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Cover Page Footnote

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ORIGINAL ARTICLE

Trimming and pH Effects on Nickel Ion Release from Stainless Steel Crowns of Primary Teeth

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ABSTRACT

Objective: Stainless steel crowns (SSCs) are preformed metal crowns used to restore severely decayed primary teeth. The aim of this study is to evaluate the effects of pH changes and SSC margin trimming on nickel release in artificial saliva solution. **Methods:** A total of 90 SSCs were divided into three groups and placed in 35 ml of artificial saliva of pH 6.8, 5, and 3.5. Another group consisting 30 SSCs with trimmed margins was placed in saliva of pH 6.8. All SSCs were incubated at 37°C. The concentration of released nickel was assessed on days 1, 7, 14, 21, and 28 by atomic absorption spectrophotometry. **Results:** The highest concentrations of nickel were released on the first day in all groups. Nickel release increased with decreasing pH, and the differences observed were statistically significant on days 1, 7, 14, and 28. SSC trimming caused a significant increase in nickel release on all days except day 21. **Conclusion:** The concentration of nickel increased in saliva of low pH. The highest levels of nickel were released with SSC margin trimming because of the loss of integrity of the margins.

Key words: artificial saliva, nickel, pH, stainless steel crown, trimming

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INTRODUCTION

Stainless steel crowns (SSCs) were originally introduced by Rocky Mountain Company and are currently used as the preferred choice for treating primary teeth. SSCs have high durability and tarnish resistance and low technical sensitivity and cost.[1] The chemical composition of SSCs is similar to that of many orthodontic wires, which contain 65%–73% iron, 17%–20% chromium, 8%–13% nickel, and less than 2% manganese, silicon, and carbon.[2] However, the frequent use of these prefabricated crowns to treat primary teeth has raised concern over the release of metals within the oral cavity in response to corrosion.[3] The occurrence of electrochemical reactions that promote the degradation of the metal surface by ion release and the loss of metal quality is called corrosion. Internal corrosion factors are associated with the composition and structure of the metal, while external corrosion factors are associated with biological environmental factors, such as pH and temperature.[4] One of the metals released from SSCs is nickel, which is a solid, silver-white, hard, malleable transition metal with an atomic number of 28.[5] Nickel is a constituent of many dental alloys that improves their physical and chemical properties, such as their durability and hardness, and lowers their cost.[6] The metal is known to be a common cause of contact dermatitis and hypersensitivity reactions.[7] Approximately 4.5%–28.5% of the population is estimated to have hypersensitivity to nickel, with a higher prevalence observed in females.[8] Such hypersensitivity is more prevalent in young patients than in older ones because of the greater susceptibility of the former to the inflammatory reactions of toxic alloys.[9] Nickel allergy signs and symptoms include hyperplastic inflamed tissue around the crown and space maintainers, loss of alveolar bone, and edematous gums and palate. In pediatric dentistry, nickel ions are released from SSCs, space-maintainers, and orthodontic appliances because of exposure to the patient's saliva. Nickel release is intensified in the pH of the oral environment following tooth-brushing abrasion.[6] Studies have indicated that alloys exhibit different responses under different conditions, such as in different pH environments.[5]

The oral environment, given its constant chemical, mechanical, temperature, microbial, and enzymatic changes, can induce the corrosion of dental materials. The liquids and foods consumed by individuals have a wide range of pH values. Acids are released during food fermentation, and bonding of food debris to metals inside dental materials can cause rapid reactions between the metal and oral medium.[8] The buffering capacity of saliva is considered the main defense mechanism of saliva in controlling the acidity of the oral cavity. Bicarbonate is the major buffer of activated saliva; phosphate also provides some buffering effects. Prefabricated crowns may not fit exactly over teeth, and the margin height may interfere with the crown arrangement or blanch the gums.[10] Thus, dentists must sometimes trim the crown, which means shortening the margins.

Although many studies have evaluated the release of nickel from other dental materials, such as orthodontic brackets, and despite the widespread use of SSCs, little information on the release of nickel from these crowns is available, and many concerns regarding the side effects of SSCs on children's health have been raised.[11] The oral pH varies according to the type of diet and saliva quality, among other factors. This study aims to evaluate the amount of nickel released under different pH following the treatment of primary teeth with SSCs and assess the effect of trimming on the amount of nickel release in artificial saliva solution.

METHODS

In this laboratory study, 120 SSCs for primary molar teeth (3M/ESPE Company, St. Paul MN, USA) were used. The SSCs were divided into four groups (30 SSCs in each group) as follows: Group 1: 30 SSCs in artificial saliva solution of pH 6.8; Group 2: 30 SSCs in artificial saliva solution of pH 5; Group 3: 30 SSCs in artificial saliva solution of pH 3.5; Group 4: 30 trimmed SSCs in artificial saliva solution of pH 6.8

The selection of different pH values was based on the average pH of the oral cavity (pH 6.8), the lowest pH found in mature dental plaque (pH 3.5), and their approximate midpoint (pH 5.0). The inner surface of the crowns was filled with polycarboxylate cement to prevent contact with the artificial saliva (AriaDent, ACT, Tehran, Iran). The SSCs in group 4 were trimmed as follows. First, a line was drawn 1 mm away from the crown margin by using a thin marker. An index was made using a thin wire and fixed at a point 1 mm from the margin to shorten all of the crowns equally. Special crown scissors (The MIB, IdeBartar Co., France) were used to cut the margins. The cut margins were then polished using pink mollet (Corundum 731, Meisinger, Germany) and Green Rubber polishers (Universal Polisher 9511H, Meisinger, Germany).[10]

The artificial saliva used in this work was prepared by Niceram Razi Company and contained different compounds ($NaCl$, KCl, NH_4Cl, $Na_2SO_4 \cdot 10\ H_2O$, $KSCN$, $CaCl_2 \cdot 2H_2O$, KH_2PO_4) with a controlled pH of 6.8. Lactic acid was used to change the pH value in groups 2 and 3. pH measurement was conducted using a digital pH meter (Jenway-3510, UK).

Before the SSCs were placed in artificial saliva, their surfaces were cleaned with a solution of 50% ethanol and 50% acetone. The SSCs were then placed in individuals containers with 35 ml of artificial saliva solution of the desired pH, and the containers were sealed and shaken well to allow full contact between the SSCs and artificial saliva. The containers were placed inside an incubator at 37°C, and the amounts of released nickel were measured on days 1, 7, 14, 21, and 28 via atomic absorption spectrophotometry. After each measurement day, the artificial saliva in the containers was replaced with fresh saliva to prevent saturation by ions in the solution.[11] Descriptive statistics-based methods, including mean ± SD were used for data analysis. For this analysis and initial comparisons of two subgroups, data normalization was performed using the Shapiro–Wilk statistical test. Based on the normalization results of all data in this study, repeated-measures analysis of variance (ANOVA) with Bonferroni's post-test was used for comparisons between groups. SPSS version 18 (SPSS Inc., Chicago, IL, USA) was used for analysis at a significance level of 0.05.

RESULTS

The Shapiro–Wilk test was employed to test the normality of the data, and results showed a normal data distribution. Thus, differences among groups in general, as well as in pairs, were studied by repeated-measures ANOVA with Bonferroni's post-test. Differences among all groups, except for those between groups 2 and 3, were significant. In other words, group 1 showed more nickel release than groups 2, 3, and 4 (0.033, 0.043, and 0.189 ppm, respectively; $p < 0.05$). Nickel release in group 2 was 0.010 ppm less than that in group 3, but this difference was not statistically significant ($p = 0.071$).

Table 1. Mean concentration of nickel released from SSCs on days 1, 7, 14, 21, and 28

Days	Groups	Mean concentrations (ppm)	SD
1	1	0.0012	0.0002
	2	0.1624	0.0082
	3	0.2081	0.0138
	4	0.9245	0.0345
7	1	0.0010	0
	2	0.0029	0
	3	0.0061	0
	4	0.0159	0.0027
14	1	0.0010	0.0001
	2	0.0024	0.0005
	3	0.0045	0.0006
	4	0.0083	0.0010
21	1	0.0009	0.0002
	2	0.0013	0.0003
	3	0.0023	0.0006
	4	0.0010	0.0002
28	1	0	0
	2	0.0012	0.0002
	3	0.0014	0.0003
	4	0.0012	0.0002

*Significant differences between two groups ($p < 0.05$). Group 1: pH 6.8, group 2: pH 5, group 3: pH 3.5, group 4: trimmed SSCs at pH 6.8.

Table 2. Comparison of mean differences between two groups of SSCs on days 1, 7, 14, 21, and 28

Days	Groups	Mean difference	Standard error	p-value
1	1&2	0.161	0.008	0*
	1&3	0.207	0.008	0*
	2&3	0.0457	0.008	0.045*
	1&4	0.0923	0.199	0*
7	1&2	0.002	0.01	0.012*
	1&3	0.005	0.001	0*
	2&3	0.0032	0.0006	0.060
	1&4	0.0148	0.0015	0.001*
14	1&2	0.001	0	0.012*
	1&3	0.004	0.001	0.014*
	2&3	0.0021	0.00048	0.011*
	1&4	0.0073	0.00061	0*
21	1&2	0	0	0.287
	1&3	0.001	0	0.080
	2&3	0.00026	0.0004	0.081
	1&4	0	0.0001	0.872
28	1&2	0.001	0	0*
	1&3	0.001	0	0.002*
	2&3	0.0002	0.0002	0.317
	1&4	0.001	0	0*

*Significant differences between two groups ($p < 0.05$). Group 1: pH 6.8, group 2: pH 5, group 3: pH 3.5, group 4: trimmed SSCs at pH 6.8.

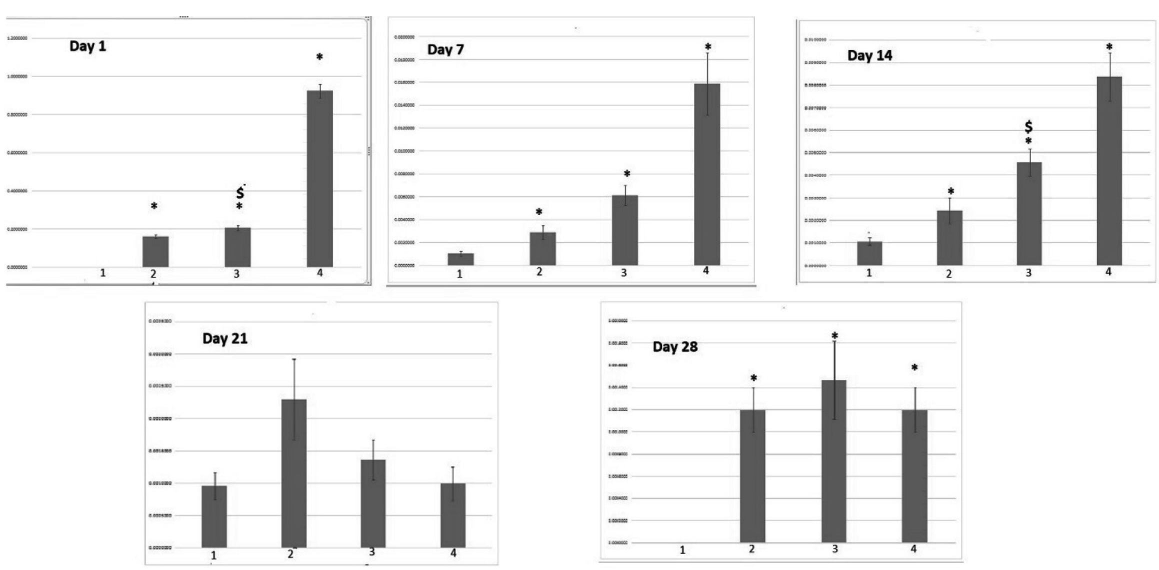

Figure 1. Comparison of nickel ion release between different groups of SSCs. Group 1: pH 6.8, group 2: pH 5, group 3: pH 3.5, group 4: trimmed SSCs at pH 6.8 on days 1, 7, 14, 21, and 28. Values are expressed as mean ± SD. *Significant difference compared with group 1 ($p < 0.05$). $ Significant difference compared with group 2 ($p < 0.05$)

According to the data in Table 1, the amount of ions released on the first day was the maximum across all groups and gradually decreased in the following days. The highest rate of nickel release among the first three groups was observed in group 3 on the first day of the study. According to Table 1, the total amount of released nickel increased from the first day to the final day of the study with pH reduction.

According to the results in Table 2 and Figure 1, nickel release increased with decreasing pH. Differences in the means of nickel release were statistically significant between groups 1 and 2, as well as between groups 1 and 3, on days 1, 7, 14, and 28 ($P < 0.05$). In addition, comparing groups 2 (pH 5.0) and 3 (pH 3.5), the amount of nickel release increased with decreasing pH in all days surveyed; however, these changes were statistically significant only on days 1 and 14.

According to the results in Table 2 and Figure 1, nickel release was significantly elevated in trimmed SSCs on different days compared with that in the first group (both groups = pH 6.8). This difference was statistically significant on days 1, 7, 14, and 28. Moreover, the highest rate of nickel release in all groups and all days in this study was observed in the trimmed group on the first day (0.924 ppm).

DISCUSSION

The use of SSCs is highly recommended to retain rotten primary molars. Saliva acts as an electrolyte in the oral cavity, the warm and humid atmosphere of which is an ideal environment for the corrosion of SSCs.[11] Nickel is added in virtually all stainless steel alloys to strengthen the austenitic phase and enhance its resistance to blackening and corrosion.[12] In our study, the highest amount of nickel released (0.9540 ppm) among the groups was observed in group 4 on the first day; however, this level of nickel is not significant in terms of toxicity (nickel toxic dose, 2.5 mg/mL; nickel lethal oral dose, 50–50 mg/kg body weight).[11] In fact, this level of nickel is lower than the daily intake limit (200–200 μg), which is consistent with many studies.[13,14] The WHO stated that intake of 0.2 ppm nickel/kg can cause systemic manifestations.[(11)] These findings were confirmed by a study conducted by Ramazani *et al.* in 2014.[11] Menek *et al.* also declared that nickel ions do not to cause allergic reactions at this level.[15] In 2010, Keinan *et al.* investigated the absorption of metallic ions released from SSCs by the root surface of primary molar teeth and found higher levels of nickel, chromium, and iron (6–5 times) in molar cementum coated with SSCs than in intact molars.[7] Because concern regarding the biocompatibility of dental materials has grown in recent years, this issue has been widely studied.

The oral environment, given its constant chemical, temperature, microbial, and enzymatic changes, can induce the corrosion of dental materials. Food has a wide range of pH. Acids are released into the oral environment during food degradation. The entry of metal ions into the human body is considered a health risk factor and can affect biological functions, eventually leading to systemic and local maladaptive effects.[16] In this study, acidification of saliva significantly influenced nickel ions release from the SSCs. Here a pH of 3.5 was applied to simulate the oral environment obtained when acidic food is consumed. A pH of 5 is also critical, and a pH of 6.8 is the normal saliva pH.

According to the present study (Table 1), the maximum nickel release was generally observed at pH 3.5, followed by pH 5.5; the lowest nickel release was observed at pH 6.8. Therefore, the amount of nickel release increases with decreasing pH. Similarly, in 2004, Huang *et al.* demonstrated that the nickel released from stainless steel brackets at pH 4 is higher than the amount of nickel released from brackets at pH 7.[17] Menek observed that the amount of nickel released from SSCs decreased with increasing saliva pH.[15] In the present study, among the different days surveyed, the highest level of nickel released in artificial saliva was observed on the first day. This finding may be related to the occurrence of nickel corrosion on the outer surface of the SSCs. The cathodic nature of nickel renders it susceptible to corrosion, which results in the release of nickel into the saliva. Barret *et al.* indicated that nickel on the surface of orthodontic appliances rapidly becomes corroded in the first 7 days, after which the release of nickel declines due to reduced surface nickel levels.[18] However, in previous studies, such as that conducted by Sahoo *et al.* on orthodontic brackets, chromium and nickel levels peaked in saliva on days 7–14 and then decreased.[19] Agaoglu *et al.* also evaluated nickel and chromium levels in saliva and found that the amounts of nickel and chromium released peaked in the first month and then decreased to their initial levels thereafter.[20] Satija *et al.* revealed that nickel and chromium released from the surface of brackets reached their maximum levels in the first week of installation.[21] In our study, on day 28, no nickel was released in group 1. This result may be attributed to the fact that the amount of nickel release is below the limit of detection of the measurement device. Indeed, in most studies, metal ions are often released in the early stages and on the first days of exposure.

The average value of released nickel was higher in group 3 than in groups 1 and 2 on all days surveyed. Differences between our present findings and the results of other studies may be related to the effects of different factors, such as temperature, saliva quality, plaque, and proteins, as well as the chemical and physical properties of foods and fluids consumed.

Although the amount of nickel released from crowns did not reach the critical level under laboratory conditions simulating the oral environment, this problem may be considered important considering the use of multiple SSCs in a child's mouth or the possibility of the simultaneous application of orthodontic appliances and the corresponding space maintenance. Yilmaz et *al.* reported the symptoms of increased delayed sensitivity reaction in a child with only one crown on a permanent molar tooth.[22] In our study, the amount of nickel released from trimmed SSCs in artificial saliva was below the critical limit (2.5 mg/mL). While the systemic toxicity effect of the metal is unusual, this low level may still cause allergic reactions because orthodontic appliances and crowns remain in the mouth for long periods of time.

Many studies have suggested the release of nickel from orthodontic appliances and SSCs. Nevertheless, the results of from Setcos et al. revealed that orthodontic appliances are not associated with increased sensitivity, and low levels of exposure could increase tolerance to the allergen.[5] The marginal adaptation of SSCs depends on many factors, including the proper size of the crowns, the appropriate length of the trimmed crowns, the crimping of the crown edges to match the prepared tooth, and the proper polishing of the crown.[23] In the present study, the amounts of released nickel significantly differed between the two treated and untreated conditions and was significantly higher in the trimmed group than in the untrimmed group. Such findings may be attributed to the loss of integrity of the crown margins, which enhances the amount of nickel release.[10] In this study, we investigated the effect of pH and margin trimming on the corrosion behavior of SSCs and compared the results with those in other studies. Future studies should examine the effect of other factors, such as temperature, halogen ions, and the chemical composition of artificial saliva, on SSC corrosion.

CONCLUSION

According to our findings, the amount of nickel release increases as the pH decreases. Furthermore, SSC trimming increases the release of nickel because of the loss of integrity of the margin. The nickel released from the crowns used in children's mouth does not exceed the acceptable daily intake limit at different pH levels and with trimming.

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CONFLICT OF INTEREST

The authors declare no conflict of interest in this study.

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