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Existence of an electrically insulating layer in amalgam-containing galvanic couples

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ABSTRACT

Objective. Avoiding the placement of amalgam and noble metal restorations in interproximal contact is recommended due to anticipated galvanic corrosion of the amalgam. There is a similar concern for amalgam/amalgam galvanic couples. It was the objective of this study to determine if an electrically insulating layer forms in the contact area of these galvanic couples. The existence of an electrically insulating layer, which could reduce the galvanic corrosion rate, would be indicated by different corrosion potentials for the two restorations of the couple.

Methods. Using a convenience sample of 158 human subjects, corrosion potentials were measured on each restoration of three types of galvanic couples: amalgam/noble metal ($n = 8$), amalgam/amalgam ($n = 93$) and noble metal/noble metal ($n = 7$). Measurements were made with a Ag/AgCl micro-reference electrode and a high impedance voltmeter. All restorations were at least 6 months old.

Results. Statistical analysis showed that the mean absolute corrosion potential differences and the simultaneous confidence intervals of the couples were, respectively, amalgam/noble metal: 62 (31) mV and (27, 99) mV, amalgam/amalgam: 11 (14) mV and (7, 15) mV and noble metal/noble metal: 7 (10) mV and (0, 19) mV.

Significance. The amalgam/noble metal couples had consistent and mostly large corrosion potential differences between their restorations, which indicated the presence of an electrically insulating layer. An electrically insulating layer was also indicated for the amalgam/amalgam and noble metal/noble metal couples. The layer is probably composed of non-metallic corrosion products, biofilms, and possibly, dental calculus, which could reduce galvanic corrosion rates to small or negligible values.

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1. Introduction

Avoiding the placement of dental amalgam and gold alloy restorations in interproximal contact is generally recommended due to the possibility of galvanic corrosion of the less noble amalgam [1–4]. The recommendation is based on application of the mixed potential theory [5]. The major consequences of the theory are a single or mixed potential for the contacting, dissimilar metals and accelerated corrosion of the less noble one. Normal alignment of the dentition provides interproximal contact between natural teeth. When a dentist restores teeth, the standard of care dictates re-creating these contacts. Consequently, the possibility of galvanic corrosion exists when restorations of dissimilar metals are placed in the abuting locations of contact-associated teeth.

The relatively large difference in the individual corrosion potentials between amalgam and gold alloys [6] and the cathodic reaction efficiency of noble metals [7] raise concerns. Short-term, in vitro studies show accelerated corrosion of amalgam restorations when electrically coupled to gold alloys, and, therefore, appear to support the recommendation to avoid contact [8,9]. While most attention has focused on amalgam/gold alloy couples, amalgam/amalgam couples may also result in galvanic corrosion due to differences in corrosion potential caused by the various compositions and microstructures among amalgam formulations and by operator manipulation [10,11].

Marek has questioned the recommendation to avoid amalgam/noble metal galvanic couples by proposing that the restorations of these couples are probably electrically insulated from each other over time due to the formation of non-metallic corrosion products at the previous contact points [12,13]. Corrosion products would introduce a large electrical resistance to the existing corrosion circuit, and consequently, the galvanic current would be reduced substantially.

There is indirect support for Marek's proposal. First, amalgam and noble metal restorations have been placed regularly in interproximal contact [2,10,11,14], yet clinical evidence showing consistent occurrence of galvanically accelerated degradation is lacking [10,14]. Second, the electrical insulation provided by corrosion product accumulation at contact points is recognized for industrial galvanic couples [15,16]. Last, short-term in vitro studies of amalgam/noble metal galvanic couples probably do not accumulate the oral films and corrosion product appearing under long-term, in vivo conditions [17–20], and the test solutions used may be much more corrosive than saliva [21].

Based on Ohm's Law, deviation from a common mixed potential would be evidence of an insulating layer in the contact area between the restorations of a galvanic couple. The deviation can be demonstrated directly by measuring the corrosion potentials of the two restorations.

It was the objective of this study to find if there were evidence that an electrically insulating layer exists in the contact area between in vivo amalgam/noble metal and amalgam/amalgam galvanic couples by determining if the restorations of these couples had different corrosion potentials. For comparison, noble metal/noble metal galvanic couples were measured because noble metals are expected to normally form little, if any, corrosion product and, therefore, the restorations of these couples should have a mixed potential. Corrosion potentials of isolated restorations were measured to obtain an indication of the likelihood and magnitude of the thermodynamic driving force for amalgam/noble metal and amalgam/amalgam galvanic couples.

2. Materials and methods

This study used a convenience sample of 158 subjects comprised of dental clinic patients ($n=62$), dental students ($n=37$), dental hygiene students ($n=32$), staff ($n=6$), dental assistants ($n=8$) and faculty ($n=13$) at the Faculty of Dentistry, Dalhousie University. There were 97 females and 61 males. The mean subject age was 36 (14) years.

Corrosion potentials of amalgam and cast noble metal restorations were measured using a Ag/AgCl (3 M KCl) microreference electrode (MI-401, Microelectrodes Inc., Bedford, NH, USA) and a high impedance voltmeter ($10^{12}\ \Omega$) (pH meter, Model HI8418, Hanna Instruments Inc., Woonsocket, RI, USA). Electrical contact with the restorations was made with the gold-plated tip of a stainless steel wax-carving instrument, using light force of $\leq 40\ g$ for approximately 3 s before reading the potential. The reference electrode was placed in the maxillary buccal sulcus, in the vicinity of the canine [22]. Preliminary tests involving three independent measurements on the same amalgam or noble metal restoration, in a 5 s period, gave values within 2 mV of each other. Cast metal restorations that appeared by their function and yellow color to be either high noble (HN) or noble (N) according to the American Dental Association classification system [23] were collectively called noble metal for the purpose of this study. These criteria may have missed some relevant restorations.

Three types of galvanic couples were measured: amalgam/noble metal ($n=8$), amalgam/amalgam ($n=93$) and noble metal/noble metal ($n=7$). The minimum acceptable age of the restorations in an amalgam-containing galvanic couple was 6 months, to allow the amalgam time to achieve passive film growth, microstructure changes and any growth of corrosion products. The minimum age of restorations in noble metal/noble metal couples that were measured was 6 months. Galvanic couples were inspected visually for existence of corrosion.

Isolated amalgam restorations that were >24 months old ($n=482$) and noble metal restorations ($n=72$) of any age that had no interproximal or occlusal contact with other metallic restorations were measured. These restorations would not have been subject to galvanic corrosion. There was no restriction on the age of isolated noble metal restorations since their corrosion potentials were not expected to change substantially over time. Corrosion potentials of amalgam restorations that were $\leq$24 months old were reported previously [24].

Subjects without a clinical record were directed to give their best, discrete estimate of restoration age for noble metal restorations <12 months old, and to round ages of older restorations to 12, 18 or 24 months [24]. For noble metal and amalgam restorations >24 months old, restoration ages were rounded to the nearest year.