Metallurgical and Materials Data 3, no. 2 (2025): 33-39

Publisher: Association of Metallurgical Engineers of Serbia

Metallurgical and Materials Data

www.metall-mater-data.com

Influence of Colgate mouthwash on corrosion resistance of orthodontic wire made of Ni-Ti alloy immersed in artificial saliva

Thangarajan Umamathi[1], P Arul Deepa[2], D Delphin[2], M Harthika[2], V Pappathi[2], A Preethi Christina[2], T Priyadharshini[2], R Yuasri[2], Anitha Nilavan[2], Susai Rajendran[*, 2, 3], Časlav Lačnjevac[4]

[1]*Sri Meenakshi Government Arts College for Women, Department of Chemistry, Madurai, India*
[2]*St Antony's College of Arts and Sciences, Corrosion Research Centre, Dindigul, India (Affiliated to Mother Teresa Women's University, Kodaikanal, India)*
[3]*Pondicherry University, Centre for Nanoscience and Technology, Puducherry, India*
[4]*University of Belgrade, Faculty of Agriculture, Serbia*

ARTICLE INFORMATION:

https://doi.org/10.56801/MMD55

Received: 28 January 2025
Accepted: 4 May 2025

Type of paper: Research paper

ABSTRACT

This study investigates the corrosion resistance of orthodontic wire made of Ni-Ti alloy when immersed in artificial saliva, both in the absence and presence of Colgate mouthwash. The evaluation was carried out using potentiodynamic polarization techniques and electrochemical impedance spectroscopy (EIS). Polarization results show that the presence of Colgate mouthwash reduces the corrosion resistance of the Ni-Ti alloy, as indicated by a decrease in linear polarization resistance and an increase in corrosion current. EIS analysis confirms this trend, revealing reductions in charge transfer resistance, impedance magnitude, and phase angle, along with an increase in double-layer capacitance. These findings suggest that the aggressive components in Colgate mouthwash accelerate corrosion processes. Therefore, individuals wearing orthodontic appliances composed of Ni-Ti alloy are advised to avoid using Colgate mouthwash to prevent potential degradation of their dental wires.

Keywords: Ni-Ti alloy, corrosion resistance, orthodontic wire, artificial saliva, Colgate mouthwash, polarization, electrochemical impedance spectroscopy (EIS).

1. Introduction

A well-aligned set of teeth significantly enhances facial aesthetics and oral health, while dental misalignment may impair both appearance and function. Orthodontic treatment frequently involves the use of wires made from various alloys, such as SS316L, SS18/8, thermoactive superelastic shape memory alloys, and Ni-Ti (nickel–titanium) alloys, which are valued for their mechanical properties and biocompatibility.

However, once installed, these wires are continuously exposed to an aggressive oral environment, including saliva, acidic foods, beverages, and oral hygiene products. Such exposure can lead to corrosion, potentially compromising the mechanical integrity and longevity of the orthodontic appliance, while also posing risks associated with the release of metal ions into the oral cavity.

Numerous studies have investigated the corrosion behavior of dental materials in artificial saliva and other simulated environments, using electrochemical and surface characterization techniques (Eduok 2024; Anees et al. 2024; Dinu et al. 2024; Zheng et al. 2023; Liaquat et al. 2023; Nichul et al. 2023; Łosiewicz et al. 2023; Kaewnisai et al. 2023; Bajt Leban et al. 2023; Xie et al. 2023). These studies have explored corrosion mechanisms in various dental alloys, the effect of surface coatings, microstructure, fluoride content, and surface modifications on corrosion resistance. A summary of relevant research is presented in Table 1.

Among the products in daily use, mouthwashes—especially those containing active chemical agents—may influence the electrochemical behavior of orthodontic alloys. Although various studies have addressed the corrosion behavior of dental materials in artificial saliva, limited data exist regarding the specific effect of commercial mouthwashes, such as Colgate, on Ni-Ti orthodontic wires.

Therefore, the present study aims to evaluate the influence of Colgate mouthwash on the corrosion resistance of Ni-Ti alloy in artificial saliva. This evaluation is conducted using two complementary electrochemical techniques: potentiodynamic polarization and electrochemical impedance spectroscopy (EIS). The results aim to provide insight into whether routine use of mouthwash may compromise the longevity and safety of Ni-Ti-based orthodontic appliances.

* Corresponding author.
E-mail address: susairajendran@gmail.com (Susai Rajendran).

Table 1. Influence of Colgate mouthwash on corrosion resistance of orthodontic wire made of Ni-Ti alloy immersed in artificial saliva

Ref	Title of paper	Methods employed	Findings
Eduok 2024	Microbiologically induced intergranular corrosion of 316L stainless steel dental material in saliva	electrochemical and surface investigations in *artificial* salivary culture media, dental substates corroded significantly upon maturation of bacterial growth	This research emphasizes the impact of oral metal contact on the corrosion of metallic dental implants, such as stainless-steel crowns, in patients affected by specific resident oral bacteria.
Anees et al. 2024	Electrochemical corrosion study of chitosan-hydroxyapatite coated dental implant	XRD, FTIR, SEM,	Chitosan-hydroxyapatite (Ch-HA) coatings demonstrated suitable adhesion to the 316L stainless steel substrate, making them viable for application in dental implants.
Dinu et al. 2024	Structural, electrochemical, biological, and mechanical assessment of functionally graded Cr-based multilayers for enhanced metal-ceramic bond strength in dental restorations	EIS	It was observed that the coating exhibiting the greatest number of interfaces also demonstrated the highest surface roughness and lower contact angles, resulting in the most favorable bond strength value.
Zheng et al. 2023	Effect of fluoride ion concentration on the corrosion behaviour of WE43 alloy in artificial saliva for dental applications	Electrochemical *corrosion* and immersion *corrosion* tests	The findings from the electrochemical corrosion and immersion corrosion tests demonstrated that the corrosion behavior of the WE43 alloy progressively worsened as the concentration of F- increased.
Liaquat et al. 2023	Comparative corrosion behavior of Au_{50}-Ag_{25}-Pd_{25} and $Ni_{88.6}$-$Cr_{11.4}$ alloys utilized in dental applications	Electrochemical studies	The findings indicated that the Au50-Ag25-Pd25 alloy exhibits significantly greater resistance compared to the Ni88.6-Cr11.4 alloy, making it a suitable recommendation for the effective treatment of patients with dental prosthetics featuring metal frameworks.
Nichul et al. 2023	Electrochemical performance of heat-treated beta titanium alloy in artificial saliva: Key role of grain size	XPS investigation confirmed that stable TiO2 passive film played a key role in preventing *corrosion*.	The ideal combination of grain size and grain boundary energy established for specimens at 900 °C is suitable for application in fluoride-treated dental materials.
Łosiewicz et al. 2023	Electrophoretic Deposition of Multi-Walled Carbon Nanotube Coatings on CoCrMo Alloy for Biomedical Applications	FTIR spectroscopy SEM	Electrophoretic deposition has been demonstrated to be an efficient, cost-effective, and rapid technique for the fabrication of nanotubes, allowing for precise control over thickness, uniformity, and packing density.
Kaewnisai et al. 2023	Effect of pulse frequency on the surface properties and corrosion resistance of a plasma-nitrided Ti-6Al-4V alloy	grazing incidence x-ray diffraction spectrometer (GI-XRD) revealed the presence of δ-TiN and ε-Ti2N phases in all nitrided samples.	The sample that underwent nitriding at a frequency of 50 kHz demonstrated the lowest corrosion current density in artificial saliva, as determined by the Tafel potential polarization method.
Bajt Leban et al. 2023	The corrosion resistance of dental Ti6Al4V with differing microstructures in oral environments	Electrochemical methods.	The corrosion resistance of dental Ti6Al4V differs depending on microstructures in oral environments
Xie et al. 2023	Electrochemical corrosion behavior and in vitro biocompatibility of Ti-Nb-Sn alloy for dental applications	The effects of Nb on the microstructure, *corrosion* behavior and in vitro biocompatibility were investigated.	The enhancement of niobium content can facilitate the adhesion and proliferation of mouse osteoblasts, thereby enhancing cellular vitality.

2. Experimental

2.1. Artificial saliva

Artificial saliva was prepared in the laboratory following the composition established by Fusayama and Meyer. The solution contained: KCl (0.4 g/L), NaCl (0.4 g/L), $CaCl_2 \cdot 2H_2O$ (0.906 g/L), $NaH_2PO_4 \cdot 2H_2O$ (0.690 g/L), $Na_2S \cdot 9H_2O$ (0.005 g/L), and urea (1.0 g/L), adjusted to a pH of 6.5.

2.2. Ni-Ti alloy

The Ni-Ti alloy wire used in this study consisted of approximately 50 atomic percent nickel and 50 atomic percent titanium, corresponding to approximately 55 wt% nickel due to the difference in atomic masses. This composition is commonly referred to as 55-Nitinol. The alloy was obtained from MERCK (Product No. GF32642669) and is specified as high-purity Ni55Ti45.

2.3. Colgate mouthwash

The corrosion resistance of orthodontic wire composed of Ni-Ti alloy has been assessed in artificial saliva, both with and without the presence of a mouthwash, specifically Colgate mouthwash. This evaluation was conducted using polarization techniques and electrochemical impedance spectroscopy (EIS).

The ingredients list for Colgate mouthwash includes the following:

- Active Ingredient: Cetylpyridinium chloride 0.075% (antigingivitis/antiplaque)
- Inactive Ingredients: Water, glycerin, propylene glycol, sorbitol, poloxamer 407, flavor, potassium sorbate, citric acid, sodium saccharine.
- Other active ingredients include peppermint oil, citric acid, castor oil, tetrasodium edta, sodium bicarbonate, sodium chlorite ($NaClO_2$), and sodium benzoate.

2.4. Electrochemical studies

Electrochemical investigations, including polarization studies and AC impedance spectroscopy, have been extensively employed in the examination of corrosion inhibition (Minagalavar et al. 2024; El Caid et al. 2023; Khanna et al. 2023; Renuka et al. 2023; Li et al. 2023; Chraka et al. 2023; Sudhakaran et al. 2023; Vashishth et al. 2023; Jalab et al. 2023; Bairagi et al. 2023).

Electrochemical characterization was performed using potentiodynamic polarization and electrochemical impedance spectroscopy (EIS), employing a CHI660A workstation with iR compensation. A conventional three-electrode setup was used, consisting of a Ni-Ti alloy working electrode, a platinum counter electrode, and a saturated calomel electrode (SCE) as reference.

Electrochemical Impedance Spectroscopy (EIS) is an advanced characterization method that provides a sensitive analysis of the electrical behavior of chemical systems without causing any damage. This technique evaluates the temporal response of chemical systems by applying low amplitude alternating current (AC) voltages across a spectrum of frequencies. The setup involves three electrodes: a working electrode, a reference electrode, and a counter electrode. A predetermined voltage is applied from the working electrode, traversing through an electrolytic solution to the counter electrode.

2.5. Polarization study

In the current study, the corrosion resistance of mild steel submerged in groundwater was assessed through potentiodynamic polarization analysis. The experiments were conducted at ambient temperature. Polarization investigations were performed using a CHI electrochemical workstation equipped with an impedance model 660A, which included an iR compensation feature.

A three-electrode cell configuration was employed, utilizing a Ni-Ti alloy as the working electrode, platinum as the counter electrode, and a saturated calomel electrode (SCE) as the reference electrode.

From polarization study, corrosion parameters such as corrosion potential (E_{corr}), corrosion current (I_{corr}), Tafel slopes anodic = b_a and cathodic = b_c and linear polarization resistance (LPR) value were calculated.

2.6. AC Impedance spectra

AC impedance spectra have been employed to examine the development of a protective layer during the corrosion protection process.

In the current investigation, the identical apparatus and cell configuration employed for the polarization study were utilized to capture AC impedance spectra as well. A duration of 5 to 10 minutes was allowed for the system to reach a stable open circuit potential. The real component (Z') and the imaginary component (-Z") of the cell impedance were recorded in ohms across a range of frequencies.

Charge transfer resistance (R_t) and double layer capacitance (C_{dl}) were calculated.

$R_t = (R_s + R_t) - R_s$; where R_s is solution resistance.

$C_{dl} = 1/2\pi f_{max} R_t$; where f_{max} is a frequency at maximum imaginary impedance.

3. Results and discussion

The corrosion resistance of orthodontic wire composed of Ni-Ti alloy has been assessed through immersion in artificial saliva, both with and without the inclusion of a mouthwash, specifically Colgate mouthwash. This evaluation was conducted using polarization techniques and electrochemical impedance spectroscopy (EIS). The findings are detailed and analyzed.

3.1. Analysis of polarization curves

The polarization curves of the Ni-Ti alloy, when immersed in artificial saliva both without and with the inclusion of a mouthwash, specifically Colgate mouthwash, are illustrated in Figures 1 and 2.

The corrosion parameters, namely, corrosion potential (E_{corr}), cathodic Tafel slope (b_c), anodic Tafel slope (b_a), linear polarization resistance (LPR) and corrosion current (I_{corr}) are given in Table 1.

In the study of polarization, a decrease in the corrosion resistance of the working electrode is associated with a reduction in corrosion current, while an increase in corrosion current occurs simultaneously (Dinu et al. 2024).

3.2. Linear polarization resistance

The application of Colgate mouthwash results in a reduction of the localized pitting corrosion (LPR) of Ni-Ti alloy when submerged in artificial saliva. This observation suggests that the corrosion resistance of Ni-Ti in artificial saliva diminishes in the presence of Colgate mouthwash. The decline in resistance can be attributed to the aggressive components found within the Colgate mouthwash (Figure 4).

3.3. Corrosion potential

The introduction of Colgate mouthwash results in a minor shift in corrosion potential, approximately 50 mV. This suggests that the components found in Colgate mouthwash enhance the corrosion processes occurring at both the anode and cathode (Figure 5). It can be noted from Figure 1 that a passive film develops at a potential of -507 mV relative to the saturated calomel electrode (SCE). At a potential of -483, the film experiences a rupture. Subsequently, the film maintains stability. The range from -507 to -483 is identified as a passive region.

3.4. Corrosion current

Linear polarization resistance suggests that the corrosion resistance of Ni-Ti in artificial saliva diminishes when exposed to Colgate mouthwash. Consequently, one would expect an increase in corrosion current. However, the data presented in the Table 2 indicates a decrease in corrosion current. This discrepancy may be attributed to the restriction of electron flow within the film.

3.5. Implication

A study on polarization reveals that the corrosion resistance of Ni-Ti in artificial saliva diminishes when exposed to Colgate mouthwash. This suggests that individuals with orthodontic wires composed of Ni-Ti alloy should refrain from using Colgate mouthwash.

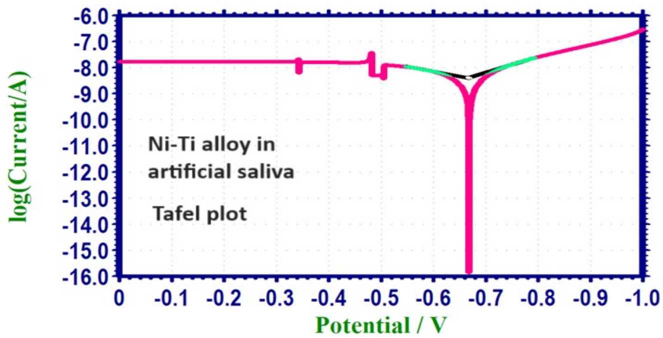

Fig. 1. Polarization curve of Ni-Ti in artificial saliva

Table 2. The corrosion parameters of Ni-Ti alloy immersed in artificial saliva in the absence and presence of Colgate mouthwash

System	E_{corr} mV vs SCE	b_c mV/decade	b_a mV/decade	LPR Ohmcm^2	I_{corr} A/cm^2
AS	-668	162	273	7820700	5.650 x10^{-9}
AS+Colgate mouth wash	-663	151	270	7762734	5.483x10^{-9}
Observation	The shift is within 50 mV			decreases	decreases
Inference	Corrosion process at anode and cathode are accelerated			Corrosion resistance decreases	The corrosion product may restrict the flow of electrons
Implication	Individuals with orthodontic wires composed of Ni-Ti alloy are advised to refrain from using Colgate mouthwash.				

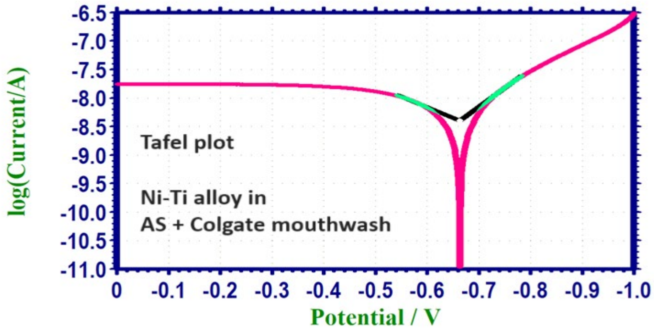

Fig. 2. Polarization curve of Ni-Ti in artificial saliva + Colgate mouthwash

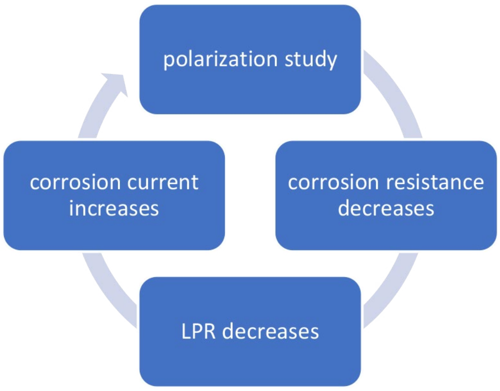

Fig. 3. Correlation among corrosion parameters of polarization study

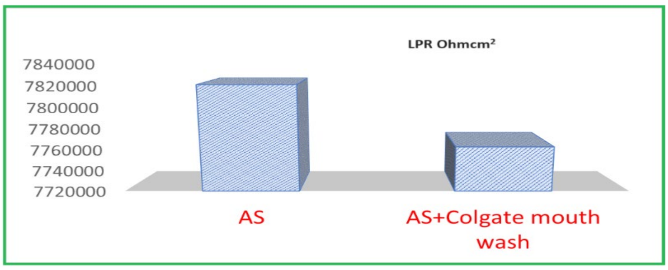

Fig. 4. Comparison of LPR values, Ω·cm²

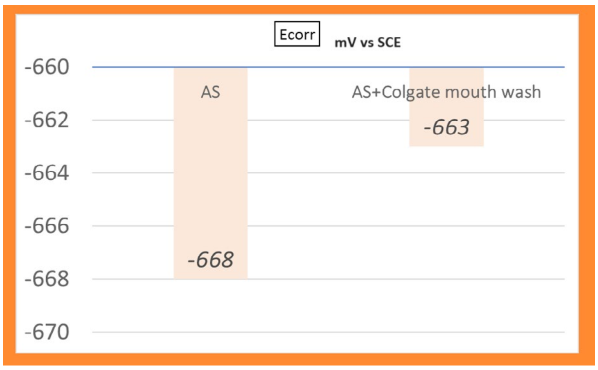

Fig. 5. Comparison of corrosion potential values

3.6. *Analysis of Electrochemical Impedance Spectra (EIS)*

Electrochemical Impedance Spectroscopy (EIS) generates quantitative measurements that facilitate the assessment of small-scale chemical processes occurring at the electrode interface and within the electrolytic solution. Consequently, EIS proves to be valuable in analyzing a diverse array of dielectric and electrical characteristics of components in research domains such as battery technology and corrosion studies.

Electrochemical Impedance Spectra (EIS) of Ni-Ti alloy immersed in artificial saliva in the absence and presence of a mouth wash, namely, Colgate mouthwash, are shown in Figures 6-15. The corrosion parameters, namely, charge transfer resistance (R_t), impedance value [Impedance, Log(Z/ohm)], phase angle and double layer capacitance C_{dl} are given in Table 3. The corrosion parameters are compared in Figure 16.

Electrochemical Impedance Spectroscopy (EIS) is an exceptionally sensitive analytical technique employed to assess the electrical behavior of chemical systems in a nondestructive fashion. EIS systems analyze the temporal response of these systems by applying low amplitude alternating current (AC) voltages across a spectrum of frequencies. This technique utilizes an electrode configuration that includes a working electrode, a reference electrode, and a counter electrode, through which a known voltage is transmitted from the working electrode, through an electrolytic solution, and into the counter electrode. The quantitative data generated by EIS facilitates the investigation of minor chemical processes occurring at the electrode interface and within the electrolytic medium. Consequently, EIS proves to be invaluable for determining a diverse array of dielectric and electrical characteristics of components in various research domains, including batteries and corrosion studies.

3.7. *Charge transfer resistance (R_t)*

Charge transfer resistance (R_t), also known as polarization resistance, denotes the limitation of charge transfer occurring at the interface between the electrode and the electrolyte. Polarization of an electrode takes place when an external voltage is applied, displacing the potential from its equilibrium state. In the effort to regain equilibrium, negative charge may be transferred via electrochemical reactions, resulting in current flow at the electrode surface and into the electrolyte. The kinetics of these reactions, along with the diffusion of reactants, will influence the interaction of the current with the electrode, thereby determining the extent of the polarization resistance.In the present investigation, in the presence of Colgate mouthwash, Charge transfer resistance (R_t) of Ni-Ti alloy immersed in artificial saliva decreases. This indicates that In the presence of Colgate mouthwash, corrosion resistance of Ni-Ti in artificial saliva decreases. This is due to the aggressive ingredients present in the Colgate mouthwash.

3.8. *Impedance value*

The impedance value [log(z/Ω)] of Ni-Ti alloy immersed in artificial saliva diminishes when exposed to Colgate mouthwash. This suggests that the corrosion resistance of Ni-Ti in artificial saliva is reduced

Table 3. The corrosion parameters of Ni-Ti alloy immersed in artificial saliva in the absence and presence of Colgate mouthwash, obtained from AC impedance spectra

System	R_t Ω·cm²	Impedance Log(Z/Ω)	Phase angle°	C_{dl} F/cm²
AS	1.81x10⁶	6.171	95.98	2.82×10^{-12}
AS + Colgate mouthwash	0.79 x10⁶	6.128	44.42	6.45×10^{-12}
Observation	decreases	decreases	decreases	increases
Inference	Corrosion resistance decreases	Corrosion resistance decreases	Corrosion resistance decreases	Corrosion resistance decreases
Implication	Individuals who have orthodontic wires composed of Ni-Ti alloy should refrain from using Colgate mouthwash.			

in the presence of Colgate mouthwash, attributed to the aggressive components contained within the mouthwash.

3.9. Phase angle

The presence of Colgate mouthwash results in a reduction of the phase angle of Ni-Ti alloy when immersed in artificial saliva. This observation suggests that the corrosion resistance of Ni-Ti in artificial saliva diminishes in the presence of Colgate mouthwash. This effect can be attributed to the aggressive components found in the Colgate mouthwash.

3.10. Double layer capacitance (C_{dl})

Electrical double layer capacitance (C_{dl}) pertains to the polarization of ionic charges at the electrodes of an electrochemical impedance spectroscopy (EIS) system. The extent of charge accumulation is directly proportional to both the surface area of the electrode and the size of the ions involved. Consequently, an increase in the electrode's surface area results in a corresponding increase in double layer capacitance.

In the current study, it was observed that the double layer capacitance (C_{dl}) of Ni-Ti alloy, when immersed in artificial saliva, increases in the presence of Colgate mouthwash. This suggests that the corrosion resistance of Ni-Ti in artificial saliva diminishes when Colgate mouthwash is present.

3.11. Implication

The study of Electrochemical Impedance Spectroscopy (EIS) reveals that the corrosion resistance of Ni-Ti in artificial saliva diminishes when exposed to Colgate mouthwash. This suggests that individuals with orthodontic wires composed of Ni-Ti alloy should refrain from using Colgate mouthwash.

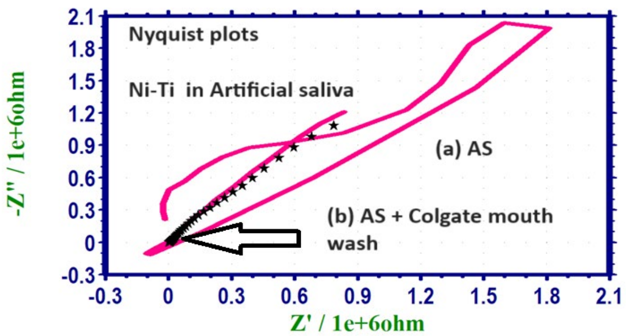

Fig. 6. Nyquists plots of Ni-Ti alloy in (a) artificial saliva (b)artificial saliva + Colgate mouthwash

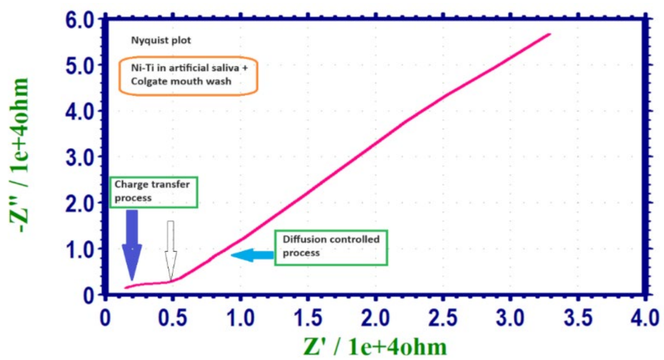

Fig. 7. Nyquists plot of Ni-Ti alloy in artificial saliva + Colgate mouthwash (enlarged image)

It can be noted from the enlarged image in Figure 7 that the process encompasses both charge transfer and diffusion-controlled mechanisms.

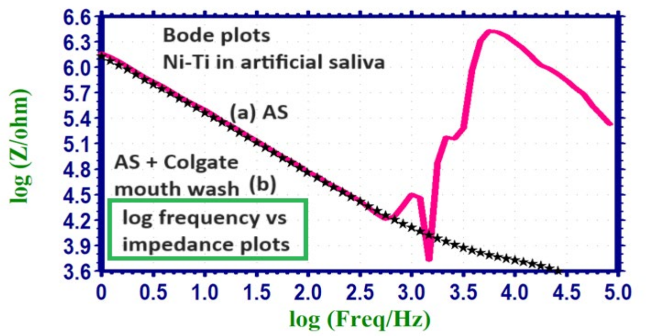

Fig. 8. Bode plots (log frequency vs impedance plots) of Ni-Ti alloy in (a) artificial saliva (b) artificial saliva + Colgate mouthwash

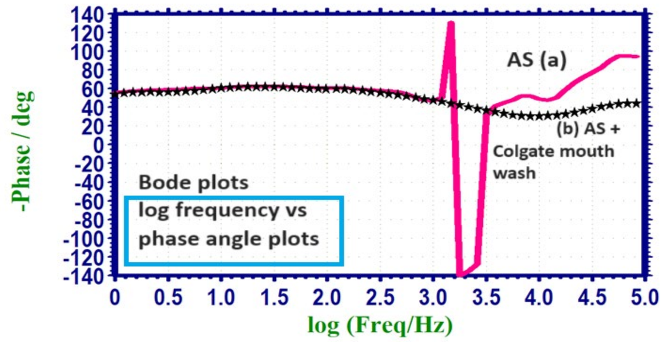

Fig. 9. Bode plots (log frequency vs phase angle plots) of Ni-Ti alloy in (a) artificial saliva (b) artificial saliva + Colgate mouthwash

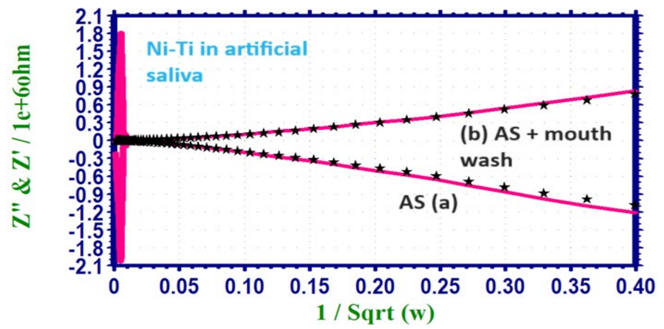

Fig. 10. Plots: 1/Sqrt(w) vs Z" &Z' of Ni-Ti alloy in (a) artificial saliva (b) artificial saliva + Colgate mouthwash

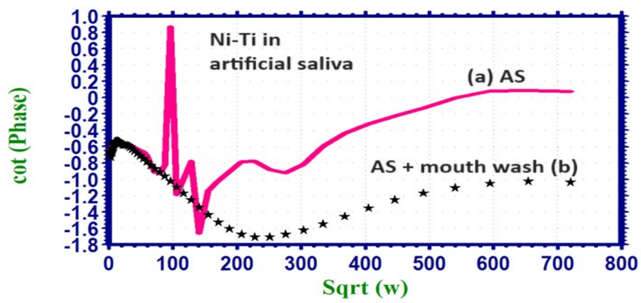

Fig. 11. Plots: sqrt(w) vs cot (phase) of Ni-Ti alloy in (a) artificial saliva (b) artificial saliva + Colgate mouthwash

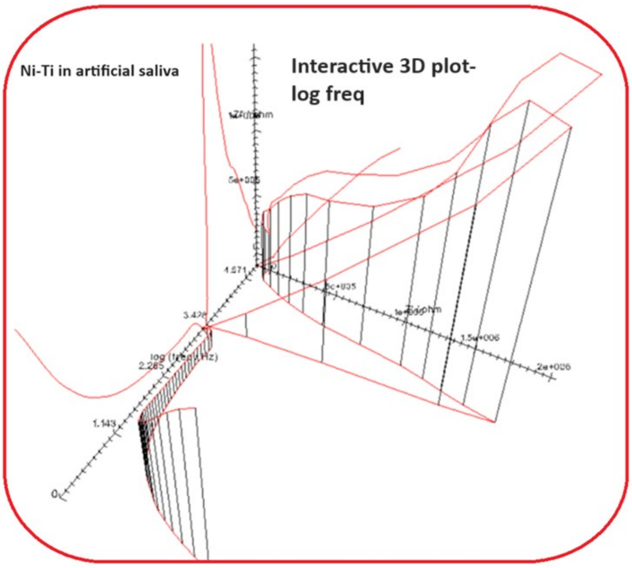

Fig. 12. Interactive 3D plot- log frequency of Ni-Ti alloy in artificial saliva

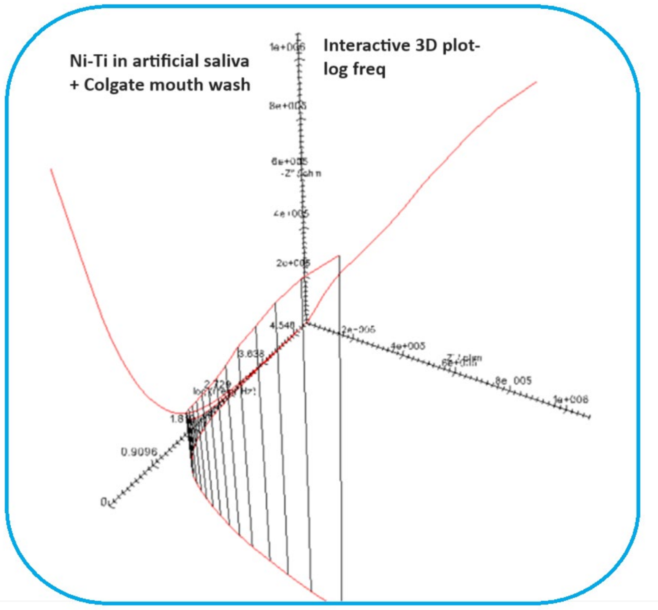

Fig. 14. Interactive 3D plot- log frequency of Ni-Ti alloy in artificial saliva + Colgate mouthwash

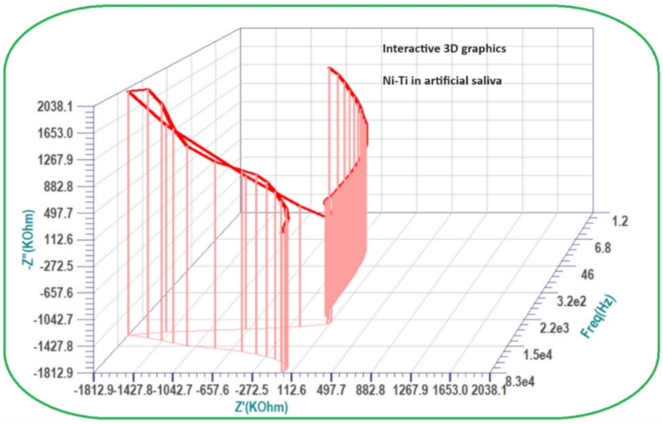

Fig. 13. Interactive 3D graphics of Ni-Ti alloy in artificial saliva

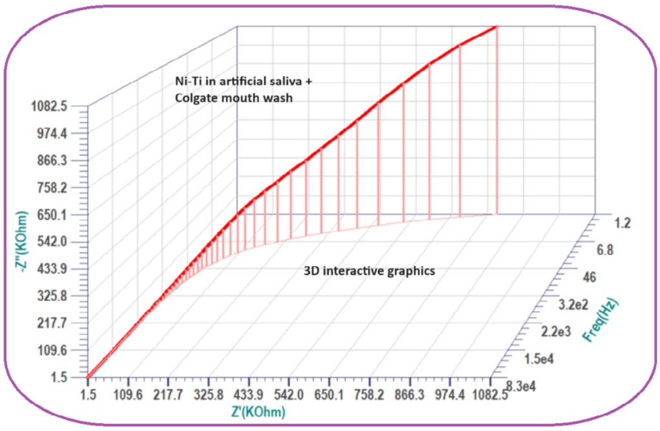

Fig. 15. Interactive 3D plot- log frequency of Ni-Ti alloy in artificial saliva + Colgate mouthwash

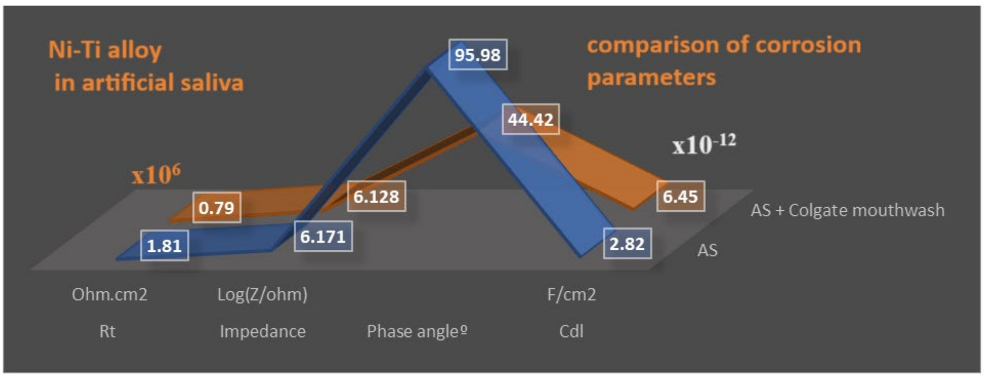

Fig. 16. Comparison of corrosion parameters of Ni-Ti alloy in various test solutions obtained from AC impedance spectra

Conclusions

The present study evaluated the corrosion resistance of orthodontic wire composed of Ni-Ti alloy when immersed in artificial saliva, both in the absence and presence of Colgate mouthwash. Two electrochemical methods—potentiodynamic polarization and electrochemical impedance spectroscopy (EIS)—were employed to assess the material's behavior under simulated oral conditions.

Results obtained from polarization studies revealed that the presence of Colgate mouthwash leads to a reduction in corrosion resistance. This was evidenced by a decrease in the linear polarization resistance and a corresponding increase in corrosion current, suggesting enhanced electrochemical activity at the wire surface. These findings were further supported by EIS measurements, which demonstrated a significant decrease in charge transfer resistance, impedance magnitude, and phase angle values. Simultaneously, an increase in the double layer capacitance was observed, indicating greater surface activity and possible degradation of passive films on the Ni-Ti surface.

The consistent trend across both electrochemical techniques confirms that Colgate mouthwash adversely affects the corrosion resistance of Ni-Ti orthodontic wires in artificial saliva. This reduction in protective behavior is likely attributed to the aggressive chemical components present in the mouthwash formulation, which may compromise the stability of the alloy's passive oxide layer.

Based on these findings, it is recommended that individuals using orthodontic appliances composed of Ni-Ti alloy avoid the regular use of Colgate mouthwash, or similar formulations, to mitigate the risk of material degradation and ensure the longevity of dental treatments.

References

Anees, E., Riaz, M., Imtiaz, H., & Hussain, T. "Electrochemical corrosion study of chitosan-hydroxyapatite coated dental implant." Journal of the Mechanical Behavior of Biomedical Materials 150 (2024): 106268. https://doi.org/10.1016/j.jmbbm.2023.106268

Bajt Leban, M., Kosec, T., & Finšgar, M. "The corrosion resistance of dental Ti6Al4V with differing microstructures in oral environments." Journal of Materials Research and Technology 27 (2023): 1982–1995. https://doi.org/10.1016/j.jmrt.2023.10.082

Chraka, A. et al. "Synergistic inhibition of copper alloy by hydrosol extract derivatives: Electrochemical, surface and computational study." Journal of Molecular Liquids 392 (2023): 123507. https://doi.org/10.1016/j.molliq.2023.123507

Dinu, M., Cotrut, C.M., Petreus, T., Hauffman, T., Baciu, F., & Vladescu, A. "Structural, electrochemical, biological, and mechanical assessment of functionally graded Cr-based multilayers for enhanced metal-ceramic bond strength in dental restorations." Materials Chemistry and Physics 312 (2024): 128655. https://doi.org/10.1016/j.matchemphys.2023.128655

Eduok, U. "Microbiologically induced intergranular corrosion of 316L stainless steel dental material in saliva." Materials Chemistry and Physics 313 (2024): 128799. https://doi.org/10.1016/j.matchemphys.2023.128799

El Caid, Z.A., Left, D.B., & Zertoubi, M. "An exploratory assessment of dinitrophenylhydrazine as a potent corrosion inhibitor for carbon steel in sulfuric acid solution." Journal of Molecular Structure 1300 (2023): 137218. https://doi.org/10.1016/j.molstruc.2023.137218

Kaewnisai, S. et al. "Effect of pulse frequency on the surface properties and corrosion resistance of a plasma-nitrided Ti-6Al-4V alloy." Materials Research Express 10, no. 11 (2023): 116505. https://doi.org/10.1088/2053-1591/ad06ff

Khanna, R. et al. "Evaluating pyrazole Schiff bases as corrosion inhibitors for mild steel in acidic medium: A synergistic experimental and computational approach." Journal of Molecular Structure 1297 (2023): 136845. https://doi.org/10.1016/j.molstruc.2023.136845

Lepojević, N. et al. "Characterisation of NiTi orthodontic archwires surface after the simulation of mechanical loading in CACO2-2 cell culture." Coatings 9, no. 7 (2019): 440. https://doi.org/10.3390/coatings9070440

Li, K. et al. "Encapsulated corrosion inhibitor for reinforcing steel in lightweight concrete." Cement and Concrete Composites 146 (2023): 105388. https://doi.org/10.1016/j.cemconcomp.2023.105388

Liaquat, I. et al. "Comparative corrosion behavior of Au50-Ag25-Pd25 and Ni88.6-Cr11.4 alloys utilized in dental applications." Journal of Electrochemical Science and Engineering 13, no. 6 (2023): 1027–1035. https://doi.org/10.5599/jese.1931

Łosiewicz, B., Osak, P., & Górka-Kulikowska, K. "Electrophoretic deposition of multi-walled carbon nanotube coatings on CoCrMo alloy for biomedical applications." Micromachines 14, no. 11 (2023): 2122. https://doi.org/10.3390/mi14112122

Maroof, Mariam, Renganathan Sujithra, and Ravi Prakash Tewari. "Superelastic and shape memory equi-atomic nickel-titanium (Ni-Ti) alloy in dentistry: a systematic review." Materials Today Communications 33 (2022): 104352. https://doi.org/10.1016/j.mtcomm.2022.104352

Minagalavar, R.L. et al. "Experimental and theoretical investigations of Cordia obliqua leaves extract as an environmentally benign inhibitor for mild steel corrosion in a 1 M HCl solution." Portugaliae Electrochimica Acta 42, no. 4 (2024): 233–254. https://doi.org/10.4152/pea.2024420401

Nichul, U., Kumar, V., & Hiwarkar, V. "Electrochemical performance of heat-treated beta titanium alloy in artificial saliva: Key role of grain size." Materials Today Communications 37 (2023): 106981. https://doi.org/10.1016/j.mtcomm.2023.106981

Renuka, P.H. et al. "Corrosion mitigation of mild steel in 1 M HCl acid using an expired drug: An experimental approach." Inorganic Chemistry Communications 160 (2023): 111871. https://doi.org/10.1016/j.inoche.2023.111871

Storehagen, Silje, Nanna Ose, and Shilpi Midha. "Dentifrices and mouthwashes ingredients and their use." Master's thesis, 2003.

Sudhakaran, R. et al. "Trisodium citrate as an eco-friendly corrosion inhibitor of copper in potable water." Journal of King Saud University - Science 35, no. 8 (2023): 102907. https://doi.org/10.1016/j.jksus.2023.102907

Szymańska, J., & Sitkowska, J. "Antimicrobial efficacy of Colgate Plax Cool Mint® mouthwash – in vivo studies." Current Issues in Pharmacy and Medical Sciences 33, no. 4 (2020): 212–217. https://doi.org/10.2478/cipms-2020-0040

Vashishth, P. et al. "Albumin as a sustainable corrosion inhibitor for low-carbon steel in HCl and H_2SO_4." Results in Surfaces and Interfaces 13 (2023): 100155. https://doi.org/10.1016/j.rsurfi.2023.100155

Xie, F. et al. "Electrochemical corrosion behavior and in vitro biocompatibility of Ti-Nb-Sn alloy for dental applications." Corrosion Science 224 (2023): 111531. https://doi.org/10.1016/j.corsci.2023.111531

Zheng, Y. et al. "Effect of fluoride ion concentration on the corrosion behaviour of WE43 alloy in artificial saliva for dental applications." Corrosion Science 226 (2023): 111672. https://doi.org/10.1016/j.corsci.2023.111672