INFLUENCE OF COFFEE ON THE CORROSION RESISTANCE OF ORTHODONTIC WIRES IN ARTIFICIAL SALIVA

A. Christy Catherine Mary,[a] S. Rajendran[b,c] and J. Jeyasundari[d]

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Corrosion resistance of Ni-Ti, Thermoactive alloy, and SS 316L alloy in artificial saliva (AS) in the absence and presence of coffee has been evaluated by electrochemical studies such as polarization study and AC impedance spectroscopy. The polarization and AC impedance spectroscopy studies lead to the conclusion that corrosion resistance of the alloys decreases in the following order: SS 316L alloy > Thermoactive alloy > Ni-Ti alloy. In all the three cases, the corrosion resistance of the wires increases in the presence of coffee. Among the three orthodontic wires, SS316L alloy is the best candidate.

Materials and methods

Introduction

Metallic materials such as Ag, Au, Ni-Ti, Ni-Cr, SS 316L, SS18/8, etc., are used as implants in regulative oral surgery to the array of teeth. The metals for complete and partial crowns and bridges should be hypoallergenic materials with good mechanical properties, corrosion resistant towards soft drinks, hot drinks, food items, and tablets. Titanium alloys are the most commonly used material for implantation of the teeth.1 Corrosion of metallic implants has vital importance because it can adversely affect the biocompatibility and mechanical integrity of implants. The electrochemical behavior of orthodontic wires in artificial saliva has been investigated by polarization study and AC impedance spectra2. The resistance to corrosion of the metallic orthodontic wires in simulated intra-oral environment has been evaluated by Ziebowicz et al.3 The effects of multilayered Ti/TiN or single-layered TiN film deposited by Pulse-Biased Arc Ion Plating (PBAIP) on the corrosion behavior of NiTi orthodontic wires in artificial saliva have also been investigated.4 Rajendran et al. have studied the corrosion behavior of SS 316L and AS in artificial saliva in the presence of electoral, spirulina powder, and glucose, respectively.5,6,7 A lot of studies have been published on the use of natural products as corrosion inhibitors.7-13 Corrosion behavior of Thermoactive super elastic shape memory alloy and Gold 22K has been investigated in artificial saliva in the presence of syzygium cumini fruit juice.15 The corrosion resistance of Ti depends on the passive film alloys formed on surface.16-20

In the present study, the corrosion resistance of Ni-Ti, SS 316L, and Thermoactive alloys has been evaluated by electrochemical studies such as polarization study and AC impedance spectroscopy in artificial saliva in presence and absence of coffee.

Materials and methods

Preparation of coffee test solution

The coffee test solution was prepared by heating 250 ml of milk to boil, and with added the 5 g of instant coffee powder (BRU Instant Coffee), the mixture was mixed with a teaspoon of sugar.

Corrosion behavior of Ni-Ti, Thermoactive alloy, and SS316L alloy have been investigated in various test solutions such as artificial saliva (AS), coffee, AS + coffee. The composition of AS is given in Table 1.

Table 1. The composition of artificial saliva

<table>
<thead>
<tr>
<th>Content</th>
<th>Concentration, g L⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl</td>
<td>0.4</td>
</tr>
<tr>
<td>NaH₂PO₄·2H₂O</td>
<td>0.690</td>
</tr>
<tr>
<td>KCl</td>
<td>0.4</td>
</tr>
<tr>
<td>CaCl₂·2H₂O</td>
<td>0.906</td>
</tr>
<tr>
<td>Na₂S·9H₂O</td>
<td>0.005</td>
</tr>
<tr>
<td>Urea</td>
<td>1.0</td>
</tr>
</tbody>
</table>

The metal specimens were immersed in Fusayama-Meyer artificial saliva.21 The pH of the solution was 6.5. In electrochemical studies, the alloys were used as working electrodes. Artificial saliva was used as an electrolyte. The experiments were carried out at 64.5 °C (temperature of the coffee drink).

Potentiodynamic polarization study

Polarization studies were carried out in a CHI-electrochemical workstation with impedance, Model 660A. A three-electrode cell assembly was used.
Table 2. Corrosion parameters of metals immersed in artificial saliva (AS) in the absence and the presence of coffee obtained by polarization study

<table>
<thead>
<tr>
<th>Metal</th>
<th>System</th>
<th>$E_{corr}$, mV vs SCE</th>
<th>$b_a$, mV decade$^{-1}$</th>
<th>$b_c$, mV decade$^{-1}$</th>
<th>$LPR$, ohm cm$^2$</th>
<th>$I_{corr}$, A cm$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ni-Ti alloy</td>
<td>AS</td>
<td>-395</td>
<td>178</td>
<td>302</td>
<td>3277970</td>
<td>1.488x10$^{-8}$</td>
</tr>
<tr>
<td></td>
<td>AS+Coffee</td>
<td>-778</td>
<td>126</td>
<td>335</td>
<td>5557295</td>
<td>7.170x10$^{-9}$</td>
</tr>
<tr>
<td>SS316L alloy</td>
<td>AS</td>
<td>-454</td>
<td>164</td>
<td>317</td>
<td>4177473</td>
<td>1.127x10$^{-8}$</td>
</tr>
<tr>
<td></td>
<td>AS+Coffee</td>
<td>-447</td>
<td>123</td>
<td>216</td>
<td>12072330</td>
<td>2.825x10$^{-9}$</td>
</tr>
<tr>
<td>Thermoactive alloy</td>
<td>AS</td>
<td>-501</td>
<td>158</td>
<td>315</td>
<td>7936745</td>
<td>5.775x10$^{-8}$</td>
</tr>
<tr>
<td></td>
<td>AS+Coffee</td>
<td>-726</td>
<td>130</td>
<td>339</td>
<td>8025230</td>
<td>5.095x10$^{-9}$</td>
</tr>
</tbody>
</table>

The working electrode was one of the three alloys. A saturated calomel electrode (SCE) was the reference electrode, and platinum was the counter electrode.

AC impedance spectra

The cell setup was the same as in the case of polarization study. The real part ($Z'$) and imaginary part ($Z''$) of the cell impedance were measured in ohms at various frequencies.

Result and Discussion

Analysis of polarization curves

Polarization analysis has been used for detection of the protective films formed on the metal surface during corrosion inhibition process. The corrosion parameters of Ni-Ti, Thermoactive alloy, and SS316L alloy in the test solutions are given in Table 2, and the potentiodynamic polarization curves are shown in Figures 1 and 2.

![Polarization curve of Ni-Ti alloy, SS 316L alloy and Thermoactive alloy immersed in AS](image)

As it is given in Table 2, when Ni-Ti alloy was immersed in AS, the corrosion potential is -375 mV vs. SCE (Figure 1a). The Linear Polarization Resistance ($LPR$) value was 3277970 ohm cm$^2$, and the corrosion current ($I_{corr}$) was 1.488 x 10$^{-8}$ A cm$^2$.

When the Thermoactive alloy was immersed in AS the $E_{corr}$ value was -501 mV vs. SCE (Figure 1c). The $LPR$ value was 7930745 ohm cm$^2$. This was found to be higher than in case of Ni-Ti alloy. The corrosion current is ($I_{corr}$) was found to be 5.775 x 10$^{-8}$ A cm$^2$. This was found to be lower than in case of Ni-Ti alloy. These observations indicated that thermoactive alloy was more corrosion resistant than Ni-Ti alloy.

In the case of Thermoactive alloys, the cathodic Tafel slope was ($b_c$) 158 mV decade$^{-1}$, and the anodic Tafel slope was ($b_a$) 315 mV decade$^{-1}$. These values suggested that during anodic polarization, the rate of change of corrosion current with potential was high, and it was less during the cathodic polarization.

When the SS316L alloy was immersed in AS, the corrosion potential was -454 mV vs. SCE (Figure 1b). The $LPR$ value was 12072330 ohm cm$^2$. The corrosion current was 1.127x10$^{-8}$ A cm$^2$. The values of Tafel slopes ($b_a$ = 164; $b_c$ = 317 mV decade$^{-1}$) indicated that the rate of change of current with potential increased in higher rate during the anodic polarization than during the cathodic polarization. A comparison of $LPR$ values and corrosion current values of these alloys investigated revealed that SS316L was more corrosion resistance than other two alloys.

Corrosion behavior of alloys in AS containing coffee

Ni-Ti alloy

AS it can be seen in Table 2, when Ni-Ti alloy was immersed in AS containing coffee, the corrosion potential was -778 mV vs. SCE (Figure 2a). It was interesting to note that in the presence of coffee the $LPR$ value increased (5557295 ohm cm$^2$) and the corrosion current value decreased (7.170 x 10$^{-9}$ A cm$^2$). It seemed that a protective layer was formed on the metal surface which controlled the rate of corrosion of Ni-Ti in AS in the presence of coffee. The values of Tafel slopes were $b_c$ = 130 mV decade$^{-1}$; $b_a$ = 339 mV decade$^{-1}$.

Thermoactive alloy

When the Thermoactive alloy was immersed in AS containing coffee the corrosion potential was -712 mV vs. SCE (Figure 2c). The Tafel slope were $b_c$ = 130 mV decade$^{-1}$ and $b_a$ = 339 mV decade$^{-1}$.
Table 3. Corrosion parameters of metals immersed in Artificial saliva (AS) in the absence and the presence of coffee obtained by AC impedance spectra

<table>
<thead>
<tr>
<th>Metal</th>
<th>System</th>
<th>Nyquist plot, $R_t$ ohm cm$^2$</th>
<th>$C_{dl}$, F cm$^{-2}$</th>
<th>Bode plot, impedance log(Z ohm$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ni-Ti alloy</td>
<td>AS</td>
<td>12278</td>
<td>4.1538</td>
<td>2.030</td>
</tr>
<tr>
<td></td>
<td>AS+coffee</td>
<td>3823.8</td>
<td>1.30759</td>
<td>4.4</td>
</tr>
<tr>
<td>SS316L alloy</td>
<td>AS</td>
<td>12468</td>
<td>4.0905</td>
<td>4.443</td>
</tr>
<tr>
<td></td>
<td>AS+coffee</td>
<td>247279.52</td>
<td>2.0235</td>
<td>4.6</td>
</tr>
<tr>
<td>Thermoactive alloy</td>
<td>AS</td>
<td>27941</td>
<td>1.8253</td>
<td>4.344</td>
</tr>
<tr>
<td></td>
<td>AS+coffee</td>
<td>88930</td>
<td>5.6224</td>
<td>4.393</td>
</tr>
</tbody>
</table>

The $LPR$ value was increased from 7936745 ohm cm$^2$ to 802530 ohm cm$^2$; the corrosion current was decreased from $5.775 \times 10^{-8}$ A cm$^{-2}$ to $5.095 \times 10^{-9}$ A cm$^{-2}$. That is, in the presence of coffee, the corrosion resistance of thermoactive alloy was increased.

**Figure 2.** Polarization curve of Ni-Ti alloy, SS316L alloy and Thermoactive alloy immersed in AS+Coffee

**SS 316 L alloy**

In the presence of coffee, the corrosion resistance of SS316L increased. This is revealed by the increase in $LPR$ value (from 4177473 ohm cm$^2$ to 12072330 ohm cm$^2$) and decrease in corrosion current (from 1.127 $\times 10^{-8}$ to 2.825 $\times 10^{-9}$) (Figure 2b). The value of Tafel slope were $b_a = 123$ mV decade$^{-1}$; $b_c = 216$ mV decade$^{-1}$. Thus polarization study leads to the conclusion that in the presence of coffee in AS the corrosion resistance of alloys decreased in the following order: SS316L alloy > Thermoactive alloy > Ni-Ti alloy. Polarization study reveals that the corrosion resistance of the three alloys in AS in absence and presence of coffee decreases in the following order; SS316L alloy > Thermoactive alloy > Ni-Ti alloy.

**Implication**

It implies that SS316L alloy is a better candidate for making orthodontic wire.

**Figure 3.** AC impedance spectra (Nyquist plot) of Ni-Ti alloy immersed in AS and AS+Coffee

**Thermoactive alloy**

When the Thermoactive alloy was immersed in AS (Figure 4a), the $R_t$ value is 27941 ohm cm$^2$. The double layer capacitance was $1.8253 \times 10^{-10}$ F cm$^2$. The impedance value [log (Z ohm$^{-1}$)] was 3.82 (Figure 8).

**AC impedance spectra**

AC impedance parameters such as charge transfer resistance ($R_t$), double layer capacitance ($C_{dl}$) (derived from Nyquist plots) and impedance value log (Z ohm$^{-1}$) (derived from Bode plots), of various alloys immersed in AS and AS containing coffee, are given in Table 3. AS impedance spectra are shown in Fig 3 to 5 (Nyquist Plots) and 6 to 11 (Bode plots).

**Ni-Ti alloy**

When Ni-Ti is immersed in AS (Figure 3a), the charge transfer resistance was 1227 ohm cm$^2$. The double layer capacitance was $4.1538 \times 10^{10}$ F cm$^2$. The impedance value [log (Z ohm$^{-1}$)] was 4.20315 in the presence of coffee (Figure 3b). $R_t$ value increased (from 1227 ohm cm$^2$ to $3823.8$ ohm cm$^2$) and $C_{dl}$ value was decreased. There was an increase in the value of impedance [log(Z ohm$^{-1}$)] (Fig 7b). These observations indicated that in the presence of coffee in AS, the corrosion rate of Ni-Ti was reduced due to the formation of the protective film formed on the metal surface.
When the $R_t$ values were compared with the value of Ni-Ti, it was noted that Thermoactive alloy was more corrosion resistant in AS than Ni-Ti alloy. Similarly, when Thermoactive alloy was immersed in AS mixed with coffee (Figure 4b) the $R_t$ value was increased from 27941 to 88930 ohm cm$^2$, the $C_{dl}$ value decreased from 1.8253 x $10^{-10}$ F cm$^2$ to 5.622 x $10^{-11}$ F cm$^2$, and the impedance value increased from 3.871 to 4.393 (Figure 9). This observation concluded that the film formation on the metal surface in AS in the presence of coffee.

**Figure 4.** AC impedance spectra (Nyquist plot) of Thermoactive alloy immersed in AS and AS+Coffee

SS316L alloy

When SS316 L alloy was immersed in AS, the $R_t$ value was 12468 ohm cm$^2$. The $C_{dl}$ value was 4.0905x $10^{-10}$ F cm$^2$, and the impedance value [log (Z ohm$^{-1}$)] was 4.443 (Figure 10). These observations suggest that the protective film formed on the SS316L alloy. SS316L was a better candidate in AS since it was more corrosion resistant than Ni-Ti and Thermoactive alloys.

**Figure 5.** AC impedance spectra (Nyquist plot) of SS 316L alloy immersed in AS and AS+Coffee

When SS316L was immersed in AS in the presence of coffee the $R_t$ value is increase from 12468 to 247279.52 ohm cm$^2$, the $C_{dl}$ value is decreased from 4.0905 x $10^{-10}$ F cm$^2$ to 2.0235 x $10^{-10}$ F cm$^2$ and impedance value increased from 4.443 to 4.6 [log (Z ohm$^{-1}$)] (Figure 11).
Conclusion

The present study led to the conclusion that in the presence of coffee in AS, the corrosion resistance of SS316L increased. In the presence of coffee in AS, the corrosion resistance of alloys decreased in the following order:

SS 316L alloy > Thermostatic alloy > Ni-Ti alloy

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References


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Section B - Research paper

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