Corrosion of dental NiCrMo alloys
Muller, A.W.J.

Citation for published version (APA):
Muller, A. W. J. (1990). Corrosion of dental NiCrMo alloys

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Thus battery behavior can be detected by performing cyclic polarization scans. In the absence of battery behavior the currents during the forward and backward scan will have identical sign and magnitude. A decreasing anodic current may also cause hysteresis during a cyclic voltage scan, mimicking battery behavior. One can check for a decreasing anodic current by performing three-way scans: forward, backward, and forward again. Battery behavior will cause the currents during the two forward scans to be equal, but time dependency shall cause the current during the second forward scan to be lower. Scanning-rate dependence of the polarization curve can also be used to detect battery behavior.

Obviously the Stern-Geary equation and Eq. (2-35) are not applicable for describing the corrosion current of passive metals that show strong battery behavior, such as the alloys of which the polarization curves are given in Figs 2.79-85.

Battery behavior cannot interfere in the potentiostatic deaeration method, as this method does not involve potential scanning, nor can non-Tafel behavior of the anodic and cathodic current interfere in this method, as the corrosion current is not calculated from Tafel constants but is instead determined directly.

3-1 Introduction

In research, agreement of in vivo and in vitro values of a parameter measurable under both conditions helps in alleviating the ever present doubt concerning the applicability of in vitro results. The electrical potential of a restoration, which can be measured in vivo as well as in vitro, is therefore of interest. In addition, it is of interest because of its possible correlation with adverse effects of metallic restorations.

However, the published measurement methods of the in vivo potential were found to have flaws. For this reason an improved measurement method was developed. Two articles have been written on in vivo potential measurement: the first one describes the new method, and the second one discusses its application to the restorations of a group of 28 healthy students.
The determination of the electrical potential of a metallic restoration in the oral cavity

A.W.J. MULLER, D.A.J. DE GROOT and C.L. DAVIDSON

Department of Dental Materials Science,
Faculty of Dentistry, ACTA, University of Amsterdam,
Louwesweg 1, 1066 EA Amsterdam, The Netherlands

Summary
An improved method for measuring the electrical potential of a metallic restoration is proposed and tested. Care was taken to avoid disturbing the restoration, hence it was not cleaned or dried. The probe tip was a gold-plated pin, insulated from the saliva by soft wax. The probe was pressed through the wax on to the restoration just before measurement. An Ag/AgCl reference electrode was in contact with the saliva. The probe and the tip of the reference electrode were disposable.

Introduction
The question of the biocompatibility of metallic restorations in the oral cavity continues to attract much attention. In this context galvanism (pain, battery taste) [Axel83], leukoplakia [Inova61], oral lichen planus [Bir0679], and toxic and allergic reactions to corrosion products [VanLo84] are of interest. To explain these phenomena in electrochemical and physiological terms, knowledge of the electrical potential of metallic restorations (EPR) is expected to be relevant.

The literature is not very clear on EPR measurement methods. The difference between two EPRs has often been measured; however, the use of a reference electrode is necessary to determine the EPR of a single restoration accurately [Stich72]. Schriever & Diamond (1952) stated they were not aware of in vivo EPR measurements of dental fillings. Since then several researchers have published methods for the measurement of the in vivo EPRs: Lukas (1973), Bergman, Ginstrup and Nilner (1978), Nomoto, Ano and Onose (1979), and Yontchev et al. (1986).

A condition for accurate EPR measurement is the use of a high impedance voltmeter [Lukas73, Meine84]. During measurement one voltmeter input leads to a probe that is in contact with the restoration, while the other input leads to a reference electrode that is in contact with the saliva or the skin. Thin oxide and grease layers on the restoration may cause a poor electrical contact between the probe and the restoration. To avoid oxidation of the probe tip, gold is proposed because of its good electrical contact properties [Comiz86].

The surface state of a metal can strongly influence corrosion, and consequently the EPR. For instance, a scratch can cause a passivated metal to become active [Fonta83], resulting in a large potential change, and Marxkors (1965) and Marek (1984) have shown that in vitro abrasion can cause potential changes (up to - 500 mV) of dental metals. Hence the restoration surface should be disturbed as little as possible; it was neither cleaned nor polished in this study.

To minimize electrochemical interaction of the probe tip with the saliva, the gold-plated tip was insulated with wax. Electrical contact was made by pressing the probe through the wax onto the restoration just before measurement.

The purpose of this study was to test this probe design in vitro and in vivo on its usefulness in EPR measurements on several dental alloys.
Materials and Methods

The probe (Fig. 3.1) consisted of a gold-plated header-and-socket-pin (Vero Electronics, Hampshire, UK; order code 66-3505A) glued by means of P-30 (St. Paul, MN, USA) to a disposable pipette tip (Kartell, Milan, Italy; blue tip). The socket pin is used in electronics for wire wrapping purposes. Electrical contact test data of this pin have been given [Mulde86]. The insulation of the tip consisted of soft wax. The empty space inside the pipette tip was filled with Blue Inlay Casting Wax (Regular Type II, Kerr, Detroit, MI, USA). The tip was checked by placing the probe in the saliva; a large electrical resistance caused erratically fluctuating voltages to be measured, which were absent in the case of an electrical leakage. The fluctuations disappeared after the probe made contact with the restoration. Care was taken that the wax covered only a small part of the surface of the restoration.

The reference electrode (Fig. 3.2) was placed in the oral cavity [Ewers85]. It was a modified MI-402 Ag/AgCl micro-reference electrode (Microelectrodes, Londonderry, NH, USA); its PVC tube was replaced by a pipette tip (Kartell, Milan, Italy; yellow tip) that contained solidified agar (1 M KCl). The tip hole had been enlarged by removing the upper three mm of the tip. For hygienic reasons a piece of parafilm (Parafilm "M", American Can Co., Greenwich, CT, USA) was placed between the tip and the teflon electrode cap. The film, the pipette tip and the teflon head were slightly greased with silicon grease. The electrolyte consisted of a 1 M KCl solution. Upon completing the measurements of the EPRs of a test person, the agar tip of the Ag/AgCl reference electrode and the parafilm were replaced and the rest of the electrode was wiped with a 0.5 % chlorhexidine in 70 % ethanol solution. After replacement of the tip, the Ag/AgCl reference electrode was left to rest overnight in order to let its potential stabilize. The stabilized potential was determined with respect to a saturated calomel reference (SCE) electrode.

The potential was measured with a Hewlett-Packard 34703A Voltmeter/34750A Display combination (input impedance > 10¹⁰ Ω). The EPRs were obtained by adding the values of the measured Ag/AgCl - SCE potential difference and the value of the SCE potential (+ 241 mV NHE) to the measured potentials.

The electrical contact between the probe and several dental alloys was tested in vitro by the method shown in Fig. 3.3. The probe was pressed onto an alloy and V₁, the voltage difference between the probe and the reference electrode, was compared with V₂, the voltage difference between the alloy and the reference; in the case of a good contact V₁ should equal V₂. Alloys studied in this manner were a gold alloy (75Au25Ag), amalgam (Cavex68, Keur & Sneltjes, Haarlem), pure copper, and a nickel-chromium alloy (Micro-Bond N/P², Austenal, Chicago, USA) that had been immersed in an artificial saliva for two months.
Results

The two voltages measured with the test method (Fig.3.3) were equal within 0.1 mV for all metals except Micro-Bond NiP2, for which no stable potential could be measured between the probe and the immersed metal.

During in vivo measurement the measured potentials were stable. Table 3.1 gives the results of some EPR measurements in two healthy test persons. The measurements were done at 0.5-h intervals. The standard deviation in the measured values is a measure of the variability of the EPR; its RMS value over all elements is 14 mV.

TABLE 3.1. MEASURED POTENTIALS OF RESTORATIONS AT HALF-HOUR INTERVALS.

<table>
<thead>
<tr>
<th>Element</th>
<th>Measured potentials [mV NHE]</th>
<th>Averaged potential</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Person A</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gold crowns:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>73</td>
<td>75</td>
<td>6</td>
</tr>
<tr>
<td>16</td>
<td>118</td>
<td>133</td>
<td>9</td>
</tr>
<tr>
<td>15</td>
<td>126</td>
<td>134</td>
<td>8</td>
</tr>
<tr>
<td>25</td>
<td>131</td>
<td>146</td>
<td>23</td>
</tr>
<tr>
<td>Crown with a low gold content:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>133</td>
<td>146</td>
<td>23</td>
</tr>
<tr>
<td><strong>Amalgam:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>124</td>
<td>137</td>
<td>11</td>
</tr>
<tr>
<td>38</td>
<td>96</td>
<td>84</td>
<td>6</td>
</tr>
<tr>
<td>37</td>
<td>86</td>
<td>89</td>
<td>7</td>
</tr>
<tr>
<td>36</td>
<td>97</td>
<td>86</td>
<td>6</td>
</tr>
<tr>
<td>44</td>
<td>86</td>
<td>77</td>
<td>8</td>
</tr>
<tr>
<td>47</td>
<td>109</td>
<td>102</td>
<td>11</td>
</tr>
<tr>
<td><strong>Aluminium temporary crown:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>46</td>
<td>112</td>
<td>110</td>
<td>15</td>
</tr>
<tr>
<td><strong>Person B</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All amalgam fillings</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>-1</td>
<td>-2</td>
<td>9</td>
</tr>
<tr>
<td>16</td>
<td>14</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>15</td>
<td>3</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>14</td>
<td>6</td>
<td>-3</td>
<td>11</td>
</tr>
<tr>
<td>35</td>
<td>-50</td>
<td>66</td>
<td>16</td>
</tr>
<tr>
<td>26</td>
<td>-19</td>
<td>352</td>
<td>15</td>
</tr>
<tr>
<td>27</td>
<td>-269</td>
<td>12</td>
<td>20</td>
</tr>
<tr>
<td>37</td>
<td>7</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>36</td>
<td>58</td>
<td>-5</td>
<td>12</td>
</tr>
<tr>
<td>35</td>
<td>-350</td>
<td>1</td>
<td>21</td>
</tr>
</tbody>
</table>

Discussion

The method

With the possible exception of Nomoto et al. (1979), who made no mention of a cleaning procedure, all previous researchers cleaned the restoration surface before EPR measurements. Lukas (1973) cleaned the tooth with alcohol, dried it with air, and covered it with wax and Bergman et al. (1978) brushed and cleaned the teeth. Drying a tooth disconnects the ionic conduction path between the saliva in contact with the restoration surface and the saliva in contact with the reference electrode, and this may result in a measurement error. Yontchev et al. (1986) isolated and dried the tooth with cotton rolls. They allowed the reference electrode to make contact to the restoration by means of a paper tip saturated in saliva.

Consider a metal probe in contact with the saliva. Electrochemical interaction will cause its potential to equal the redox potential of the saliva. A new contact of the probe with the restoration will result in no stable potential, lying between the EPR and the redox potential of the saliva, and it is this average potential that is measured. If the probe has a high electrochemical activity, as is the case for platinum (often used for redox potential measurements), then the measured average potential may deviate strongly from the EPR. For this reason, the probe tip is insulated by wax and the use of platinum as probe tip material is avoided, this in contrast to previous researchers.

Placing the reference electrode on the cheek (Bergm78) increases the chance of measurement artifacts [Hagem85], and introduces an additional source of measurement errors because of possible physiological voltages on the path between the saliva and the cheek.

The results

In the case of Micro-Bond NiP2, the probe test (Fig.3.3) did not give two equal potentials. This can be attributed to the electrical insulation caused by the passivating oxide layer upon the nickel-chromium alloy. One must therefore be careful when measuring the EPR of nickel-chromium alloys using the method.

Ten of the nineteen EPR values of amalgam fillings in Table 3.1 lie in the range of -143 to +41 mV NHE. This range covers 90% of the EPR's of 407 amalgam restorations in the study of Nilner and Holland (1985), in which the method of Bergman et al. (1978) was used. Seventeen of the nineteen EPR values lie within the range of -159 mV to +141 mV NHE given by Yontchev et al. (1986) for 92.8% of the measured EPR values of amalgam restorations.

The EPRs of the 5 gold crowns lie between +75 and +150 mV NHE, well within the range of +41 to +341 mV NHE of measured EPRs given by Yontchev et al. (1986).

Consequently the EPR values found in this study fall within the ranges given by previous researchers.

The fluctuation of about 14 mV in the measured EPRs is attributed to changes in the oral environment.

As it gives minimal disturbance of the restoration surface and minimal leakage current between the probe and the saliva, it is concluded that the probe may be useful for in vivo electrochemical experiments on metallic restorations in the oral cavity. More generally, the probe may also be useful in field studies of the corrosion of metals in environments other than the oral cavity.

Acknowledgements

We thank Jeanne Kruchowski for proofreading this article.
This article has been accepted by the Journal of Oral Rehabilitation [Mulle90c].

Electrical potentials of restorations in subjects without oral complaints

A.W.J. MULLER, L.A.J. VAN LOON and C.L.DAVIDSON

Department of Dental Materials Science, Faculty of Dentistry, Academic Centre of Dentistry Amsterdam, University of Amsterdam

Summary
The electrical potentials of 183 amalgam and 11 precious metal restorations, and one set of brackets, were measured. None of the 28 subjects had galvanism, leukoplakia, oral lichen planus, or toxic or allergic reactions to restorations. The potentials of the amalgam restorations increased with age, from about -350 mV NHE (Normal Hydrogen Electrode) at 30 days, to about +100 mV NHE after more than 1000 days. In most subjects potential differences of more than 50 mV were present between restorations; this phenomenon is therefore assumed to be common in healthy populations.

Introduction
The electrical potential of a restoration (EPR) is highly relevant to improvement of our understanding of in vivo corrosion. It may also be important in the aetiology of galvanism (pain, battery taste) [Axell83], leukoplakia [Inova61], oral lichen planus [Bánóc79], and toxic and allergic reactions to corrosion products [VanLo84]. A detrimental effect of metallic restorations results from frequent remission of leukoplakia and oral lichen planus after removal of restorations [Bánóc79]; in this context, a difference of more than 50 mV between EPR values has been described as pathological [Inova61]. To investigate this claim and, more generally, the link between EPRs and these illnesses and complaints, EPRs were initially measured in healthy subjects first.

For this purpose, the EPRs of all metallic restorations in 28 healthy dental students were measured using a recently developed method [Mulle89b], which differs from previous measurement techniques [Lukas73, Bergm78, Nomot79, Yontc86, Cohen86] in that the restoration is not polished or cleaned before measurement, and the probe tip is insulated by soft wax to avoid electrochemical interaction with the saliva. Polishing and abrasion were avoided because they can disturb the potential, causing either an increase [Shimi71], or a decrease [DeMel85, Marxk65, Marek84]; a scratch can result in a passivated metal becoming active [Fonta83].
Materials and Methods

The study sample consisted of 28 dental students at the Academic Centre of Dentistry in Amsterdam. They were questioned about complaints resembling galvanism, i.e. pain, battery taste, 'burning mouth', or toxic or allergic reactions that could be attributed to oral metallic restorations. The presence of leukoplakia and oral lichen planus was checked visually. All questions and examinations gave negative results.

In the 28 subjects 183 amalgam restorations and 11 restorations cast from noble alloys were found. In one subject orthodontic brackets were present; the potentials of these brackets were also measured.

Details of the manufacture and use of the probe and reference electrode were given in the previous study [Mulle89]. The probe and the tip of the reference electrode were disposable. The tip of the probe consisted of a gold-plated header-and-socket-pin (Vero Electronics, Hampshire, UK).

The previous use of a composite resin in the probe was found to be unnecessary and was therefore discontinued in the present study. The probe was pressed through the wax on to the restoration prior to measurement. The contact with the restoration was preferentially made at the occlusal surface. The reference electrode consisted of a modified MI-402 Ag/AgCl micro-reference electrode (Microelectrodes, Londonderry, NH, USA), the potential of which was determined relative to a saturated calomel reference electrode (SCE) before measurement. A Hewlett-Packard 34703A Voltmeter/34750A Display combination (input impedance > \(10^{10}\) Ω) measured the potential difference between the probe and the reference electrode. The reference electrode was placed in the oral cavity, under the tongue. The EPR value relative to the Normal Hydrogen Electrode (NHE) was obtained by adding the potential difference between the Ag/AgCl and SCE reference electrodes, and the SCE potential (+241 mV NHE), to the measured potential.

Results

Table 3.2 shows the EPR values of 10 subjects. In 20 of the 28 subjects, potential differences of more than 50 mV were present between restorations, e.g. between the 37 (−147 mV) and 45 (−299 mV) in subject 2; 152 mV; between the 14 and 26 in subject 3; 310 mV; between the 17 and 46 in subject 4, etc. In 11 subjects such differences were present between restorations in antagonistic teeth, e.g. between the 27 and 37 in subject 7 and between the 15 and 45 in subject 10.

The average potential (± S.D.) of the 183 amalgam restorations was 17 ± 111 mV. Fig. 3.4 shows a histogram of these EPR values, most of which lie in the range -50 to +150 mV, but a few are as low as -400 mV, the lowest being -417 mV.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Potential (mV NHE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-53</td>
</tr>
<tr>
<td>2</td>
<td>-299</td>
</tr>
<tr>
<td>3</td>
<td>-168 18</td>
</tr>
<tr>
<td>4</td>
<td>-92 126</td>
</tr>
<tr>
<td>5</td>
<td>100 84 82 86 105</td>
</tr>
<tr>
<td>6</td>
<td>71 87 90 97 99</td>
</tr>
<tr>
<td>7</td>
<td>41 54 53 36 47 18</td>
</tr>
<tr>
<td>8</td>
<td>17 68 72 84*</td>
</tr>
<tr>
<td>9</td>
<td>37 38 50 134 32</td>
</tr>
<tr>
<td>10</td>
<td>75 58 88 119 74 4 53</td>
</tr>
<tr>
<td></td>
<td>94 107 89 195 203 219</td>
</tr>
</tbody>
</table>

* crown made of a precious alloy
= electrical contact between two restorations
The increasing trend is clear, the maximum being about 125 mV; wide scattering with a bandwidth of 150 mV is apparent. Fig. 3.5 shows that only one of the EPR values of amalgam restorations of age >1000 days was lower than -100 mV. However, one subject categorically stated that an amalgam restoration that had an EPR of -388 mV was more than 8 years old, the precise date of placement being unknown.

In the previous study, the r.m.s deviation of the scatter in EPR values determined at 30-min intervals was 14 mV. This measure of the accuracy of the measurement method is much smaller than the scattering bandwidth of 150 mV shown in Fig. 3.5. Such wide scattering can be attributed to the effect of (marginal) fracture or of abrasion, which can occur during chewing. These processes can intermittently bring previously unexposed amalgam into contact with saliva, resulting in a temporary drop in corrosion potential: the less noble amalgam components at the freshly exposed surface will show accelerated corrosion, which would result in a rapid return to the earlier corrosion potential. The scattering may also be related to the distinct behaviour of different alloys, the effects of polishing or abrasion [Shimi71, DeMel85, Marxk65, Mezge89, p.10], or to the idiosyncrasy of patients encountered in in vivo tarnish studies [Mege89, p.18].

Fig. 3.4 shows that the distribution of the EPR values is skewed towards lower potentials. This can be explained by the time behaviour of the EPR illustrated in Fig. 3.5, which shows that restorations of age > 1000 days have an EPR of approximately +50 mV, but that younger restorations have much lower EPR values. The probability of encountering a recently placed restoration is much lower than that of encountering an older one, accounting for the small number of low EPR values.

Discussion

It is concluded that differences between EPR values of more than 50 mV are common in healthy individuals. Thus it is unlikely that such a large difference is pathological. Whether or not it is a predisposing factor warrants further research.

Restorations consisting of noble alloys

The average EPR value (± S.D.) observed, 154 ± 55 mV, is of the same magnitude as the average EPR found by Yontchev et al. (1986), namely 192 ± 91 mV. Because there were only 11 noble restorations in the present study it is not possible to draw further conclusions apart from the assessment of a rather high EPR for noble restorations in the oral cavity.

Amalgam restorations

The average EPR of 17 ± 111 mV is in good agreement with the previously reported value of 8 ± 153 mV of 1293 restorations [Yontc86] (value obtained by adding the SCE potential of 241 mV NHE to the given average).

Nilner and Holland (1985) found that younger restorations have lower potentials. Another study [Cohen86] stated that the EPR is approximately -760 mV directly after placement, but gradually decreases to 40 mV (-200 mV SCE) or to a 'more positive' value. This increase is confirmed by the present study, and is in contrast with the stationary and decreasing potentials reported in an in vitro study of 245 days duration (Meber87).

The increase can be explained by selective corrosion of less noble components, resulting in a more noble behaviour of the alloy, which in turn causes an increase in the corrosion potential [Kaesc79, Cohen86].

In the previous study, the r.m.s deviation of EPR values determined at 30-min intervals was 14 mV. This measure of the accuracy of the measurement method is much smaller than the scattering bandwidth of 150 mV shown in Fig. 3.5. Such wide scattering can be attributed to the effect of (marginal) fracture or of abrasion, which can occur during chewing. These processes can intermittently bring previously unexposed amalgam into contact with saliva, resulting in a temporary drop in corrosion potential: the less noble amalgam components at the freshly exposed surface will show accelerated corrosion, which would result in a rapid return to the earlier corrosion potential. The scattering may also be related to the distinct behaviour of different alloys, the effects of polishing or abrasion [Shimi71, DeMel85, Marxk65, Marxk84], or to the idiosyncrasy of patients encountered in in vivo tarnish studies [Mege89, p.18].

Fig. 3.4 shows that the distribution of the EPR values is skewed towards lower potentials. This can be explained by the time behaviour of the EPR illustrated in Fig. 3.5, which shows that restorations of age > 1000 days have an EPR of approximately +50 mV, but that younger restorations have much lower EPR values. The probability of encountering a recently placed restoration is much lower than that of encountering an older one, accounting for the small number of low EPR values.

Brackets

We are not aware of any previous determination of the in vivo potential of brackets. The high potential of the brackets in the jaws, 71 and 74 mV, respectively, shows that they are in the passive, and not in the active state; in the passive state, the release of possibly discoloring corrosion products is minimal.

As the brackets in one jaw are electrically connected, their potentials must be equal. Hence the standard deviations of the EPR values of the brackets in the jaws, 9 and 3.3 mV, respectively, provide a measure of the accuracy of the method. These values are
comparable to the r.m.s deviation of EPR values determined at 30-min intervals, i.e. 14 mV, that was found in the previous study [Mulle89b].

Conclusion

In most of the subjects potential differences of more than 50 mV were present between restorations. From this frequent occurrence, and the rarity of adverse reactions attributed to metallic restorations, it is concluded that the presence of the latter does not necessarily indicate a health hazard that should be terminated by removal of restorations. Most of the scattering in potential values of amalgam restorations can be explained by the effect of differences in age of restorations.

Acknowledgements

We thank the subjects for their participation, their dentists for providing information on their restorations, and Jeanne Kruchowski for proofreading.

3-4 Commentary

3-4.1 The method

One additional advantage of not disturbing the restoration is that the oxygen concentration in the immediate environment of the restoration remains low. Mechanical mixing increases the contact with air, and the associated oxygen concentration rise would, by its oxidizing power, increase the EPR.

Drying the tooth [Yontz86] disturbs the electrical connection of the restoration with the 'soft tissues', this could change the EPR and should therefore be avoided.

Platinum (as well as palladium and rhodium) is an unsuitable probe tip material as it is very sensitive to hydrogen, which can cause its potential to decrease as much as 800 mV [Cates56]. Hydrogen may be present in the oral cavity as hydrogen-dependent microorganisms have been found in the gingival crevice [VanPa76].

An advantage of not polishing the restoration before potential measurement is that the oxidation layer on the metal, which may stabilize its potential, is not disturbed; a disadvantage is that a good electrical contact between the probe and the bare metal becomes less certain because of possible insulation by this layer.

![Figure 3.6](image1)

**FIG. 3.6.** Effects of abrasion on the in vitro corrosion potential of several amalgams [Marek84, Figs 3-4].

![Figure 3.7](image2)

**FIG. 3.7.** Effects of abrasion by a toothbrush and by enamel on the in vitro corrosion potential of Wironium (a CoCr alloy) [Demold85, Fig.3].
Fig. 3.6 gives figures published by Marek [1984, Figs 3-4] of the effect of abrasion upon the corrosion potential of several amalgams. Fig. 3.7 similarly gives the effect of abrasion upon the corrosion potential of Wironium [Demel85, Fig. 3]. Abrasion is seen to decrease the corrosion potential strongly. Similar curves have been given for amalgam [Marek65b, Figs 11-12, 15-16] and for a gold alloy (Degulor M) and a CoCr alloy (Remanit) [Marek65c, Figs 29-30, 35].

3-4.2 Significance
In this study the potential of a restoration is called the 'electrical potential of a restoration', and not the 'corrosion potential of a restoration', as the potential is not necessarily a corrosion potential. The potential may instead be built up during simultaneous reduction (for instance of oxygen) and oxidation (for instance of lactic acid) of some salivary components at the metal surface in the absence of an anodic current caused by metal ion release [Yontc86].

Presently, little is known about the significance of the potential of a restoration. The potential can indicate whether a metal is in a passive or active state. Noble metals tend to have higher potentials, but some passive metals also show high potentials.

Some EPRs of amalgams are lower than the H⁺-reduction potential: - 420 mV at pH 7. Such low potentials are a necessary condition for hydrogen damage [Bockr70, p. 1342], consequently hydrogen damage is possible in amalgam restorations, and could indeed be the mechanism behind delayed expansion of amalgam [Schoo50, Phil82, p. 344]. This should be verified by EPR measurement.

Most EPRs of amalgams, and all EPRs of the other alloys, are however higher than the H⁺-reduction potential. Contribution by H⁺-reduction [Phil82, p. 292] to the cathodic current during the in vivo corrosion of dental restorations will consequently be rare.

Rheinwald initially claimed a potential difference between pairs of restorations larger than 100 mV to be pathological [Rhein53], but later retracted this assertion [Marek65a].

3-4.3 Possible applications
Correlation should be established between EPRs and the effects attributed to the corrosion of dental restorations mentioned at the beginning of Chapter 1.

The distinct influence of salivary or food components upon the in vivo corrosion of dental restorations can be studied by determining the effect upon the EPR of rinsing the mouth with solutions containing those components. The effect of polishing and abrasion can similarly be determined, which is of importance for wear corrosion.

The good electrical contact between the probe and the metallic restoration can be used for other purposes, such as recording the current that flows after connecting two restorations.

CHAPTER 4
Conclusions

On corrosion of dental NiCrMo alloys

- The uniform corrosion rate of dental NiCrMo alloys can be measured by the potentiostatic deaeration technique and by chemical analysis by means of ICP-AES of the medium of a corrosion test cell.
- The uniform corrosion rates of dental NiCrMo alloys are low and decrease monotonically with time, approaching zero. Hence uniform corrosion by itself is probably unimportant; in the long run, wear, pit and crevice corrosion may be more important. The wear corrosion current is probably similar to the decaying corrosion current during uniform corrosion; hence the importance of an understanding of uniform corrosion.
- The uniform corrosion rate of dental NiCrMo alloys decreases with the molybdenum content.
- The present study has not considered the influence on corrosion of metallurgical properties such as pore presence and heat treatment. To obtain a comprehensive picture the effects of these factors should be studied.
- The uniform corrosion rate of passive alloys cannot be measured with the polarization resistance method, as the Stern-Geary equation is not valid in the case of passivation.
- The cathodic current of dental NiCrMo alloys, and possibly of other dental alloys as well, shows Tafel behavior. This allows the determination of the corrosion current from the corrosion potential.
- An equation similar to the Stern-Geary equation can be derived for passive alloys for which the anodic current decreases with time as t⁻α, the cathodic current shows Tafel behavior, and battery behavior (section 2-7.3) is absent.