

Potential Leaching of Hazardous Metal Ions from Soldered Orthodontic Appliance

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Abbreviations: SSA: Silver soldered appliances; TPA: Transpalatal arch; QH Quad helix

ABSTRACT

Orthodontic soldered appliances used in a dynamic environment of the oral cavity may undergo corrosion process hence exposing patients to possible toxic effect of metal ions released from the process. This exploratory study aimed to assess and compare the leaching potential of hazardous metal ions from two types of silver soldered orthodontic appliance and to determine the conformity of the leached metal ions with the established health and safety standards published by World Health Organisation (WHO). Two types of soldered appliances (Transpalatal arch and Quad helix) were immersed in solutions with pH 2.5 to 5.5 (Hydrochloric acid) for a prolonged period of 22 weeks. The release of silver (Ag) and nickel (Ni) was determined by using a spectrophotometer. Results showed that metal ions were released the highest in the most extreme acidic condition (pH 2.5) and the pattern of metal release was dissimilar between types of metal ion and pH. There was no significant difference ($p > 0.05$) in the release of ions between two types of soldered appliance and some of the metal release exceeded safety value published by WHO. Leaching of metal ions from silver soldered appliance immersed in acidic solutions was observed in this study. The potential of metal toxicity carried by this appliance must be carefully considered when advocating this appliance to patients.

INTRODUCTION

Oral cavity has a dynamic environment where various factors may influence the corrosion process of metallic appliance used in orthodontic treatment. Among the components contributing towards the dynamicity of oral environment are salivary pH (which composed of enzymatic activity of the saliva, organic acids produced by the bacterial flora, and variability of food pH) and mechanical activities occurring within the oral cavity^[1-3].

In orthodontics, soldering is a standard method used for the application of auxiliaries and for the modification of force systems by joining wires of different cross-sections. Among commonly used silver solder appliance are transpalatal arch (or lingual arch), quad helix and rapid maxillary expander. In both appliances, a stainless steel wire of certain design is joined to the molar bands across the palate (or mandible) to serve their designated function. These joints are established by mean of soldering technique. Silver based solder alloy used in certain orthodontic appliances may create a galvanic couple with stainless steel alloys, inducing leaching of metal ions from the appliances^[4]. Therefore, the biocompatibility of these appliances has been a topic of concern of many literatures since some of the metal used in these appliances was classified as mutagenic, allergenic and cytotoxic to living tissue^[5-7]. Leaching of metallic ions from corrosion activity can produce metal discoloration of adjacent soft tissues and caused allergic reaction to susceptible patients^[8-10]. Besides, some of these ions may accumulate in organs and tissues thus interfere with the normal physiology of body systems^[11].

Many studies have been conducted to examine the corrosion effect of orthodontic appliance. The most common appliances

researched are orthodontic brackets, archwires and bands [1,12,13]. However, studies that looked into the corrosion effect of silver solder appliance (SSA) are still lacking. Therefore, the aim of this study was to assess and compare the leaching patterns of hazardous metal ions from two types of silver soldered orthodontic appliance and to determine the conformity of leached metal ions with the established health and safety standards.

MATERIALS AND METHODS

Fabrication of Transpalatal Arch and Quad Helix

For the purpose of investigating the leaching of metal ions from silver soldered appliances, five transpalatal arches and five quad helices were constructed. Alginate impression (Kromopan, Lascod, Italy) has been used to duplicate an existing (randomly selected from the laboratory) upper arch working model with molar bands. Ten duplications were made and molar bands (Ormco, Glendora, CA) sizes 14 were seated in place of 16 and 26. Five impressions were sent for fabrication of transpalatal arches and another five were sent for fabrication of quad helices made a total of 10 silver soldered appliances (SSA). One laboratory technician was assigned to construct the SSAs. Each of the appliance consisted of two molar bands conjoin to a 1.00 mm stainless steel wire (KC Smith, Monmouth) by silver soldering (Ormco, Glendora, CA) technique. The composition of metal alloy used in fabrication of SSA (Table 1).

Table 1. Composition of metal used in fabrication of SSA (in percentage).

Component	Compositional element (%)							
	C	Mn	Si	Cr	Ni	P	S	Fe
Stainless steel (K.C.Smith, Monmouth)	0.15	2.0	1.0	17.0-19.0	8.0-0.0	0.045	0.03	Balance
Molar bands (Ormco, Glendora, CA)	0.12	2.0	1.0	17.0-19.0	10.5-13	-	-	Balance
	Cu	Ag	Tin	Zn				
Silver solder (Ormco, Glendora, CA)	20.0-41.0	24.0-57.0	1.5-5.5	15.0-35.0				

Preparation of Immersion Solution (Hydrochloric Acid)

Hydrochloric acid (HCl) was prepared from stock solution into four different pH namely 2.5, 3.5, 4.5 and 5.5. Preparation of HCl solutions of different pH was made based on a formula;

$$pH = -\log [H^+]$$

$$M_1V_1 = M_2V_2$$

Hydrochloric acid was prepared fresh every two weeks (every interval) to make sure no contamination and change of pH will occur from prolong storing of the solutions. Checking and adjustment of pH was done using pH meter (Mettler Toledo, Mettler-Toledo, Swiss).

IMMERSION PROCEDURE

Each of the four transpalatal arches (TPA) and four quad helices (QH) were soaked in a glass beaker containing 200 ml of diluted hydrochloric acid (HCl) of pH 2.5, 3.5, 4.5 and 5.5 (3.16 mM, 0.316 mM, 0.0316 mM and 0.00316 mM HCl). As for control, one TPA and one QH were soaked in deionised distilled water in the same manner as test solution. Storage of the SSAs was done for 14 days/2 weeks at a temperature of 37 °C. After 2 weeks, the SSAs then were transferred to new bottles with fresh solution and kept for another 2 weeks and so on. Measurement was done at the end of every 2 weeks. This same procedure was repeated until 22 weeks.

SAMPLE ANALYSIS

Analysis of the sample was done using Spectrophotometer (DR 3900TM, Hach Company, Loveland, CO). The DR 3900 is a bench top spectrophotometer, designed for a simpler, step by step guided water analysis procedure. Two types of metal ions have been selected for analysis; silver and nickel. DR 3900 has the ability to detect silver in the range of 0.02-0.7 mg/L and nickel 0.006-6.0 mg/L. Analysis of the sample were done according to the manual given by the manufacturer.

STATISTICAL ANALYSIS

Data collected was analyzed using IBM SPSS Data Editor Version 22. Shapiro-Wilk normality test was used to check for normality. Mann-Whitney U test was used to compare difference of total ion release between Transpalatal arch (TPA) and Quad helix (QH).

RESULT

Silver Ion Leaching from Silver Soldered Appliance (TPA and QH)

For TPA, silver ion was not detected in any of the sample until week 14 where it was found has been leached from sample

with the most extreme pH (pH 2.5) at week 14 to week 22. The amount of silver leaching was constant at 0.04 mg/L for a few earlier intervals. The highest silver ion detected was 0.06 mg/L at week 20, and reduced back to 0.04 mg/L on the last measurement at week 22. Silver ion was not detected in solution with pH 3.5, 4.5, 5.5 and control (**Figure 1**).

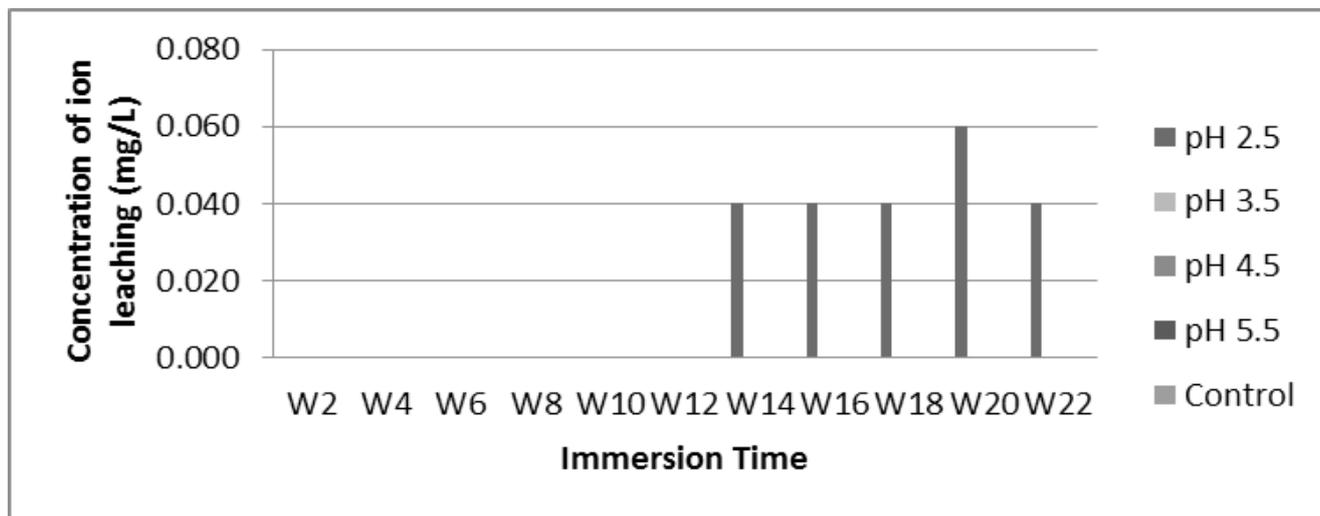


Figure 1. Silver ion leaching from transpalatal arch (TPA) immersed in hydrochloric acid of different pH and control as expressed in mg/L. ('Control' used in this study was deionised distilled water).

Similar to TPA, silver ion from QH only leached out in the most extreme pH of 2.5 (**Figure 2**). Silver ion started to leach at week 14 in increasing manner from 0.03 mg/L to 0.06 mg/L, with the highest concentration occurred at the last interval. Silver ion was not detected in hydrochloric acid with pH 3.5, 4.5, 5.5 and control.

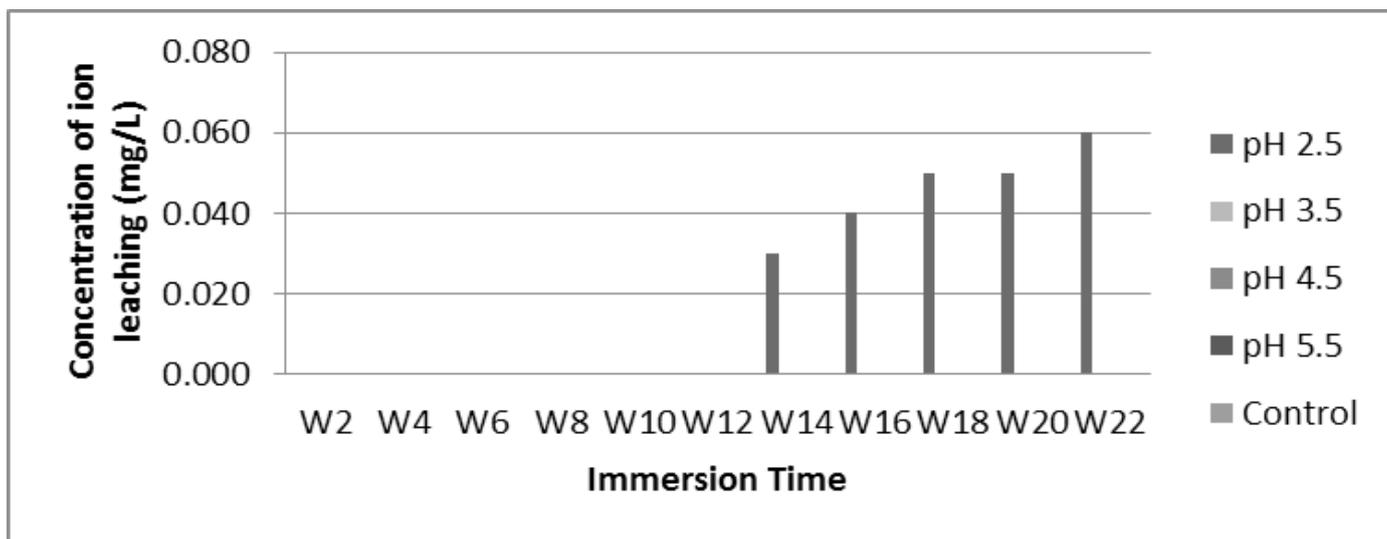


Figure 2. Silver ion leaching from quad helix (QH) immersed in hydrochloric acid of different pH and control as expressed in mg/L. ('Control' used in this study was deionised distilled water).

Nickel Ion Leaching from Silver Soldered Appliance (Tpa And Qh)

Nickel leaching from TPA occurred in a bigger amount when compared to silver ion leaching (**Figure 3**). The pattern of nickel leaching was different between each pH. In pH 2.5, nickel was leached at high amount between 1.644-1.776 mg/L at the first four intervals. Nickel leaching was abruptly reduced at week 10, not detected at week 16 and 18, and leached again in small amount at the last two measurements. In pH 3.5, TPA released a fairly same amount of nickel between 0.279-0.467 mg/L from the beginning of week 2 through week 18. However towards the end of the immersion period, there were slight increases in the nickel release, which the highest was 0.670 mg/L at week 20. The pattern of nickel leaching was almost the same from all TPA immersed in pH 4.5, 5.5 and control solution. In the first interval, the nickel leaching was above 0.1 mg/L. In the following intervals, the amount of nickel release was in the range of 0.039-0.078 mg/L for pH4.5. TPA immersed in pH 5.5 and control solution released nickel in the range 0.026-0.052 mg/L.

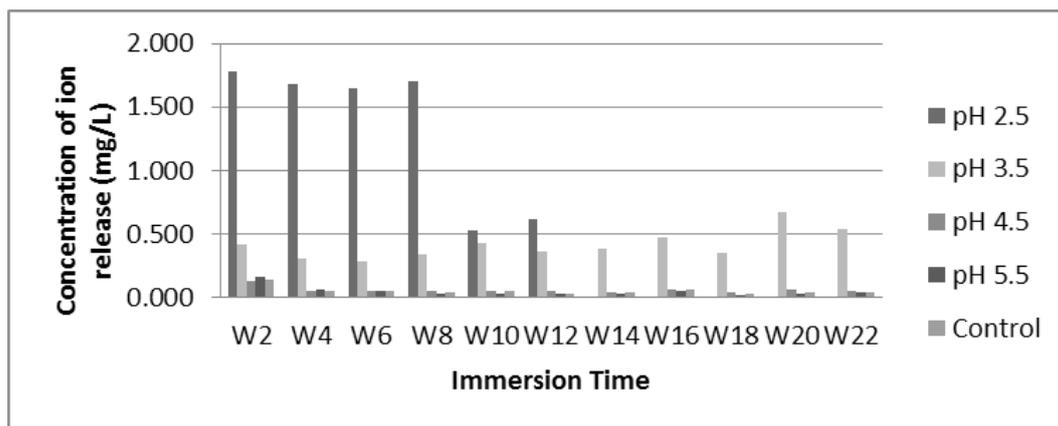


Figure 3. Nickel ion leaching from transpalatal arch (TPA) immersed in hydrochloric acid of different pH and control as expressed in mg/L. ('Control' used in this study was deionised distilled water).

Similar to TPA, QH in pH 2.5 released nickel ion at the higher amount during the earlier intervals, which is from week 2 to week 8 (1.259-1.722 mg/L) (**Figure 4**). Also similar to TPA, at week 10, the amount of nickel leaching started to drop from 0.199 mg/L to the lowest amount of 0.007 mg/L at the last interval. In pH 3.5, QH leached a fairly constant amount of nickel ion throughout the study ranging from 0.284-0.553 mg/L. As in the TPA, the leaching of nickel ion from QH immersed in pH 4.5, 5.5 and control solution was almost equal. In the first interval, the leaching was above 0.1 mg/L. For the following intervals, QH immersed in pH 4.5 released nickel ion in range 0.039 to 0.078 mg/L. QH in pH 5.5 and control solution released slightly lower amount of nickel ion in range 0.021 to 0.052 mg/L.

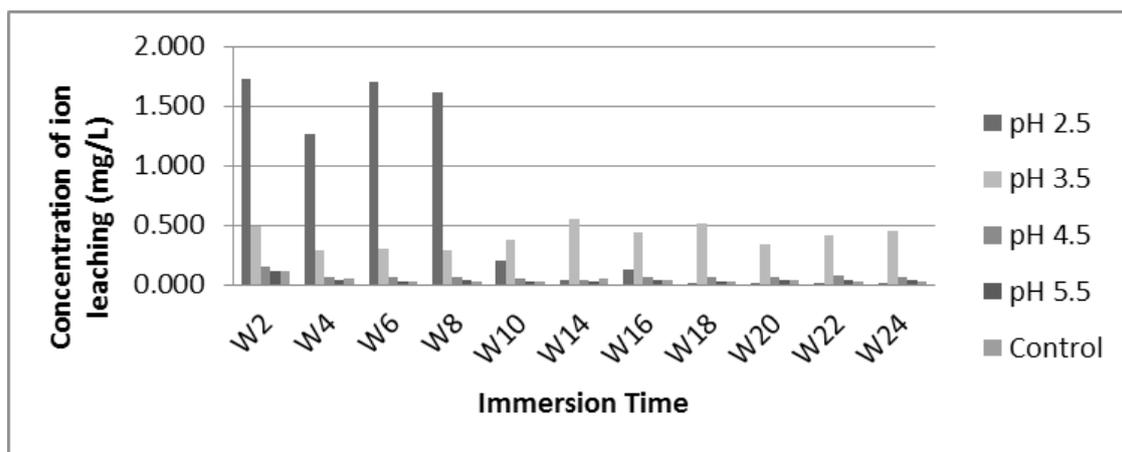


Figure 4. Nickel ion leaching from quad helix (QH) immersed in hydrochloric acid of different pH and control as expressed in mg/L. ('Control' used in this study was deionised distilled water).

Comparing Difference of Total of Ion Leaching Between Tpa And Qh

A Mann-Whitney U test indicated that the leaching of silver and nickel from QH were not significantly different than those released from the TPA ($p > 0.05$) (**Table 2**).

Table 2. Summary of the ion leaching from TPA and QH.

		n	Ion leaching (mg/L)	p Value
Silver	TPA	4	0.06 ± 0.06	0.89*
	QH	4	0.06 ± 0.06	
Nickel	TPA	4	3.42 ± 1.78	0.89*
	QH	4	3.09 ± 1.51	

Values are expressed as mean ± SEM

*Not significant ($p > 0.05$).

Comparison of Leached Metal Ions to Health and Safety Standards

Total amount of silver and nickel leaching were calculated to determine their conformity with the established standard value allowed in drinking water. The standard value used for comparison was those established by WHO (2003, 2005) (**Tables 3 and 4**).

Table 3. Conformity of silver ion leaching to the WHO Health and safety standard value.

SSA	pH	Daily ion leaching (mg/L) ¹	Daily ion leaching in first two weeks of leaching onset (mg/L)
TPA	2.5	0.004	0.003
QH	2.5	0.004	0.002
¹ Average of 8 weeks			
WHO standard value=0.1 mg/L			

Table 4. Conformity of nickel ion leaching to the WHO health and safety standard value.

SSA	pH	Daily ion leaching (mg/L) ²	Daily ion leaching in first two weeks of leaching onset (mg/L)
TPA	2.5	0.052	0.127*
	3.5	0.030	0.030
	4.5	0.004	0.009
	5.5	0.003	0.011
QH	2.5	0.044	0.123*
	3.5	0.029	0.035
	4.5	0.005	0.011
	5.5	0.003	0.008
² Average of 22 weeks			
WHO standard value=0.07mg/L			
*Exceed WHO standard value			

DISCUSSION

Acidic condition, chloride and fluoride ions are detrimental to the passive surface oxide film, which protects the metal alloy from corrosion [14]. Barret et al. [1] proposed that in the oral cavity, enzymatic activity and acidity of the saliva, and also bacterial flora activity might create an environment that favours corrosion. Stainless steel material lost its corrosion resistance when being heated during soldering process [4]. As a result, metal ions were easily leached out as a result of intergranular corrosion as shown by the present study. Furthermore, the presence of silver soldered joint in SSA is believed to create a galvanic current within the oral cavity that induces the metal ion release.

In this study, we observed release of silver from the SSA immersed in the extreme pH of 2.5 after 14 weeks of immersion period. The total amount of silver leaching after 22 weeks is 0.22 mg/L for TPA and 0.23 mg/L for QH. This is in contrast with where their study revealed a minimal amount of silver (0.193 µg/L) when they immersed fixed orthodontic appliance in acidic solutions [15]. The difference is predictable as one SSA comprises of more significant amount of silver component compared to a full set of fixed orthodontic appliance. An *in vitro* study by Berge et al. [4] also showed a minimal amount of silver released (1.1 µg/L) from soldered wire after 24 days. Shorter experiment duration and smaller sized soldered wire sample used by them compared to the present study, may have contributed to the smaller amount of silver release. Freitas et al. [16] in their *in vivo* study assayed larger amount of silver ion (11.53 µg/L), 10 minutes after hyrax placement in the patient’s mouth. Hyrax, by design comprises larger component of silver solder compared to TPA and QH, thus the high amount of silver release was not surprising. However the study by Freitas et al. [16] was done *in vivo*, thus the results could also be attributed by various confounding factors.

Nickel release on the other hand, occurred in different pattern according to the pH of the immersion solution. The highest release occurred in the first interval of all pH solutions. This finding is in agreement with those by Staffolani et al. [15] and Huang et al. [17] who found that the release of nickel ion was the highest on the first day of immersion compared to the subsequent days. The excessive amount of nickel released from SSA immersed in pH 2.5 in the early intervals could be due to the effect of the extreme corrosive effect of pH 2.5 compared to other pH. The quick and marked release of nickel at the early phase resulted in early exhaustion of the nickel ion from the SSA forming a plateau stage after week 10 to the week 22. Nickel release in weaker acids (pH 3.5 and above) were less compared to those released in pH 2.5. This finding agreed with the conclusions of other studies by Huang et al. [17] Kuhta et al. [18] and Staffolani et al. [15] which concluded that the most acidic condition favours more ion release compared to the less acidic condition. The amount of nickel release at pH 3.5, 4.5 and 5.5 were small and continuous throughout the study period and no plateau stage was reached. Since the pH of 3.5, 4.5 and 5.5 are the common acidic pH of the oral environment; our study demonstrated that SSA has a poor long term corrosion resistant.

The release of silver and nickel at an extreme pH after a prolonged immersion period as obtained from this study was as predicted due to the prolonged nature of this study. To our surprised, the silver and nickel ion seems continuously being leached until 22 weeks. Hypothetically, based on these findings, there is a likelihood that prolong acidic condition intra orally can induce the similar continuous leaching pattern of these metal ions from silver soldered appliance. This is a serious concern due to the leached ion intra orally most definitely being ingested by patients or absorbed by their oral mucosa and subsequently accumulates in the body and risk toxicity effect in the long run.

The toxicity risk of the metal release was assessed by comparing the daily release amount to the health and safety value published by the WHO. According to WHO, the concentration of silver in drinking water must not exceed 0.1 mg/L per day. The average daily release of silver encountered by this study is 0.04 mg/L/day makes it considered within the safe range of silver content in drinking water.

Overall daily nickel release from this study was 0.052 mg/L. The highest average nickel release, which was encountered from the first interval of sample with pH 2.5, was 0.127 mg/L/day. Based on this value, during the first two weeks in extreme acidic environment, nickel release exceeds the health and safety limit of nickel exposure determined by WHO, 0.1 mg/L/day^[19,20].

CLINICAL IMPLICATION

Orthodontic appliances including silver soldered appliances tested in this study are worn by orthodontic patients for a long term period. Orthodontic appliance in mouth is an additional metal exposure borne by orthodontic patients compared to other people without the appliance.

The result of the present study indicates that SSA might contribute to additional exposure of silver and nickel to the patient. Silver soldered joint was proven as a potent corrosion inducer and may be a potential toxicant; therefore, orthodontist must recognize the risk of prescribing this appliance to patient. Other alternatives are available as substitutes to the present design of silver soldered appliance. Removable pre-formed TPA or QH slotted into palatal sheath of the bands can be a good alternative to avoid having soldered joints. Furthermore, laser welding is another option to be considered when joining metal in place of silver soldering. As for the alternative of anchorage device as served by the TPA, mini implant is known for its promising skeletal anchorage device. Besides, mini implant also has been proven to have low toxicity and corrosion level due to its titanium content.

To reduce the metal ion leaching from SSA, orthodontist must remind their patients to maintain a good oral hygiene throughout the treatment. Advice such as avoiding acidic food should be given to patients to avoid similar condition of leaching that has been shown by our study.

CONCLUSION

Silver leaching started at week 14 from SSA immersed in the most acidic pH of 2.5. The leaching of silver has not reduced at the end of experiment. Nickel was leached from SSA in all conditions. Nickel leaching was the highest in pH 2.5 and reached plateau stage at week 8-12. SSA in pH above 3.5 released lower concentration of nickel, and the release was consistent until week 22.

Quad helix (QH) leached more silver than Transpalatal arch (TPA) after 22 weeks of immersion period. TPA leached more nickel than QH in all pH except for pH 4.5. There was no significant difference in the total of ion leaching between TPA and QH ($p>0.05$).

Silver leaching was within the health and safety standard for drinking water (WHO 2003). Nickel leaching in pH 2.5 exceeds the WHO, value for drinking water during the first two weeks. However, nickel leaching were within safety standard for appliances in other immersion solutions throughout the 22 weeks. Both appliances were considered safe in pH higher than 2.5.

REFERENCES

1. Barrett RD, et al. Biodegradation of orthodontic appliances Part I biodegradation of nickel and chromium in vitro. *Am J Orthod Dentofacial Orthop.* 1993;103:8-14.
2. Bumgardner JD, et al. Effect of titanium-dental restorative alloys galvanic couples on cultured cells. *J Biomed Mat Res.* 1998;43:184-191.
3. Geurtsen W. Biocompatibility of dental casting alloys. *Crit Rev Oral Biol Med.* 2002;13:71-84.
4. Berge M, et al. Corrosion of silver soldered orthodontic wires. *Acta Odont Scand.* 1982;40:75-79.
5. Faccioni F, et al. In vivo study on metal release from fixed orthodontic appliances and DNA damage in oral mucosa cells. *Am J Orthod Dentofacial Orthop.* 2003;124:687-694.
6. Freitas MPM, et al. Cytotoxicity of silver solder employed in orthodontics. *Angle Orthod.* 2009;79:939-944.
7. Milheiro A, et al. Nickel release from orthodontic retention wires- The mechanical loading and pH. *Dent Mater.* 2012;28:548-553.
8. Dunlap CL, et al. Allergic reaction to orthodontic wire: report of case. *J Am Dent Association.* 1989;118:449-500.
9. Kerosuo H, et al. Nickel allergy in adolescents in relation to orthodontic treatment and piercing of ears. *Am J Orthod Dentofac Orthop.* 1996;109:148-154.
10. Hussaini HM, et al. Silver solder "tattoo" a novel form of oral pigmentation identified with the use of field emission scanning

- electron microscopy and electron dispersive spectography. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod.* 2011;112:e6-e10.
11. Drake PL and Hazelwood KJ. Exposure-related health effects of silver and silver compounds: A review. *Ann Occup Hyg.* 2005;49:575-585.
 12. Hwang CJ, et al. Metal release from simulated fixed orthodontic appliances. *Am J Orthod Dentofacial Orthop.* 2001;120:383-391.
 13. Eliades T, et al. Characterization and cytotoxicity of ions released from stainless steel and nickel-titanium orthodontic alloys. *Am J Orthod Dentofacial Orthop.* 2004;125:24-29.
 14. House K, et al. Corrosion of orthodontic appliances- should we care? *Am J Orthod Dentofacial Orthop.* 2008;133:584-592.
 15. Staffolani N, et al. Ion release from orthodontic appliances. *J Dent.* 1999;27:449-454.
 16. Freitas MPM, et al. Release of toxic ions from silver solder used in orthodontics: An in-situ evaluation. *Am J Orthod Dentofacial Orthop.* 2011;140:177-181.
 17. Huang HH, et al. Ion release from Niti orthodontic wires in artificial saliva with various acidities. *Biomaterials.* 2003;24:3585-3592.
 18. Kuhta M, et al. Type of archwire and level of acidity: effects on the release of metal ions from orthodontic appliances. *Angle Orthod.* 2009;79:102-110.
 19. WHO. Silver in drinking water. Background document for development of WHO Guidelines for drinking water quality, Geneva. World Health Organization. 2003.
 20. WHO. Nickel in drinking water. Background document for development of WHO Guidelines for drinking water quality, Geneva. World Health Organization. 2005.