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Nickel and Chromium Ion Release from Orthodontic Wires Subjected to Various Drinks and Distilled Water

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ABSTRACT

Objectives: The aim of this in vitro study was to assess the quantity of nickel and chromium ions released from orthodontic wires when subjected to various beverage solutions and distilled water.

Materials and Methods: Orthodontic appliances composed of five brackets, one band and 0.016-inch stainless steel and nickel titanium wires were immersed in Coke, tea, coffee and distilled water. The samples were incubated at 37°C for 1 hour, 6 hours, 24 hours, and one week. There was a total of 120 appliances divided into 24 groups (n=5 in each group). Atomic absorption spectroscopy was used to examine the amount of released ions. Two-way and one-way ANOVA followed by Tukey test were used for statistical analysis and $P<0.05$ was considered significant.

Results: The release of nickel ions from both wires was highest in Coke and lowest in distilled water at all time points. Coffee and tea demonstrated values in-between these two limits. Similarly, chromium ion release from both wires was highest in Coke at all time-points compared to all other solutions ($P<0.05$). None of the other tested drinks showed significant differences in chromium ion release compared to distilled water.

Conclusion: Restricting the intake of acidic drinks, particularly carbonated beverages like Coke, plays a critical role in safeguarding orthodontic wire components. Educating patients and providing dietary guidelines are essential for maximizing treatment effectiveness. Further research is required to investigate additional factors impacting ion release and devising methods to mitigate potential harm.

Keywords: Ions; Nickel; Chromium; Coffee; Tea; Carbonated Beverages; Orthodontics

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INTRODUCTION

Alloys such as stainless steel, nickel-titanium are commonly used in orthodontic appliances. Metals undergo corrosion when exposed to thermal and chemical changes in the oral cavity, which facilitates ion release [1]. In this process, ions such as nickel and chromium are released, which may lead to toxic and biologic effects such as soft tissue pigmentation and allergic reaction when passing a specific threshold [2,3].

Foods and drinks are among the factors that lead to corrosion in the oral cavity. Currently, consuming acidic and caffeinated drinks, such as soft drinks, coffee, and tea is growing. These drinks contain phosphoric acid, citric acid, tartaric acid, lactic acid, maleic acid, polyphenol, and methyl-xanthines [4]. Acidic foods and drinks not only damage enamel but also shorten the lifetime of dental repairs [5]. These drinks weaken the surface hardness, surface integrity, and solubility of the substances and lead to metal corrosion [6,7].

Given the significant implications of ion release and its potential impact on biological structures, a comprehensive evaluation of prevalent orthodontic alloys becomes essential across varying environmental conditions. This evaluation should encompass both corrosion behavior and the quantification of released ions [8].

Various studies have previously assessed ion release of alloys in different aqueous environments, including mouthwashes and saliva. However, information on the acidic environment produced by soft drinks is limited. Thus, considering the increase in soft drink consumption and inclination towards orthodontic treatment, it is important to assess the possible effect of these drinks on the appliances used for orthodontic therapy. The aim of this study was to evaluate the amount of nickel and chromium ions released from orthodontic wires subjected to various beverage solutions and distilled water.

MATERIALS AND METHODS

In this laboratory study, we examined the amount of nickel and chromium ions released from a combination of a 0.016-inch wire (made of either nickel-titanium or stainless steel), five brackets, and one band (manufactured by American Orthodontics, Sheboygan USA). These specimens were immersed in three different solutions (coke, tea, coffee) as well as distilled water. 120 wires including 60 NiTi and 60 SS wires were obtained. The wires were cleaned with acetone, then washed with distilled water, dried, and finally placed in a 10mL laboratory a screw-top 10mL vial. Subsequently, the samples were divided into 24 groups and subjected to incubation at 37°C for different time durations (1 hour, 6 hours, 24 hours, and one week) with five samples in each group. The groups were designated as follows:

- SS+Coke: SS complex samples were immersed in 10mL Coke
- SS+tea: SS complex samples were immersed in 10mL tea
- SS+ coffee: SS complex samples were immersed in 10mL coffee
- Negative controls^{SS}: SS complex samples were immersed in 10mL distilled water
- Nickel titanium (NiTi)+coke: NiTi complex samples were immersed in 10mL Coke
- NiTi+tea: NiTi complex samples were immersed in 10mL tea
- NiTi+coffee: NiTi complex samples were immersed in 10mL coffee
- Negative control^{NiTi}: NiTi complex samples were immersed in 10mL distilled water

Upon completion of each designated time period, the wires were carefully extracted from the respective solutions and a drop of 65% nitric acid was added to stabilize the released ions.

A volume of 0.5 mL was collected from each solution, and the released concentrations of Ni and Cr ions were measured using an atomic absorption spectrophotometer (GBC Avanta, Australia). Each sample underwent analysis for both ions, and the concentrations were averaged across three replicates, reported in parts per billion (ppb).

The Kolmogorov-Smirnov test verified a normal pattern of data distribution. Consequently, two-way ANOVA was employed to assess the release of both ions at four time points. One-way ANOVA was utilized to examine the amount of Ni and Cr released from different solutions. Post-hoc Tukey test was conducted for pairwise comparisons. The significance level was set at $P<0.05$.

RESULTS

The release rate of Ni and Cr ions exhibited an increase across all solutions and time-points for both wire types (Tables 1 and 2). Notably, the release of Ni ions from both wires was most pronounced in Coke, while the lowest release occurred in distilled water across all observed time-points. The release pattern of Ni in coffee and tea, fell between these extremes.

The release of Cr ions from both wires was the highest in the Coke solution at all time-points, which was significantly higher compared to those of the other solutions. No significant differences were observed among coffee, tea, and distilled water.

The ion release rate from the NiTi wire was higher in tea compared to coffee. The lowest amount of Cr release from both wires was observed in distilled water at all time points. However, the release rate of Cr ions from the stainless-steel wires in distilled water and coffee solutions reached similar levels one hour after immersion.

While variations existed in the consistency of ion release, a prevailing trend emerged. The release rate of Ni and Cr ions was consistently higher in the Niti wires compared to the SS wires. Additionally, across all solutions and time intervals, the release rate of Cr ions remained consistently lower than that of the Ni ions from both wire types.

Table 1. P-values of comparisons for Ion release from nickel-titanium (NiTi) and stainless steel (SS) wires in different time intervals

Ion	Wire type	Time points	Coffee vs distilled water	Tea vs distilled water	Coke vs distilled water	Coffee vs Tea	Coffee vs Coke	Coke vs tea
Nickel	SS	1h	0.414	0.845	<0.001	0.845	<0.001	<0.001
		6h	0.031	0.525	<0.001	0.225	<0.001	<0.001
		24h	<0.001	0.046	<0.001	0.005	<0.001	<0.001
		168h	<0.001	<0.001	<0.001	1.000	<0.001	<0.001
	NiTi	1h	<0.001	0.845	<0.001	0.000	<0.001	<0.001
		6h	<0.001	0.031	<0.001	0.000	<0.001	<0.001
		24h	<0.001	0.001	<0.001	0.003	<0.001	<0.001
		168h	<0.001	0.001	<0.001	0.000	<0.001	<0.001
Chromium	SS	1h	1	0.414	0.002	0.414	0.002	0.015
		6h	0.845	0.845	<0.001	1	0	0
		24h	0.225	0.225	<0.001	1	0	0
		168h	0.225	<0.001	<0.001	0.005	0	0
	NiTi	1h	0.845	0.845	0.002	0.414	0.001	0.005
		6h	0.225	0.012	0.001	0.012	0.225	0.225
		24h	0.012	0.000	0.000	0.001	0.000	0.225
		168h	0.012	0.000	0.000	0.000	0.000	0.012

Table 2. The amount (Mean±Standard deviation) of ion release from nickel-titanium (NiTi) and stainless steel (SS) wires at different time intervals in ppb

Ion	Solutions		Time points			
			1 hour	6 hours	24 hours	168 hours
Nickel	Distilled water	SS	10	13.3±2.8	20	23.3±2.8
		NiTi	10	13.3±2.8	18.3±7.6	46.6±2.8
	Coffee	SS	13.3±2.8	21.6±2.8	36.6±2.8	51.6±2.8
		NiTi	26.6±2.8	46.6±2.8	61.6±2.8	86.6±2.8
	Tea	SS	11.6±2.8	16.6±2.8	26.6±2.8	51.6±2.8
		NiTi	11.6±2.8	26.6±2.8	41.6±2.8	61.6±2.8
	Coke	SS	81.6±2.8	121.6±2.8	136.6±2.8	171.6±2.8
		NiTi	101.6±2.8	116.6±2.8	136.6±2.8	151.6±2.8
Chromium	Distilled water	SS	6.6±2.8	10	11.6	16.6±2.8
		NiTi	10	11.6±2.8	16.6±2.8	41.6±2.8
	Coffee	SS	6.6±2.8	11.6±2.8	16.6±2.8	21.6±2.8
		NiTi	8.3±2.8	16.6±2.8	26.6±2.8	51.6±2.8
	Tea	SS	10	11.6±2.8	16.6±2.8	33.3±2.8
		NiTi	11.6±2.8	26.6±2.8	41.6±2.8	91.6±2.8
	Coke	SS	18.3±2.8	26.6±2.8	51.6±2.8	71.6±2.8
		NiTi	21.6±2.8	31.6±2.8	46.6±2.8	81.6±2.8

DISCUSSION

Owing to their advantageous characteristics, nickel and chromium have found extensive application in the fabrication of orthodontic appliances and materials. Consequently, a considerable body of research has been devoted to investigating the release kinetics of Ni and Cr ions, often in comparison to other ions. [8]. Nickel adds a number of desirable properties, including shape memory and superelasticity, to an alloy [9]. Cr can protect metals from rusting and a Cr content of less than 4% increases the strength of an alloy. Stainless steel, a remarkable and extremely versatile family of engineering alloys, contains a minimum of 10.5% Cr [9,4]. On the other hand, the release of Ni and Cr ions have undesirable and harmful effects that have led researchers to focus on evaluating the release rate of these ions in different settings. In a systematic review, Mirhashemi et al. [8], found that 25 studies were carried out in order to evaluate the release rate of ions from orthodontic appliances from 2005 to 2018, in which the primary focus was on Ni and Cr ions. In the current study we evaluated the release of Cr and Ni ions from stainless steel and nickel titanium wires in tea, coffee, Coke and distilled water, and found that the release rate of ions from stainless steel wires was significantly less than that of nickel-titanium wires. At all-time points and in both orthodontic wires, the rate of ions released from Coke was significantly higher compared to the other solutions followed by coffee, tea and distilled water, respectively. None of the other solutions showed significant differences in either of the time points.

According to previous studies, the rate of ion released from in nickel-titanium alloy is more than stainless steel [10-13]. Jamilian et al. [13] immersed nickel-titanium and stainless steel wires in Oral-B and Orthokin mouthwashes and artificial saliva (control) for 1, 6 and 24 hours and 7 days. They demonstrated that the rate of Ni released in three solutions from Nickel-titanium was more than stainless steel wires. Kararia et al. [14] evaluated ion-release in two types of 0.016” nickel-titanium wires from two different manufacturers and two types of 0.025” * 0.019” stainless steel wires and found that the rate of Ni and Cr ion release from the stainless-steel wires was less than the nickel-titanium wires.

Sabzevari et al. [15] evaluated the rate of Ni ion release in saliva from 0.016” Nickel-titanium wires after 3 months, 0.018” stainless steel wires after 6 months and 0.021” * 0.025” after 2 months. Their results showed that the released Ni ranged from 825.5 to1290.5 microgram/Pico liter, and it had a significant difference with the permissible value (2500 ppb). They also showed that the rate of Ni released from nickel-titanium wires was higher than the stainless steel ones.

Butt et al. [16] found that the Ni concentration in the salvia of adolescents using orthodontic wires containing Ni had no significant difference compared to those without these wires.

These studies are in line with the current investigation and show that the rate of ions released from stainless steel wires is remarkably less than the nickel-titanium ones. Conversely, Suárez et al. [17], maintained Ni, stainless steel and CuNiTi for 7, 14 and 30 days in saline solution and found that stainless-steel wires released the maximum rate of Ni. Based on previous study, nickel and chromium ion release from stainless steel wires was more than nickel-titanium wires and the highest amount was in the first 7 days of immersion. Also, release rate was more pronounced in rectangular wires in comparison to round ones [8]. Two other studies reported higher Cr ion release in stainless steel alloy compared to that found in nickel-titanium [18,19]. The discrepancy in the results of various studies can be due to different study conditions. Investigations have shown that some variables affect the rate of ion release depending on the type of alloy, frequency of using orthodontic appliances (controversial reports, which were also dependent upon type of appliance, i.e., bracket vs wire), cross sectional shape of a wire and pH of the intended solutions (low pH causes increased release of Ni ions) [11,18,20-28].

The latter phenomenon can be attributed to the increase in corrosion rate when the environment becomes more acidic. This occurs due to the higher concentration of free H+ ions present in the environment [15]. Therefore, acidic foods like juices, coffee, yoghurt, and vinegar have significant effects on releasing ions.

Shahabi et al. [29] have evaluated the corrosion rate of stainless-steel brackets in three solutions including lemon juice, vinegar, and Cola within 6 weeks and found that the amount of corrosion in orthodontic brackets was the most for Cola, followed by vinegar and lemon juice, respectively [29]. Similarly, Mikulewicz et al. [4] suggested that Coke released the maximum rate of ions; which was in accordance with our findings and may be possibly due to the acidic property of this beverage.

Our study showed that release of Ni and Cr ions in different solutions and wires increased within 7 days. Likewise, Wendl et al. [26] found that Ni released from brackets within 58 days had a constant value. Regarding Cr, the maximum release rate was in the first 35 days and then it was released to a lesser extent in the following days [26]. Bhaskar et al. [9] declared that Ni ions were highly released in the first 7 days of immersion, especially in comparison to the following days. Also, Kuhta et al. [18] showed that the rate of releasing ions was highest within first 7 days.

Another finding of our study was that the rate of Ni ions release was more than Cr ions in both wires, in any types of solutions and in different times. Mikulewicz et al. [4] also stated that the rate of Ni ion release was more than the other ions including Cr ions. Bhaskar et al. [9] also showed that Ni ion release was generally higher than Cr ions.

CONCLUSION

The results of the current study indicated that the rate of ions released from stainless steel wires was significantly less than nickel-titanium wires.

The maximum ion release rate was observed in the presence of Coke, while tea, coffee, and distilled water solutions exhibited comparable behavior. Furthermore, the release of both ions displayed an ascending trend within the initial 7-day period. These outcomes emphasize the need to limit the consumption of acidic solutions, especially carbonated beverages like Coca-Cola, within the diet of individuals undergoing orthodontic treatment. Such restrictions are crucial in mitigating the potentially deleterious impacts of these drinks on the wire components of orthodontic appliances, a concern particularly pronounced during the initial stages of treatment.

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CONFLICT OF INTEREST STATEMENT

None declared.

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