Original Article

Evaluation of the Corrosion of Five Different Bracket-Archwire Combination: An *In-vitro* Analysis Using Inductively Coupled Plasma Mass Spectrometry

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KEY WORDS
Bracket;
Corrosion;
Ion release

Received April 2015;
Received in Revised form May 2015;
Accepted June 2015;

ABSTRACT

Statement of the Problem: Stainless steel brackets release metallic ions following the process of corrosion in the oral environment. These released ions have potential adverse effects on health, friction between wire and bracket, staining, strength of brackets. Choosing a bracket with favorable corrosive properties; therefore, should be a goal of every practitioner.

Purpose: The goal of this study is to compare the amount of corrosion among five different brands of brackets using inductively coupled plasma (ICP) mass spectrometry.

Materials and Method: Five different brands of brackets (Dentaurum, 3M, Ortho Organizer, Cobas and O.R.G) were chosen and ten brackets were selected from each brand. A piece of stainless steel wire was ligated to each bracket. The bracket-archwire complex was then immersed in artificial saliva. Subsequently, the samples were analyzed using an ICP device and the levels of iron, chromium, nickel, and manganese ions were measured.

Results: The findings of this study demonstrated that iron was released the most from the tested brackets, followed by nickel. We also found that the Cobas bracket had the most ion release among the tested brackets ($p < 0.05$), while Ortho Organizer and ORG performed favorably. There was no significant difference between Dentaurum and 3M ($p > 0.05$).

Conclusion: Based on the results, Ortho Organizer and ORG brackets are suggested in terms of resistance to corrosion.

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Cite this article as: Behroozi Z., Momeni Danaei Sh., Sardarian AR., Moshkelghosha V., Sardarian AR. Evaluation of the Corrosion of Five Different Bracket-Archwire Combination: An *In-vitro* Analysis Using Inductively Coupled Plasma Mass Spectrometry. *J Dent Shiraz Univ Med Sci.,* 2016 September; 17(3 Suppl): 262-267.

Introduction

Stainless steel alloys have remained the material of choice despite the emergence of the more recent titanium, composite and polycarbonate orthodontic brackets. [1] The popularity of the stainless steel brackets results from their excellent mechanical properties. [2] Stainless steel alloy contains 8%-12% nickel, 17%-22% chromium and other elements such as copper, iron molybdenum, manganese, silicon and sulfur [3-5] In the oral environment, orthodontic brackets are subjected to mechanical and chemical damaging which results in susceptibility to corrosion. Corrosion leads to loss of substance from the material, change in its structural characteristics, or loss of structural integrity. Due to the electrolytic capabilities of saliva, many forms of electrochemical corrosions can occur in the oral cavity. [6]

Various types of brackets are commercially available and each demonstrates a unique pattern of corrosion. In soldered brackets, the joints are more severely affected leading to possible fracture. This corrosion is

Table 1: The details of the brackets selected for the study

Brand	Dentaurum (Germany)	3M (American)	Ortho Organizer (American)	Cobas (MIB-France)	ORG (Chinese)
Type	MIM	MIM	MIM	Soldered	soldered
Size	Pre-adjusted 0.022 *0.028	Pre-adjusted 0.022 *0.028	Pre-adjusted 0.022 *0.028	Pre-adjusted 0.022 *0.028	Pre-adjusted 0.022 *0.028

due to the presence of dissimilar metals (i.e. the silver solder and the stainless steel), a phenomenon termed galvanic corrosion. [7] Metal injection molding (MIM) brackets are manufactured as a single unit and therefore do not demonstrate galvanic corrosion. Instead, MIM brackets display increased porosity which renders them vulnerable to pitting corrosion. [4] Corrosion can have detrimental effects on the surface of stainless steel brackets due to the continuous loss of metal ions. [1] Replacing damaged and fractured brackets causes treatment hold up and wastes valuable office time. Corrosion can increase the surface roughness of the bracket which leads to elevated friction forces between the bracket and the archwire. This increase in friction results in unfavorable distribution of forces and reduces the effectiveness of archwire guided orthodontic tooth movement. [7-8] Moreover, by means of increased stress, the friction would further accelerate the corrosion process. [9]

The release of metal ions following the corrosion of brackets has concerned clinicians and has instigated research in this field. Among these metal ions, nickel has been linked to allergic reactions and chronic fatigue syndrome. [3, 7] Furthermore, direct and prolonged contact of orthodontic appliances and the resulting corrosion products have been shown to cause local pain and swelling in the adjacent tissues. [10] Edema, gingivitis, gingival hyperplasia, perioral stomatitis, DNA instability and altered cellular metabolism are among other reported side effects. [11] Corrosion also has detrimental effects on the teeth, and permanent staining around the bracket base has been reported. [5]

Due to the wide diversity of options regarding bracket selection, orthodontists look for brackets which possess satisfactory biomechanical properties while presenting with a reasonable price. It was mentioned that corrosion has a detrimental effect on the physical properties of brackets and causes unwanted biological side effects; therefore, brackets with minimal corrosion tendencies are more desirable. The present study aimed to investigate five different brands of stainless steel brackets and compare their tendency towards corrosion by measuring ion release in an *in-vitro* setting.

Materials and Method

Five different brackets (Dentaurum, 3M, Ortho Organizer, Cobas and O.R.G) were selected based on their popularity among faculty members of the orthodontic department. (Table 1) Ten central incisor brackets were selected from each brand. In order to simulate conventional orthodontic treatment, 8mm of 0.016” stainless steel archwire (Dentaurum, Germany) was tied in each bracket using 10 mm of 0.25 mm ligature wire (Dentaurum, Germany). [11] Once the brackets were prepared, they were placed in poly-ethylene capped vials containing 10 mL of artificial saliva at a pH of 7.2. The vials were incubated at 37°C [12] for 6 weeks and then they were subjected to thermocycling with 500 temperature cycles from 5°C to 55°C to simulate the effect of temperature changes in the oral cavity. [13] The brackets were immersed in each bath for 30 seconds with 2 seconds at air temperature in-between the immersions.

After thermal-cycling the solutions from the vials were analyzed to determine the amount of nickel, chromium, manganese, and iron using an inductively coupled plasma (ICP) spectrometer (ICP-OES; Varian, Vista-Pro model, Mulgrave, Victoria, Australia; 1400W applied power). For the purpose of analysis, the ICP device had to be calibrated for each of the metal ions. [12] Calibration was performed using standard stock solutions (100 mg/mL) prepared by dissolving nitrate salts of the aforementioned ions in distilled deionized water. The standard stock solutions were then diluted to render the concentrations necessary (0.1- 10 mg/mL). [14] Once the ICP device was calibrated and a standard calibration curve obtained, the samples were analyzed and the readings were recorded. Before each reading a drop of 65% nitric acid was added to each vial and the vial was placed in a mixer. The addition of nitric acid facilitates the stabilization of the released ions by producing nitrate salts. [6] A vial containing only the artificial saliva was used as the device blank so that the ions

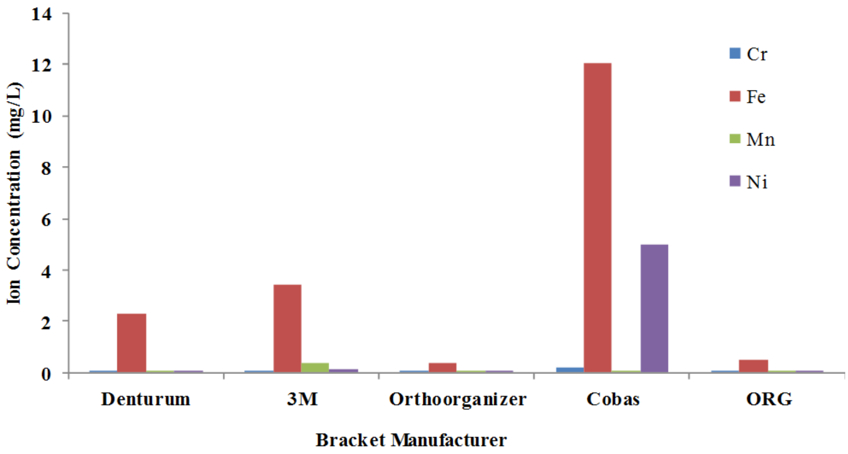

Figure 1: Ion release from brackets made by 5 different manufacturers measured in milligram per Liters (mg/L)

present in the saliva itself do not compromise the readings.

Statistical analyses were performed using SPSS software for windows (version 11; SPSS Inc, Chicago, III). The Kruskal-wallis test was used to analyze the differences among mean ion concentrations in the 5 groups. The Mann Whitney test was applied to show differences among groups.

Results

The median levels of ion release were measured for chromium, iron, manganese and nickel using an ICP device (Figure 1). The overall amount of ion release was greatest in the Cobas bracket, while Ortho Organizer and ORG brackets demonstrated minimal corrosion.

The level of chromium release was highest in the Cobas bracket followed by 3M, Dentaurum, ORG and Ortho Organizer. It should be noted that the difference between Cobas and 3M was statistically insignificant ($p> 0.05$) as was the difference between ORG and Ortho Organizer ($p> 0.05$). Iron release presented the same order that was observed for chromium; however, the levels were generally higher for iron especially in the Cobas bracket.

Considering manganese, it can be observed that the levels are higher in 3M followed by Cobas, Dentaurum, ORG and Ortho Organizer. The differences between all brackets except Dentaurum and ORG were statistically significant ($p< 0.05$). Nickel release however was more pronounced in Cobas followed by 3M, ORG, Ortho Organizer and Dentaurum.

Only the Cobas bracket demonstrated statistically significant differences with the other brackets ($p> 0.05$). From the ions that were analyzed, iron was released the most, followed by nickel, manganese and chromium (Figure 2).

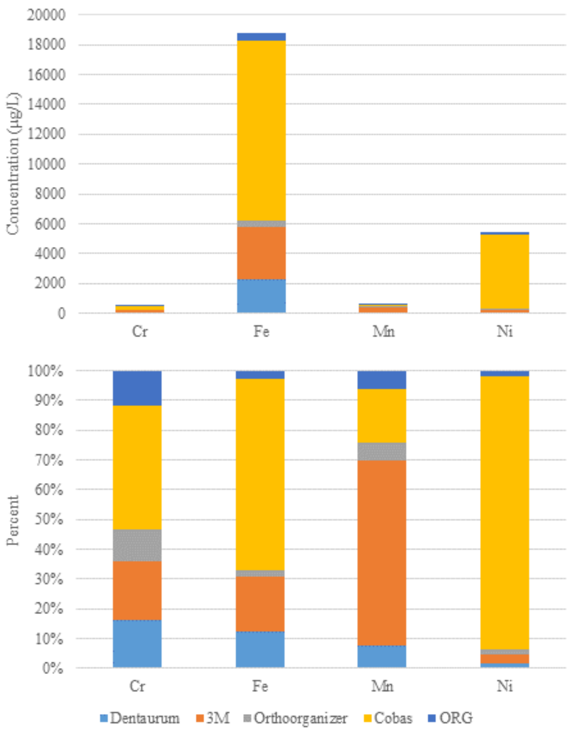

Figure 2a: Total iron release, rendered by adding the median values for the analyzed brackets. **b:** Percentage of total ion release attributed to each bracket

If we consider looking at the brackets separately, iron release was found to be greater than the other ions in every bracket. However, each bracket displayed a unique pattern of iron release. (Table 2)

Discussion

Due to the importance of the biocompatibility of orthod-

Table 2: Percentage of each ion released by the brackets.

Brackets	Ions (%)			
	Cr	Fe	Mn	Ni
Dentaurum	3.6	91.5	1.8	3.1
3M	2.6	84.1	9.2	4.1
Ortho Organizer	10.4	69.2	6.2	14.2
Cobas	1.4	69.4	0.6	28.6
ORG	9.4	70	5.4	15.2

ontic armamentaria, in the present study we chose five popular brackets among orthodontists and determined their susceptibility to corrosion by measuring ion release in an in-vitro environment. The brackets and wires in this study were all manufactured from 18-8 stainless steel (18% chromium, 8% nickel). Based on the results of this study, we found that except for manganese, the Cobas bracket had the highest level of ion release. Furthermore, we observed that among the studied brackets, iron was released more than the other ions. This is in agreement with the results of Kuhta *et al.* [15] and in contrast with the findings of Huang *et al.* [3] in which nickel release was more profound. Moreover the amount of ion release in our samples was higher compared to similar studies. [3, 16-17] This difference in ion release may be due to the fact that we chose to tie a segment of archwire to the bracket to better simulate conventional orthodontic treatment. Adding an archwire component can increase the ion release in two ways. First, by increasing the amount of alloy available to be subjected to corrosion and second, the potential for galvanic corrosion increases since the alloy for the archwire is different from the alloy used in the bracket. Another reason for greater levels of ion release may be due to the technique used for detection of ions. The values obtained in the present study closely match the values presented by Kuhta *et al.* [15] who elected to use an ICP device for ion detection.

The results of the present study indicated that soldered brackets do not necessarily demonstrate less resistance to corrosion when compared to brackets made by metal injection molding (MIM). When the ORG (soldered) and the Dentaurum (MIM) bracket are compared we observed that, except for iron which was released more by the Dentaurum bracket, the other ions were not significantly different. While it has been argued that soldered brackets present a tendency towards galvanic corrosion, MIM brackets have increased porosity rendering them susceptible to another kind of chemical breakdown, termed pitting corrosion. [4] This may be the reason why similar studies also found no measurable advantage regarding the utilization of MIM brackets. [4, 18] The presence of an archwire may be a confounding factor which may induce galvanic corrosion to MIM brackets that cancels out any possible differences.

The results of the present study indicated that iron was released more than the other ions, followed by nickel. Chromium and manganese demonstrated relatively equal amounts of release. While this was the overall pattern, in the 3M bracket, it was observed that manganese was released more than nickel. This finding is in contrast to the findings of Karnam *et al.* who reported that nickel was the major ion released from orthodontic brackets. [11] The findings of this study also suggest that there were no statistically significant differences between the 3M and Dentaurum brackets in any of the ions studied. Previous studies have reported that Dentaurum brackets release more nickel than 3M brackets. [3, 16] These differences could be due to study design, addition of an archwire element, testing conditions and measurement methods. It is noteworthy that in the present study, an ICP-MS was used to measure the released ions. ICP-MS has shown lower detection limit compared to atomic absorption spectrometry used in similar studies. Another advantage of the ICP device over atomic absorption is that it can measure several ions simultaneously without interference from other ions. [19]

This study in agreement with previous findings declares that the values of ions released from orthodontic brackets falls short of the permissible daily doses determined by the world health organization. The maximum tolerable dose of nickel, iron, manganese and chromium for a 60-kg individual is 1.2, 15, 10 and 50-200 Mg/day, respectively. [20] However the chronic nature of metallic exposure resulting from orthodontic treatment is a cause for concern. It has been reported that chronic exposure to metal ions can cause alterations in cell morphology and metabolism leading to inflammation and DNA instability. [21-26] Iron ions in particular have been demonstrated to cause mitochondrial dysfunction in cells with active mitochondrial activity. [21, 25] They have also been linked with lysosome instability which could result in cell death and apoptosis. Regarding irreversible damage to oral tissues resulting from orthodontic treatment however, Hafez *et al.* [9] concluded that 6 months after the removal of the orthodontic appliance, no difference was observed between the orthodontic patients and the controls.

The findings of this study are based on an *in-vitro* experimental design, and therefore suffer from the inadequacies related to the simulation of the *in-vivo* environment. A bracket in the oral environment is subjected to many kinds of chemico-thermal insults including rapid changes in pH, the intake of hot and cold beverages and mechanical challenges. While in many senses the *in-vitro* design is a drawback, in measuring ion release such a setup is rather useful. Not all of the ions released from orthodontic brackets are found in the oral fluids. Some of the ions are absorbed into the oral and gingival tissues, while others are ingested and could disperse into distant organs. The advantage of the *in-vitro* design is that it presents the total ions released from the bracket, which could better show the true effect of this phenomenon. Another drawback to this study is that we did not evaluate the effects of different wire-bracket combinations and only used a single wire for all of the brackets. This was due to financial limitations and should be addressed in future.

Conclusion

Based on the findings of the present study, regarding ion release levels, the ORG and Ortho Organizer brackets were superior while Dentaurum and 3M did not demonstrate any significant differences.

Acknowledgements

The authors thank the Vice-chancellor of Shiraz University of Medical Science for supporting this research (Grant number: 7227). This manuscript is based on the thesis of Dr. Zeinab Behroozi. The authors would also like to thank Dr. M Vossoughi of the Dental Research Development Center, of the school of Dentistry for his help on statistical analysis and also thank Shiraz Orthodontic Research Center and Shiraz Biomaterial Research Center of the school of dentistry.

Conflict of Interest

There is no Conflict of Interest pertaining to any of the authors.

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