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In Vivo Changes in Open Circuit Corrosion Potentials After Fixed Orthodontic Appliance Placement: Prospective Clinical Study

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Abstract

Fixed orthodontic appliances introduce metallic elements into the oral cavity and may affect the local electrochemical environment during treatment. Continuous exposure to saliva, dental biofilm, dietary factors, and changes in oral acidity may influence the corrosion behavior of orthodontic materials under clinical conditions. The aim of this prospective clinical study was to evaluate changes in open circuit corrosion potentials in vivo after placement of fixed orthodontic appliances and to monitor their dynamics over time. Measurements were performed in 85 patients with metallic elements of fixed orthodontic appliances immediately after appliance placement, at 1 month, and at 6 months of treatment. The recorded values were predominantly within a negative potential range. A shift toward more negative values was observed at 1 month compared with the initial measurement obtained immediately after appliance placement, followed by partial recovery at 6 months. Most values remained within a moderate range, while a limited number of cases showed low positive values, indicating individual variability in the electrochemical response. The observed temporal pattern suggests that fixed orthodontic treatment is associated with measurable changes in oral corrosion potential during the early phase of therapy, followed by partial stabilization over time. These findings support the clinical relevance of in vivo monitoring of open circuit corrosion potentials for assessment of the electrochemical behavior of metallic orthodontic appliances under real oral conditions.

Keywords: orthodontic treatment; open circuit potential; corrosion; fixed orthodontic appliances; in vivo

Introduction

Fixed orthodontic treatment requires prolonged intraoral use of metallic components, including brackets, bands, tubes, and archwires, which remain in continuous contact with saliva, dental biofilm, dietary chemical factors, temperature fluctuations, and mechanical loading for months or years (1,2). Under these conditions, orthodontic alloys are exposed to a complex oral environment that may influence surface stability and electrochemical behavior over time (2,3).

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Corrosion of orthodontic materials is clinically relevant because it may alter surface characteristics, affect passive oxide layers, and promote the release of metallic ions or corrosion products (1,2). Previous studies indicate that corrosion-related behavior depends on multiple factors, including alloy composition, surface condition, oral acidity, fluoride exposure, and intraoral service time (2,4,5).

A substantial part of the available evidence has been obtained under laboratory conditions, where wires, brackets, or alloys are tested in artificial media (2,4,5). Although such studies are essential for understanding basic material behavior, they cannot fully reproduce the dynamic clinical setting, where multiple metallic elements are exposed simultaneously to biological, chemical, and mechanical influences (1,2). In vivo investigations and retrieval analyses have further shown that orthodontic alloys undergo intraoral ageing and measurable surface changes during service (3,6,7,8).

For this reason, in vivo assessment of electrochemical behavior during active orthodontic treatment is of particular interest. Monitoring open circuit corrosion potentials under clinical conditions may provide clinically relevant information on temporal changes after appliance placement and during follow-up (2,3).

Aim

The aim of the present prospective clinical study was to evaluate in vivo changes in open circuit corrosion potentials after placement of fixed orthodontic appliances and to monitor their dynamics immediately after appliance placement, at 1 month, and at 6 months of treatment.

Materials and Methods

This prospective clinical study was designed to evaluate open circuit corrosion potentials in vivo in the oral cavity of patients with metallic elements of fixed orthodontic appliances. The electrochemical behavior of the orthodontic alloys was assessed by recording open circuit corrosion potential values under clinical conditions.

Electrochemical measurements

Open circuit corrosion potentials were measured intraorally using the Dentotest SIX device (Atlantis Ltd., Bulgaria) equipped with an Ag/AgCl reference electrode. The measuring probe was placed in stable contact with the metallic bracket of the first premolar, while the oral environment served as the electrolyte. For follow-up, measurements were performed on the same first premolar (same side) in each patient at all time points. Potentials were recorded after stabilization, defined as the time point at which the displayed value showed no further visible drift; stabilization was typically achieved within up to approximately 1 minute. Measurements were performed under comparable clinical conditions at each visit.

Measurements were performed at three time points during treatment: immediately after placement of the fixed orthodontic appliance (T0), at 1 month (T1), and at 6 months (T6). The recorded values

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were documented in an individual clinical protocol for each patient and were used for evaluation of temporal changes in corrosion potential during follow-up.
For documentation and interpretation of the results, a standardized clinical record form with reference ranges was used. The protocol included the following reference values: −150 mV per tooth for amalgam and non-noble alloys, with a cumulative value up to −800 mV for all teeth, and +150 mV per tooth for gold and noble alloys, with a cumulative value up to +800 mV for all teeth. According to the recorded values, the findings were categorized as within normal limits, elevated single values, or cumulatively elevated values.

Participants

Participants were consecutive patients undergoing fixed orthodontic treatment with metallic appliance elements. Inclusion criteria were fixed orthodontic treatment with metallic appliance elements and availability of measurements at the planned follow-up time points (T0, T1, and T6). No additional stratification by smoking status, medication use, systemic diseases, history of metal hypersensitivity, or the presence of other metallic restorations was performed, as these variables were not systematically recorded for the purpose of the present study. All participants (and parents/legal guardians for participants under 18 years of age) provided written informed consent.

Statistical Analysis

The collected data were subjected to statistical analysis using descriptive and comparative methods. Quantitative variables were summarized by mean values, standard deviations, medians, and ranges, whereas categorical variables were presented as absolute numbers and percentages. The distribution of open circuit corrosion potential values at the three follow-up time points was assessed for normality. As the data did not show normal distribution, comparisons between paired measurements obtained at T0, T1, and T6 were performed using the Wilcoxon signed-rank test for related samples. Overall differences across the three related time points were additionally assessed using the Friedman test. A level of statistical significance of $p < 0.05$ was accepted for all analyses.

Ethics statement

The study was approved by the relevant Ethics Committee of the Medical University of Plovdiv (Protocol No. 5/06.06.2024; Project HO-15/2024). Written informed consent was obtained from all participants and from the parents or legal guardians of participants under 18 years of age.

Results

A total of 122 patients were included in the study. Of them, 85 had metallic elements of fixed orthodontic appliances and were included in the analysis of open circuit corrosion potentials. The study group consisted of 58 females and 27 males, with a mean age of 25.28 ± 15.42 years.
All measured open circuit corrosion potential values remained within the predefined reference limits of ±150 mV at all three follow-up time points. Immediately after appliance placement (T0),

the mean value was −59.06 ± 43.13 mV and the median was −61 mV. At 1 month (T1), the mean value was −67.94 ± 48.76 mV, with a median of −77 mV. At 6 months (T6), the mean value was −62.46 ± 44.68 mV and the median was −64 mV. The interquartile ranges were −90 to −30 mV at T0, −101 to −39 mV at T1, and −91 to −30 mV at T6. The minimum and maximum values were −136 mV and 25 mV at T0, −148 mV and 35 mV at T1, and −137 mV and 22 mV at T6. Positive values at all three time points were observed in 11 of 85 patients (12.9%). Descriptive statistics for corrosion potential values at T0, T1, and T6 are presented in Table 1.

Table 1. Descriptive statistics of open circuit corrosion potential at T0, T1, and T6

Time point	n	Mean ± SD (mV)	Median (mV)	IQR (mV)	Min (mV)	Max (mV)
T0	85	−59.06 ± 43.13	−61	−90 to −30	−136	25
T1	85	−67.94 ± 48.76	−77	−101 to −39	−148	35
T6	85	−62.46 ± 44.68	−64	−91 to −30	−137	22

Testing for normality showed non-normal distribution of the measured values; therefore, non-parametric statistical methods were applied. Overall comparison demonstrated a statistically significant difference in open circuit corrosion potential across the three follow-up periods (Friedman test, $\chi^2 = 82.92$, $p < 0.001$).

For interpretation of temporal electrochemical change, the absolute magnitude of the corrosion potential values (|mV|) was considered in addition to the signed values, because the sign reflects direction relative to the reference electrode, while higher absolute values indicate a greater deviation from 0 mV. Accordingly, although the mean signed values became more negative at T1 compared with T0, the mean absolute magnitude increased from 59.06 mV at T0 to 67.94 mV at T1, indicating higher absolute corrosion potential values at 1 month. At T6, the mean absolute magnitude decreased to 62.46 mV, suggesting partial stabilization; however, the absolute values at T6 remained higher than those recorded at T0.

Pairwise analysis demonstrated a statistically significant increase in the absolute magnitude of corrosion potential values at T1 compared with T0 (Wilcoxon signed-rank test, $p < 0.001$). A statistically significant difference was also found between T0 and T6 ($p < 0.001$). Comparison between T1 and T6 also demonstrated a statistically significant difference ($p < 0.001$), indicating partial recovery over time. On an individual level, 73 of 85 patients (85.9%) showed higher absolute corrosion potential values at T1 than at T0, while 66 of 85 (77.6%) showed lower absolute values at T6 than at T1. However, in 71 of 85 patients (83.5%), the absolute values at T6 remained higher than those measured at T0.

Discussion

This prospective clinical study showed that open circuit corrosion potentials in patients with metallic elements of fixed orthodontic appliances remained predominantly within the negative

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range and demonstrated statistically significant temporal changes after appliance placement, with a change at 1 month and partial recovery at 6 months. This pattern is consistent with the concept that electrochemical behavior of orthodontic alloys changes dynamically after intraoral placement and during service (3,6).

Corrosion-related behavior of orthodontic materials depends on continuous interaction between alloy surfaces and the oral environment. Exposure to saliva and biofilm, fluctuations in pH, and fluoride-containing products may affect passive oxide layers and contribute to changes in electrochemical parameters and ion release (1,2,15). Experimental evidence supports the role of acidic conditions and fluoride-containing agents in increasing corrosion-related changes or ion release from stainless steel, nickel–titanium, and titanium-based orthodontic components (4,9,10,15).

The more pronounced change observed at 1 month may reflect early intraoral adaptation of newly placed metallic components. In vivo studies have reported measurable metal ion release during fixed orthodontic treatment, supporting the presence of clinically detectable material-related changes under real oral conditions (11,12). In addition, intraoral ageing of orthodontic alloys has been discussed as a clinically relevant phenomenon that may differ from short-term laboratory behavior (3,6,7).

The partial recovery at 6 months may indicate relative electrochemical stabilization over time, potentially related to maturation or reorganization of surface oxide films and adaptation of the metal surface to intraoral conditions. Similar interpretations have been proposed in the context of intraoral ageing and surface characterization after clinical exposure (3,6,7,8).

Despite statistically significant temporal differences, the recorded values remained overall within moderate ranges, and all measurements remained within the predefined reference limits of ±150 mV. This supports a clinically balanced interpretation: electrochemical changes are measurable during fixed orthodontic treatment, while the magnitude of recorded corrosion potentials remained within reference thresholds in this cohort (2,3).

The present study has limitations. The analysis focused on temporal changes in open circuit corrosion potentials and did not include systematic recording of factors such as smoking status, medication use, systemic diseases, history of metal hypersensitivity, or the presence of other metallic restorations, which may influence intraoral electrochemical measurements (1,2). Further prospective studies with standardized electrochemical protocols and broader clinical characterization would be useful to clarify sources of interindividual variability and the clinical significance of these electrochemical changes (6,8).

Limitations of Current Evidence and Future Directions

The findings of the present study should be interpreted in light of several limitations. Open circuit corrosion potential reflects the electrochemical behavior of metallic orthodontic elements under clinical conditions, but it does not provide direct information on metal ion release, microscopic surface degradation, or biological effects (1,2,6,11). In addition, the present study focused on temporal changes in corrosion potential in vivo and did not include parallel analysis of salivary biomarkers, microbiological parameters, or detailed surface characterization of metallic components after intraoral exposure (6-8,13).

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Electrochemical behavior in the oral cavity is influenced by multiple patient-related and local factors, including salivary composition, oral hygiene, plaque accumulation, dietary habits, fluoride exposure, and the presence of other metallic contacts (1,2,4,5,13,14). These variables may contribute to interindividual variability and should be considered when interpreting clinical corrosion measurements. In addition, direct comparison between in vivo corrosion potential values and laboratory corrosion data remains limited because in vitro models cannot fully reproduce the biological and mechanical complexity of the oral environment (1,2,4,5,9,10).
Future research should focus on larger prospective clinical studies using standardized protocols for electrochemical assessment under orthodontic conditions. Combined evaluation of open circuit corrosion potential, metal ion release, surface morphology, and biofilm-related factors would provide a more comprehensive understanding of the in vivo behavior of metallic orthodontic appliances (6-8,11,12). Long-term follow-up studies would also be valuable for clarifying whether the early electrochemical changes observed after appliance placement remain stable over time or are associated with additional material-related changes during prolonged treatment (3,6-8).

Conclusion

Fixed orthodontic treatment with metallic appliances is associated with significant in vivo changes in open circuit corrosion potentials over time. The recorded values remained predominantly within the negative range, with a more pronounced shift toward negative values at 1 month and partial recovery at 6 months. These findings indicate that the electrochemical behavior of metallic orthodontic elements is dynamic during treatment and appears to undergo early change followed by relative stabilization. Monitoring open circuit corrosion potentials under clinical conditions may provide useful information about the in vivo electrochemical performance of fixed orthodontic appliances and may contribute to a more comprehensive assessment of their behavior in the oral environment.

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