inside the dentinal tubules after subjected to iontophoresis⁵. On the other hand, it has been suggested that galvanic activity in oral cavity could be affected by undergoing corrosion of oral prostheses⁶. As a result, this electrical potential might be the driving force for penetration of corroded metal ions from cast posts into periodontal ligament. However, it has not been clarified whether metal ions can penetrate through radicular dentin to outer root surface by electrical potential in the range of intraoral galvanism or those would be somehow trapped the inside of dentin.

Ag-Pd-Cu-Au alloy (40% ↑ Ag, 20% ↑ Pd, 12% ↑ Au by mass; JIS T6109-1991) is mostly used for casting post core in Japan. It has been reported that silver and copper ions were observed as the main corroded ions of the alloy⁷. Thus, silver and copper ions were chosen in this study. From metal allergic point of view, although it is of great importance to know the penetration ability of metal ions in dentin, little is known about this subject due to lack of to-date relevant studies. The purpose of this study was to investigate the effect of electrical potentials on the penetration of silver and copper ions through radicular dentin.

Materials and Methods

Dentin Disc Preparation

Intact premolar teeth extracted for orthodontic reasons were collected, and stored in isotonic solution at 4°C and used within 6 months after the extraction. The anatomical crowns were cut through the cementoenamel junction using a turbine aerator with copious water spray. The root slabs were prepared by buccolingual sectioning of the root, parallel to the long axis using a low-speed diamond saw (Isomet, Buehler, USA). The pulpal side of the sectioned root was further reduced by 400-grit SiC paper until the pulp canal disappeared. Then the external side of root was ground to be flat and parallel to the pulpal side plane. Dentin discs (4.00±0.05 mm in diameter and 0.70-0.75 mm in thickness) were prepared from the cervical part of the root slabs by a turbine aerator with plenty of water spray, followed by 600-grit SiC paper (Fig. 1).

Eighty-eight dentin discs were obtained and geometry of the dentin discs was confirmed by a digital caliper (Absolute digimatic, Mitutoyo, Japan). Smear layer of external side of all dentin discs was removed by 10% phosphoric acid solution (Wako, Japan) for 15 seconds followed by water rinse for 20 seconds. The smear layer of pulpal side of all dentin discs except four discs was not removed in order to simulate the clinical condition. The smear layer of four discs was removed by aforementioned manner.

Experimental Model and Metal Ions Measurements

The experimental model was modified from the device introduced by Fujimasa et al⁵ (Fig. 2). Two metal solutions (1 ppm AgNO₃, 1 ppm Cu(NO₃)₂) and a mixed metal solution (1 ppm AgNO₃: 1 ppm Cu(NO₃)₂) were prepared by diluting 1000 ppm standard metal solutions (Wako, Japan) with a 0.1N nitric acid solution (Wako, Japan). The concentrations of metal solutions used for this experiment were determined based on previous study⁷. Two 5 ml polyethylene containers (GGJ, Akafuda, Japan), polytetrafluoroethylene (PTFE) cap for supporting dentin disc and silicone O-ring (4-mm external diameter, 2-mm internal diameter) were used to setup the model. 100 mm² platinum plate and wire were inserted into the container, and then the container was closed by the PTFE cap. The dentin disc was placed on the cap over the silicone O-ring. Two containers were connected together by a PTFE tube, plastic plates and screws as shown in figure 3. Thus, the dentin disc was located between two containers.

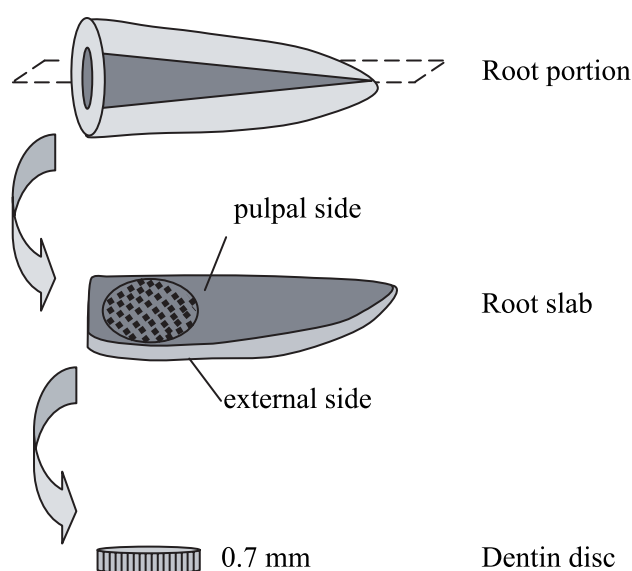


Fig. 1. Schematic representation of dentin disc preparation

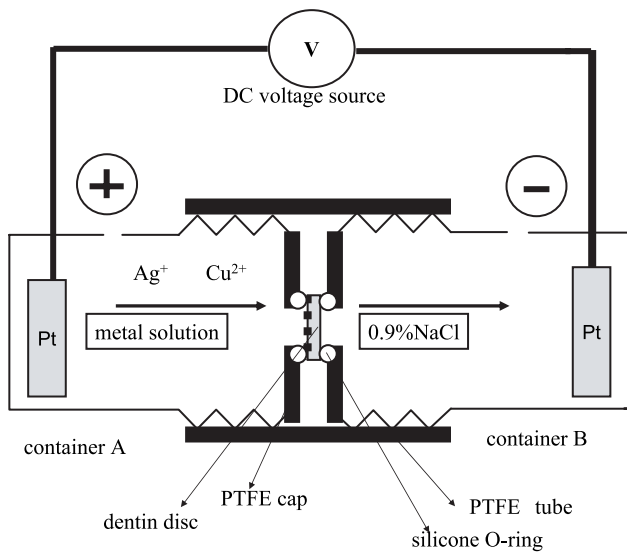


Fig. 2. Schematic representation of experimental model

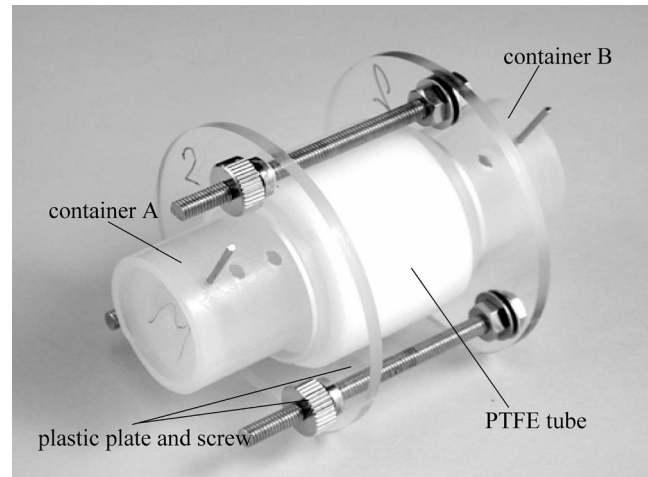


Fig. 3. Model set up

Table 1. Description of each experiment

Group	Solution	Smear layer on pulpal side	Potential (mV)	Duration (hr)	Number
G1	AgNO ₃	+	0, 125, 250, 500, 1000	1	4
G2	Cu(NO ₃) ₂	+	0, 125, 250, 500, 1000	1	4
G3	AgNO ₃ +Cu(NO ₃) ₂	+	0, 125, 250, 500, 1000	1	8
G4	AgNO ₃ +Cu(NO ₃) ₂	+	125	24	4
G5	AgNO ₃ +Cu(NO ₃) ₂	-	125	24	4

Concentrations of AgNO₃ and Cu(NO₃)₂ were 1 ppm.

The silicone O-ring defined surface area available for penetration was 3.14 mm². One container (A) was filled with 5 ml of each of three different metal solutions. Another container (B) was filled with 5 ml of 0.9% sodium chloride solution (Otsuka normal saline, Otsuka, Japan). The pulpal side of dentin discs was exposed to metal solution. Five levels of electrical potential (0, 125, 250, 500 and 1000 mV) were applied to the model at 37°C by a DC voltage source (DC voltage/current standard, San-ei, Japan). The dentin discs were assigned for five experimental groups as described in table 1. After the application of electricity, the concentrations of silver and copper ions in container B in all specimens were measured using an inductively coupled plasma emission spectrophotometer (ICP-ES, JICP-PS3000UV, Leeman Labs, USA). The detectable minimum concentrations of silver and copper ions by ICP-ES are 1 ppb and 0.5 ppb, respectively.

Prior to measuring metal ions, it was confirmed that

no silver or copper ions existed in 0.9% sodium chloride solution. Leakage between two containers was also checked by dying process and proved to be completely sealed.

Statistical Analysis

The concentrations of metal ions were compared within each group for the five levels of electrical potentials by one-way analysis of variance and Tukey multiple comparison ($P < 0.05$). The student's t-test with Bonferroni adjustment was performed to determine significant difference of metal ions concentration between experimental groups ($P < 0.05$).

Results

Figure 4 shows the results of metal ion concentration in each experimental group by ICP-ES. The concen-

trations of metal ions significantly increased as the electrical potentials increased when above 250 mV were applied after 1 hr. At 1000 mV, the concentration of silver ion in G1 was significantly greater than that of copper ion in G2. Within G3, the concentrations of silver ions at 250, 500 and 1000 mV were also significantly greater than those of copper ions, respectively. Differences of concentrations of silver ion between G1 and G3 at each electrical potential were not statistically significant. However, the concentrations of copper ion in G2 at electrical potential of 250, 500 and 1000 mV were significantly greater than those in G3 at 250, 500 and 1000 mV, respectively. No metal ion was found in 0 mV and 125 mV for 1 hr (G1, 2 and 3). However, low concentrations of silver and copper ions were detected after 24 hrs at 125 mV (G4) (Ag^+ : 18.8 ± 5.6 ppb, Cu^{2+} : 6.2 ± 2.6 ppb). Both concentrations of silver and copper ions without smear layer (G5) were significantly greater than those with smear layer (G4).

Discussion

Previous study reported that metal ions could be distributed and deposited in coronal dentin when electrical current was applied⁵. In this study, instead of coronal dentin, radicular dentin was used to investigate the pen-

etration of metal ions simulating the corroded ions from Ag-Pd-Cu-Au cast post. It is known that permeability of radicular dentin is only 20% of coronal dentin⁸ and the number of tubules decreases along coronal-apical direction⁹. Consequently, the cervical dentin could likely be the route for metal ions penetration. Thus, this was a reason for selecting cervical part of root slabs.

One study has shown that increasing molecular radius may result in decreasing rate of permeation¹⁰. Even though the ionic radius of the silver ion (Ag^+ : 1.30 Å) is larger than that of the copper ion (Cu^{2+} : 0.73 Å),¹¹ the concentration of the silver ions was higher than that of the copper ions (Fig. 4). One reason of this finding is because of higher conductivity of the silver ion¹². Another plausible explanation is the binding of metal ion to dentin. Lamina limitans, a sheet-like structure inside of a dentinal tubule, contains high content of proteoglycan which is composed of high density of negatively charged glycosaminoglycan and core protein¹³. Divalent cation such as Zn^{2+} could bind to both of them¹⁴. Therefore, copper ion might react in the same way. Since the sizes of these ions are far smaller than the diameter of dentinal tubules, the electrical property of these ions may be working as a key determinant.

Interestingly, the concentration of copper ions from the mixed metal solution (G3) showed significantly lower than that from the single solution (G2). This result

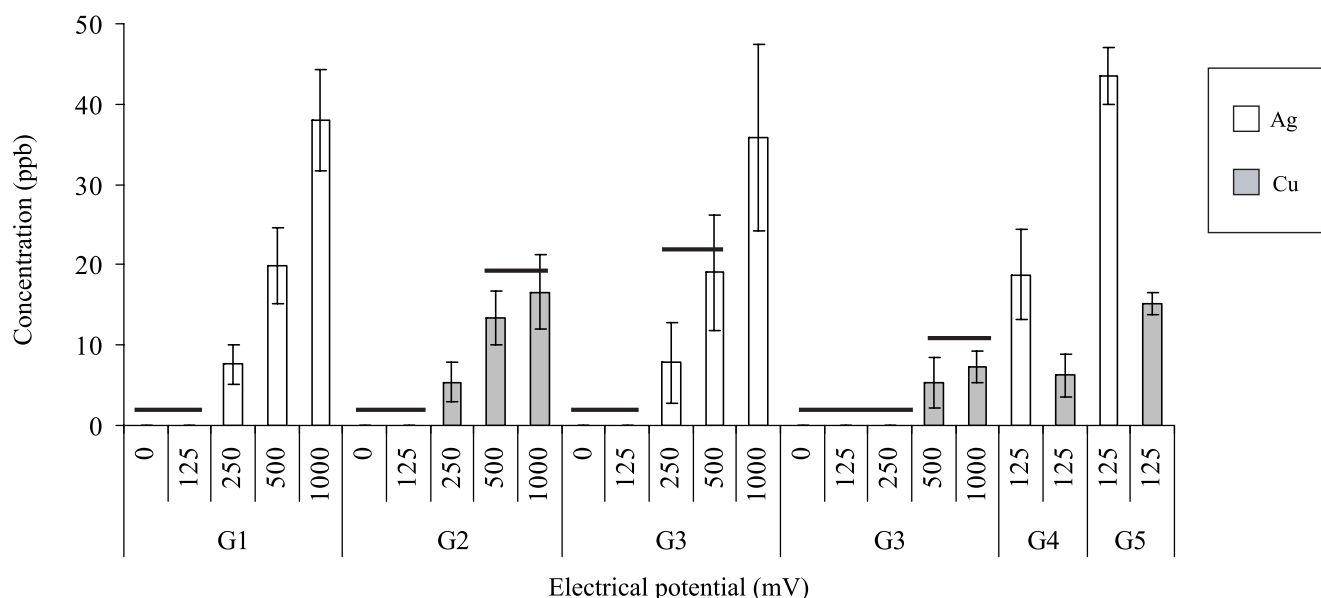


Fig. 4. The results of metal ion concentration in each experimental group by ICP-ES. Horizontal line connects values that are not significant differences within each experimental group at $P \geq 0.05$

might imply that the penetration of copper ions might be attenuated by silver ions. As the previous iontophoresis study⁴, the present results clearly showed that increasing electrical potential increased the concentration of metal ions. However, we found that the rates of penetration of these metal ions were not determined solely by electrical potential.

From a clinical point of view, there may be several implications in the results of this study. Oral potential varies depending on types of dissimilar metal restorations. It is reported that electrical potential in oral cavity between an aluminum splint and a gold crown has been shown to be up to 950 mV¹⁵. In the case of Ag-Pd-Cu-Au alloy, the estimated electrical potential was 100 mV when this alloy contacted with another noble alloy such as a gold alloy^{16,17}. According to these facts, the result that no metal ions could be found after 125 mV for 1 hr application may indicate the least possibility of these ions to pass through radicular dentin to periodontal ligament. Furthermore, the following facts support this hypothesis; firstly, existing cementum may impede permeation of metal ions¹⁸, secondly, luting cement may serve as barrier to prevent the penetration of metal ions¹⁹, thirdly, the dentin disc used in the experiments were thinner than the actual conditions and finally, the characteristic of electrical resistance of radicular dentin²⁰ would work against metal ion penetration.

Pashley *et al*, mentioned that removal of the smear layer opened the tubules, allowing fluid flow across the dentin to 5-fold compared with roots with an intact smear layer²¹. The effect of removing smear layer on metal ions penetration was also obviously confirmed in this study (G4 and G5).

The concentrations of silver and copper ions at 125 mV for 24 hrs were very low (Ag^+ : 18.8 ± 5.6 ppb, Cu^{2+} : 6.2 ± 2.6 ppb). The averages of penetrated silver and copper ions for 1 hr were 0.8 and 0.3 ppb, respectively. They are lower than the detectable minimum concentration of ICP-ES. The total amounts of penetrated silver and copper ions at 125 mV after 24 hrs were 9.4×10^{-2} and 3.1×10^{-2} μg , respectively. If these ions would be diffused to 0.2 mm thickness (this value is assumed from normal periodontal space) at 3.14 mm² area (penetrated dentin sheet), the calculated concentrations of silver and copper ions were approximately 150 ppm and 50 ppm, respectively. In terms of allergic potentials of these metal ions, even though no study of sensitizing thresholds of silver and copper has been reported because silver and copper are low allergic potential and rarely observed as sensitizers²², the concentrations of these ions were higher than 20-50

ppm at which nickel ion could trigger allergic reactions.

Nevertheless, our model was under static condition without blood circulation which may serve as a route to eliminate metal ions out of periodontal space. If the duration of teeth contact during mastication would be 0.2 second²³ and frequency of mastication per day would be 2000 cycles, 24 hrs with electrical potential in the experiment was supposed as 7 months in oral cavity. Abovementioned considerations suggest altogether that the concentration of metal ions in periodontal ligament *in vivo* should be less than the calculated concentrations.

In fact, clinical situation may include many factors which might affect the penetration of metal ions. For instance, the ages of patients, dental treatment history, tooth type and so on. In this experimental study, the extracted teeth were obtained from young patients. However, a great number of metal allergic patients are found in around 50 years of age¹ whose size and number of radicular dentinal tubules might decrease^{9,24}. We might also have to take the fact into account that even if the conventional endodontic treatment reduced the dentin thickness, permeability of remaining radicular dentin would be reduced by 30%-58%²⁵. These imply that penetration of metal ions across radicular dentin in metal allergic patients might be minimal.

Conclusion

As a result, the amount of silver and copper ions penetrated radicular dentin was increased along with the electrical potential applied. However, the possibility of these ions originated from metal posts to get through the dentin was minimal in intraoral circumstances.

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