Corrosion Resistance of Stainless Steel Brackets After Thermal Recycling by Direct Flaming

Suci Novianti[1], Erwin Siregar[2], Haru Setyo Anggani[3]

[1]Orthodontic Residency Program, Department of Orthodontics, Faculty of Dentistry, Universitas Indonesia, Jakarta, Indonesia. 0000-0003-2930-3921

[2]Department of Orthodontics, Faculty of Dentistry, Universitas Indonesia, Jakarta, Indonesia. 0000-0002-0382-1221

[3]Department of Orthodontics, Faculty of Dentistry, Universitas Indonesia, Jakarta, Indonesia. 0000-0001-5210-0482

Author to whom correspondence should be addressed: Suci Novianti, Department of Orthodontics, Faculty of Dentistry, Universitas Indonesia, Salemba Campus Jl. Salemba Raya No. 4 Jakarta 10430, Indonesia. Phone: +62 81212451495. E-mail: adis_dentist@yahoo.com.

Abstract

Objective: To determine and compare the corrosion resistance (based on the release of nickel and chromium in artificial saliva) of various brands of stainless steel brackets after thermal recycling by direct flaming. **Material and Methods:** This research study employed 40 stainless-steel maxillary premolar brackets from different brands (Ormco, GAC, Versadent, S-Ortho, and Protect), which were divided into 5 groups consisting of 8 brackets. The nickel and chromium content of the metal brackets were analyzed by inductively coupled plasma mass spectrometry (ICP-MS), conducted before immersion. For the first treatment, each group was immersed in artificial saliva without direct flaming (recycling); for the second treatment, each group was immersed in artificial saliva with direct flaming (recycling) for 30 days in a pH-neutral (pH=7) solution. ICP-MS was employed to analyze the nickel and chromium released in saliva. The mean differences were measured with Wilcoxon, Kruskal Wallis test, and Post-Hoc Mann Whitney test. Differences were considered statistically significant when p-value<0.05. **Results:** The mean corrosion resistance based on the nickel content released by the new brackets was 99.95%, 99.87%, 87.09%, 90.58%, and 90.26% for groups A, B, C, D, and E, respectively. The mean corrosion resistance based on the nickel content released by the recycled brackets was 99.90%, 99.80%, 98.19%, 89.76%, and 72.82%, respectively. There was a significant difference in corrosion resistance among the 5 groups after recycling by direct flaming and between new and recycled brackets in each group. **Conclusion:** The corrosion resistance of the brackets in groups A (Ormco), B (GAC), D (S-Ortho), and E (Protect) decreased after thermal recycling by direct flaming. The Ormco brackets had the highest corrosion resistance after thermal recycling by direct faming.

Keywords: Orthodontic Brackets; Stainless Steel; Nickel; Chromium; Corrosion.

Introduction

Stainless-steel brackets remain in patients' mouths for extended periods, during which the brackets are exposed to chemical and physical processes that can damage the metal structure, resulting in decreased corrosion resistance [1,2]. A study indicated that in addition to environmental conditions in the oral cavity, thermal recycling (direct flaming) can affect the stability of the metal ion content of the bracket, resulting in the release of metal ions and the decrease of corrosion resistance of the bracket [3].

Orthodontic appliance corrosion can cause adverse effects resulted from the absorption of free metal ions in the saliva, such as altered cellular functions, decreased DNA synthesis, and enzyme inhibition, as well as to the mechanical properties that affect the effectiveness of the orthodontic appliance [2].

Commercially available stainless-steel brackets vary according to their composition and method of manufacture. However, not all brands of stainless-steel brackets indicate their composition and not all stainless steel brackets have been tested for corrosion resistance and their toxic effects on the body [3]. The aim of this study was to assess the amount of nickel and chromium released after thermal recycling by direct flaming for 5 brands of stainless-steel brackets.

Material and Methods

Study Design

The study employed 40 stainless-steel maxillary premolar brackets from 5 brands (Ormco, GAC, Versadent, S-Ortho, and Protect). These brackets were divided into 5 groups consisting of 8 brackets, namely: Group A – Ormco; Group B – GAC; Group C – Versadent; Group D – S-Ortho, and Group E – Protect (Table 1). The nickel and chromium content for all metal bracket specimens were analyzed by inductively coupled plasma mass spectrometry (ICP-MS), which was conducted before immersion in artificial saliva.

Table 1. Distribution of groups according to manufacturer.

Groups	Brand	Manufacturer
A	Ormco	Ormco Corporation, Orange County, CA, USA
B	GAC	Dentsply GAC International, Islandia, NY, USA
C	Versadent	G&H Orthodontic, Franklin, IN, USA
D	S-Ortho	Hangzhou Sinye Orthodontic Products Co., LTD., China
E	Protect	Zhejiang Protect Medical Equipment Co., Ltd., China

All stainless-steel brackets were prepared before being soaked in artificial saliva. Adhesive bonding primer was smeared on the mesh brackets, followed by bonding paste (Transbond XT Light Cure Adhesive, 3M Unitek Dental Products, Monrovia, CA, USA). Light curing was applied to all bracket surfaces for approximately 10 seconds to boost the polimerization. All specimens were then soaked in fresh artificial saliva in borosilicate glass tubes and placed in an incubator for 30 days. After the first 30 days of immersion, all brackets were removed from the tubes and the saliva samples

were delivered to the BPPT Serpong Biotechnology Laboratory. The saliva's nickel and chromium content were then analyzed with inductively coupled plasma mass spectrometry (ICP-MS).

The removed brackets were then recycled by direct flaming (thermal recycling). The mesh brackets that were applied with bonding adhesive prior to the first immersion were fired with a mini-torch for 10 seconds in the outermost zone (D burned gas zone) of the flame, and then dipped in water. The mesh brackets were then cleaned with sonde until the remaining adhesive material was removed. All specimens were then soaked in fresh artificial saliva in borosilacete glass tubes and placed in the incubator for a further 30 days. After the second 30-day immersion period, all brackets were removed from the tubes and the saliva samples were delivered to the BPPT Serpong Biotechnology Laboratory. ICP-MS was once again employed to analyze the saliva's nickel and chromium content.

Data Analysis

Descriptive statistics, means and standard deviations were calculated. The mean differences were measured with Wilcoxon, Kruskal Wallis test, and Post-Hoc Mann Whitney test. Differences were considered statistically significant when P-value<0.05. All data were analyzed using SPSS (Special Package for Social Science), 17.0 version (IBM Corp., Armonk, NY, USA).

Results

The mean corrosion resistance based on the nickel content released by the new brackets was 99.95%, 99.87%, 87.09%, 90.58%, and 90.26% for groups A, B, C, D, and E, respectively. The mean corrosion resistance based on the nickel content released by the recycled brackets was 99.90%, 99.80%, 98.19%, 89.76%, and 72.82%, respectively. There was a statistically significant difference in mean corrosion resistance (based on nickel content) between the new brackets and the recycled brackets in groups A (p=0.010), B (p=0.020), C (p=0.005), D (p=0.006), and E (p=0.000) (Table 2).

Table 2. Comparison of the mean corrosion resistance values based on the nickel content released by the new brackets and recycled brackets.

Group	Corrosion Resistance Cr_{t1} (%)	Corrosion Resistance Cr_{t2} (%)	p-value[1]
A	99.95	99.90	0.010*
B	99.87	99.80	0.020*
C	87.09	98.19	0.005*
D	90.58	89.76	0.006*
E	90.26	72.82	0.000*

[1]Wilcoxon test; *Statistically Significant; t1: After first 30-day period of incubation; t2: After second 30-day period of incubation.

Statistically significant differences in mean corrosion resistance (based on nickel content) were found among the 5 groups (p=0.001). We also employed a post-hoc tests to examine the differences between two groups, which revealed differences in mean corrosion resistance (based on nickel content) between groups A and D (p=0.027), groups A and E (p=0.004), groups B and D (p=0.027), groups B and E (p=0.004), and groups C and E (p=0.015) (Table 3).

Table 3. Comparison of the mean corrosion resistance values based on the nickel content released by the recycled brackets.

Groups		p-value
A	B	1.000
	C	0.317
	D	0.027*
B	E	0.004*
	C	0.317
	D	0.027*
C	E	0.004*
	D	0.125
D	E	0.015*
	E	0.388

*Statistically Significant.

The mean corrosion resistance based on the chromium content released by the new brackets was 99.93%, 99.82%, 99.6%, 99.75%, and 98.77% for groups A, B, C, D, and E, respectively. The mean corrosion resistance based on the chromium content released by the recycled brackets 99.85%, 99.82%, 99.38%, 99.58%, and 96.21%, respectively. There was a statistically significant difference in mean corrosion resistance (based on chromium content) between the new brackets and the recycled brackets in groups A (p=0.009), B (p=0.010), C (p=0.004), D (p=0.005), and E (p=0.001) (Table 4).

Table 4. Comparison of the mean corrosion resistance values based on the chromium content released by the new brackets and recycled brackets.

Group	Corrosion Resistance Cr_{t1} (%)	Corrosion Resistance Cr_{t2} (%)	p-value[1]
A	99.93	99.85	0.009*
B	99.82	99.82	0.010*
C	99.60	99.38	0.004*
D	99.75	99.58	0.005*
E	98.77	96.21	0.001*

[1]Wilcoxon test; *Statistically Significant; t1: After first 30-day period of incubation; t2: After second 30-day period of incubation.

The differences in corrosion resistance of recycled brackets (based on nickel content) were then analyzed. Statistically significant differences in mean corrosion resistance (based on chromium content) were found among the 5 groups (p=0.001). Once again we employed a post-hoc tests to examine the differences between two groups, which A and C (p=0.043), groups A and D (p=0.011), groups A and E (p=0.022), groups C and E (p=0.002), and groups D and E (p=0.003) (Table 5).

Table 5. Comparison of the mean corrosion resistance values based on the chromium content released by the recycled brackets.

Groups		p-value
A	B	0.465
	C	0.043*
	D	0.011*
B	E	0.022*
	C	0.224
	D	0.083
C	E	0.160
	D	0.433
D	E	0.002*
	E	0.003*

Kruskal-Wallis and post-hoc Mann Whitney tests; *Statistically Significant.

Discussion

The aim of this study was to evaluate the corrosion resistance of new brackets and bracket recycled using a thermal method for 5 bracket brands after these brackets were soaked in artificial saliva for 30 days. The bracket brands selected for this study were based on the commercially available brands most often employed by orthodontists in Indonesia. A signicant difference in corrosion resistance in the recycled bracket groups was noted when compared with the new bracket groups. The result of the present study proved that recycled using a thermal method can affect the corrosion resistance of the new bracket. These findings agree with the statement that thermal recycling (direct flaming) can affect the stability of the corrosion resistance of the bracket [3].

Stainless steel brackets are the most widely used due to their good mechanical properties, corrosion resistance and biocompatibility [1]. Despite their high corrosion resistance, stainless-steel brackets can corrode in the oral environment [4]. The quality of stainless-steel brackets varies depending on their composition and manufacturing method [5]. Orthodontists currently tend to focus on the bracket's shear bond strength and price, without considering aspects of biocompatibility and corrosion resistance. The main corrosion products of stainless-steel are iron (Fe), chromium (Cr), and nickel (Ni), which have a potentially detrimental effect on the body; however, Ni and Cr ions receive the most attention because they have been reported to cause allergic, toxic, and even carcinogenic reactions. The corrosion process can also degrade the quality of the bracket due to the release of the metal ions of stainless steel [6,7]. Stainless steel brackets with the best corrosion resistance are there for clinically important for biocompatibility needs. Orthodontists need to know the corrosion resistance of various brands of commercially available brackets, as an additional consideration when choosing brackets.

The results showed that group A had the highest chromium content, followed by group B, group D, group C, and group E. Chromium increases the stainless-steel's resistance to corrosion by forming a layer of chromium oxide (Cr_2O_3) on the surface of the stainless-steel [4,8]. Based on the chromium content, group A had the highest corrosion resistance and group E had the lowest. The results showed that group D had the highest nickel content, followed by group A, group C, group E, and group B. The presence of nickel helps increase the hardness of the metal and increase corrosion resistance by maintaining the stability of the protective layer of chromium oxide [9]. Based on the nickel content, group D provided the greatest corrosion resistance.

Based on the combination of nickel and chromium ions released, group A had the highest corrosion resistance, followed by group B. Based on the analysis of the elemental content of the bracket's metal elements, group A showed the highest number of chromium ions, followed by group B. Chromium ions form a layer of Cr_2O_3 on a metal surface, which protects the bracket from salivary corrosion, thereby preventing the release of metal ions from the bracket into the saliva [10]. Based on the amount of nickel ions released into the saliva, group C had the third highest corrosion resistance, followed by group D. In terms of chromium ions released into the saliva, however, group D had more chromium than group C, which would indicate that group D had greater corrosion

resistance. The bracket's corrosion resistance based on the metal ions released is influenced not only by the presence of chromium ions in the metal but also by each bracket's manufacturing and finishing process [11]. A stainless steel bracket manufactured using a soldering method will easily result in galvanic corrosion, which can increase the release of metal ions from the bracket [5]. Areas of the bracket that are rough and not well polished will easyly oxidize, resulting in the release of metal ions into the saliva [12].

The third highest corrosion resistance based on chromium ions released in saliva is group D and the fourth is group C. This is appropriate, when associated with the amount of chromium ion content in the bracket. Group E had the lowest corrosion resistance based on the amount of nickel and chromium ions in saliva. Based on the analysis of the elemental metal content of the bracket, group E had the least amount of chromium compared with the other bracket groups.

Group A still had the highest corrosion resistance based on the nickel and chromium ions released into saliva, followed by group B. Group C had the third highest corrosion resistance based on the nickel ions released into the saliva, followed by group D. In terms of free chromium ions released into saliva, group D had the third highest corrosion resistance; followed by group C. Group E had the lowest corrosion resistance for the recycled brackets when viewed from the amount of nickel ions and chromium ions released into saliva. The range of corrosion resistance in the recycled brackets is influenced by the composition of the alloys (chromium and other metal elements) and the brackets' metal manufacturing method, which, agrees with the statement that the bracket's quality is influenced by the composition of the metal and by the metallization method [11]. Some bracket brands that have the same metal ion composition can have differing corrosion resistance, which demonstrates that different manufacturing methods can produce different corrosion resistance [13].

All bracket groups showed decreased corrosion resistance after being recycled by direct flaming, except for group C, a result that agrees with the statement that the direct flaming recycling method of stainless-steel brackets reduces their corrosion resistance due to the high combustion temperature, causing chromium carbide deposition at the grain boundary [14]. The objective of thermal recycling by direct flaming is to remove residual adhesive material from the mesh bracket and mini-torches are often used for this purpose. Heating to 350-800°C is required to burn off the adhesive polymer matrix [15]. Based on the manufacturer's information on the product's container, we set the mini-torch's temperature to 600°C. Heating stainless-steel to a temperature range of 400-900°C, will cause the formation of chromium carbide deposits at the grain boundaries, thereby losing the protective metal layer and increasing the degradation of the stainless-steel in a corrosive (saliva) environment resulting in intergranular corrosion [15,16].

Group C had improved corrosion resistance after the thermal recycling by direct flaming, showing that the brackets had high temperature resistance, resulting in no chromium carbide deposition at the grain boundary and no intergranular corrosion. This finding can be explained by the statement that increasing the strength of the stainless-steel against high temperatures by increasing its strength against intergranular corrosion, can be achieved by several methods: (1)

reducing the carbon content of the stainless-steel; (2) adding other metals such as molybdenum, titanium, and niobium; and (3) applying certain finishing treatments to the metal to withstand heating [9]. A bracket with a small amount chromium but other metals such as molybdenum, titanium, and niobium can better resist the heating process and thereby prevent chromium deposition and granular corrosion.

The amount of nickel and chromium ions released into the saliva by the new and recycled brackets (even those with the lowest corrosion resistance) was still below the recommended daily limit. However, if we were to simulate this experiment in the oral cavity, with an average of 20 brackets in the maxilla and mandible, the amount of nickel and chromium ions released into the saliva will be greater. The nickel and chromium ions released into the saliva due to the corrosion process can be absorbed by the body and potentially can cause carcinogenic, allergenic, mutagenic and cytotoxic effects [17]. A study showed that nickel, at a minimum concentration of 1.18 ug, damages on human gingival fibroblasts. Even nontoxic concentrations can result in adverse biological effects on oral mucosal cells, when combined with lengthy orthodontic treatments [17]. Another effect of stainless-steel brackets with low corrosion resistance is the presence of surface roughness on the bracket, resulting in increased friction between the bracket and archwire, thereby slowing the movement of the teeth. Surface roughness in stainless-steel brackets occurs due to the damage to the protective layer of the stainless-steel surface by corrosion.

The weakness of our study is that we only tested the brackets' chromium and nickel content. The influences of the brackets manufacturing method and other metal ions such as molybdenum and silicone on the study results were not analyzed. Further studies are required to evaluate the corrosion resistance of various brands of bracket related with many other ion contents (other than chromium and nickel) and different type of bracket's manufacturing method.

Conclusion

The corrosion resistance of new and recycled brackets (based on the nickel and chromium ions released from the 5 brands of brackets after soaking in saliva) differs significantly. The comparison of the corrosion resistance of the new brackets based on the nickel released into saliva showed that group A had the highest corrosion resistance, followed by group B, group C, group D, and group E. The comparison of the corrosion resistance of the new brackets based on the chromium released into saliva, showed that group A had the highest corrosion resistance, followed by group B, group D, group C, and group E.

The comparison of the corrosion resistance of the recycled brackets based on the nickel released into saliva, showed that group A had the highest corrosion resistance, followed by group B, group C, group D, and group E. The comparison of the corrosion resistance of the recycled brackets based on the chromium released into saliva, showed that group A had the highest corrosion resistance, followed by group B, group D, group C, and group E.

The corrosion resistance differed between the new and recycled brackets in each study group. The corrosion resistance decreased after thermal recycling by direct flaming in groups A, B, D, and E. However, the corrosion resistance after thermal recycling by direct flaming increased for group C. It is therefore important that orthodontists chose brackets carefully, considering the many brands on the market that cannot account for their quality and biocompatibility.

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