European Journal of Orthodontics 27 (2005) 237–244
doi:10.1093/ejo/cji005

A stainless steel bracket for orthodontic application

Keun-Taek Oh, Sung-Uk Choo, Kwang-Mahn Kim and Kyoung-Nam Kim
Research Institute of Dental Biomaterials and Bioengineering, College of Dentistry, Yonsei University, Seoul, Korea

SUMMARY Aesthetics has become an essential element when choosing orthodontic fixed appliances. Most metallic brackets used in orthodontic therapy are made from stainless steel (SS) with the appropriate physical properties and good corrosion resistance, and are available as types 304, 316 and 17-4 PH SS. However, localized corrosion of these materials can frequently occur in the oral environment. This study was undertaken to evaluate the accuracy of sizing, microstructure, hardness, corrosion resistance, frictional resistance and cytotoxicity of commercially available Mini-diamond (S17400), Archist (S30403) and experimentally manufactured SR-50A (S32050) brackets.

The size accuracy of Mini-diamond was the highest at all locations except for the external horizontal width of the tie wing ($P < 0.05$). Micrographs of the Mini-diamond and Archist showed precipitates in the grains and around their boundaries. SR-50A showed the only austenitic phase and the highest polarization resistance of the tested samples. SR-50A also had the highest corrosion resistance [SR-50A, Mini-diamond and Archist were 0.9×10^{-3}, 3.7×10^{-3}, and 7.4×10^{-3} mm per year (mpy), respectively], in the artificial saliva. The frictional force of SR-50A decreased over time, but that of Mini-diamond and Archist increased. Therefore, SR-50A is believed to have better frictional properties to orthodontic wire than Mini-diamond and Archist. Cytotoxic results showed that the response index of SR-50A was 0/1 (mild), Mini-diamond 1/1 (mild+), and Archist 1/2 (mild+). SR-50A showed greater biocompatibility than either Mini-diamond or Archist.

It is concluded that the SR-50A bracket has good frictional property, corrosion resistance and biocompatibility with a lower probability of allergic reaction, compared with conventionally used SS brackets.

Introduction

Orthodontic brackets are an essential component of modern fixed appliances. In order to deliver the exact force from the wire to the teeth, brackets should have the correct hardness and strength (Feldner *et al.*, 1994; Flores *et al.*, 1994). They should have a smooth archwire slot to reduce frictional resistance (Arici and Regan, 1997), and an otherwise smooth surface to reduce plaque deposition (Wheeler and Ackerman, 1983). Because most orthodontic brackets are produced with a three-dimensional prescription for each tooth, they should be accurately manufactured to reflect this (Creekmore and Kunik, 1993). They should also have a high corrosion resistance and good biocompatibility.

Many efforts have been made since 1909 to improve orthodontic brackets. Ceramic (Michael, 1988) and plastic have been introduced, but both have shown significant disadvantages when used for orthodontic therapy. Plastic brackets (Feldner *et al.*, 1994) were found to be easily discoloured by water absorption and to have low deformation resistance to high applied torque. Ceramics brackets (Pratten *et al.*, 1990; Arici and Regan, 1997; Komori and Ishikawa, 1997; Olsen *et al.*, 1997; Sinha and Nanda, 1997) proved to be too brittle and the part of the enamel layer bound by adhesive tended to be detached with the ceramic bracket when the bracket was removed from the teeth. However, metallic orthodontic brackets have demonstrated properties that are closer to the ideal, and have been used most frequently for fixed orthodontic treatment (Creekmore and Kunik, 1993; Arici and Regan, 1997; Bazakidou *et al.*, 1997).

The majority of metal brackets are made from stainless steel (SS) (Maijer and Smith, 1982). Deguchi *et al.* (1996) reported on the properties of an experimental bracket made of titanium, and the corrosion behaviour of brackets made of 2205 duplex SS has been studied (Platt *et al.*, 1997). Recently, the recycling of brackets has been attempted, and while Wheeler and Ackerman (1983) reported that the bond strength did not decrease, Maijer and Smith (1982) presented contradictory results showing that bond strength and corrosion resistance were markedly decreased.

Most orthodontic brackets are made from AISI type 304L SS. Such steel contains 18–20 per cent chromium and 8–10 per cent nickel with a small amount of manganese and silicon, and has a low carbon content, typically less than 0.03 per cent. One manufacturer uses type 316L SS, which has a higher nickel content, 2–3 per cent molybdenum, and a lower carbon content for better welding characteristics and improved intergranular corrosion resistance. Another manufacturer uses type 17-4 PH SS, which has a higher mechanical property, and similar corrosion resistance to type 304 SS. However, localized corrosion of these materials can frequently occur in the oral cavity due to their low localized corrosion resistance in a solution containing aggressive chloride ions.

Super SS is defined strictly as SS with a pitting resistance equivalent (PRE) value above 40. The super SS (SR-50A) used in this study has localized corrosion resistance that is as good as the titanium alloys, because its passive film is enhanced by the synergistic effect (Clayton and Lu, 1986; Kim, 1990) of high concentrations of nitrogen (0.331 per cent) and molybdenum (6.77 per cent). It also has good mechanical properties due to a 'solution strengthening effect'. It is thought that these properties allow the material to minimize the amount of metal ions released in the oral environment. Therefore, in this study, a metal bracket was constructed of SR-50A and investigated with regard to size accuracy, microstructure, hardness, corrosion resistance, frictional properties and cytotoxicity, and compared with conventionally used SS brackets.

Materials and method

Materials

SR-50A was manufactured in rod form by investment casting, and then underwent homogenization heat treatment for 270 minutes at 1100°C in an argon environment, before being cooled in a water bath. The discharge cutting technique was used to make a rectangular cross-section. This was then machine milled, polished and cleaned. Commercial type 17-4 PH and 304L SS were used for comparison.

A maxillary central standard edgewise metal bracket was manufactured using SR-50A, with a slot size of 0.018 × 0.025 inch. Mini-diamond (Ormco, Sybron, USA) and Archist (Daeseung, Seoul, Korea) brackets of the same size were used as the controls (Table 1). The chemical compositions of these three groups of brackets are described in Table 2.

Rectangular 0.017 × 0.025 inch SS wire (Ormco, Glendora, USA) was used to examine the friction between the brackets and orthodontic wire. Lig-a-Ties (TP Orthodontics, LaPorte, USA) was selected as the ligature wire. Five samples were prepared for statistical analysis.

Method

A measurescope (MM-11, Nikon, Kawasaki, Japan) was used to determine the size accuracy of each 10 brackets selected randomly. A schematic diagram of the four measured locations (A: internal size of the slot; B: external vertical width of the tie wing; C: internal horizontal width of the tie wing; D: external horizontal width of the tie wing) is presented in Figure 1.

To observe the bracket microstructure, after each bracket was mounted in epoxy resin, it was ground using SiC paper, and then polished using alumina powder and diamond paste to 0.05 µm. The bracket samples were etched in methanolic aqua regia (45 ml HCl, 15 ml HNO_3, 20 ml methanol). The microstructure of the brackets was observed using an optical microscope (Versamet II, Nikon).

A microVickers tester (DMH-2, Matsuzawa, Tokyo, Japan) was used to measure the hardness of the brackets. Each five brackets were prepared, mounted in epoxy resin, and polished. The measured locations were the bracket base, stem, tie wing, slot wall and base. Under 100 g loading, the hardness values were measured five times at each location and averaged.

To evaluate the corrosion properties of the brackets in an oral environment, potentiodynamic testing was performed in artificial saliva (Table 3) at 37 ± 1°C. The exposed area of the samples to the solution was 1 cm^2. A saturated calomel electrode was used as the reference electrode. The cathodic polarization was performed to a certain potential below the open circuit potential to eliminate the scale. The specimens were stabilized at an open circuit potential for 5 minutes. The potential scan was started from the corrosion potential at a scan rate of 50 mV/minute. To evaluate the corrosion potential, polarization resistance and corrosion rate of the samples according to ASTM designations G3 and G102, the linear polarization and Tafel extrapolation techniques were used (Fontana, 1987). The corrosion potential and

Table 1 Orthodontic brackets used in this study.

Bracket	Manufacturer	Batch no.	Type
SR-50A	Yonsei University, Korea	–	Super stainless steel UNS S32050
Mini-diamond	Ormco	7B291B	17-4 PH stainless steel UNS S17400
Archist	Daeseung Ltd	101-001	304L stainless steel UNS S30403

Table 2 Chemical compositions of the orthodontic brackets used in this study (wt%).

Bracket	C	Si	P	S	Ni	Cr	Mo	Cu	N	Fe
SR-50A	0.025	0.80	0.024	0.006	19.43	23.23	6.77	–	0.331	Balanced
Mini-diamond	0.030	0.56	0.019	0.025	5.94	16.76	0.26	3.33	0.033	Balanced
Archist	0.028	0.59	0.026	0.003	10.12	18.15	0.17	–	0.029	Balanced

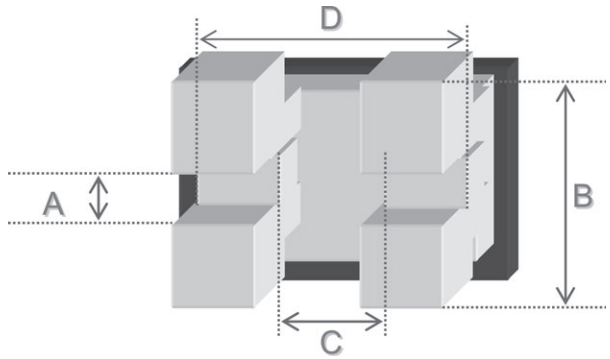

Figure 1 A schematic diagram for measuring the size of the brackets. A: internal size of the slot; B: external vertical width of the tie wing; C: internal horizontal width of the tie wing; D: external horizontal width of the tie wing.

Table 3 Composition of artificial saliva.

	NaH_2PO_4	KCl	$CaCl_2 \cdot 2H_2O$	$MgCl_2$	$NaHCO_3$	Sucrose
Concentration (g/l)	0.33	0.77	0.30	0.07	0.105	25 ml

polarization resistance were obtained from the linear polarization and corrosion rate, as calculated using the Stern–Geary equation (Bockris and Khan, 1993), after measuring the anodic and cathodic Tafel slopes from the polarization curves.

The frictional resistance between the bracket slot and the wire was measured at different incubation times. To make the test jig, a plate with dimensions of 30 × 10 × 1 mm was made of SS. A hole 2 mm in diameter was made on one side to fix this plate to a tensile testing machine. The bracket was bonded on the other side of the plate with a self-curing resin (System 1+, Ormco), as shown in Figure 2. A 0.017 × 0.025 inch rectangular wire was cut to 30 mm in length, and one end was then formed into a loop for fixation to the tensile test machine (Instron 6022, Instron Co., Buckinghamshire, UK). The maximum force was recorded in Newtons to a 4 mm displacement at a crosshead speed of 10 mm/minute. All specimens for frictional resistance measurements were stored in an incubator at a temperature of 37°C and 100 per cent humidity for 1 day, 3 days, 2 weeks, and 4 weeks.

The agar overlay method, described in ISO 7405, was used to evaluate the cytotoxicity of these materials. Copper alloy (NPG, Albadent Co., Concord, USA) and polyethylene were used as the positive and negative controls, respectively. Three replicates were prepared for the test samples and controls. The cell line used in this study was L-929 (NCTC clone 929). After making the cell suspension it was distributed evenly over a 10 ml Petri dish, and cultured for 24 hours. The culture medium was removed from the vessel, and 10 ml of Eagle's agar medium with melted agar

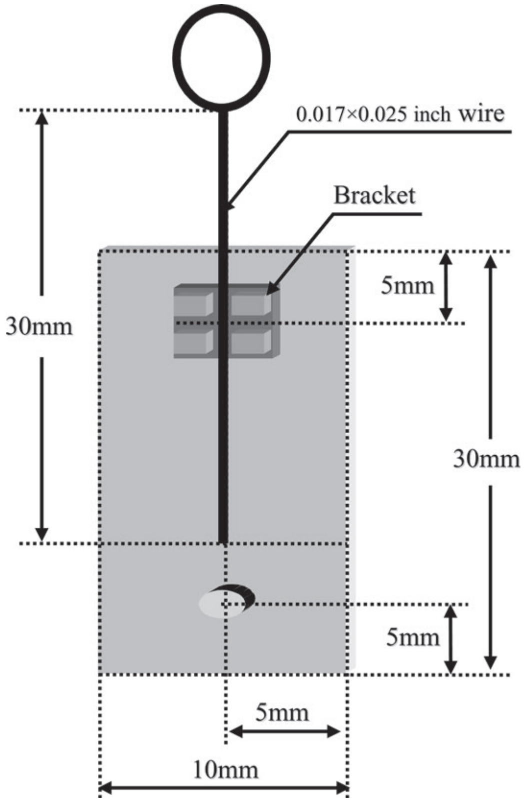

Figure 2 A schematic diagram of the sample configuration for the frictional test.

was added. Ten millilitres of neutral red was slowly added to the centre of the Eagle's agar medium and solidified at room temperature. The replicate metal samples were then carefully placed on the solidified agar layer, and the dishes were incubated at 37 ± 1°C with carbon dioxide as appropriate for the buffer system. The zone index was obtained from the discoloured area and the cell lysis index was evaluated as the lysed cell fraction in which discoloured separates using a phase contrast microscope (CK2, Olympus, Tokyo, Japan). The response index was calculated by averaging the zone and lysis indices obtained from the three samples.

One-way ANOVA Tukey grouping and Wilcoxon sum rank test were used to analyse the electrochemical test results, and repeated measures two-way ANOVA was used for friction test results. The significant difference was accepted at the 95 per cent confidence interval.

Results

The size accuracy of the brackets is presented in Table 4. SR-50A had the narrowest internal slot size and Mini-diamond the widest in the internal horizontal width of the tie wing ($P < 0.05$). There was a significant difference among the three brackets in the external, vertical, and

Table 4 Size accuracy of the brackets ($\times 10^{-2}$ inch).

Bracket	Internal size of the slot		External vertical width of the tie wing		Internal horizontal width of the tie wing		External horizontal width of the tie wing	
	Median	Range	Median	Range	Median	Range	Median	Range
SR-50A	1.86[a]	0.13	12.08[a]	0.41	5.00[a]	0.18	11.99[a]	0.19
Mini-diamond	1.94[b]	0.07	11.90[b]	0.10	8.27[b]	0.14	14.81[b]	0.20
Archist	1.93[b]	0.16	11.75[c]	0.51	5.08[a]	0.28	12.02[c]	0.35

[a, b, c]Significant difference between materials at the same location ($P < 0.05$).

horizontal width of the tie wing ($P < 0.05$). The size accuracy of the Mini-diamond was the highest for all locations except for the external horizontal width of the tie wing.

The SR-50A bracket showed the only austenitic phase (Figure 3a). Micrographs of the Mini-diamond and Archist brackets (Figure 3b, c) showed precipitates in the grains and around their boundaries. The Mini-diamond and Archist brackets had magnetic properties, but not the SR-50A. The microhardness values at each location for the three types of bracket are presented in Table 5. SR-50A had the lowest hardness value at the tie wing and bracket stem ($P < 0.05$). There were no significant differences in hardness at the base ($P < 0.05$). SR-50A and Mini-diamond showed significant difference among the measured locations for each bracket.

The corrosion potential, polarization resistance, and corrosion rate measured in the artificial saliva are presented in Table 6. The polarization resistance of SR-50A was higher than the other samples tested, and the corrosion current density calculated from the polarization resistance was lowest: these results were significantly different ($P < 0.05$). The corrosion rates converted to mm per year (mpy) of SR-50A, Mini-diamond, and Archist were $(0.9 \pm 0.2) \times 10^{-3}$, $(3.7 \pm 1.0) \times 10^{-3}$ and $(7.4 \pm 2.0) \times 10^{-3}$, respectively. SR-50A showed the lowest corrosion rate of the samples tested ($P < 0.05$). These various results indicate that SR-50A had the highest corrosion resistance. In terms of the anodic polarization curves, SR-50A had higher corrosion and pit potentials, and lower passive current density than Mini-diamond and Archist. However, all samples showed a passive region in which a protective film was formed at the higher potential, which prevented current density increases by an increasing potential.

The measurement results of the frictional force between the wire and the bracket slot are presented in Table 7. The frictional force of the SR-50A bracket showed a tendency to decrease with an increase in incubation time at 37°C and 100 per cent relative humidity ($P < 0.05$), but Mini-diamond and Archist showed a tendency to increase ($P < 0.05$). No significant difference in terms of the frictional force of the SR-50A bracket was apparent at 3 days ($P > 0.05$), but after 2–4 weeks of incubation, the frictional force decrease became significant ($P < 0.05$). The frictional force of Mini-diamond significantly increased with increasing incubation

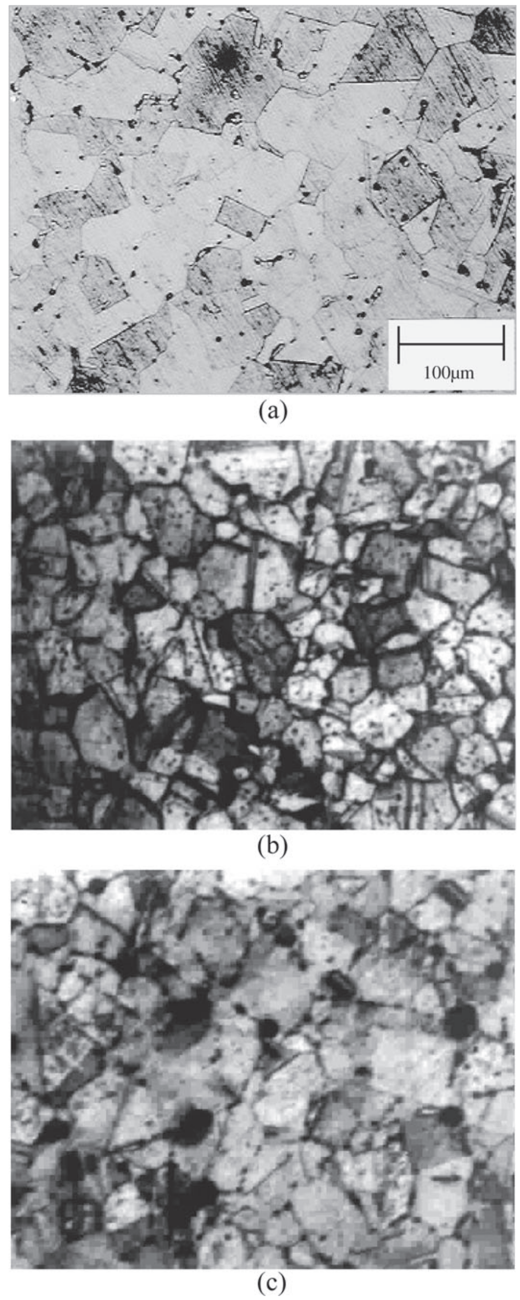

Figure 3 Optical micrographs of the brackets. (a) SR-50A (S32050), (b) Mini-diamond (S17400), (c) Archist (S30403).

Table 5 Microhardness at each bracket surface (kg/cm^2).

Code	Slot wall	Slot base	Tie wing	Bracket body	Bracket base
SR-50A	231 ± 6[aC]	233 ± 3[aC]	243 ± 7[aB]	228 ± 7[aD]	334 ± 14[aA]
Mini-diamond	326 ± 19[bA]	315 ± 4[bB]	297 ± 13[bD]	309 ± 16[bC]	327 ± 10[aA]
Archist	306 ± 7[cA]	306 ± 3[cA]	301 ± 28[bB]	309 ± 8[bA]	333 ± 15[aA]

[a, b, c]Significant difference between materials at the same location ($P < 0.05$).
[A, B, C, D]Significant difference between locations with the same material ($P < 0.05$).

Table 6 Corrosion resistance results for the orthodontic brackets used in this study.

Code	Ecorr (V)	Rp (Ω/cm^2)	Icorr $\times 10^{-3}$ ($\mu A/cm^2$)	Mpy ($\times 10^{-3}$)
SR-50A	–0.26 ± 0.06[a]	7556 ± 190.4[a]	2.01 ± 0.3[a]	0.9 ± 0.2[a]
Mini-diamond	–0.30 ± 0.02[a]	6126 ± 96.3[b]	7.93 ± 2.07[b]	3.7 ± 0.9[b]
Archist	–0.25 ± 0.11[a]	3534 ± 307.9[c]	19.96 ± 9.02[c]	7.4 ± 2.0[c]

[a, b, c]Significant difference between materials in the corrosion test ($P < 0.05$).
Ecorr, corrosion potential; Rp, polarization resistance; Icorr, corrosion rate; mpy, mm per year.

time ($P < 0.05$), while Archist showed no significant difference at 3 days, but a significant increase at 2 weeks ($P < 0.05$).

For the cytotoxicity results (Table 8), SR-50A, Mini-diamond and Archist all demonstrated a mild response. Nevertheless, SR-50A showed the lowest response index.

Discussion

Orthodontic metal brackets are made of materials with high corrosion resistance. However, they can be corroded in the oral cavity while under conditions of low pH, the presence of dental plaque, and a high chloride ion concentration. The pH of the environment in which orthodontic brackets are used has a significant effect on the rate of corrosion. When the bracket and wire are combined with a ligature wire or an elastomeric O-ring, crevice and galvanic corrosion can occur in the oral cavity, and further types of corrosion may develop when the bracket is soldered to the metal band. Pitting corrosion of orthodontic appliances is common due to the aggressive action of Cl^- ions in saliva, or from food and drink. Although chloride ion attack is probably the major cause of corrosion, bacteria and their waste products, and selective interactions with gases, such as, oxygen and carbon dioxide, may all contribute to the corrosion of orthodontic brackets in the mouth. The large population of bacteria and fungi present in the oral environment may accelerate the corrosion of orthodontic appliances. Organic acids and enzymes in particular may affect various metal brackets.

Table 7 Frictional force between orthodontic bracket slot and wire.

Code	1 day	3 days	2 weeks	4 weeks
SR-50A	0.82 ± 0.31	0.65 ± 0.13	0.47 ± 0.14[a]	0.59 ± 0.19[a]
Mini-diamond	0.39 ± 0.21	0.99 ± 0.24[a]	0.66 ± 0.21[a]	0.84 ± 0.24[a]
Archist	0.54 ± 0.41	0.56 ± 0.29	0.80 ± 0.41[a]	0.71 ± 0.20

[a]Significant difference between the incubation periods ($P < 0.05$).

Table 8 Cytotoxicity of the orthodontic bracket materials.

	SR-50A	Mini-diamond	Archist	+ (NPG)	– (Polyethylene)
Zone index	0~0	1~1	1~1	2~4	0~0
Lysis index	0~1	1~1	1~2	4~4	0~0
Response index	0/0 none	0/1 mild	1/1 mild(+)	1/2 mild(+)	2/4 moderate(++)

Currently, orthodontic metallic appliances are made mainly of SS containing chromium and nickel. The advantage of SS is primarily its low cost, greater strength, higher modulus of elasticity, good formability and high corrosion resistance in the mouth. Orthodontists have recognized these advantages, and as a result SS is used extensively for bands, brackets and archwires (Wilkinson, 1962). However, recently it has become apparent that there is a need for even higher corrosion resistance, greater strength, improved formability and lower cytotoxicity. Many attempts to satisfy those needs and improve the properties of SS have been made. Super SS has been developed that has higher corrosion resistance and greater mechanical strength than conventionally used SS (Willenbruch *et al.*, 1990; Olefjord and Clayton, 1991; Halada *et al.*, 1996). SS with a higher molybdenum and nitrogen content than conventionally used SS and PRE values of over 40 is considered to belong to the group of super SS. Especially, austenitic SS attracts attention for its high elongation and low temperature strength. The corrosion resistance of SS should be as high as possible in the human body, and its nickel content should be reduced to a minimum, because nickel is a known toxin and allergen (Fisher, 1986). Nickel is one of the most common causes of allergic contact dermatitis, especially in females (Fisher and Rosenblum, 1982; Fisher, 1986; Bass *et al.*, 1993). Tsalev and Zaprianov (1983) reported that nickel is a toxic element, but essential in animal and humans, and a carcinogen, which induces neoplasms in the respiratory system and in the nasal sinuses. Some clinical evidence of carcinogenicity resulting from implanted alloys is available in the literature (Smith, 1981; Smith and Williams, 1982). However, because nickel has an essential role in the stabilization of the austenitic phase and in the corrosion resistance of SS, it is difficult to totally exclude this metal. Chromium (Lugowski *et al.*, 1987; Klein, 1996) is essential to life and must be supplemented as a trace element in the diets of humans and animals, and to the corrosion resistance of SS. However, it is a recognized human allergen, as well as a human and animal carcinogen that most frequently results in respiratory cancers, and nasal tumours predominate. Hexavalent chromium is highly toxic and allergenic. While chromium compounds are mutagenic in most bacterial and mammalian assays, hexavalent chromium has rarely been detected in *in vivo* and *in vitro* testing. Therefore, the purpose of this study was to evaluate the potential of SR-50A containing high nickel, chromium and molybdenum for orthodontic applications and to determine the effect of passive film characteristics on corrosion resistance and cytotoxicity.

The microstructure of the Mini-diamond showed a martensitic phase and precipitates, such as $(Cr, Fe)_{23}C_6$, which are formed in the grains as well as the grain boundaries. Archist showed austenitic and martensitic phases and precipitates around the grains. No precipitates were observed in SR-50A. This is probably because SR-50A has a stable austenitic phase containing a high concentration of nickel and nitrogen, which are known as the austenitic stabilizing species. As the Archist bracket made from type 304L SS with the metastable austenitic phase could form the martensitic phase by stress-induced transformation during the manufacturing process, it was magnetized and formed many carbides due to the carbon content and high driving force of carbide precipitates $[(Cr, Fe)_{23}C_6]$ introduced during cold working. These can contribute to the low corrosion resistance of Mini-diamond and Archist brackets, and these brackets can release a large amount of metallic ions into the oral cavity due to carbide precipitation, which can induce intergranular corrosion in SS. This carbide precipitation can occur at lower temperatures if the SS has also been cold worked. To restrict localized corrosion of the chromium depleted zone caused by carbide precipitation, cold-worked SS with a low carbon content should be used.

Kerosuo *et al.* (1997) demonstrated, *in vitro*, that metal brackets experiencing orthodontic forces release more nickel and chromium than brackets free of orthodontic force. Therefore, bracket material with high corrosion resistance must be used to inhibit the release of nickel ion from the metal bracket. Super SS (SR-50A) has a higher resistance to pitting, crevice corrosion, intergranular corrosion, stress corrosion cracking and corrosion fatigue than conventionally used SS, such as type 17-4 PH, 316L and 304L. SR-50A has been reported to have localized corrosion resistance because the passive film is enhanced by the synergistic effects of the high nitrogen and molybdenum content (Clayton and Lu, 1986; Kim, 1990). As a result, SR-50A shows a higher polarization resistance and an even lower general corrosion rate than Mini-diamond and Archist, which indicates that SR-50A has better corrosion resistance than 17-4 PH and 304L SS. Corrosion pits were observed in the Archist and Mini-diamond surfaces, but not in the SR-50A surface. From the above results it is believed that these properties allow SR-50A to minimize the levels of metal ions released into the oral cavity.

The other problem related to the corrosion of an orthodontic bracket is its frictional behaviour, which can wear the contact surface by relative motion of the two materials. As is generally known in the corrosion–wear phenomenon, oxides formed by a chemical reaction on a surface can increase the frictional force. For this reason, if a metal with good corrosion resistance is used, it may decrease the frictional force between the two metal surfaces and help reduce the total treatment period, by inducing more precise tooth movements. In the frictional force test, the SR-50A bracket showed a tendency for the frictional force to decrease with increasing incubation time ($P < 0.05$), but Mini-diamond and Archist showed a tendency for the frictional force to increase ($P < 0.05$). These results mean that the oxide layer formed by surface corrosion on the Mini-diamond and Archist brackets increased the frictional force with increased incubation time. It is believed that surface corrosion products are substantial contributors to frictional force.

Dental materials necessarily require biocompatibility. Brackets contacting teeth directly and exposed to saliva must not detrimentally affect the human body as a result of the toxicity of the metallic ions released from their surface. The results of the agar overlay test showed that SR-50A had the lowest response index and released fewer metallic ions than Mini-diamond or Archist. Therefore, orthodontic application of SR-50A is believed to be more likely to result in clinical success.

It is believed that SS with a higher nickel content releases more nickel. However, more research should be directed to improving the stability of the passive film and the corrosion resistance of the SS than its nickel content. As passive films are formed by alloys containing elements, such as chromium and titanium, they play a role in protecting the alloys from aggressive ions, such as fluoride and chloride. The passive film has to be kept dense and uniform over the matrix. If not, localized corrosion can occur. When the passive film is damaged by aggressive ions, re-passivation kinetics become important.

The experimental SR-50A bracket was made from super SS with good corrosion resistance, and improved properties, including corrosion resistance, frictional behaviour, and cytotoxicity, than conventionally used metal brackets, and thus is applicable for clinical use.

Conclusions

Super SS brackets (SR-50A) made experimentally were investigated and compared with Mini-diamond and Archist commonly used in orthodontics. The following results were obtained:

1. SR-50A had a higher polarization resistance than the other tested samples, and the highest corrosion resistance. The corrosion rates of SR-50A, Mini-diamond and Archist in the artificial saliva solution were 0.9×10^{-3}, 3.7×10^{-3} and 7.4×10^{-3} mpy, respectively.
2. The frictional force of the SR-50A bracket decreased with time, whereas that of Mini-diamond and Archist increased with time. Therefore, the SR-50A bracket is thought to have better frictional characteristics to orthodontic wire than Mini-diamond and Archist.
3. From the results of the cytotoxicity test, the SR-50A bracket showed a response index of 0/1 (mild), Mini-diamond 1/1 (mild+) and Archist 1/2 (mild+). The SR-50A bracket showed greater biocompatibility than Mini-diamond and Archist.

Brackets made from super SS (SR-50A) with good corrosion resistance demonstrated improvement in a range of properties, such as corrosion resistance, frictional behaviour, and cytotoxicity, than conventionally used metal brackets. As a result, it is believed that the SR-50A bracket is more cytocompatible, presents a lower probability of allergic reaction, and may be safely applied in clinical orthodontics.

Address for correspondence

Kyoung-Nam Kim
Research Institute of Dental Biomaterials and Bioengineering
College of Dentistry
Yonsei University
134 Shinchon-Dong
Seodaemun-Gu
Seoul
Korea
E-mail: okt0505@yonsei.ac.kr

Acknowledgements

This work was supported by Brain Korea 21 Project for Medical Science, Yonsei University in 2003 and by grant no. R13-2003-13 from the Medical Science and Engineering Research Program of the Korea Science and Engineering Foundation.

References

Arici S, Regan D 1997 Alternatives to ceramic brackets: the tensile bond strengths of two aesthetic brackets compared *ex vivo* with stainless steel foil-mesh bracket bases. British Journal of Orthodontics 24: 133–137

Bass J K, Fine H, Cisneros G J 1993 Nickel hypersensitivity in the orthodontic patient. American Journal of Orthodontics and Dentofacial Orthopedics 103: 280–285

Bazakidou E, Nanda R S, Duncanson Jr M G, Sinha P K 1997 Evaluation of frictional resistance in esthetic brackets. American Journal of Orthodontics and Dentofacial Orthopedics 112: 138–144

Bockris J O, Khan S U M 1993 Surface electrochemistry. Plenum Press, New York, p. 748

Clayton C R, Lu Y C 1986 A bipolar model of the passivity of stainless steel: the role of Mo addition. Journal of the Electrochemical Society 133: 2465–2473

Creekmore T D, Kunik R L 1993 Straight wire: the next generation. American Journal of Orthodontics and Dentofacial Orthopedics 104: 8–20

Deguchi T, Ito M, Obata A, Koh Y, Yamagishi T, Oshida Y 1996 Trial production of titanium orthodontic brackets fabricated by metal injection molding (MIM) with sintering. Journal of Dental Research 75: 1491–1496

Feldner J C, Sarkar N K, Sheridan J J, Lancaster D M 1994 *In vitro* torque-deformation characteristics of orthodontic polycarbonate brackets. American Journal of Orthodontics and Dentofacial Orthopedics 106: 265–272

Fisher A A 1986 Contact dermatitis. Lea and Febiger, Philadelphia, p. 711

Fisher J R, Rosenblum G A 1982 Asthma induced by nickel. Journal of the American Medical Association 248: 1065–1066

Flores D A, Choi L K, Caruso J M 1994 Deformation of metal brackets: a comparative study. Angle Orthodontist 64: 283–290

Fontana M G 1987 Corrosion engineering. McGraw-Hill, New York, pp. 445–481

Halada G P, Kim D, Clayton C R 1996 Influence of nitrogen on electrochemical passivation of high-nickel stainless steels and thin molybdenum-nickel films. Corrosion 52: 36–46

Kerosuo H, Moe G, Hensten-Pettersen 1997 A salivary nickel and chromium in subjects with different types of fixed orthodontic appliances. American Journal of Orthodontics and Dentofacial Orthopedics 111: 595–598

Kim Y S 1990 A study on effects of nitrogen and molybdenum additions on passivity of stainless steels. Thesis, Yonsei University, Seoul, p. 8

Klein C B 1996 Carcinogenicity and genotoxicity of chromium. In: Chang L W, Magos L, Suzuki T (eds) Toxicology of metals. CRC Press, Boca Raton, pp. 205–219

Komori A, Ishikawa H 1997 Evaluation of resin-reinforced glass ionomer cement for use as an orthodontic bonding agent. Angle Orthodontist 67: 189–195

Lugowski S J, Smith D C, Loon J C 1987 The determination of Al, Cr, Co, Fe, and Ni in whole blood by electrothermal atomic absorption spectrophotometry. Journal of Biomedical Materials Research 21: 657–674

Maijer R, Smith D C 1982 Corrosion of orthodontic bracket bases. American Journal of Orthodontics 81: 43–48

Michael L S 1988 Ceramic brackets. Journal of Clinical Orthodontics 22: 82–87

Olefjord I, Clayton C R 1991 Surface composition of stainless steel during active dissolution and passivation. ISIJ International 31: 134–141

Olsen M E, Bishara S E, Jakobsen J R 1997 Evaluation of the shear bond strength of different ceramic bracket base designs. Angle Orthodontist 67: 179–182

Platt J A, Guzman A, Zuccari A, Thornburg D W, Rhodes B F, Oshida Y 1997 Corrosion behavior of 2205 duplex stainless steel. American Journal of Orthodontics and Dentofacial Orthopedics 112: 69–79

Pratten D H, Popli K, Germane N, Gunsolley J C 1990 Frictional resistance of amic and stainless steel orthodontic brackets. American Journal of Orthodontics and Dentofacial Orthopedics 98: 398–403

Sinha P K, Nanda R S 1997 The effect of different bonding and debonding techniques on debonding ceramic orthodontic brackets. American Journal of Orthodontics and Dentofacial Orthopedics 112: 132–137

Smith D C, Williams D F 1982 Biocompatibility of dental materials. CRC Press, Boca Raton

Smith G K 1981 Systemic biocompatibility of implant materials. In: Williams D F (ed.) Systemic Aspects of Biocompatibility. CRC Press, Boca Raton, p. 1

Tsalev D L, Zaprianov Z K 1983 Atomic absorption spectrometry in occupational and environmental health practice, Volume 1. CRC Press, Boca Raton

Wheeler J J, Ackerman R J 1983 Bond strength of thermally recycled metal brackets. American Journal of Orthodontics 83: 181–186

Wilkinson J V 1962 Some metallurgical aspects of orthodontic stainless steel. Angle Orthodontist 48: 192–206

Willenbruch R D, Clayton C R, Oversluizen M, Kim D, Lu Y C 1990 An XPS and electrochemical study of the influence of molybdenum and nitrogen on the passivity of austenitic stainless steel. Corrosion Science 31: 179–190