Release of nickel ions and changes in surface microstructure of stainless steel archwire after immersion in tomato and orange juice

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Abstract. Stainless steel archwire is an important component of orthodontic appliances that have the potential to corrode. Consumption of foods and beverages with a low pH, such as fruit-based juices, can trigger the release of nickel ions in stainless steel archwire. This study aimed to determine the difference in the amount of nickel ions release and the surface microstructure of stainless steel archwire after immersed in tomato and orange juice. The sample used is stainless steel archwire with a diameter of 0.016 inches and length of 5 cm immersed in 15 ml of solution and then stored at 37°C in an incubator for 24 hours. The samples were divided into three groups (immersed in tomato juice, orange juice and artificial saliva), each group consisted of 9 samples. The solution was tested using an Inductively Coupled Plasma Mass Spectrometer (ICP-MS) to determine the number of nickel ions released. The archwire surface microstructure was tested using a Scanning Electron Microscope (SEM). The results showed that the average amount of nickel ion release in orange juice is more than tomato juice. There was a significant difference between the amount of nickel ion released and surface microstructure on stainless steel archwire after being immersed in tomato and orange juice.

1. Introduction

The orthodontic archwire is an important component of orthodontic appliances [1]. One type of archwire that is often used in fixed orthodontic appliances is stainless steel [2]. Stainless steel orthodontic archwire contains iron, chromium, nickel, and carbon [3]. Stainless steel orthodontic archwire is generally used because it has a good modulus of elasticity, high strength, corrosion resistance, and economical price [2]. Although stainless steel is believed to be corrosion resistant, several studies have shown that stainless steel archwire has the potential to corrode. Corrosion can occur because the orthodontic archwire is constantly in contact with saliva [4]. In the oral cavity, the archwire gradually corrodes, resulting in the release of the metal elements that make up the archwire. The release of metal ions is influenced by various factors such as changes in temperature, microflora, diet, enzymes, and salivary acidity (pH) [5].

Food and beverages that have an acidic pH such as fruit juices, vinegar and carbonated drinks can increase the release of nickel ions from orthodontic appliances [6]. Fruit-based juice is a drink that is consumed daily and it is recommended because of its nutritional value. The chemical composition of fruit-based juice mostly consists of two or more organic acids [7]. Tomato juice is a beverage with an acidic pH (3.7 < pH < 4.5) and orange juice is a beverage with a high acidic pH (pH < 3.7) [8]. The dominant organic acids contained in oranges and tomatoes are citric acid and malic acid [9,10].
Metallic elements released can provide biological effects such as allergic reactions, carcinogenic, mutagenic, and cytotoxic effects [11]. Nickel is considered one of the most common allergens, with allergy prevalence rates of up to 30% depending on age, sex, and race [12-13]. Several studies have shown that nickel causes changes in periodontal and immunological conditions in patients allergic to nickel [14-16].

This study aimed to determine the release of nickel ions and microstructural changes on the surface of stainless steel archwire after being immersed in tomato and orange juice.

2. Materials and Method
This research was experimental laboratory study using post-test only with control group design. The sample used was stainless steel orthodontic archwire with a diameter of 0.016 inches and a length of 5 cm. The samples were divided into three groups, each group consisted of 9 samples. Treatment group 1 sample was immersed in tomato juice, treatment group 2 was immersed in orange juice, and the control group was immersed in artificial saliva. The tomatoes used were red tomatoes from Berastagi (Solanum lycopersicum L.). The orange used was a sweet orange from Berastagi (Citrus sinensis). The juice was made with a concentration of 100% without the addition of water and sweeteners. Then, the immersed samples were stored in an incubator at 37ºC for 24 hours. The measurement of nickel ion levels in the sample test solution was conducted by using the ICP-MS (Inductively Coupled Plasma Mass Spectrometer) at BTKL-PP Medan. Samples were also tested with a Scanning Electron Microscope (SEM) at the UNIMED Physics Laboratory to observe the microstructure of the wire surface after immersed. The normality test of the research data was carried out using the Shapiro-Wilk normality test. If the data is normally distributed (p> 0.05), the test is continued with the One Way ANOVA parametric statistical test with a 95% confidence level. This research has received ethical approval from the Research Ethics Commission of the Faculty of Medicine, Universitas Sumatera Utara.

3. Result
This study showed that the average amount of the release of nickel ions in group 1 was 0.008 ± 0.000 mg/L, group 2 was 0.012 ± 0.000 mg/L, and the control group was 0.000 ± 0.000 mg/L. The results of the Shapiro-Wilk normality test show that the data distribution is normally distributed. Group 1 had a significance value of p = 0.941 (p > 0.05), group 2 had a significance value of p = 0.890 (p > 0.05) and the control group had a significance value of p = 0.276 (p > 0.05). The homogeneity test results using the Levene test showed that the data was homogeneous with a significance value of p = 0.605 (p> 0.05). Data analysis was continued by using the One-way ANOVA test. The test results showed that there was a significant difference between the amount of nickel ion released in stainless steel orthodontic archwire after being immersed in tomato juice and orange juice with a significance value of p = 0.001 (p < 0.05) (Table 1).

| Group             | The average amount of the release of nickel ions (mg/L) (X±SD) | p-value |
|-------------------|---------------------------------------------------------------|---------|
| 1 (Tomato Juice)  | 0.008 ± 0.000 mg/L                                            |         |
| 2 (Orange Juice)  | 0.012 ± 0.000 mg/L                                            | 0.001   |
| Control (Artificial Saliva) | 0.000 ± 0.000 mg/L                                      |         |
Figure 1. SEM image of stainless steel archwire after being immersed in tomato juice  
(a) 250x magnification (b) 500x magnification (c) 1000x magnification

SEM examination of stainless steel archwire immersed in tomato juice shows roughness on the surface (Figure 1).

Figure 2. SEM image of stainless steel archwire after being immersed in orange juice  
(a) 250x magnification (b) 500x magnification (c) 1000x magnification

Stainless steel archwire immersed in orange juice shows widespread surface damage (Figure 2).

Figure 3. SEM image of stainless steel archwire after being immersed in artificial saliva  
(a) 250x magnification (b) 500x magnification (c) 1000x magnification

SEM examination of stainless steel archwire immersed in artificial saliva show a smoother surface compared to the surface of the archwire immersed in tomato and orange juice.

4. Discussion
Stainless steel archwire immersed in tomato juice (pH = 4.9) and orange juice (pH = 4.8) shows a more significant release of nickel ions than archwire immersed in artificial saliva (pH = 7.9). The highest average amount of nickel ions release occurred in stainless steel archwire immersed in orange juice. The
results of this study are in line with the study of Bonde et al., who stated that the amount of nickel ion released on stainless steel orthodontic archwires after being immersed in coconut water (pH = 4.75) was higher than artificial saliva [17]. The research of Pakpahan and Handali showed that the average amount of the release of nickel ions in stainless steel bracket immersed in lemon juice is more significant than in artificial saliva [18]. Sumule et al.’s study also stated that the release of nickel and chromium ions in stainless steel brackets immersed in carbonated drinks was higher than the control group [19].

The amount of nickel ions released in stainless steel archwire after being immersed in orange juice is more significant than tomato juice. This is because the pH of orange juice is lower than tomato juice. The content of organic acids such as citric acid, malic acid, lactic acid, and several other acids causes orange juice to have an acidic pH, thus affecting the release of nickel ions [10]. Citric acid (C₆H₈O₇) has a fairly high H⁺ particles [20]. An increase in H⁺ ions from the reacting acid will react and reduce, resulting in more metal ions being oxidized so that it can accelerate the corrosion rate. This is caused by the oxidation rate, which is proportional to the reduction rate during the corrosion process of stainless steel wire, characterized by the increase in the release of nickel and chromium ions from the wire [21].

This study indicates a significant difference between the release of nickel ions in stainless steel orthodontic archwire after being immersed in tomato juice and orange juice. This study is in line with the research of Kristianingsih et al., who showed that there was a significant difference between the release of nickel and chromium ions in stainless steel archwire after immersed in a carbonated beverage with an acidic pH [21]. This study is also in line with the study of Situmeang et al., who showed that there were significant differences in the release of nickel and chromium ions in stainless steel archwire after immersed in vinegar [22].

The SEM examination results in this study show that there were differences in the surface microstructure of stainless steel archwire after being immersed in tomato and orange juice. The surface image of stainless steel archwire immersed in tomato juice shows the surface roughness (Figure 1). Meanwhile, stainless steel archwire after immersion in orange juice shows extensive damage to its surface (Figure 2). The surface of the stainless steel archwire immersed in artificial saliva was smoother than the surface of the archwire immersed in tomato and orange juice (Figure 3).

The results of this study are in line with the research of Sharma et al., who showed that there was surface damage in stainless steel archwires immersed in tomato juice [7]. The results of this study are supported by the research of Kao and Huang, who stated that lower pH increased corrosion of orthodontic archwires. The results showed that the surface of the stainless steel archwire in the treatment group with artificial saliva (pH = 4) and NaF had scratches and pitting corrosion [23]. This study is in line with the research of Pataijindachote et al., who stated that the surface of the archwire immersed in artificial saliva with pH 2.5 for 90 days showed significant changes in the archwire surface, especially in Australian archwire [24].

Stainless steel orthodontic appliances rely on the formation of a passive oxide layer to prevent corrosion. The addition of nickel and chromium to stainless steel alloys provides corrosion resistance. Chromium in stainless steel forms a passive protective oxide layer (Cr₂O₃) which provides a barrier against oxygen diffusion and other corrosive environments [25]. Even if a protective oxide layer is present on the metal surface, release of metal ions can still occur. The oxide layer can also slowly dissolve when the metal is exposed to oxygen from the surrounding environment [26].

Acidic drinks such as fruit-based juices can degrade the surface quality of orthodontic archwires. Damage and surface roughness of stainless steel archwire after being immersed in tomato and orange juice occurs due to the acidic pH of the juice. Tomato and orange juice contain two or more organic acids. The corrosion mechanism on metal surfaces in the presence of organic acid media occurs by the adsorption of acid molecules to the surface [7]. Decreasing the pH can damage the oxide layer on the surface of the wire, it will cause corrosion and the release of elements from metal that can change the surface microstructure to become rough. Surface roughness increases over time and can lead to pitting corrosion [24]. The release of metal ions results in characteristic changes and damage to the metal structure, which can weaken the strength and affect the wire's aesthetics, quality, and physical shape [1].
5. Conclusions
Based on the results of the above research, tomato juice and orange juice can cause the release of nickel ions and changes in the surface microstructure of stainless steel orthodontic archwire. With a pH of 4.8, orange juice caused higher damage with an average nickel ion release of 0.012 mg/L compared to tomato juice with a pH of 4.9 which had an average nickel ion release of 0.008 mg/L.

Acknowledgments
The authors are thankful to the Faculty of Pharmacy University of North Sumatera, Physics Laboratory University of Medan, and Medan Environmental Health Engineering Center (BTKL) for providing facilities in this study.

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