Quality Evaluation of Toothpaste Using Advanced Electrochemical Techniques

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Abstract
The following work presents a new method that aims to study the quality of toothpastes, in particular, excessive presence of fluoride, which is a corrosive agent for dental alloys. Results showed that the proposed method allowed analysis of electrochemical properties from compounds that exist in these oral hygiene products, generally based on the concentration effect of fluoride present in toothpastes. Excess doses of fluoride can cause serious effects, such as corrosion of dental alloys. Cyclic voltammetry (CV), linear voltammetry (LV) and electrochemical impedance spectroscopy (EIS) curves were herein recorded to identify characteristic electrochemical signals of different ingredients, in particular, fluoride concentration

Keywords: CV; EIS, fluor; LV; toothpastes.

Introduction•

Brushing teeth daily with fluoride toothpastes is essential to prevent childhood cavities. It plays a vital role in removing dental plaque, and limits proliferation of cariogenic bacteria. It also ensures good oral hygiene from a young age, helping to preserve teeth health [1-3].

Two essential compounds that can be used instead of a commercial toothpaste are: sodium bicarbonate and salt. Toothpastes are generally useful and beneficial for dental health and oral hygiene. They also help preventing dental problems such as cavities, and removing plaque buildup [4]. In some countries, groundwater may contain a higher amount of fluoride and drinking water may be artificially fluoridated [5-7].

There are several methods of quality control of toothpastes such as gravimetric detection [8, 12], the use of device-sampling based on a photoelectric counter [9] or shell and table [10], and stellerite, an anti-staining friction agent [11].

The method proposed in this work highlights the electrochemical interaction between employed electrode and toothpaste used as reagent. This interaction is

•The abbreviations list is in page 178.

interpreted by a curve giving electric current as a function of potential. Reactions that can occur are of two types: oxidation, which appears in the form of a peak in the region of positive currents; and reduction, of which peak is in the region of negative currents. These peaks are specific to the initial toothpaste. If expired, these peaks appear at different potential values.

Experimental

All chemicals used in this work are of best analytical qualities. Co-Ni alloy used in this work was prepared in ideal conditions. The electrochemical study was carried out using a Voltalab Potentiostat (model PGSTAT 100, Ecochemine BV, Netherlands), in order to analyze electrochemical results. The electrochemical cell used in this work consisted of a plate based on a Co-Ni alloy, saturated calomel and Pt used as working, reference and auxiliary electrodes, respectively, which ensured closing of the electrical circuit and passage of current. Processing of obtained results was performed with Voltalab Master 4 software.

Results and discussion

Fig. 1 presents CV recorded on the surface of an electrode made of a portion of Co-Ni dental alloy, in a salivary medium, with or without toothpaste. It was noted that this paste altered from a potential value of 1 V, which corresponds to onset. It should be noted that, in oral cavity, saliva and food composition have an ionic moment able to trigger electrochemical reactions.

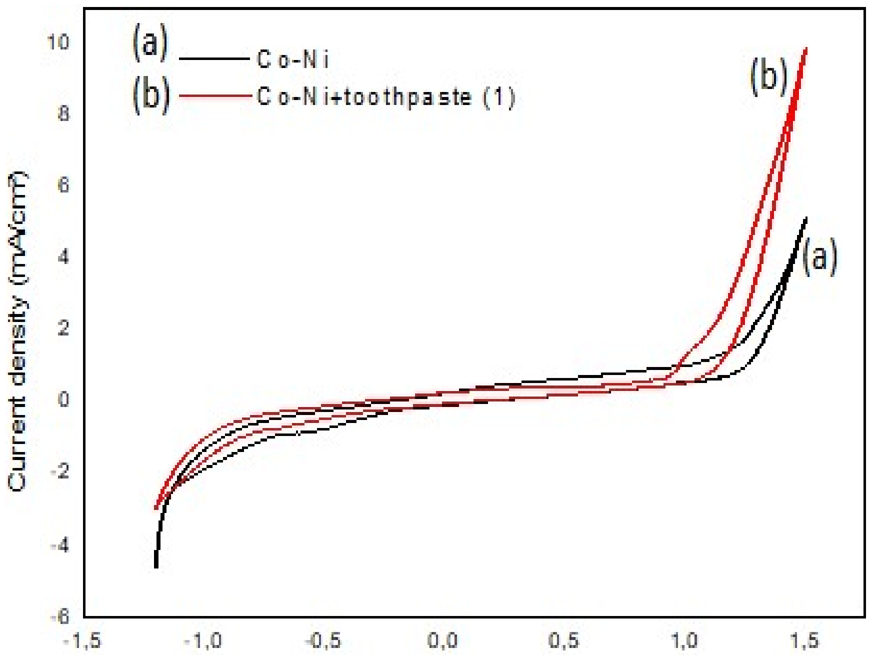

Figure 1: CV recorded at the surface of **(a)** Co-Ni and **(b)** Co-Ni/toothpaste (1) electrodes.

Fig. 2 illustrates a stability comparison of the different toothpastes, considering onset. The order of alteration was: toothpaste 1 < toothpaste 3 < toothpaste 2.

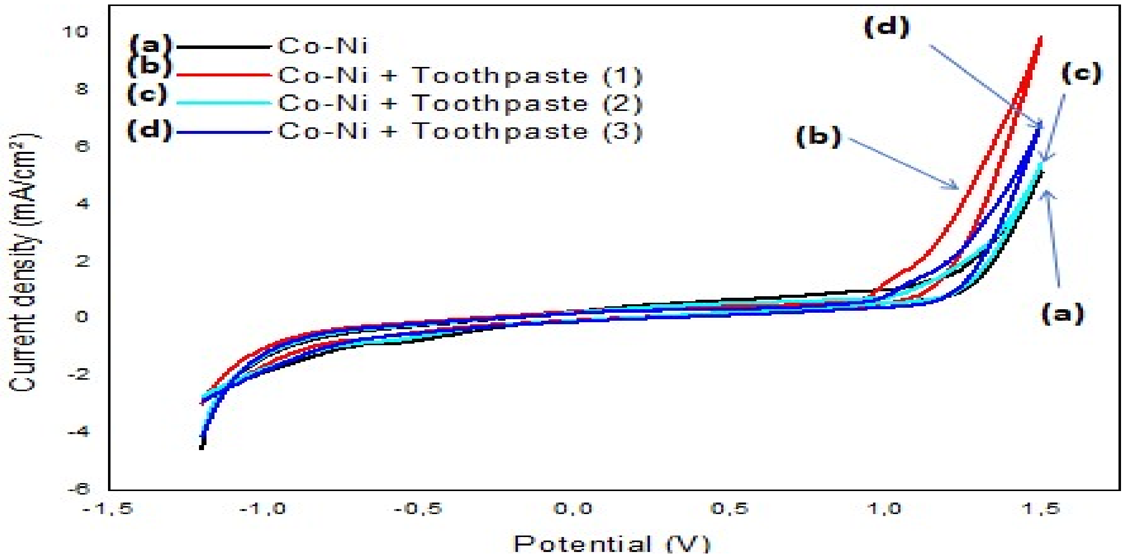

Figure 2: CV recorded at the surface of **(a)** Co-Ni; **(b)** Co-Ni/toothpaste (1); **(c)** Co-Ni/toothpaste (2); and **(d)** Co-Ni/toothpaste (3) electrodes.

Fig. 3 presents EIS curves recorded in the presence and absence of the different studied toothpastes. These curves have the appearance of half loops, of which diameter corresponds to electron transfer resistance of Co-Ni alloy to corrosion. The order of protection was: toothpaste 2 < toothpaste 1 < toothpaste 3.

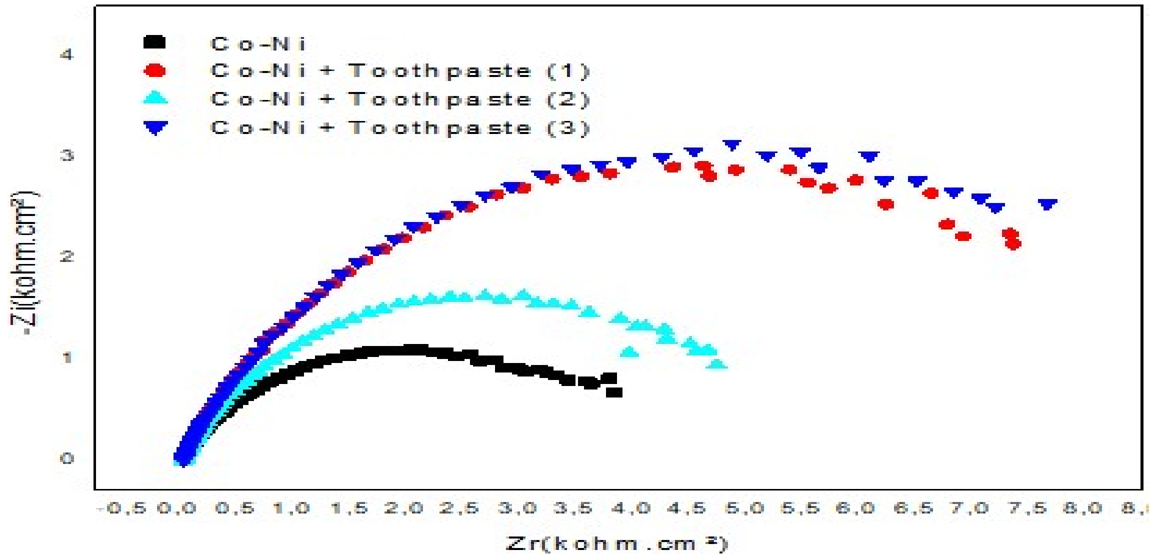

Figure 3: Impedance diagram recorded at the electrode surface of Co-Ni, Co-Ni/toothpaste (1), Co-Ni/toothpaste (2); and Co-Ni/toothpaste (3) electrodes.

Fig. 4 presents Tafel lines recorded on the Co-Ni electrode surface. Current densities are expressed in mA/cm^2, and potential in mV. Equilibrium potentials E(i = 0), indicate basic electrochemical behavior of the electrode made from Co-Ni alloy in the supporting electrolyte. It was noted that the electrode electrochemical behavior changed remarkably in the presence of the studied toothpastes. This change was stronger in the presence of toothpastes 1 and 3. However, equilibrium current densities were not significantly different, which suggests that electron transfer kinetics was not affected by the toothpastes presence in the solution. Table 1 shows electrochemical parameters deduced from Tafel lines.

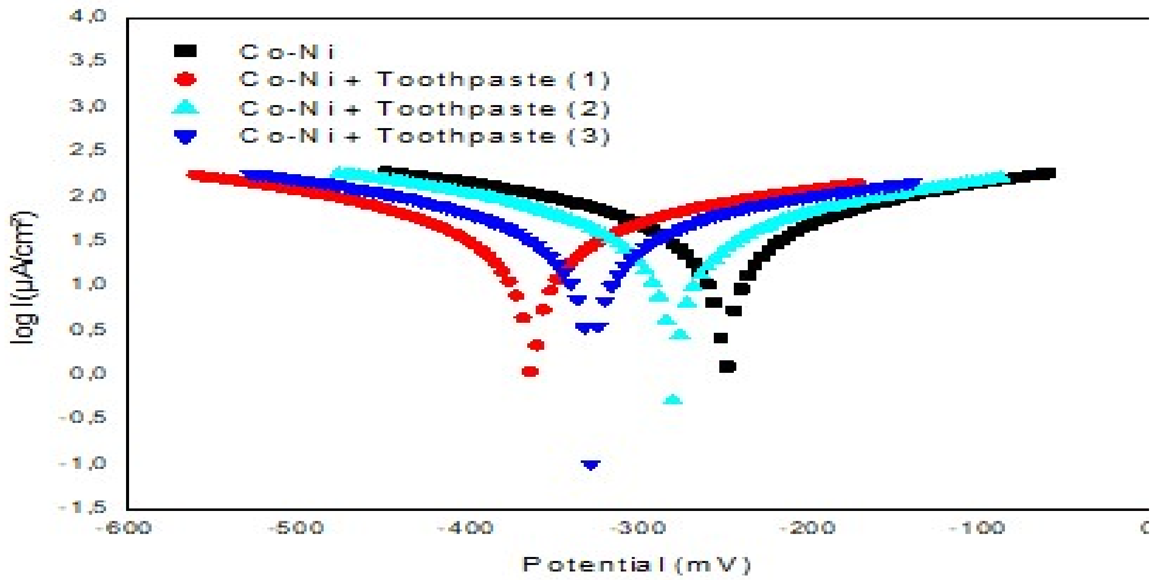

Figure 4: LV recorded on the surface of Co-Ni, Co-Ni/toothpaste (1), Co-Ni/toothpaste (2); and Co-Ni/toothpaste (3) electrodes.

Table 1: Electrochemical parameters deduced from Tafel lines.

	E(i=0) (mv)	i_{corr} (µA/cm^2)	B_a (mV)	B_c (mV)	B_a/B_c	Coef	Corrosion (mm/Y)
Blank	-249.5	47.1	319.2	318	1.00	0.99	551.4
Toothpaste (1)	-362.5	41.8	358.3	-309	1.15	0.99	489.3
Toothpaste (2)	-279.1	39.2	303.8	-280	1.08	0.99	459.3
Toothpaste (3)	-327.8	44.0	367.2	-316	1.15	0.99	515.7

From Fig. 5, one can deduce a new physical quantity called specific capacity, which represents the amount of electricity exchanged between different toothpastes and Co-Ni electrode. It was calculated according to Eq. (1).

$$C_p = A/2\ mK * (V_2 - V_1) \qquad (1)$$

where C_p is specific capacity, A is the electrode's electrochemical surface (m^2), m is NaCl electrolyte's mass (g), V_1 and V_2 are applied potentials (V), at the level of potential range scanned in the electrochemical experiment, and K is scan rate (50 mV/s). Values of the electrodes 'specific capacitance are grouped in Table 2.

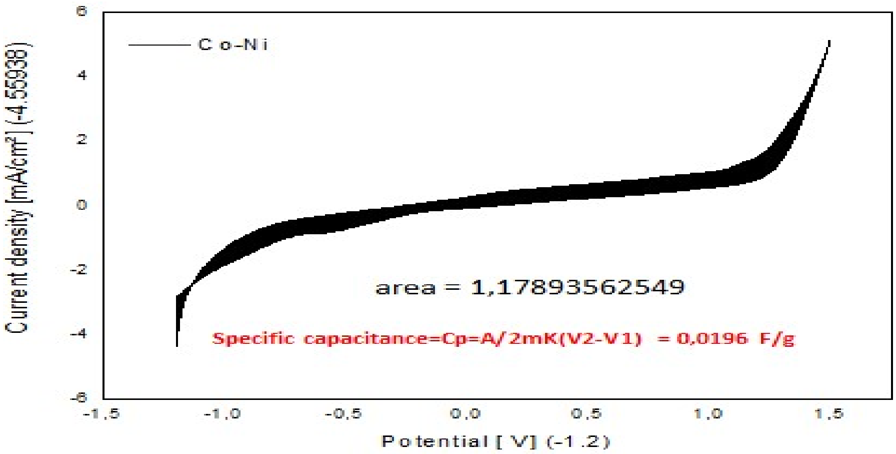

Figure 5: Specific capacity exchanged between Co-Ni electrode and the 0.1 M NaCl electrolytic medium.

Table 2: Values of electrodes' specific capacitance in the presence of different toothpastes.

Toothpastes	Toothpaste (1)	Toothpaste (2)
C_p F/g	0.021	0.015

Conclusion

This study presents a novel electrochemical approach to assess the quality of toothpastes, by investigating the effect of fluoride concentration in an electrolytic medium composed of 0.1 M NaCl and 20 mL distilled water. Three main electrochemical techniques (CV, LV and EIS) were used to evaluate the behavior of dental plaque under various fluoride conditions. Results show that excessive fluoride concentrations have a negative impact on dental health, as evidenced by accelerated plaque erosion in fluoride-rich environments. These findings suggest that, while fluoride is important for preventing cavities, its excessive use can lead to enamel deterioration and other side effects. These insights open new avenues for research in pharmaceutical and dental hygiene product development, particularly in optimizing fluoride formulations to balance efficacy and safety. Future studies could explore long-term exposure effects, alternative anticavity agents, or fluoride delivery mechanisms to minimize potential harm, while maintaining protective benefits.

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Authors' contributions

M. Oukbab: conceptualization; experimental; investigation; data analysis; original draft preparation and writing; review and editing. **M. Enasraouy**: conceptualization; methodology. **M. Oubaouz**: experimental; investigation. **R. Najih**: methodology; review and editing. **R. Maallah**: conceptualization; investigation and **A. Chtaini**: conceptualization; methodology; original draft preparation and writing; review and editing; supervision.

Abbreviations

CO-Ni: Cobalt-Nickel alloy
CV: Cyclic Voltammetry
EIS: Electrochemical Impedance Spectroscopy
LV: Linear Voltammetry
NaCl: Sodium chloride

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