Galvanic Corrosion and Ion Release from Different Orthodontic Brackets and Wires in Acidic Artificial Saliva

[1]Soodeh Tahmasbi [2]Mohammad Ghorbani *[3]Tahere Sheikh [4]Yadollah Yaghoubnejad

[1]Assistant Professor, Dept. of Orthodontics, School of Dentistry, Shahid Beheshti University of Medical Sciences, Tehran, Iran.
[2]Professor, Dept. of Materials Science & Engineering, Sharif University of Technology, Tehran, Iran.
*[3]General Practitioner. E-mail: tahere_sheikh9870@yahoo.com
[4]PhD student, Dept. of Materials Science & Engineering, Sharif University of Technology, Tehran, Iran.

Abstract

Objective: Corrosion resistance is among the most important properties of metal alloys used in the oral cavity. Consumption of acidic foods reduces the salivary pH and intensifies the corrosion of brackets and orthodontic wires. This study aimed to compare electro galvanic corrosion of different orthodontic brackets and wires and determine the amount of ions released into acidic artificial saliva.
Methods: In this *in vitro* experimental study, 24 mandibular incisor brackets of 4 different manufacturers (Dentaurum, American Orthodontics, Shinye and ORJ) with stainless steel (SS) or nickel-titanium (Ni-Ti) round wires 0.016 were immersed in acidic artificial saliva for 28 days and their potential difference with the reference electrode was recorded. The amount of released ions was measured in the solution using atomic absorption method. Data were analyzed using two-way ANOVA and repeated measures ANOVA.
Results: The mean amount of ions released was not significantly different between groups ($p>0.05$). The potential difference of Shinye brackets coupled to SS wire was significantly lower than that of other combinations and was negative throughout the study. The potential difference of Dentaurum bracket-NiTi wire, ORJ bracket-NiTi wire, Shinye bracket-SS wire and ORJ bracket-SS wire combinations at the end of experiment was negative as well.
Conclusion: The galvanic corrosion of Shinye bracket coupled to SS wire in acidic artificial saliva was greater than that of other bracket-wire combinations. The specimens were not significantly different in terms of the released ions.
Key words: Acidic artificial saliva, Corrosion resistance, Galvanic corrosion, Metal ion release, Orthodontic bracket, Orthodontic wire.
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Introduction:

Corrosion of orthodontic appliances in the oral environment is a concern of clinicians (1). High cost of dental alloys has led clinicians to use low-cost alloys (2). The first requirement for using any metal alloy in the oral environment is not producing harmful corrosion products (3). Orthodontic brackets and wires are made of different metal alloys namely stainless steel, chrome-cobalt-nickel (Cr-Co-Ni) and nickel-titanium (4). Orthodontic appliances are used in the oral environment with a high potential of corrosion (5-7). Electrochemical properties of saliva depend on the concentration of its constituents, its pH, surface tension and buffering capacity. Each of these factors may affect the power of electrolytes (3). On the other hand, acidic foods reduce the salivary pH and studies have shown that decreased salivary pH significantly increases the corrosion of orthodontic wires and brackets (8, 9).

Galvanic corrosion is a type of corrosion that occurs in the oral cavity. When two or more dissimilar metals or alloys are exposed to the oral fluids, difference between their corrosion potential causes an electric current between them. In the clinical setting, two different alloys with different corrosion potentials are sometimes placed next to one another like brackets and orthodontic arch wires and lead to the release of metal ions from the metal or alloys. The surface area ratio of two different alloys is an important factor affecting the galvanic corrosion (3).

Corrosion causes surface roughening, weakening of the appliance and release of ions from the metal or alloys. Such ion release can lead to discoloration of the adjacent soft tissue and allergic reactions in susceptible patients. Corrosion can significantly compromise the final strength of materials. Moreover, corrosion increases the friction forces between the bracket and arch wire due to an increase in surface roughness. Corrosion products can cause pain or swelling in absence of infection that can lead to secondary infection (1). Thus, orthodontic brackets and wires should be fabricated of metal or alloys resistant to corrosion.

To date, two main techniques have been used for the assessment of corrosion resistance of alloys under *in vitro* conditions.

The first technique is to use atomic absorption spectrometry for ion release analysis and the second technique is to use electrochemical tests in artificial saliva for the assessment of electrochemical properties (10).

Metal ions released from the stainless steel include copper (Cu), chromium (Cr), iron (Fe) and nickel (Ni). NiTi alloys release nickel and titanium (11). The possible risk of nickel-containing alloys is due to the biological adverse effects of nickel. It has been confirmed that release of nickel ions due to the process of corrosion can cause allergy, toxicity and carcinogenicity (10, 12).

Release of ions from the orthodontic wires and brackets produced by different manufacturers needs to be further investigated (13). By the import and introduction of low-cost Chinese products into the Iranian market, assessment of the corrosion behavior of these brackets in comparison with that of other products seems necessary. This study aimed to assess the galvanic corrosion and release of ions from the Dentaurum, American Orthodontics, Shinye and ORJ brackets coupled with/to American orthodontics wires in acidic artificial saliva.

Methods:

This was an *in vitro* experimental study. Considering the 0.05 level of significance and 80% power, the sample size in each group was calculated to be 3 using PASS software. Overall, 24 specimens were required for the 8 understudy groups.

A total of 24 mandibular incisor Roth brackets Slot Roth 0.022 of 4 different manufacturers (n=6 from each manufacturer) including Dentaurum (Dentaurum, Ispringen, Germany), American Orthodontics (American Orthodontics, Wisconsin, USA), Shinye (Hangzhou Shinye Orthodontic Products Co., Ltd., Zhejiang, China) and ORJ (Medical Instruments & Material Co., Hangzhou ORJ, Zhejiang, China) were selected, coupled to 6 stainless steel (SS) or Ni-Ti American Orthodontics round 0.016 wires 0.016 and evaluated in 8 groups of 3 each. The electrolyte used was Fusayama-Meyer (Morvabon, Iran) acidic artificial saliva solution (pH=4.5). The wire/bracket surface area ratio was 1:1 and the excess wire was coated with insulating varnish to prevent the penetration of electrolyte. In each group, the bracket was coupled to the wire by an elastomeric ligature. Understudy groups are shown in Table 1.

The amount of elements in each type of bracket and wire was assessed by a Quantometer (ARL, USA). The results based on weight percentages are shown in Table 2.

Table 1- Under study groups (wire-bracket combinations)

Wire / Bracket	Dentaurum	American Orthodontics	Shinye	ORJ
NiTi	Group 1	Group 2	Group 3	Group 4
Stainless steel	Group 5	Group 6	Group 7	Group 8

Table 2- Weight percent of elements in wire-bracket combinations

Element	Dentaurum bracket	American ortho bracket	Shinye bracket	ORJ bracket	NiTi wire	Stainless steel wire
Si	0.28	1.05	0.26	0.77	0	0.65
Cr	16.91	15.55	17.83	17.79	0	18.98
Mn	0.63	0.68	1.39	1.25	0	0.99
Fe	67.61	72.16	72.12	71.02	0	70.09
Ni	11.25	6.14	7.60	7.49	53.78	7.67
Cu	0.16	1.61	0.24	0.67	0	0.69
Mo	3.16	2.81	0.56	1.00	0	0.94
Ti	0	0	0	0	46.22	0
Total	100	100	100	100	100	100

The prepared bracket-wire combinations were placed in separate containers with saturated calomel reference electrode (Ag/AgCl in saturated KCl, Azmiran, Iran). Each combination along with the reference electrode was connected to the voltmeter by connecting wires. In each container, 80cc of acidic artificial saliva was poured as an electrolyte (in accordance with the ASTM G71-81 standard) (14) and the circuit was completed (Figure 1). Samples were stored at 37 (0.1)°C.

Figure 1- Samples and their complete circuits

The potential difference of each bracket-wire combination with the related reference electrode was recorded hourly for 28 days.

The obtained values were collected (Data Logger, Mv-02) and transferred to a computer. After 28 days, the electric circuit was opened and the wire and bracket were rinsed with mild distilled water pressure for 30s and dried. The electrolyte solution was analyzed for the amount of released ions using Atomic Absorption Spectrometer (GBC model Avanta PM, USA).

Two-way ANOVA was applied for the assessment of released ions in different groups and repeated measures ANOVA was used for the calculation of potential difference.

Results:

The mean amounts of Fe ions released from different bracket-wire combinations are shown in Table 3. In terms of the amount of Fe ions released, the wire-bracket interaction and also the interaction between two wires and 4 brackets based on two-way ANOVA were not significant (p<0.05).

The mean amounts of Ni ions released from different combinations are shown in Table 3.

Table 3- The mean amount of Fe and Ni ions released from the specimens based on the type of wire and bracket (µg/L)

Type of wire	Type of bracket	mean (SD) of Fe ions (µg/L)	mean (SD) of Ni ions (µg/L)
NiTi	Dentaurum	<10 (0)	38.7 (49.65)
	American orthodontics	<10 (0)	<10 (0)
	Shinye	16.7 (11.55)	83.3 (35.12)
	ORJ	16.7 (11.55)	166.7 (210.79)
Stainless steel	Dentaurum	16.7 (11.55)	<10 (0)
	American orthodontics	16.7 (11.55)	<10 (0)
	Shinye	<10 (0)	343.3 (423.60)
	ORJ	<10 (0)	93.3 (92.38)

Although the mean amount of Ni released from Shinye brackets coupled to SS wire and ORJ brackets coupled to NiTi wire was higher than that in other groups, the interaction between the wire and bracket and also the interaction of two wires and 4 brackets based on two-way ANOVA was not significant ($p<0.05$).

The amount of Cu and Cr ions in all 24 specimens was less than 10µg/L; which is the atomic absorption limit for detection of these ions. The amount of Ti ions released from all 24 specimens was less than 300 µg/L; which is the atomic absorption limit for detection of this ion.

Regarding the potential difference, repeated measures ANOVA showed that the interaction of wire and bracket was statistically significant. For NiTi wires (Diagram 1), significant differences existed in the potential difference between different bracket groups. A significant difference existed between American Orthodontics brackets and other brackets; however, no significant differences existed in the trend of alterations in potential difference between different brackets and this trend was almost similar.

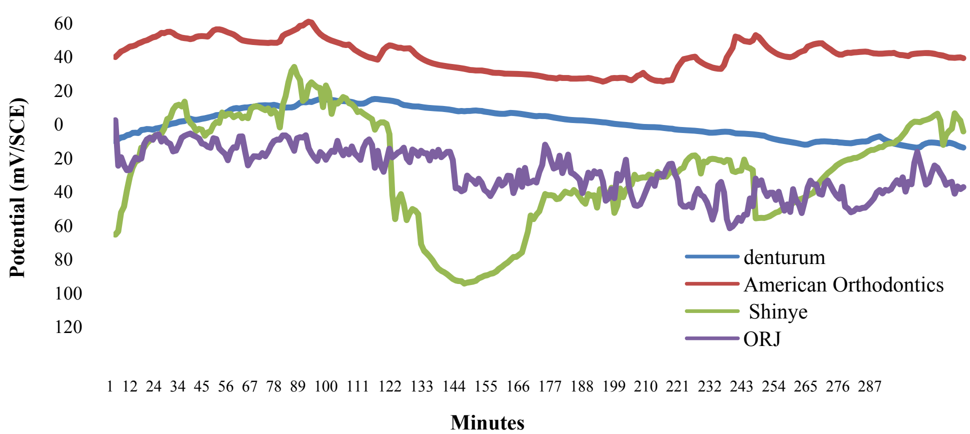

Diagram 1- Changes in potential difference during the experiment in Dentaurum, American Orthodontics, Shinye and ORJ brackets coupled to NiTi wire in acidic artificial saliva at 37°C.

For SS wires (Diagram 2), a significant difference existed in the mean potential difference between different bracket groups; Dentaurum did not have a significant difference with American Orthodontics, but the remaining groups were significantly different. Moreover, significant changes were found in the potential difference of groups. The potential difference of Dentaurum, American Orthodontics and ORJ remained unchanged but the potential difference of Shinye at different times gradually changed from negative to zero.

Table 4 summarizes the potential difference of wire-bracket and calomel electrode complex. Based on the results of Table 4, the change in baseline potential difference of all brackets coupled to SS wire remained within the positive or negative range during the experiment. For American Orthodontics and ORJ brackets coupled to NiTi wire, the change in baseline potential difference during the experiment was similar to that of SS wire. Whereas, the baseline potential difference of Dentaurum brackets coupled to NiTi wire changed from positive to negative during the experiment; however, in Shinye brackets coupled to NiTi wire, the potential difference changed from negative to positive during the experiment.

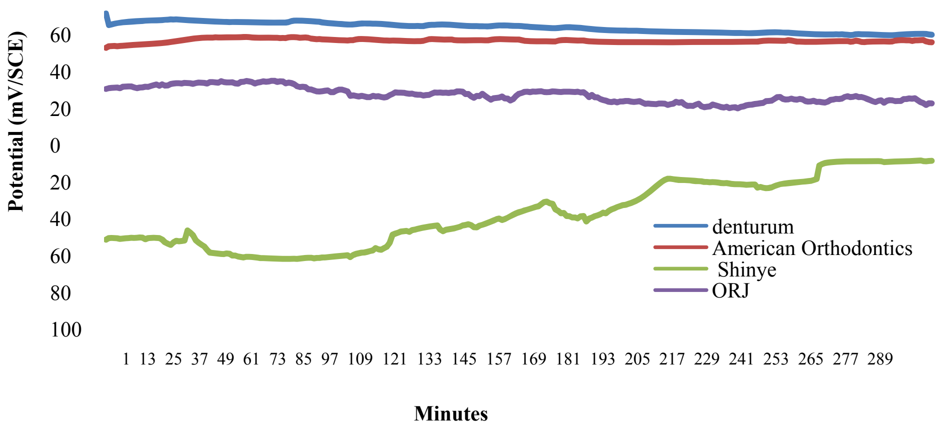

Diagram 2- Changes in potential difference during the experiment in Dentaurum, American Orthodontics, Shinye and ORJ brackets with SS wire in acidic artificial saliva at 37°C.

Table 4- The potential difference of wire-bracket andcalomel electrode complex

Wire	Bracket	Baseline potential difference	Final potential difference	Descriptions
NiTi	Dentaurum	52.77	-14.14	Passive at first and active in the end
	American Orthodontics	32.16	30.68	Passive at first and in the end
	Shinye	-183.19	0.41	Active at first and passive in the end
	ORJ	-36.84	-33.90	Active at first and in the end
Stainless Steel	Dentaurum	104.63	79.77	Passive at first and in the end
	American Orthodontics	71.40	87.09	Passive at first and in the end
	Shinye	-224.35	-119.13	Active at first and in the end
	ORJ	-1.16	-14.19	Active at first and in the end

Discussion

Considering the possible corrosion of metals and alloys in the oral environment and also the variable quality and price of orthodontic products available in the Iranian market, it is necessary to compare the corrosion resistance of different wires and brackets. Several methods are available for the assessment of corrosion. In this study, we measured the amount of ions released and assessed the potential difference with the reference electrode.

Variable degrees of corrosion of bracket surfaces are attributed to several factors: the alloy used in different parts of a bracket (i.e. in the wings and base), the alloy used for welding, the nobility of metal, the manufacturing process and the angle between the bracket base and wings (that can affect oxygen retention and initiation of corrosion).

Moreover, saliva pH, microorganisms and the dietary regimen can also play a role in corrosion in the oral cavity (15).

Welding alloys used for manufacturing orthodontic brackets can also cause galvanic corrosion. However, this can be significantly decreased by laser welding instead of metal welding. Changes in manufacturing and finishing and polishing techniques can also affect the corrosion behavior of brackets. Corrosion also depends on the microstructure of alloys (1).

In terms of the amount of ions released, the amount of Cu, Mo, Cr and Ti ions was lower than the atomic absorption limit for detection of these ions. The mean amount of Fe and Ni ions released was not significantly different in various groups. The amount of Ni ions released from some of the Shinye bracket-SS wire combinations was about 350μg/L. But, due to the high dispersion of data and high standard deviation, the statistical test did not report a significant difference with other groups. About 10% of the general population are allergic to Nickel. Prevalence of Nickel allergy in women is 10 times the rate in men. Nickel can cause hypersensitivity, contact dermatitis, asthma and cytotoxicity (1, 7).

Although the amount of Ni ions released from the specimens was less than the allergic dose (7, 15), it should be noted that patients usually have 20 brackets for about 2 years in their mouth.

In a study by de Souza and de Menezas (2008) (16), the amount of Ni, Cr and Fe released from different brackets into the oral environment was assessed and it was revealed that the amount of Ni, Cr and Fe ions released in the 3 groups of brackets was not significantly different; which is in accord with our results.

Barrett *et al.* (1993) (17) showed that SS wires compared with NiTi wires released higher amounts of Cr ions. This finding was also reported by Hwang *et al.* (2001) (18) and is in contrast to our results. The difference between their results and ours may be due to different study designs and the used solution. Gürsoy *et al.* (2005) (19) evaluated the amount of Ni, Mn, Cu, Ti and Fe ions released from 4 bracket-wire combinations. The amount of released ions between groups had statistically significant differences.

On the other hand, the present study results were not in agreement with those of Schiff *et al.* (2006) (20) and Iijima *et al.* (2006) (4).They demonstrated that coupling SS to NiTi alloy increased the pace and magnitude of corrosion of NTi alloy. In our study, coupling SS bracket to NiTi wire did not increase the amount of ion release compared to the combination of SS bracket and SS wire.

The potential difference of specimens was constantly recorded for 28 days. The potential difference of Shinye brackets coupled to SS wire was significantly lower than that of other combinations and remained negative throughout the study. Also, Dentaurum-NiTi, ORJ-NiTi, Shinye-SS and ORJ-SS combinations all had negative (active state) potential difference at the end of experiment. Negative potential difference indicates higher galvanic activity and therefore higher susceptibility of Shinye brackets to corrosion compared to other brackets.

The change in potential difference (at the end of experiment compared to the baseline value)of brackets coupled to SS wire remained within the positive or negative range; whereas, in Dentaurum brackets coupled to NiTi wire, the potential difference during the experiment changed from positive to negative. This finding may be due to the fact that chromium oxide layers on the surface of brackets (rendering corrosion resistance) were eliminated enhancing the susceptibility of this bracket to corrosion. On the other hand, in Shinye brackets coupled to NiTi wire, the potential difference changed from negative to positive. In other words, layers deposited on the brackets rendered them passive. The deposition on the bracket surface depends on factors such as surface roughness of brackets and wires and their surface potential.

Forming and welding processes also cause porosities on the bracket surface creating a surface potential that leads to the accumulation of deposits on the bracket.

On the other hand, the variable forming processes of brackets are also responsible for varying amounts of depositions on different brackets (3).

This *in vitro* study showed the corrosion of specimens under controlled *in vitro* conditions. However, in the dynamic oral environment, the results may change. Due to the limited budget, we could not evaluate a larger sample size. For the assessment of electrochemical corrosion, the wire/bracket surface ratio is very important. In this study, we only evaluated the 1:1 wire/bracket surface ratio; however, this ratio is usually different in the clinical setting. Corrosion of brackets and wires needs to be evaluated under simulated oral conditions. Assessment of corrosion of wires and brackets in artificial saliva with a variable pH is also recommended.

Conclusion:

Based on the obtained results, the corrosion potential of Shinye brackets coupled to SS wire was higher than that of other combinations.

The understudy brackets did not show significant differences in the mean amount of ions released into acidic artificial saliva.

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Conflict of Interest: "None Declared"

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