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ORIGINAL ARTICLE

Metal ion quantification in the saliva of patients with lingual arch appliances using silver solder, laser, or TIG welding

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Abstract

Objectives

Quantify metal ion release in the saliva, considering that orthodontic appliances with soldered or welded parts may suffer corrosion and release metal ions into saliva, which can trigger adverse effects, such as hypersensitivity.

Methods

Sixty-four patients were distributed into four groups: G1 (control), G2 (silver-soldered lingual arch), G3 (laser-welded lingual arch), and G4 (TIG-welded lingual arch). Saliva samples were collected at four different points and were analyzed for ion release with ICP-MS.

Results

For Cr, Fe, Cu, and Sn ion concentrations among groups, there was no difference along collections and no statistically significant difference throughout collections for any group ($P > 0.05$, with release values between 3.3 and 4.2 μg/L for Cr, 201 and 314.8 μg/L for Fe, 23.1 and 40.7 μg/L for Cu, and 13 and 27.7 μg/L for Sn). For Ni, G4 showed an increased ion release at T2 (14.3 μg/L) and T4 (34.5 μg/L), values with an interaction effect ($P < 0.001$) comparing the groups and the points of collection. For Zn, Ag, and Cd ions there was no difference along the points in time ($P > 0.05$). For Zn ions, there was a statistic difference from G4 to G1 and G2 ($P = 0.007$ and $P = 0.019$), with median values ranging from 741.7 to 963.4 μg/L for G4, and for Ag ions, from G4 to G2 and G3 ($P < 0.001$ for both), with lower medians for G4 (3.7–6.1 μg/L). For Cd ions there was a statistic difference from T1 to T4 in all groups ($P = 0.016$), with lower values for T4.

Conclusions

Different welding procedures may affect salivary ion concentrations. For most ions there was no significant increase comparing welding and comparing throughout points in the same group. Although TIG welding presented greater Ni ion release, this possibly occurred due to a bigger corrosion of the welded.

Clinical relevance

Determining the amount of released metal ions from the use of orthodontic appliances is relevant to ensure the safest method for patients. Welding procedures affect salivary ion concentrations, when comparing ion release triggered by one of the most common devices used for preventive/interceptive orthodontic treatments.

Keywords Welding · Soldering · Orthodontics · Lingual arch

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Introduction

Biocompatibility refers to the ability of a material to perform its function without undesired local or systemic effects, generating an appropriate cellular or tissue response and optimizing clinical performance therapy [1]. The oral environment favors biodegradation of metallic materials, associated with corrosion, due to chemical, physical, and biological variations [2]. Corrosion releases metallic ions and the products of these reactions may trigger adverse effects, such as hypersensitivity [3]. The process depends chemically on the solvent in which it is immersed and on the pH of the solution [4, 5], as well as temperature conditions, salivary composition, mechanical properties, microbiological and enzymatic activities, physical and chemical properties of food, and oral hygiene [6].

Although an increase of metal ions is detected after placing orthodontic appliances, levels may not be alarming; however, further studies are necessary to clarify and determine safe levels of metal ion release [2, 4]. Even though the amount of release is low and below the mean intake without reaching toxic levels, the possibility of biological effects on cells cannot be excluded [2, 7–10]. Lower amounts of ions can cause allergic reactions [5, 10], especially when the devices remain in the oral cavity for an extended period of time [5, 10]. Increased Ni and Cr release in saliva after placing orthodontic appliances has been reported in previous studies [10–13] with a maximum increase soon after the installation and gradually decreasing [10, 11]. Evaluation of Ni and Cr levels scalp hair from patients with fixed orthodontic appliances during 1 year also showed statistic mean differences when compared with patients who were not undergoing orthodontic treatment [14]. Even so, further research should be carried out to study the effect of corrosion and the toxic consequences of long-term ion release [13].

In orthodontics, welding is very common, especially in auxiliary devices such as the lingual arch. Among the appliances, those composed of welds are the most susceptible to corrosion and have possible toxic effects [15, 16]. Silver solder is a widespread method due to its proven effectiveness, low cost, and ease of use [17]; and it contains Ag, Cu, and Zn. In the oral cavity, metals may exhibit a strong tendency of ionic release [13, 18, 19] and may cause cytotoxic effects, resulting in decreased cell viability [16, 20]. Silver solder caused severe cellular toxicity, with inhibition of fibroblasts proliferation, growth and development, suggesting cell death, in an in vitro study [16]. Ion concentrations in the saliva of children with and without the use of silver solder appliances were evaluated in an in situ study. According to other authors, results showed low values in the control group for Cd, Cu, and Zn ions and for Ag ions, the values did not reach the detection limit. In the study group, all ions increased within 10 min after being placed in the metallic device group [13]. In addition, soldering is done at 300 to 900 °C and, as a result, induces surface roughness and disintegration of crystal structure increasing corrosion susceptibility and releasing more ions [21].

Laser welding is an alternative to silver solder, in which the use of a third metal or alloy is avoided as the energy generated by the laser already promotes the melting of the metals. As such, it appears to be less susceptible to corrosion and more biocompatible [17, 22, 23]. Some authors [24, 25] support the fact that laser welding is less toxic than silver solder. The adhesion and proliferation of human gingival fibroblasts in contact with both silver and laser welded lingual arches were analyzed and the results highlighted the biocompatibility of fibroblasts with laser welding [24]. As for periodontal tissue response, there was no significant difference between laser or silver solder [26].

TIG welding, although widely used in engineering, is not commonly used in dentistry. Characterized by plasma welding, the process uses an electric arc formed with a tungsten electrode and the part to be welded, with local protection using an inert gas to prevent oxidations [27–29]. As with laser solder, joints formed by TIG appears to suffer less galvanic corrosion [28]. However, corrosion resistance of stainless steel in orthopedic prostheses welded with TIG showed that the joints were more susceptible to corrosion than the base metal [30]. In another study, conventional soldering with common metals and TIG welding showed similar results for electrochemical corrosion tests in artificial saliva samples. Corrosion density of welded Ni and Cr alloys was significantly higher than the corrosion density of the TIG-welded method. It is suggested that TIG is a suitable welding method, since the final structure does not reduce corrosion resistance in artificial saliva [19]. Studies demonstrate technical superiority compared with conventional soldering methods in relation to mechanical properties, with similar results found in laser welding [27, 31]. When comparing corrosion resistance, soldering method presented a lower performance than TIG welding [19]. However, studies comparing metal ion release among the three types of welds described are still lacking, requiring further clinical trials that also include TIG welding as a method for joining metals in orthodontics.

The literature suggests that metal ions are released during orthodontic treatment, but the level is far lower than that ingested in a routine daily diet [4]. Nevertheless, the impact of corrosion during orthodontic treatment and on the health of our patients is not well understood. With soldered wires, the problem is especially about the release of Ag, Fe, Zn, Cu, and Cd ions. Stainless steel is particularly susceptible to corrosion, releasing Cr ions too, and yet Cr and Ni can be added to impart corrosion resistance [4]. Therefore, this study evaluated metal ion release in the saliva of patients with different soldered or welded appliances, comparing them to a control group, without orthodontic appliances to further contribute to elucidate this question and to ensure the safest method for patients.

Materials and methods

This randomized clinical trial was submitted, approved, and authorized by the Research Ethics Committee of the Pontifical

Catholic University of Rio Grande do Sul (PUCRS) (approval number 67430117.7.0000.5336).

Sample

Patients from the Dental Program at the School of Health and Life Sciences of PUCRS were selected. The research was conducted in patients ranging from 6 to 13 years old with similar health conditions, where some needed the use of a lingual arch and others did not, according to the inclusion and exclusion criteria described further on. The children and their parents were invited to participate in the study and, upon agreeing to participate, the parents signed an informed consent term.

A sample calculation was performed to determine the number of individuals required, based on a previous study [13]. According to it, we considered each group as having a normal distribution. Considering the concentration data of this study, an error of 3.75 μg/L, 80% power and 95% confidence, where the *n* individuals should be 11 per group.

Groups

The sample was comprised of a total of 64 individuals (34 males and 30 females, distributed in 4 groups, as shown in Table 1). Within this sample, 43 patients were selected for the 3 experimental groups, all in need of a lingual arch. The remaining 21 individuals made up the control group with no need for an orthodontic intervention at the time of the study. It is of note that there was no difference in the treatment among the 3 experimental groups apart from how the appliances were soldered or welded. The sample mean age was 8.9 for males and 9.0 years for females; the youngest patient was 6 years old, and the oldest, 13. The children were randomly allocated into one of the 3 experimental groups (2, 3, or 4).

The inclusion criteria for the control and experimental groups were:

1. Mixed dentition;
2. Good general and oral health;
3. Absence of metallic restorations that could suffer corrosion in the mouth;
4. No history of previous orthodontic treatment performed in the last 6 months;
5. For the experimental groups, the need of a lingual arch due to early deciduous teeth loss and/or leeway space maintenance.

The exclusion criteria for the control and test groups were:

1. Presence of syndromes;
2. Ongoing use of medications or diseases related to genetic disorders;
3. The need of any other associated orthodontic appliance than the lingual arch during the study period, apart from the control group that could not use any orthodontic appliance.

Control (group 1–G1)

Twenty-one individuals were selected for saliva collection, with no need for an orthodontic intervention at the time of the study.

Experimental (groups 2, 3, and 4—G2, G3, and G4)

Forty-three individuals were selected for the 3 experimental groups, all in need of a lingual arch. The lingual arches were made using stainless steel bands for the lower first left and right molars (Morelli™, Sorocaba, SP, Brazil) and a 0.9 mm stainless steel wire (Morelli™, Sorocaba, SP, Brazil) soldered or welded to the bands according to the corresponding method in each experimental group, described as follows:

Silver soldering (G2): soldering of a 0.9 mm stainless steel wire (Morelli™, Sorocaba, SP, Brazil) using 10 cm of a silver solder alloy and 20 mg of flux (Morelli™, Sorocaba, SP, Brazil) with a torch (Blazer™ Gb2001, Farmingdale, NY, USA) containing butane gas.

Laser welding (G3): welding of a 0.9 mm stainless steel wire (Morelli™, Sorocaba, SP, Brazil) using a 0.5 mm

Table 1 Division of groups and distribution of collected samples

	Group	*n*	Male	Female	T1	T2	T3	T4	Total
1	Control (without appliance)	21	10	11	21	19	17	13	70
2	Lingual arch, silver soldering	16	10	6	16	16	16	16	64
3	Lingual arch, laser welding	14	6	8	14	14	14	12	54
4	Lingual arch, TIG welding	13	8	5	13	13	13	11	50
	Total	64	34	30					238

n represents the number of patients selected; T1, T2, T3, and T4 columns indicate the quantity of samples collected for each period in the groups; *n* represents the number of patients selected and the Total represents the number of samples collected in each group during the periods evaluated stainless steel wire (Morelli™, Sorocaba, SP, Brazil) as a filling material, according to the cord technique. Laser welding was carried out in a specialized laboratory (Portodent™ Laboratory, Porto Alegre, RS, Brazil) using a laser equipment (Sisma™ LM-D 60, Vicenza, VI, Italy), with a nominal power of 60 W, 90 J pulse energy, pulse duration of 0.3–25 ms and pulse diameter of 0.2–2.0 mm.

TIG welding (G4): welding of a 0.9 mm stainless steel wire (Morelli™, Sorocaba, SP, Brazil) without a filling material, according to the plasma cord technique. Welding was performed using a TIG equipment (Lampert™ PUK D2/SM D2, Werneck, BY, Germany) with 99.8% pure argon gas. Power of 22% to 25% were used; welding time and pulse duration were of maximum 10 ms.

After soldering or welding, a carborundum disc was used to remove the excess of material. The surfaces were then polished with a white silicone rubber for 15 s (polishing rubber L22, EVE™, Pforzheim, BW, Germany), a brown rubber (EVEFLEX 708, EVE™, Pforzheim, BW, Germany) for 30 s and finally a green rubber (EVEFLEX HP 808, EVE™, Pforzheim, BW, Germany) for 30 s. The appliances were cemented with glass ionomer (3M Unitek™, Saint Paul, MN, USA).

Saliva collection and sample management

In the experimental groups (2, 3, and 4) saliva samples were collected at T1 (before placing the appliance), T2 (07 days after placing the appliance), T3 (15 days after placing the appliance), and T4 (30 days after placing the appliance). In the control group (group 1), saliva samples were collected at the same four points in time (T1, T2, T3, and T4), without the use of any appliance. The patients were instructed not to ingest food or liquids (except for water) within 30 min prior to collection. The patients were instructed to accumulate saliva in the mouth for 5 min and to spit into a plastic bottle (50 mL falcon tube) labeled and identified with the patients' name and moment of collection. Each sample was frozen at − 80 °C, in a freezer for future use.

Sample processing and analysis for metal quantification

The samples were prepared and evaluated at the Institute of Toxicology and Pharmacology (INTOX) at PUCRS, using an inductively coupled plasma spectrometer (ICP-MS) to separate and quantify the ions, considering a previous study methodology [32]. After thawing, 1 mL volume of each sample was transferred to glass vials and heated at 85 °C to evaporate volatile components. For organic matter digestion, 65 μL of nitric acid and 200 μL of hydrochloric acid were added and samples were sealed in a box for 24 h. Each one was diluted with 4 mL of ultra-pure Milli-Q™ water and individually filtered (Captiva Filter Seringa Econofilter PES 25 mm 0.45 μm Agilent™, Santa Clara, CA, USA). The diluent was prepared with 500 mL of Milli-Q water and 15 mL of nitric acid. The internal standard was prepared with 10 mL of diluent and 100 μL of germanium. The diluent (250 mL) and the internal standard (310 μL) were prepared for curves. The multi-elemental pattern (500 μL) was prepared with 100 mL of diluent, added to 50 μL Ag, Zn, and Sn. The calibration curve included 10 μL, 50 μL, 250 μL, 2.5 μL, and 200 μL of internal standard and 25 μL of diluent. For the analysis, four blank standards with 100 μL of diluent, P1 standards (1000 μL of diluent) and P2 to P6 (1 mL of the respective calibration curve points) were used. Of the samples prepared, 1 mL of each was used and 4 mL of internal standard was added with diluent to each one, sonicated for 5 min and then placed in the ICP-MS machine for analysis and quantification of metallic ions (Cr, Fe, Ni, Cu, Zn, Ag, Cd, and Sn).

Statistical analysis

Cr, Fe, Ni, Cu, Zn, Ag, Cd, and Sn ions were measured and quantified for each saliva sample. Summary measures were taken, such as mean and median for each point in time and for each group and the percentile 25–75/interquartile range. Data analysis was performed with SPSS 20.0 and the generalized estimated equation (GEE) model was used to compare them. A level of significance of 5% was considered.

Results

Data were collected from a total of 64 patients. Each patient was supposed to be evaluated at four specific time points (T1, T2, T3, T4), as some patients skipped some saliva collections, totalizing 238 samples for analysis (Table 1). Patients without appliances were the ones who most lacked appointments, evidencing a lack of motivation to return. Salivary ion concentration levels of Cr, Fe, Ni, Zn, Ag, Cd, and Sn were measured, in μg/L.

Comparing Cr, Fe, Cu, and Sn among groups, there was no difference in variation along the collections among groups ($P = 0.320$, $P = 0.711$, $P = 0.578$, and $P = 0.442$, respectively) (Tables 2, 3, 4, and 5). There was also no statistically significant difference throughout the collections for any of the groups, with Cr median varying at most 0.4 μg/L for G1, 0.7 μg/L for G2, 0.8 μg/L for G3, and 0.4 μg/L for G4 (Table 2); Fe median varying at most 62 μg/L for G1, 84.2 μg/L for G2, 110.5 μg/L for G3, and 66.1 μg/L for G4 (Table 3); Cu median varying at most 11.1 μg/L for G1, 10.0 μg/L for G2, 0.9 μg/L for G3, and 23.7 μg/L for G4 (Table 4); Sn median varying at most 5.7 μg/L for G1, 3.2 μg/L for G2, 7.0 μg/L for G3, and 13.9 μg/L for G4 (Table 5).

Table 2 Concentrations of Cr ions (μg/L)

		Group 1 control	Group 2 silver soldering	Group 3 laser welding	Group 4 TIG welding	*P*
T1						0.320
	Median	3.9	4.2	3.6	3.3	
	P25-P75	2.8–5.0	2.6–7.6	2.6–10.5	2.8–7.1	
T2						
	Median	3.9	3.6	4.1	3.7	
	P25-P75	2.8–4.1	2.6–4.9	2.6–4.9	3.3–4.4	
T3						
	Median	3.7	3.5	4.0	3.6	
	P25-P75	3.2–5.9	2.7–4.7	2.6–4.9	2.7–5.6	
T4						
	Median	3.5	3.5	3.3	3.6	
	P25-P75	2.9–4.8	2.9–5.2	2.6–6.6	2.9–5.5	

P25-P75: percentile 25–75/interquartile range. *P* obtained with GEE

When Ni values were compared in the groups and in the points of collection, an interaction effect was seen ($P < 0.001$) (Table 6, Fig. 1). For G1 there was no difference among collections. For G2 there was difference between collections T1 and T2 ($P = 0.007$) and T1 and T3 ($P = 0.007$), indicating regression of ion release in about 4.2 μg/L and 5.6 μg/L respectively. For G3 there was no difference among the collections (ranging from 6.3 to 8.5 μg/L) and for G4 there was a difference from T4 for T1 ($P = 0.001$), T2 ($P = 0.017$), and T3 ($P = 0.001$), indicating increased ion release of these ions at T4 compared with the other points in time. At T2, there was a statistically significant difference for G4 in relation to G1, G2, and G3 ($P = 0.020$, $P = 0.024$, $P = 0.040$, respectively), with median of 14.3 μg/L for G4, which is 8.9 μg/L more than G1, 7.6 μg/L more than G2, and 5.8 μg/L more than G3. At T4, the differences among groups were between G4 and G1, G4 and G2 and G4 and G3 ($P < 0.001$, $P < 0.001$, $P = 0.001$ respectively), with median range for G1 varying from 4.8 to 8.0 μg/L, for G2 from 5.3 to 10.9 μg/L, for G3 from 6.3 to 8.5 μg/L and G4 from 5.8 to 34.5 μg/L, this one showing a much larger range of values and the highest release value for T4 compared with all groups (Table 6).

Comparing Zn among groups, there was no difference in the variation along the collections ($P = 0.186$) (Table 7, Fig. 2). Overall, there was difference from G4 to G1 and G4 to G2 ($P = 0.007$, $P = 0.019$, respectively), with median ranging from 741.7 to 963.4 μg/L in G4, G1 from 461.0 to 499.8 μg/L and G2 from 384.3 to 653.9 μg/L. There was no significant difference among collections for each group (G1 varying 38.8 μg/L at most, G2 269.6 μg/L, G3 319.5 μg/L, and G4 290.5 μg/L). For Ag, there was no difference in the variation along the points in time among groups ($P = 0.202$)

Table 3 Concentrations of Fe ions (μg/L)

		Group 1 control	Group 2 silver soldering	Group 3 laser welding	Group 4 TIG welding	*P*
T1						0.711
	Median	274.7	259.9	311.5	286.8	
	P25-P75	225.3–540.0	203.5–511.1	145.2–421.6	206.9–583.5	
T2						
	Median	289.9	230.6	216.6	248.5	
	P25-P75	162.5–416.2	178.5–391.0	114.8–422.3	171.1–340.1	
T3						
	Median	238.4	263.1	201.0	233.5	
	P25-P75	144.1–456.3	170.4–353.8	116.0–345.5	178.1–429.7	
T4						
	Median	227.9	314.8	268.1	299.6	
	P25-P75	144.2–406.8	106.6–448.9	133.0–424.9	202.2–598.2	

P25-P75: percentile 25–75/interquartile range. *P* obtained with GEE

Table 4 Concentrations of Cu ions (μg/L)

		Group 1 control	Group 2 silver soldering	Group 3 laser welding	Group 4 TIG welding	*P*
T1						0.578
	Median	34.2	36.6	29.7	31.3	
	P25–P75	24.2–40.0	22.5–60.6	22.9–72.6	25.0–64.9	
T2						
	Median	30.5	30.7	28.4	28.0	
	P25–P75	25.5–44.9	27.0–41.0	17.8–36.6	22.1–69.4	
T3						
	Median	33.2	32.4	29.5	34.6	
	P25-P75	15.1–66.1	23.3–48.4	17.4–42.8	23.9–80.1	
T4						
	Median	23.1	40.7	30.4	51.7	
	P25-P75	16.0–50.0	18.9–54.2	19.5–37.6	32.0–116.8	

P25-P75: percentile 25–75/interquartile range. *P* obtained with GEE

(Table 8, Fig. 3). Overall, there was difference from G4 to G2 and G3 ($P < 0.001$ for both comparisons), indicating smaller medians for Ag ion release for G4 (Table 8). There was no statistically significant difference among the points in time within each group, with median ranging from 10.1 to 18.3 μg/L in G1, from 15.1 to −20.8 in G2, from 8.8 to 13.4 μg/L in G3 and from 3.7 to 6.1 μg/L in G4. Comparing Cd among groups, there was no difference in the variation along the points in time ($P = 0.109$) (Table 9, Fig. 4). Overall, there was no difference among groups, with values of minimum 0.5 μg/L and maximum 1.5 μg/L and there was a statistically significant difference from T1 to T4 in all groups ($P = 0.016$), reducing values in all groups from T1 to T4, except for the control, G1, which increased from 0.6 to 1.0 μg/L (Table 9).

Most of the highest means were located in G4 (Fe, Ni, Cu, Zn, and Sn), with statistically significant difference for T1 only for Ni ($P = 0.001$). For highest values located at T4, the increase was significant only for Ni in G4; for the other ions that showed highest means at T4 (Cr, Fe, Cu, Zn), the values were similar to T1 in the same group (Tables 2, 3, 4, and 7). For Ni ion, the highest mean release was 51.3 μg/L in G4, at T4. At T4, all averages reduced to baseline values, except for G4 that had the highest mean at T4, which was the highest release mean for all groups (Table 6). For Ag ion, after placing the appliance, the highest mean value was 22.1 μg/L, 7 days after in group 2 at T2. At T4, all averages reduced to baseline values, except for G3, that had the highest mean at T4 (Table 8). For Cd, the highest mean release was 6.5 μg/L in group 2 at T2, 7 days after placing the appliance, as well as for

Table 5 Concentrations of Sn ions (μg/L)

		Group 1 control	Group 2 silver soldering	Group 3 laser welding	Group 4 TIG welding	*P*
T1						0.442
	Median	16.6	13.2	18.2	27.0	
	P25-P75	8.2–54.0	10.1–18.2	13.7–26.3	24.7–29.5	
T2						
	Median	25.3	14.6	17.8	27.7	
	P25-P75	8.9–54.2	10.8–25.7	12.9–46.0	13.4–38.2	
T3						
	Median	21.1	11.4	18.1	26.6	
	P25-P75	9.4–53.3	9.6–17.3	12.2–48.6	13.7–35.9	
T4						
	Median	21.5	13.0	24.8	13.8	
	P25-P75	9.7–54.2	10.1–18.3	13.2–50.4	12.7–27.7	

P25-P75: percentile 25–75/interquartile range. *P* obtained with GEE

Table 6 Concentrations of Ni ions (μg/L)

		Group 1 Control	Group 2 Silver soldering	Group 3 Laser welding	Group 4 TIG welding	*P*
T1						< 0.001
	Median	8.0	10.9	6.6	8.0	
	P25-P75	4.1–9.3	4.9–23.8	6.1–18.8	6.1–22.1	
T2						
	Median	5.4	6.7	8.5	14.3	
	P25-P75	3.9–6.9	5.0–9.4	6.1–12.6	5.1–68.9	
T3						
	Median	6.0	5.3	7.9	5.8	
	P25	4.1–9.1	3.8–7.4	4.5–13.3	3.5–70.5	
T4						
	Median	4.8	8.2	6.3	34.5	
	P25-P75	2.4–9.4	3.7–10.9	2.6–13.8	20.1–83.9	

P25-P75: percentile 25–75/interquartile range. *P* obtained with GEE

Ag ion. At T4, all averages reduced to baseline values. For Sn, the highest mean release, after placing the appliances, was 47.5 μg/L in G4, at T3. At T4, all averages reduced to baseline values, except for the control group G1 and G3 that had the highest mean in T4 (Table 5).

In the TIG group G4, the results demonstrated that 7 days after placing the appliance the Ni ion concentration increased significantly (an increase of 19.1 μg/L) and the values did not decrease along the collection moments (Table 6). For Ni ions, there was a statistically significant difference for T2 in group 4 compared with G1, G2, and G3 ($P = 0.020$, $P = 0.024$, and $P = 0.040$ respectively), showing greater tendency for Ni ion release 7 days after placing the appliance with TIG welding. There also was a statistically significant difference at T4, 30 days after placing the appliance, with TIG welding (group 4), in groups 1, 2, and 3 ($P < 0.001$; $P < 0.001$; $P = 0.001$ respectively).

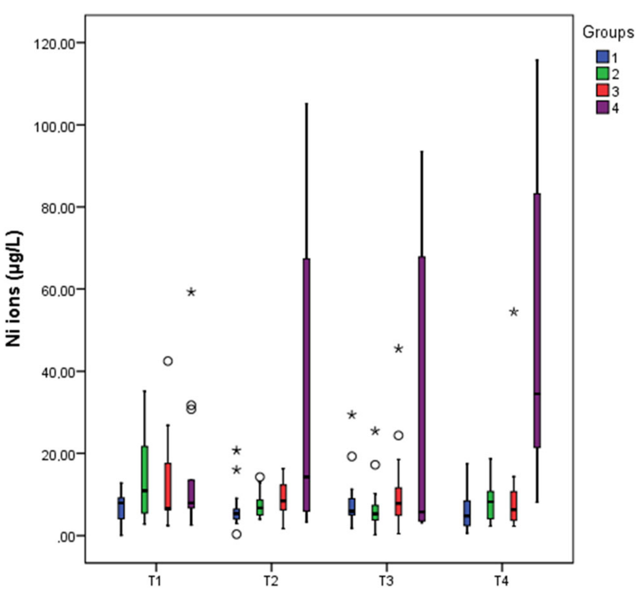

Fig. 1 Ni ion release compared in the groups and in the points of collection. Ni ions: nickel ions concentrations; T1: before placing the appliance, T2: 07 days after placing the appliance, T3: 15 days after placing the appliance and T4: 30 days after placing the appliance; Group 1: control, Group 2: silver solder, Group 3: laser welding, Group 4: TIG welding

Discussion

Orthodontic appliances may suffer corrosion and release metal ions into saliva, which can trigger adverse effects, such as hypersensitivity and inflammatory process leading to DNA damages, visible only after 30 days from application of fixed orthodontic devices [33]. Besides this, cell lines showed decreased viability percentages after exposure to extracts of orthodontic bands containing silver solder joints [34]. Therefore, determining the amount of released metal ions from the use of orthodontic appliances is relevant to ensure the safest method for patients. In the present study, most of the ions concentrations did not presented statistically significant changes, remaining stable over the assessed period; however, ion release into saliva, even if not significant, may be sufficient to cause an allergic reaction in sensitive individuals [5, 10]. Clinical manifestations such as gingival hyperplasia, labial desquamation, angular cheilitis, multiform erythema, and periodontitis might be associated with inflammatory response induced by the corrosion of orthodontic appliances [35].

The large variability in ion concentration among the evaluated patients may be related to several factors as saliva does not present a constant composition and may be different among individuals or even among periods for the same individual. Physical properties, amount, and composition of the saliva are influenced by factors such as diet, time of day, and

Table 7 Concentrations of Zn ions (μg/L)

		Group 1 Control	Group 2 Silver soldering	Group 3 Laser welding	Group 4 TIG welding	*P*
T1						0.186
	Median	461.0	653.9	783.7	963.4	
	P25-P75	354.6–597.1	306.4–857.4	282.9–986.6	747.1–1034.0	
T2						
	Median	496.3	502.0	498.0	741.7	
	P25-P75	249.4–744.6	264.9–895.4	218.1–704.7	617.8–1308.0	
T3						
	Median	493.4	447.2	464.2	672.9	
	P25-P75	386.4–649.5	199.4–666.3	387.4–611.3	596.3–936.6	
T4						
	Median	499.8	384.3	465.0	790.3	
	P25-P75	337.6–759.7	211.1–496.4	339.1–718.4	708.0–1035.2	

P25-P75: percentile 25–75/interquartile range. *P* obtained with GEE

psychological conditions [2]. A diet rich in sodium chloride and acidic carbonated drinks, for example, can provide a regular supply of corrosive agents [4]. Food, water, tobacco, and air itself are substances that can affect salivary Ni levels [12]. Due to the present sample size and that it was composed of patients of varied ages and social levels, it was not possible to control factors such as dietary and hygiene habits. Patients received basic hygiene instructions but were not supervised for this factor. Although it is known that some mouthwashes cause greater ion release [36], the use of this product was not considered nor requested in this study.

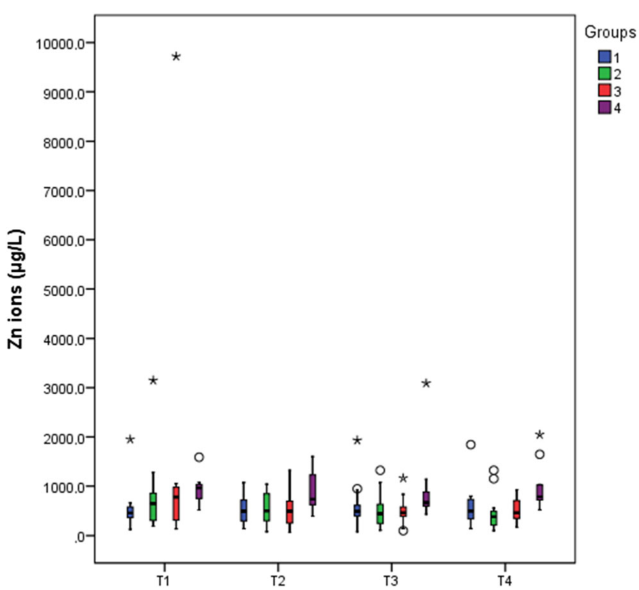

Fig. 2 Zn ion release compared in the groups and in the points of collections. Zn ions: zinc ions concentrations; T1: before placing the appliance, T2: 07 days after placing the appliance, T3: 15 days after placing the appliance and T4: 30 days after placing the appliance; Group 1: control, Group 2: silver solder, Group 3: laser welding, Group 4: TIG welding

Kuhta et al. reported that if salivary pH is reduced from 6.75 to 3.5, it could increase the release of metal ions from orthodontic appliances [5]. In this study, there was no pH value control which may have influenced the results. Still according to Kuhta et al. there was statistically significant stimulation of ion release at a lower pH. This is in line with the hypothesis that organic acids in dentobacterial plaque affect the release of ions, emphasizing the major role of oral hygiene in minimizing corrosion [5].

In relation to Cr, Fe, Cu, and Sn ions, this study demonstrated that there was no statistically significant difference at T1, T2, T3, and T4 in any group. There was also no statistically significant difference among groups and among points in time. The values measured were similar to the baseline data (T1) and when there was an increase, even without statistically significant difference, concentrations regressed during the study period, as found in previous investigations [11, 13, 37]. Kocadereli et al. [38] and Staffolani et al. [39] did not find differences in the concentration of metallic ions in the saliva of patients with and without orthodontic appliances, although other types of appliances were tested without comparing the kind of soldering or welding in their studies. Therefore, regardless of the type of solder or welding method, there was no significant increase in the quantity of ions released. Within each group, there was also no difference in the concentration of these ions along the collection moments.

Previous studies comparing silver solder and laser welding showed more metal ion release for soldering [16, 22, 40]. In this study, Zn, Ag, and Cd ions showed no difference in variation along the periods among the groups, concluding that there was no significant increase in the release of these ions when comparing the groups. However, for Zn ions, there was

Table 8 Concentrations of Ag ions (μg/L)

		Group 1 Control	Group 2 Silver soldering	Group 3 Laser welding	Group 4 TIG welding	*P*
T1						0.202
	Median	18.3	16.5	13.4	6.1	
	P25-P75	8.1–28.9	9.7–23.4	8.3–26.8	4.4–7.2	
T2						
	Median	13.3	20.8	12.5	3.8	
	P25-P75	9.7–28.7	9.1–34.8	5.9–20.3	2.9–6.7	
T3						
	Median	13.3	17.7	9.9	4.3	
	P25-P75	6.4–22.6	11.7–23.0	6.3–18.7	2.5–6.4	
T4						
	Median	10.1	15.1	8.8	3.7	
	P25-P75	7.2–14.9	10.5–23.6	5.3–19.7	2.8–7.4	

P25-P75: percentile 25–75/interquartile range. *P* obtained with GEE

a statistically significant difference from group 4 to groups 1 and 2, presenting more ion release in patients with appliances using TIG welding. For Ag ions, there was a statistically significant difference from group 4 to groups 2 and 3, showing more Ag ion release in patients with silver-soldered appliances and in patients with appliances using laser welding, compared with patients with TIG-welded devices. For Cd ions, there was a statistic difference between T1 and T4 in all groups, presenting a decrease in the values in the assessed period. For the highest values located at T4, the increase was significant only for the Ni ions in group 4; for the other ions the groups that showed the highest means at T4, the value was similar to T1 for the same group. Despite that, it would be interesting to evaluate the long-term ion release to check for reduction. In group 4, for Ni ions, there was a statistic difference from T4 to T1 ($P = 0.001$), T4 to T2 ($P = 0.017$), and T4 to T3 ($P = 0.001$), indicating that TIG-welded appliances had greater Ni ion release and that this increase in ions did not regress during the assessed period. The level of metal ion release from samples of silver soldering was higher than from samples of laser welding in a previous study [22], with greater amounts of Ni, Cr, and Fe released from silver soldering by different types of mouthwash [22]. Whereas the methods of the experiments vary, the results differ, and the comparison is difficult to be made. This was the first in vivo study that evaluated metal ion release from orthodontic welded appliances, including the TIG welding method. Until now, ionic releases for these three types of welding had not been measured and compared in the same study.

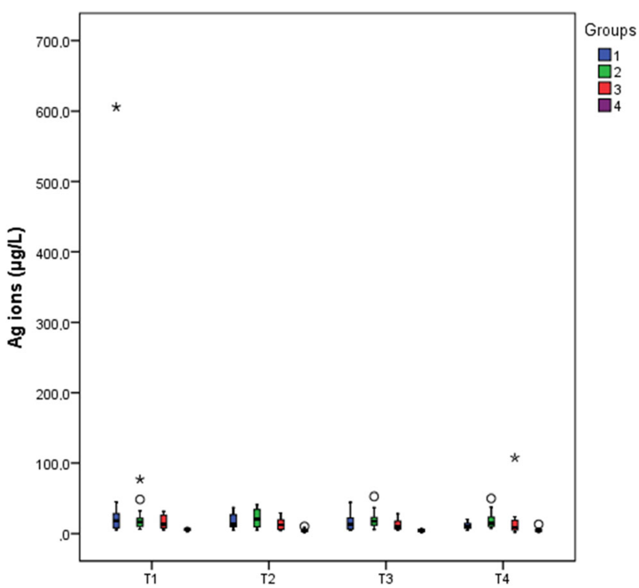

Fig. 3 Ag ion release compared in the groups and in the points of collections. Ag ions: silver ions concentrations; T1: before placing the appliance, T2: 07 days after placing the appliance, T3: 15 days after placing the appliance and T4: 30 days after placing the appliance; Group 1: control, Group 2: silver solder, Group 3: laser welding, Group 4: TIG welding

The TIG equipment costs less than the laser welding devices and the welding procedure seems to be quick and simple, being a viable alternative to conventional soldering [19, 31]. According to Bock et al., although expensive, the laser technique is a sophisticated but a simple method [31]. Grimsdottir et al. claimed that increased corrosion on silver solder surfaces is caused by high temperature and galvanic reaction [15]. Hwang et al. reported that surface roughness of silver soldering causes crystal structure decomposition and becomes more sensitive to corrosion [41]. Besides that, silver solder needs to be spread over a wide area for resistance, covering a wider area than with laser welding. In the laser welding method, the welded area is reduced and the region sensitive to corrosion is smaller, thereby possibly decreasing the metal ion release [22].

Table 9 Concentrations of Cd ions (μg/L)

		Group 1 control	Group 2 silver soldering	Group 3 laser welding	Group 4 TIG welding	*P*
T1						0.109
	Median	0.6	0.9	0.9	1.5	
	P25-P75	0.4–1.2	0.5–3.0	0.5–1.7	0.7–2.3	
T2						
	Median	0.7	0.7	0.6	0.9	
	P25-P75	0.4–1.2	0.3–0.9	0.4–0.9	0.7–1.3	
T3						
	Median	0.8	0.5	0.7	1.0	
	P25-P75	0.4–1.2	0.3–0.7	0.5–1.0	0.7–1.8	
T4						
	Median	1.0	0.6	0.7	1.0	
	P25-P75	0.3–1.3	0.3–1.5	0.4–0.9	0.8–1.2	

P25-P75: percentile 25–75/interquartile range. *P* obtained with GEE

In this study, some appliances presented failures after 30 days (1 in group 2, 5 in group 3 and 4 in group 4). The welded surface broke and needed to be redone. A study [42] compared fracture strength of different soldered and welded joints, with and without filling material, showing a clear tendency to higher mean values in TIG and laser welding. The fracture resistance strength of welded joints was positively influenced by the additional use of filling material. Silver soldering showed a low mechanical strength and there were no statistically significant difference in the fracture loads between joints done using TIG or laser welding [42]. Therefore, filling material should be considered in welding techniques. Bock et al. concluded that TIG and laser welding are soldering free alternatives for orthodontic purposes and produce a high mechanical stability. The strength of silver-soldered joints used to fabricate space maintainers and orthodontic appliances is critical for their success. Broken appliances complicate the orthodontic treatment including the possibility of soft tissue irritation, loss of orthodontic anchorage, or aspiration of the broken parts [28]. Laser welding appears to transfer less heat to the weld than the TIG process, as it has a focused heat source, which causes less distortion and decreases the size of the heat affected zone [27].

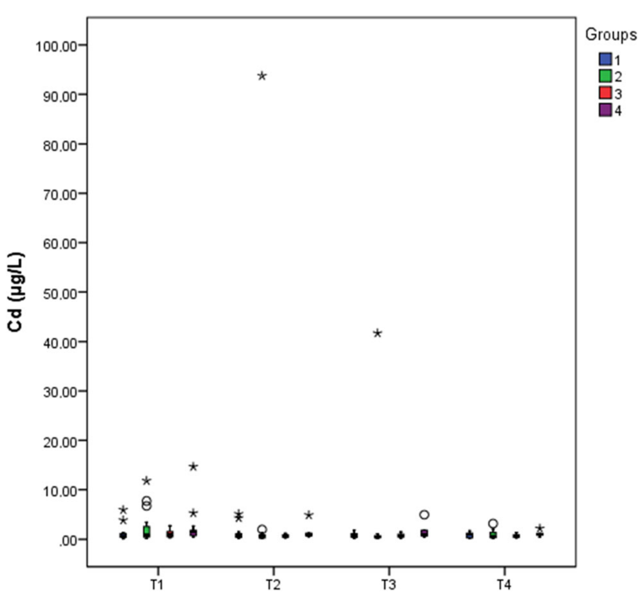

Fig. 4 Cd ion release compared in the groups and in the points of collections**.** Cd ions: cadmium ions concentrations; T1: before placing the appliance, T2: 07 days after placing the appliance, T3: 15 days after placing the appliance and T4: 30 days after placing the appliance; Group 1: control, Group 2: silver solder, Group 3: laser welding, Group 4: TIG welding

According to a previous study, an unstimulated method was used to collect the saliva samples [32]. With no stimulation, about two-thirds of all the produced saliva is secreted by the submandibular gland. When salivation is stimulated, all the salivary glands participate and at least half of all the saliva is released by the parotid gland. Thus, the stimulated method can change the protein composition of the saliva and, as Ni ions have a tendency to rapidly combine with protein, they may affect the concentration in the saliva [11, 37].

In some studies, the saliva sample was collected after patients rinsed their mouths with distilled and deionized water [43]. This could change the equilibrium of Ni ion concentration in the oral cavity [37] and was not done in this study. Samples were stored at − 80 °C until they were processed [10]. Then, the saliva was diluted with deionized water to eliminate interference and reduce the effects of the biological matrix [32]. ICP-MS was chosen for the analysis because it has a lower threshold and a better resolution by factor of at least 10^{15} [5, 37]. Other investigators used atomic absorption spectrometry [12, 43]. Unlike atomic emission spectrometry, the ICP-MS method extracts each metal simultaneously and detects heavy metals without the interference of other ions [41].

For most ions evaluated in this study there was no significant release increase comparing types of soldering/welding and comparing values throughout the points in time in the same group. There was a significant increase in Ni ion release in the TIG welding group, especially 7, 15, and 30 days after placing the appliance. Levels resembled those already documented and remained below the daily dietary metal intake. Group 4 showed a statistic difference from T4 to T1 ($P = 0.001$), T4 to T2 ($P = 0.017$), and T4 to T3 ($p = 0.001$), indicating that TIG welded appliances had greater Ni ion release and that this increase did not regress during the assessed period. Oral daily intake of nickel by food is estimated from 300 to 600 μg [44]. According to Hensten-Pettersen and Jacobsen [45] and Catalanatta and Sunderman [46], the amount of Ni in human saliva ranges from 0.8 to 4.5 μg/L.

Methodological aspects, such as other sources of exposure and a multitude of factors related to everyday living habits, can affect the results of an in vivo study but the results are enough to cause concern. Further controlled long-term studies should be performed.

In general, although not statistically significant, metal ions were released into saliva after placing the orthodontic appliances tested during the study. Ni levels, especially, increased in TIG welding group, indicating that probably there was greater corrosion in the welded area. Therefore, we consider that the TIG welding technique should be detailed and further studied for use in metallic orthodontic appliances. Finally, also considering results from other studies related to silver solder biocompatibility, including proven cytotoxicity events, laser welding appears to be a safer and biocompatible method in terms of corrosion and ion release.

Conclusions

1. This randomized clinical trial investigated the metal ion release comparing three different types of soldering and welding used in orthodontics during a short period of 30 days and showed that the orthodontic lingual archs used affected the salivary in vivo ion concentrations over the short-term period evaluated.
2. For most ions evaluated there was no significant increase comparing types of soldering/welding and comparing values throughout the points in time in the same group. Group 4 showed a statistically significant difference, indicating that TIG welded appliances had greater Ni ion release although this increase did not regress during the assessed period, possibly due to a bigger corrosion of the welded surface.
3. Levels resembled those already documented; nevertheless, the data need to be considered since allergic reactions can be induced in sensitive people even bellow toxic levels. Thereby, this data should be of concern to orthodontic patients.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The study was submitted and approved in the research ethics commitee of Pontifícia Universidade Católica do Rio Grande do Sul (CEP-PUCRS) with the approval number 67430117.7.0000.5336. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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