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Effect of Artificial Saliva on the Corrosion Behavior of Dental Alloys: A review

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Abstract: Dental erosion is the chemical dissolution of the tooth structure. Factors like eating disorders and gastrointestinal diseases are recognized as intrinsic factors for dental erosion. To regulate the growth of teeth, people are implanted with orthodontic wires made of different materials. These are exposed to the influence of oral environment, food intake, toothpastes, and mouthwashes. During this process, the materials may undergo corrosion. Hence, various researchers have made a study on the influence of artificial saliva (AS) on the corrosion behavior of these alloys. The excellent corrosion resistance to the oral environment of dental alloys is important for biocompatibility as well as for orthodontic employment permanence. Various types of metal alloys are being used for the orthodontic treatment, which undergo chemical or electrochemical reaction with the oral environment. The oral environment is highly belligerent under several situations and leads to corrosion. This article reviews the effects of fluoride concentration, the pH value and protein content in AS and the composition of the metal alloys on the corrosion resistance of orthodontic appliances using electrochemical methods and surface characterization techniques such as scanning electron microscopy inductively coupled plasma-optical emission spectroscopy (ICP-OES) and X-ray photoelectron microscopy.

Key words*:* Alloys, Electrochemical methods, Scanning electron microscopy, X-ray photo electron spectroscopy, Corrosion.

I. INTRODUCTION

Dental implants are manufactured using metallic materials. They have to exhibit high corrosion resistance to avert metal release in the oral environment. Oral cavity represents a multivariate environment with a wide range of conditions including broad range of temperatures, pH, metal alloys and the presence of bacteria and effect of abrasion [1].

Depending on the environment of mouth the traces of corrosion on the surfaces of metals used in any application can be observed after an episode [2]. Dental alloys in a mouth are showing to the influence of chemical, biological, mechanical, thermal, and electrical forces. These forces significantly diminish their durability by a negative effect on functional and esthetic individuality of dental works. Electrochemical corrosion is the most essential damaging factor of dental works [3]. Corrosion is the unplanned wearing down of the metal surfaces. By experience to chemical or electrochemical reaction of the surrounding area, the outer and inner layers of the metallic surface get smashed [4]. The electrolyte is required for electrochemical reaction. Saliva has the role of electrolyte in the mouth. Saliva is a media of strong corrosive effect. As its pH factor decreases and as chloride concentration increases, the increase in corrosion potential of saliva is observed. The corrosion process occurs, as a result, either of the loss of metal ions directly into the solution or the dissolution of the surface films.

The stainless steel, cobalt-chromium, and titanium alloys used in orthodontic appliances depend on the formation of passive surface oxide films to defend against corrosion. The protective layers produced on the surface of these alloys are not reliable as they are inclined to both mechanical and chemical degradation. Even without destruction, oxide films often slowly dissolve only to restructuring as the metal surface is exposed to oxygen from the air or from the surrounding medium [5]. The acidic drinks and foods, containing sodium chloride are corrosive resources. The process of corrosion is accelerated by the belligerent media such as chloride ions and acidic conditions. It is further enhanced by the fluoride ions in toothpaste and in the products used as mouthwash as it plays the role of an essential factor accelerating corrosion [5-9].

Corrosion resistance of biomaterials made up of various metals and alloys has been investigated in artificial saliva (AS); various metals and alloys such as Ti-Co alloy [10], Ti30Ta alloy [11], Ti metal, Ti6-Al-7Nb, and Ti-6Al-4V alloy [1,12], Ti-6Al-7Nb alloy [13], Co-Cr alloy [14-18], CP-Ti and Ni-Cr-Ti alloy [19], Co-Cr-Mo alloy [20,21], Ni-Cr alloy [18,22,23], Ti-Cu [24], Ti-20Zr alloy [25], Ti12Mo and Ti60Ta [26], Ni-Ti shape memory alloy and stainless steel wire [27], Ti-Mo [28], mild steel coated with zinc[29], NaOCl[30], and 60NiTi[31].

Corrosion resistance of various metals has been investigated in AS.The composition of artificial saliva is given in Table 1. The corrosion resistance of metals and alloys in AS and biological solutions has been reviewed recently.

1.1 Medium

Generally, corrosion behavior of metals and alloys have been studied in AS whose composition is given in Table 1[32].In several studies AS containing fluoride [19,33], hydrogen peroxide [23], protein [27] and NaF [1,11] have been used.

1.2 Temperature

Usually artificial saliva on corrosion studies carried out at 37°C in some cases either increases or decreases at1°C.

II. EXPERIMENTS ADOPTED

Polarization study, AC impedance spectra, inductively coupled plasma-optical emission spectroscopy (ICP-OES), environmental scanning electron microscopy (ESEM). Atomic force microscopy images (AFM) have been used to evaluate the corrosion resistance of various metals and alloys in AS [1, 10-13, 19, 24, 34,35]. The protective film formed on the surface of the metal has been analyzed by various surface analysis techniques such as scanning electron microscopy (SEM) [1, 11, 14], X-ray diffraction [1], and Fourier series expansion method [19]. The metal ions released from dental alloy were detected by inductively coupled plasma mass spectrometry [23].

Table 1: Composition of artificial saliva

Name of compound	Weight g/L
KCl	0.4
NaCl	0.4
$CaCl_2.2H_20$	0.906
$NaH_2PO_4.2H_2O$	0.690
$Na_2S.9H_2O$	0.005
Urea	1

III. RESULTS AND DISCUSSION

3.1. Effects of the chloride ion

The corrosive effect of the artificial saliva-based solutions is due to the presence of chloride ions. If the environment contains certain amounts of chloride ions, then they lead to the formation of pitting corrosion. It is a form of symmetrical localized corrosion in which pits form on the metal surface. It frequently occurs in the base metals, which are secluded by a naturally forming thin film of an oxide. It locally breaks down and hasty dissolution of the underlying metal occurs in the form of pits in the presence of chlorides in the environment. The existence of chloride ions in the saliva solutions causes pitting corrosion is well visible in the experimental studies after SEM examinations of the surface of metals and alloy. Evidence of pitting corrosion formed on the wire surface is shown by Stainless steel [27], Co-Cr [14-18], Ni-Cr [18, 22, 23], Ni-Ti alloy [27,36], uncovered to electrochemical study.

3.2. Effects of Fluoride Ion on Corrosion Resistance of Dental Alloys

Fluoride content is added in toothpastes and in the products also used as mouthwash to strengthen the teeth and enhance the lifetime of the teeth. This addition of fluoride may influence the strength of dental alloys. To recognize these effects, numerous investigations were undertaken. Corrosion resistance of metals and alloys in AS, in the presence of fluoride has been investigated [1, 10, 11, 12, 14,19,24]

The presence of fluoride ions (added as NaF) drastically affects the corrosion behavior of Ti metal, Ti-6Al-7Nb, and Ti-6Al-4V alloys and constituent metals in AS as confirmed by electrochemical methods [1]. All the titanium alloys in fluoridated acidified saliva show an active behavior due to the presence of major concentrations of HF and HF2− species that dissolve the spontaneous air-formed oxide film giving rise to surface activation [13].

Diverse electrochemical methods were used to observe the effect of fluoride ion concentration on the corrosion behavior of Ti and Ti6-Al-4V implant alloys, in AS when coupled with either metal/ceramic or all ceramic superstructures. This lead to the conclusions that while fluoride concentration increases corrosion resistance of Ti and its Ti6-A1-4V alloy decreases [12]. Ti-Co alloy [10] and Ti-Cu alloy [24] gave parallel consequences. Unpredictably, the presence of Ta in the Ta30Ta alloy has a valuable achieve on its behavior in acidified fluoridated AS [11]. The corrosion resistance of pure titanium in AS containing fluoride ions decreased was observed [19].

Clinically, with a decline of risk factors a re-precipitation of the mineral on the surface could be possible and the loss of dental substrate could be interrupted. However, in the absence of modification of the patient habits, there may be the need of new TiF_4 applications so its action is prolonged and may prevent the continuation of the erosive process. Within the limitations of the study, 4% gel TiF_4 was able to reduce the progression of erosive/abrasive lesions in dentin in the first application and multiple applications reduced the evolution of the erosive process [35].

3.3. Effect of Hydrogen Peroxide on Corrosion Resistance of Dental Alloys

The consequence of hydrogen peroxide on the electrochemical corrosion and metal ions release of nickel-chromium dental alloys was investigated. When observed that the series of charge transfer resistance (Rct), corrosion potential (Ecorr), pitting breakdown potential (Eb), and the difference between Ecorr and Eb representing the "pseudo-passivation" (δE) of nickel-chromium alloys in AS was 30% <10% <0% ($P<0.05$). Furthermore, the metal ions including Ni, Cr, and Mo were released from the Ni-Cr alloys to the AS, and the order of the concentrations of metal ions was 0%<10%<30% ($P<0.05$). Nickel-chromium dental alloys are more prone to corrosion in the AS. As the concentration of hydrogen peroxide increases more metal ions are released in the AS and the corrosion resistance of nickel-chromium dental alloys decreased after immersed in different concentrations of hydrogen peroxide for 112 h [23].
Metal ions were released from Ni-Cr and Pd-Cu-Ga dental alloys following all kind of treatments. The rate of ions released for all elements except Au increased with increasing hydrogen peroxide concentrations (except for molybdenum between 10% and 30% HP and indium between 3% and 10% HP) and was statistically significant ($P < 0.05$). Differences in surface roughness values before and after bleaching were not statistically significant ($P > 0.05$). An increase in elemental ion release into the oral cavity from dental casting alloys following bleaching can trigger allergic reactions and caution need to be exercised in particular when applying hydrogen peroxide at high concentrations[37].

3.4. Effects of Chemical Composition on Corrosion Resistance of Dental Alloys

In galvanic couples composed by keeper and different alloys, PdAu and AuPt alloys acting as the cathode were secluded, but CoCr alloy as the anode was corroded, owing to its low free corrosion potential. Whether cast or laser-welded, the fusion zone was the most sensitive corrosion area. From the Ecorr values among them, we could conclude that the corrosion resistance of cast AuPt–keeper was most optimal and cast CoCr–keeper was the worst. Corrosion –resistance of the three alloy castings was such that AuPt4, PdAu4, CoCr. The edges of all keepers developed a Fe-poor and Cr-rich band that experienced accelerated corrosion when casting. Similarly, an abundance of oxide and the Ecorr value indicated that the corrosion resistance of laser-welded CoCr–keeper was the worst. However, the laser-welded CoCr–keeper could maintain the existence of a keeper surface passive and the original metallographic structure, revealing that its corrosion resistance is superior to the cast CoCr–keeper. The keeper area of the laser-welded PdAu–keeper also kept its original metallographic structure while the cast PdAu–keeper suffered the appearance of intergranular corrosion, illustrating that the former's anti-corrosion property was better. However, no obvious differences in corrosion resistance were observed between the cast and laser-welded AuPt–keepers. On the basis of chemical elements analysis, the alloy and keeper areas adjacent to the fusion area had Fe- and Co-based corrosion that occurred in the CoCr–keeper complex, and the keeper area closing to the

fusion zones of the PdAu- and AuPt–keeper complexes was the main corrosion sites where Fe reduced most and Cr followed [38].
The effect of the oral environment on the corrosion of dental alloys with different compositions, using electrochemical methods was studied. The dissolution of the ions occurred in all tested dental alloys, and the results were strongly dependent on the general alloy composition have been observed. Regarding the alloys containing nickel, the Ni-Cr and Ni-Cr-Ti alloys released 0.62 mg/L of Ni on average while the Co-Cr dental alloy released ions between 0.01 and 0.03 mg/L of Co and Cr, respectively. The open circuit potential stabilized at a higher level with the lower deviation (standard deviation: Ni-Cr-6Ti=32 mV/SCE and Co-Cr=54 mV/SCE). The potentiodynamic curves of the dental alloys showed that the Ni-based dental alloy with >70 wt% of Ni had a similar curve and the Co-Cr dental alloy showed a low current density and hence a high resistance to corrosion compared with the Ni-based dental alloys [39].

3.5. Effect of pH on Corrosion Resistance of Dental Alloys

Most of metals and their alloys undergo corrosion at lower pH, because of acidic environment. Similar results are observed in the case of dental alloys in the oral environment. Corrosion resistance of Ti-Co alloy decreased with low pH value. According to Mott-Scotty analysis with decrease in pH value of AS, the defect density increased [10].
A different surface topography was observed on the NiTi wires from various manufacturers. The corrosion tests showed that both the wire manufacturer and solution pH had a statistically significant influence on the corrosion potential, corrosion rate, passive current, breakdown potential, and crevice-corrosion susceptibility. Regardless of the wire manufacturer, decreasing the solution pH led to an increase in the corrosion potential, corrosion rate, and passive current of the NiTi wires but a decrease in the pitting potential and susceptibility to crevice corrosion [40].
The effect of pH value on the corrosion resistance of pure Ti and Ni-Cr-Ti alloy in the AS was investigated by Liang et al. He observed that with the lower pH value, the Ecorr and Icorr of pure titanium and Ti-Ni-Cr alloy increased, the Rp decreased and the corrosion resistance of pure titanium and Ti-Ni-Cr alloy was decreased with decrease in pH value [19].

3.6. Effects of Protein on Corrosion Resistance of Dental Alloys

Protein addition to the AS had a significant influence on the corrosion behavior of composite arch wires (CoAW) with Cu interlayer between NiTi shape memory alloy and stainless steel wire. Low concentration of protein caused the corrosion resistance of CoAW decrease in electrochemical corrosion and immersion corrosion tests. High concentration of protein could reduce corrosion effect [27].
Protein supplementation may be an alternative to reduce the erosive potential of acidic drinks. A commercially available orange juice was added 0.2 g/L casein, 2.0 g/L ovalbumin and their combination. The juice with no additives and a commercially available calcium-modified juice were used as negative and positive controls, respectively. Human enamel and dentin specimens (n=11) were tested in an erosion-remineralization cycling model. Enamel was analyzed by surface microhardness and profilometry, whilst dentin by profilometry only. Statistical analyses were performed using one-way ANOVA followed by Tukey's test ($p<0.05$). Calcium modified juice showed the lowest erosive potential for both analyses ($p<0.05$). For enamel, the protein-added groups did not differ from each other ($p>0.05$) and showed significantly lower enamel loss compared to negative control ($p<0.05$). Regarding surface microhardness, casein showed the highest values compared to negative control ($p<0.05$). For dentin, none of the protein-added

groups showed lower values of surface loss compared to negative control ($p>0.05$). In conclusion, for enamel the protein-modified orange juices presented reduced erosion of enamel, with casein showing a trend for better protection. For dentin, no reduction in the erosive potential was observed for the tested protein-modified orange juices [41].

3.7. Effects of Metal Coating on Corrosion Resistance of Dental Alloys

The corrosion behaviour of three metals namely, mild steel (MS), mild steel coated with zinc (MS-Zn) and SS 316L have been studied in artificial saliva in the absence and presence of spirulina. Polarization study has led to the following conclusions. In the absence of spirulina, the order of corrosion resistance was: SS 316L > MS – Zn > Ms. In the presence of spirulina, the order of corrosion resistance was SS 316 L > MS > MS – Zn. MS was more corrosion resistant in the presence of spirulina than in the absence of spirulina. MS-Zn was more corrosion resistant in the absence of spirulina than in the presence of spirulina [29].

IV. CONCLUSION

The crucial obligatory of any dental alloys is that they must not produce corrosion products that will be harmful to the body. The corrosive resistance of metal is its important feature during implantation into a mouth. Several metals and alloys are used in orthodontic treatment. Consequently, it is essential to recognize the corrosion resistance of these materials in AS;

- The subsistence of chloride ions in the saliva solutions definitely produces pitting corrosion.
- The concentration of the fluoride ions increases in the saliva solutions the corrosion resistance will be decreased. The 4% gel TiF_4 was able to reduce the progression of erosive/abrasive lesions.
- The chemical composition of the alloys, hydrogen peroxide, and fluoride concentration in saliva play significant role in corrosion resistance of dental alloys.
- Protein supplementation may be an alternative to reduce the erosive potential of acidic drinks.
- Corrosion resistance increases with high protein content in saliva.
- Decreasing the solution pH led to an increase in the corrosion potential and corrosion rate.

V. SIGNIFICANCE

This study will be valuable to the researchers to recognize the work that has been already done in evaluating the corrosion resistance of materials in AS so that they can go further in this research. This is also useful to the dentists to recommend the appropriate orthodontic wires to their patients and imply the necessary precautions. The patients who are implanted with these orthodontic wires are aware of their effects in the oral environment.

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