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In Vitro Assessment of Nickel Ion Release from Orthodontic Wires

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Abstract: *Most of orthodontic alloys contain nickel. The consumption of acidic drinks may have an impact on these alloys in particular with respect to corrosion resistance. The corrosion is accompanied by nickel ion release that can generate hypersensitivity reactions.*

This study will quantify the release of nickel ions from orthodontic wires of stainless steel and nickel-titanium submitted to a bending constraint after a static immersion in acidified medium. Wire segments from Nickel-Titanium and stainless steel of which some are submitted to a bending constraint are immersed in acid media and then immersion solutions are analyzed using the inductive coupling plasma mass spectrometer (ICP-MS) with a detection threshold of 0.5ppb (µg/L). Nickel ions were detected in all analyzed samples. The results range from 2.4ppb to 9404ppb. Even with constraint, the release of nickel would be well below the level of daily food intake. The corrosive behavior depends on the properties of material, the manufacturing process, the environment, the pH values and the constraints. The surface condition is an important factor for corrosion. More the surface is rougher and the more likely it is to be attacked by corrosion especially by injection corrosion. The manufacturers should take this issue into account.

Keywords: *Ion release, Nickel-Titanium, Stainless Steel, ICP-MS*

1. Introduction

Orthodontics requires the introduction of often metallic devices on the teeth in order to move them. As soon as a bracket or an arch is inserted into the mouth, chemical reactions are set up. The consumption of acidic drinks may have an impact on these devices in particular with respect to corrosion resistance.

The corrosion is accompanied by a loss of material that can have consequences on the body and generate hypersensitivity reactions.

The superficial atomic layers are the first to act with the surrounding environment because they remain reactive from an electronic point of view. Then corrosion can lead gradually to deep alterations in biomaterials.

The corrosion level of any metal depends on the chemical composition of the solvent in which it is immersed [1].

Most of orthodontic alloys contain nickel, varying from 8% in the stainless steel to more than 50% in the nickel-titanium alloys; nickel is classified as non-biocompatible and even toxic. The release of nickel ions from these alloys is a concern because of its toxic, immunogenic, mutagenic, local and systemic chemotactic effects [2].

Nickel, a main ingredient of orthodontic materials, can cause severe health hazards in biologic tissues. Hypersensitivity is the most common consequence of exposure to nickel-containing products, with incidence ranging from 4.5% to 20% in the literature [3-6]. The cytotoxic effect of nickel has been shown in cell culture studies [7-9]. Subtoxic levels of nickel are capable of causing DNA strand breaks and DNA base damage [10] and inhibition of DNA lesions repair [11]. Small quantities of nickel ion are capable of activating monocytes and possibly enhance an inflammatory response in soft tissues [9].

Nickel is nevertheless an essential chemical element for normal functioning of the human body. The total nickel content of the body of an individual with 75 kg weight is estimated at about 11 mg. The level of daily food intake is 300-500µg [12].

The biocompatibility assessment of orthodontic wires containing nickel is very important and therefore deserves a thorough investigation.

This study will quantify the release of nickel ions from orthodontic wires of stainless steel and nickel-titanium submitted to a bending constraint after a static immersion in acidified medium.

2. Materials and Methods

Four types of maxillary arc wires of 0.016" (0.041cm) diameter are used.

- Speed Supercable (Speed System): Coaxial 6 strands, twisted
- Sentalloy (Dentsply GAC): Monostrand
- Co-Ax Steel (American Orthodontics): Twisted, 6 strands
- Stainless Steel (American orthodontics): Monostrand

The ends of the arcs are sectioned in order to obtain wire segments of a length of 5cm. A bending constraint is applied to a segment of each wire using an elastic.

The wire segments are then immersed in 2mL of each of three solutions contained in bottles at 37°C for 16 days.

- Ringer + lactic acid ($C_3H_6O_3$): 31 drops for 30mL, pH 2
- Distilled water + nitric acid (HNO_3): 2 drops for 30mL, pH 2
- Distilled water pH 7

Only some samples will be evaluated because of the high cost of analysis.

Immersion solutions are analyzed using the inductive coupling plasma mass spectrometer (ICP-MS) with a detection threshold of 0.5ppb (µg/L) in order to quantify nickel ion release.

Nickel ion release per unit of surface is calculated by considering a surface of 0.64cm^2 for each wire segment.

3. Results and Discussion

ICP-MS results were presented in table 1.

Table1. *ICP-MS Results*

	Immersion medium	Concentration of Ni ions (ppb)	Ion release per unit of surface (µg/cm^2)
Speed Supercable	$H_2O + HNO_3$	9404	14.69
	Ringer + $C_3H_6O_3$	824.12	1.28
	Ringer + $C_3H_6O_3$ *	599.31	0.93
	H_2O	2.4	0.0037
Acier Co-Ax	$H_2O + HNO_3$	12.6	0.019
Stainless Steel	$H_2O + HNO_3$	78.4	0.12
Sentalloy	$H_2O + HNO_3$	74.8	0.11

** No constraint*

Nickel ions were detected in all analyzed samples. The results range from 0.003µg/cm^2 to 14.69µg/cm^2.

The Speed Supercable immersed in $H_2O + HNO_3$ shows the highest level of nickel ion release. The low concentration of ions is found with distilled water as an immersion medium and there is more release in the inorganic medium ($H_2O + HNO_3$) than in the organic medium (Ringer + $C_3H_6O_3$).

So, pH is an important factor in nickel ion release.

In the same medium (Ringer + $C_3H_6O_3$) and for the same type of Nickel-Titanium wire (Speed Supercable) the ion release is higher with the wire submitted to a constraint. This is in line with the study of Liu et al. [13], for whom the Nickel-Titanium arcs submitted to a constraint would release more nickel ions than the not stressed arcs.

The reduced number of samples makes it possible to obtain some descriptive conclusions and observations which do not however have statistical signification.

The results will be discussed in relation to certain aspects of biocompatibility. The release values will be converted to µg/day. In the calculation, a total length of 14cm will be considered for each orthodontic arc and therefore the surface is estimated at 3.6cm^2 for upper and lower round arcs.

The maximum quantity of detected ions (Speed Supercable in $H_2O + HNO_3$) will be 52.88µg for the upper and lower arcs which corresponds to a 3.3µg/day ion release even if one could expect to more release of nickel in the first few days.

This quantity is much lower than the daily food intake (300-500µg) and the critical concentration (600-2500µg) needed to induce an allergy [14]. Arndt et al. [14] used Fusayama artificial saliva + lactic acid with different types of arcs and got a maximum nickel ion release of 8.2µg/day.

According to the US directive limiting the nickel use on the skin (94/27/CE), the amount of released nickel from products intended to enter to direct and extended contact with the skin should not exceed 0.5µg/cm^2/week [15]. It would be possible that the Nickel-Titanium arcs may be the cause of allergic reaction, but this remains a rare phenomenon.

The diffusion of metallic nickel may occur through defective layers of TiO_2, which could be the case of layers affected by the constraint. The tension area of the constraint could be victim of micro tear at the surface of the wire, which would favor the release of nickel ions. These areas, with a defective layer of passivation, would be more corrosive [16].

For Briceno et al. [17], the presence of martensite improves corrosion resistance and decreases the release of nickel into the saliva at 37°C. Because of the number of involved factors, it is difficult to see this in the present study.

The present study was carried out with static conditions in vitro. In clinical conditions the friction between wire and bracket could induce corrosion phenomenon and thus increase the release of nickel ions. The corrosive behavior was very much medium dependent; in vivo tests would allow to have more reliable results. The use of artificial saliva was not possible due to the difficulty of getting a constant acid pH throughout the study.

The pH 2 of media represents an extreme situation, which should not be clinically met. In vivo, the rate of release should therefore be reduced. Other factors of the medium such as fluorine inducing the corrosion are not taken into account in this study.

4. Conclusion

Nickel-Titanium and stainless steel appear to be biocompatible materials for orthodontic treatment and should not present health hazards.

The low release of nickel ions may be a source of concern for allergic patients, but it does not lead to problems in the majority of orthodontic patients because toxic levels are never achieved.

Even with mechanical and thermal constraint, the release of nickel would be well below the level of daily food intake.

The corrosive behavior depends on the properties of material (chemical composition, microstructure), the manufacturing process, the environment, the pH values and the constraints.

The surface condition is an important factor for corrosion. More the surface is rougher and the more likely it is to be attacked by corrosion especially by injection corrosion. The manufacturers should take this issue into account.

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