An Evaluation and Comparison of Surface Corrosion of Orthodontic Archwires using Scanning Electron Microscope: An \textit{in vitro} Study

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\textbf{ABSTRACT}

\textbf{Objectives:} To determine and compare the surface morphological changes with stainless steel (TruForce), nickel-titanium (TruFlex) and beta-titanium (BetaForce) archwires obtained after a period of 6 and 12 weeks of incubation in artificial saliva with the help of scanning electron microscope (SEM), are to assess the color changes macroscopically in the archwires after a period of 6 and 12 weeks of incubation in artificial saliva.

\textbf{Materials and methods:} Simulated fixed orthodontic appliances were constructed with band material, brackets, archwires, and ligature wires. All these samples were immersed in artificial saliva of pH 6.76 in three different petri dishes and incubated for a period of 6 and 12 weeks at 37°C in an incubator. Wire samples were examined under SEM for surface corrosion.

\textbf{Results:} Stainless steel archwire was more corroded as compared to the beta-titanium; which in turn was more corroded than nickel-titanium archwire (TruForce > BetaForce > TruFlex). The surface corrosion of intrabracket span was more than interbracket span of the archwire. Rust color was observed at the weld spots which increased with the incubation period from 6 to 12 weeks.

\textbf{Conclusion:} Nickel-titanium appears to be the most corrosion resistant archwire, making it an excellent choice for corrosive oral environment.

\textbf{Keywords:} Corrosion, Archwire, Scanning electron microscope.


\textbf{INTRODUCTION}

For many years stainless steel has been used for brackets, bands, and wires. With the introduction and current popularity of archwires that have a high concentration of nickel and/or titanium, such as nickel-titanium and beta-titanium and with the increasing use of recycled brackets, it is conceivable that a greater liability to corrosion products may occur. The potential of an alloy to cause an allergic reaction is related to the pattern and mode of corrosion with subsequent release of metal ions, such as nickel, into the oral cavity.

The oral environment because of its microbiologic and enzymatic phenomena is an ideal climate for corrosive attack of orthodontic appliances. This phenomenon requires an electrolyte and two dissimilar metals or a concentrated cell solution. Although electrolytic attack is likely to be the major cause for corrosion, bacteria and their waste products, and selective interactions with gases, such as oxygen and carbon dioxide may all contribute to breakdown of orthodontic appliances placed in the oral cavity. Organic acids and the pH of the oral environment have a significant effect on the rate of metal breakdown.

The fixed orthodontic appliances are subjected to corrosive damage which acts to degrade the physical properties and increase the potential for failure. The rate of this damage is of particular interest when considering the life span of an appliances. Also, corrosion on the brackets and archwires plays an important role in sliding mechanics and may affect the anchorage.

The objectives of this study were:
1. To evaluate and compare the corrosion rate of stainless steel (TruForce), nickel-titanium (TruFlex) and beta-titanium (BetaForce) archwires, using scanning electron microscope (SEM), which were obtained after a period of 6 and 12 weeks of incubation in artificial saliva.
2. To assess the color changes macroscopically in the archwires after a period of 6 and 12 weeks of incubation in artificial saliva.

\textbf{MATERIALS AND METHODS}

The corrosion of archwires was detected using SEM after a period of 6 and 12 weeks of incubation in artificial saliva.
Artificial saliva was prepared with the following composition — 0.4 gm NaCl, 0.4 gm KCl, 0.8 gm CaCl₂·2H₂O, 0.01 gm NaS·5H₂O, 1 gm CO(NH₂)₂ (urea), 1 liter distilled water.

The three sample of archwires: (1) stainless steel (TruForce), (2) nickel-titanium (TruFlex), (3) beta-titanium (BetaForce) were from Ortho Technology Inc, Boulevard, Tampa, Florida, USA; each with the dimension of 0.017 × 0.025 inch and 50 mm length.

Simulated fixed orthodontic appliances were constructed with band material, brackets, archwires and ligature wires. Molar band materials (Ortho Technology Inc.) of 0.180 × 0.005 inch dimensions were cut into strips of 60 mm each. Standard edgewise brackets of 0.022 × 0.028 inch slot size (Ortho Technology Inc) were welded on these band stripes equidistantly with two welds each, leaving 10 mm of space on either ends and 10 mm distance in between each bracket. Six such samples of five brackets each were prepared.

Archwires were engaged into the bracket slots and ligated with 0.010 inch ligature wire of length 40 mm each. After ligation, the ligature wire was cut to 10 mm length from the wings of the brackets and tucked below the archwire in unidirectional.

Six such samples were prepared and divided into three groups according to the alloy used. Group I: Comprised of simulated appliances with stainless steel (TruForce) archwires. Group II: Comprised of simulated appliances with nickel-titanium (TruFlex) archwires and Group III: Comprised of simulated appliances with beta-titanium (BetaForce) archwires.

Each group consists of two samples. All these samples were immersed in artificial saliva of pH 6.76 (pH meter Slope model: 111E) in three different Petri dishes according to the group and incubated for a period of 6 and 12 weeks at 37°C in an incubator. According to the period of incubation each group is divided into two subgroups. Subgroup A was incubated for a period of 6 weeks. Subgroup B was incubated for a period of 12 weeks. Three members who were blind to this study observed the color changes of each sample macroscopically.

After the incubation, wire from one sample of each subgroup was sectioned into six segments so that it included three interbracket areas and three intrabracket areas; which were examined using SEM (Hitachi, Japan) at 10 kV with 250× magnification.

Grid of 1 mm² (Fig. 1A) was used for overlapping the SEM pictures to evaluate and compare the amount of corrosion between stainless steel, beta-titanium and nickel-titanium archwires. The grid was overlapped on the SEM pictures, (Fig. 1B) and the total area showing corrosion was measured for each sample at 250× magnification.

Statistical Analyses

Student’s unpaired t-test was carried out for the comparison of corrosion rate between these three archwires, the comparison of corrosion rate between 6 and 12 weeks of incubation and the comparison of corrosion rate between the interbracket span and intrabracket span of the archwires. Conventional levels of significance were used: p < 0.05, significant; p > 0.05, not significant.

RESULTS

Table 1 shows the area of corrosion (calculated by overlapping the grid) of three archwires at 250× magnification after 6 and 12 weeks of incubation.

Mean and standard deviation for corroded area of the wires after 6 and 12 weeks of incubation is calculated (Table 2).

Comparison of Surface Corrosion among Three Wires

The comparison of corroded area after 6 weeks of incubation among the three wires for the interbracket span and intrabracket span of the archwires.
bracket span (Figs 2 and 3) at 250× magnification, showed that stainless steel (TruForce) archwire was more corroded as compared to the beta-titanium (BetaForce); which in turn was more corroded than nickel-titanium (TruFlex) archwire. The wires showed similar results even after 12 weeks of incubation (Tables 3 and 4).

**Comparison of Surface Corrosion between Interbracket Span and Intrabracket Span**

The comparison of corroded area of interbracket span and intrabracket span, for all the three wires, after 6 weeks of incubation at 250× magnification, showed that intrabracket span was more corroded than interbracket span. The wires showed similar results even after 12 weeks of incubation (Table 5).

**Comparison of Surface Corrosion at 6 and 12 Weeks of Incubation**

The comparison of surface corrosion at 6 and 12 weeks of incubation of interbracket span and intrabracket span, of all the three wires, at 250× magnification showed that more corrosion was observed after 12 weeks of incubation in comparison with 6 weeks of incubation (Table 6).

**Assessment of Color Changes**

Rust color was observed at the weld spots on all the samples and it increased with the incubation period from 6 to 12 weeks.

**DISCUSSION**

The overall results of the present study showed that the stainless steel (TruForce) archwire was more corroded than...
the beta-titanium (BetaForce) and nickel-titanium (TruFlex). Between beta-titanium and nickel-titanium, beta-titanium was more corroded than that of nickel-titanium (TruForce > BetaForce > TruFlex). The intrabracket span of the wire, showed more corrosion than the wire, which was interbracket. The surface corrosion was increased with the increase in the incubation time from 6 weeks to 12 weeks for all the archwires. The intrabracket span, showed more crevice type of corrosion. During crevice corrosion, the attack is localized within shielded area, while the remaining surfaces suffer little or no damage. This phenomenon was observed under deposits of oxide layer, the wire beneath the ligature wire, and at the interface between the bracket and the band. Such corrosion may weaken the wire or weld leading to fracture.

Shin and Hwang\(^4\) conducted a study in which they compared the corrosion behavior of stainless steel and nickel-titanium and they found that stainless steel archwires were more corrosion prone than the nickel-titanium archwires. Similar to our study this result is consistent with most of the reports that stainless steel is more susceptible to corrosion than nickel-titanium.\(^5\)\(^,\)\(^6\)\(^,\)\(^7\)

In the present study the intrabracket span showed more corrosion than the interbracket span for all the archwires which may lead to fracture of the archwire, resulting in failure of the fixed orthodontic appliance.

Movements of the archwire in the brackets may cause fretting corrosion, which accelerates metal loss from both the archwire and the brackets. The corrosion resistance of the bracket, bands, tubes and archwires relies to some extent on the presence of uniform passivated layer of chromium oxide on the metal surface. Mechanical rupturing or damage of this passivating layer will reduce the corrosion resistance property.\(^11\) Berradja et al evaluated the fretting wear patterns of orthodontic archwires in dry and wet conditions and reported that stainless steel and nickel-titanium archwires exhibited higher wear rates in the solutions than in air, indicating some synergism between the wear and corrosion processes. In the solutions the stainless steel archwires had a much lower corrosion-wear resistance than the nickel archwires.\(^12\)

Stabilization is a method employed in the introduction of some element that precipitates as carbide in preference to chromium. Titanium is often used for this purpose. Stainless steel that has been treated in this manner is said to be stabilized. Unfortunately, very few, if any, of the stainless steels used in orthodontics are so stabilized.\(^13\)

Muller and Chen\(^8\) compared the surface corrosion of stainless steel, nickel-titanium, beta-titanium and cobalt chromium, and found that beta-titanium exhibited good corrosion resistance, as did cobalt-chromium, whereas stainless steel and nickel-titanium wires showed pitting type of corrosive attack. Kim and Johnson\(^9\) conducted a study on corrosion of stainless steel, nickel titanium and beta-titanium orthodontic archwires. The results showed that corrosion occurred readily in stainless steel and in some nickel-titanium wires and the breakdown potential for titanium wire could not be reached and wire remained passive throughout the entire range of 2,000 mV. Sarkar et al\(^6\) reported that nickel-titanium is somewhat less corrosive resistant than the other orthodontic archwires. However, the present study indicates that corrosion resistance of nickel-titanium archwire is better than that of beta-titanium archwire, which is similar to the results of the study conducted by Edie et al,\(^7\) who observed nickel-titanium wire from a period of 1 to 8 months and they found no evidence of corrosion.

Speck and Fraker\(^10\) reported that nickel-titanium archwires have excellent corrosion resistance because the wire surface

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**Table 5:** The values of Student’s unpaired t-test for surface corrosion of interbracket span vs intrabracket span of the wire after 6 and 12 weeks of incubation at 250× magnification

<table>
<thead>
<tr>
<th>Statistics</th>
<th>6 weeks</th>
<th>12 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SS inter vs SS intra</td>
<td>NiTi inter vs NiTi intra</td>
</tr>
<tr>
<td>t-calculated</td>
<td>135.77</td>
<td>81.07</td>
</tr>
<tr>
<td>DF</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>t-tabulated</td>
<td>2.78</td>
<td>2.78</td>
</tr>
<tr>
<td>p-value</td>
<td>S</td>
<td>S</td>
</tr>
</tbody>
</table>

p < 0.05, significant (S)

**Table 6:** The values of Student’s unpaired t-test for surface corrosion at 6 weeks vs 12 weeks of incubation for interbracket span and intrabracket span of the wire at 250× magnification

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Interbracket span</th>
<th>Intrabracket span</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SS 6 weeks vs SS 12 weeks</td>
<td>NiTi 6 weeks vs NiTi 12 weeks</td>
</tr>
<tr>
<td>t-calculated</td>
<td>33.25</td>
<td>3.87</td>
</tr>
<tr>
<td>DF</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>t-tabulated</td>
<td>2.78</td>
<td>2.78</td>
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<tr>
<td>p-value</td>
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</table>

p < 0.05, significant (S)
is covered with chemically stable passive layer of TiO₂ and surface finish of the alloy is the major influence on the corrosion resistance of nickel-titanium. Hunt and Cunningham⁴⁴ reported that nickel-titanium archwire in the as-received state corroded faster than the polished wire. According to the study by Schwaninger et al⁴⁵ if the manufacturing defects are present before in a specimen, the corrosion increase may significantly. Neumann et al⁴⁶ reported that Teflon coating prevented the corrosion of the orthodontic wires. Pun et al⁴⁷ reported that the corrosion of various nickel-titanium wires increase with temperature and different phases present may influence corrosion trends. The result of the present in vitro study is comparable to the in vivo study of Petoumeno et al.⁴⁸ They investigated the corrosion susceptibility of nickel-titanium wires, in which a total of 115 wires of different manufacturers were retrieved after intraoral application lasting 1 to 12 months. Surface analysis revealed no differences in the degree of corrosion of the different products and observed extremely small and isolated corrosion defects. In a recent study by Lee et al⁴⁹ it was reported that four different commercial nickel-titanium archwires had dissimilar corrosion resistance in acidic fluoride containing artificial saliva, which did not correspond to the variation in the surface topography of the archwires. The presence of fluoride in artificial saliva was detrimental to the corrosion resistance of the test nickel-titanium archwires, especially at a 0.5% NaF concentration. Study by Shin and Hwang⁵⁰ had shown that the artificial saliva in the polyethylene tubes containing stainless steel archwires became cloudy with increasing immersion time, and rust colored precipitates accumulated at the bottom of the tubes. Present study does not support these results. But rust colored corrosion was observed near the weld spots, which were in favour with the study conducted by Barrett and Bisshara.⁵¹

Limitations of the Study
Physiologic conditions in the oral cavity differ from the in vitro arrangements. Fixed orthodontic appliances in the oral cavity are exposed to stress and friction due to masticatory function, and these factors may affect the release of metals from the appliances and increase the corrosion property.

CONCLUSION
1. Stainless steel archwires were more corroded as compared to the beta-titanium and nickel-titanium archwires, and among beta-titanium and nickel-titanium, the beta-titanium archwires were more corroded than nickel-titanium. There was a significant difference in the corrosion behavior of these three alloys.
2. In all the three archwires, the surface corrosion was more with the wire that was in the intrabracket span as compared to the wire that was in interbracket span.
3. In all the three archwires, the surface corrosion was increased with the increase in the incubation period from 6 to 12 weeks.

Based on the present study, nickel-titanium archwire is the most corrosion resistant, which makes it a desirable wire for use in oral environment. However, in patients with nickel sensitivity, beta-titanium is the best alternative to nickel titanium, as it does not contain nickel.

REFERENCES
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