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Orthodontic Application of Super Stainless Steel

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Generally, the orthodontic stainless steel wires have been made of 18-8 stainless steel, the metal brackets made of 316L or 17-4 PH stainless steel, but because of their low localized corrosion resistance such as pitting and crevice corrosion, in a solution with chloride ions, the probability of the corrosion in an oral cavity is high. To use the orthodontic appliances in an oral cavity, it is necessary to have high corrosion resistance and optimum biomechanical properties. Therefore, in this study, rectangular wires and metallic brackets were made of super stainless steel (S32050) with high corrosion resistance by drawing or machining. The corrosion resistance, ion release property and cytotoxicity of S32050 and conventionally used appliances were examined.

S32050 showed the low passive current density of about 1 $\mu A/cm^2$ and the stable passive region to a high potential in artificial saliva solution. S32050 appliances did hardly release nickel and chromium ions in artificial saliva. But pitting and crevice corrosion were visually observed in the appliances made of 316L and 302 stainless steel after 4-week immersion, and amount of nickel ion release increased from 2-week immersion. S32050 had none cytotoxicity in agar overlay test.

Conclusively, it is considered that S32050 orthodontic appliances with high corrosion resistance could inhibit the release of metallic ions in an oral cavity in which localized corrosion may occur, and that they could satisfy the requisite of the orthodontic appliances such as cytotoxicity, biomechanical properties.

Keywords : *super stainless steel, orthodontic appliances, corrosion resistance, ion release, cytotoxicity*

1. Introduction

Metallic orthodontic appliances are known to release metal ions in an electrolyte such as saliva and human body solution, and as a result, to lead to changes of mechanical properties and appliance's shape. It has been reported that ions released from metallic brackets could discolor an enamel of teeth permanently and occur a hypersensitivity to human body, and heat treatment of archwires and recycling of brackets could increase amount of metal ions release.[1-3] Toms[4] reported that corrosion of orthodontic appliances could have serious clinical implications ranging from a loss of dimension resulting in lower forces being applied to the teeth, to stress corrosion failure of the appliance, and the production of possibly toxic corrosion products by the surrounding tissues.

Nickel and chromium ion are main constituents released from stainless steels, especially metallic nickel is known as one of the most causes of allergenic contact dermatitis.[5),6)] It was reported that nickel ion could be released from nickel containing alloys in saliva by electrogalvanic currents, and nickel could induce hypersensitivity, contact dermatitis, asthma etc., and moderate cytotoxicity as the strong immunologic reaction medium.[7),8)] Fernandez, Spiechowicz, Romaguera et al.[9-11)] reported that the symptoms such as loss of taste burning sensation, and soreness of the involved area were provoked in the patient using prosthetic appliances made of nickel containing alloys. Kalkwarf[12)] reported the allergic gingival inflammation to esthetic crowns, and Loon[13)] reported the contact stomatitis occurred in the surrounding area when nickel plates attached to the buccal side of one lower premolar. Bass et al,[14)] Moffa et al,[15)] Prystowsky et al.[16)] suggested that the hypersensitivity reaction be provoked by orthodontic or prosthetic treatments because the long term exposure to metals could increase the hypersensitivity. Dunlap[17)] reported that contact stomatitis and pain were elicited on the surrounding areas of NiTi wires, while Rickles[18)] and Schriver[19)] reported that severe gingivitis during orthodontic treatment might be caused not only by poor oral hygiene but also by contact hypersensitivity from the appliances.

It is not advisable that the toxicity of corrosion products derived from corrosion of appliances is absorbed into the surrounding tissue and the body. Metal ions released from stainless steel orthodontic appliances is known to have an effect on the result of orthodontic treatment and systemic health, so many studies on the development of the new materials with high corrosion resistance has been carried out. Orthodontic stainless steel wires are generally manufactured with 302, 304 stainless steel types. However these types are known that the possibility of corrosion is high in an oral cavity, since the localized corrosion resistance is low in an environment containing the chloride ions. In order to use safely in an oral cavity, the appliances should have high corrosion resistance and biomechanical properties required for the orthodontic treatment. Recently, super stainless steels with higher corrosion resistance than conventionally stainless steels have been developed and applied to the industrial fields, besides they have been tried to apply clinically to the orthopedic field up to date. Super stainless steel (S32050) has higher resistance to pitting, crevice corrosion, intergranular corrosion, stress corrosion cracking, corrosion fatigue, and hydrogen embrittlement, than conventionally used AISI 300 series stainless steels such as type 316L and 304L. S32050 has similar localized corrosion resistance to titanium alloys, because its passive film is enhanced by high nitrogen and molybdenum addition.

In this study, orthodontic brackets and rectangular wires were made of super stainless steel(S32050) by drawing and machining. Corrosion resistance, ion release properties and surface corrosion behavior of each wire and bracket and the combinations of bracket and wire were evaluated, and compared with conventionally used stainless steel, NiTi, TMA wires and Tomy bracket.

2. Experimental

Super stainless steel(S32050) wire was experimentally made in size of 0.016 × 0.022 inch. Remanium(Dentaurum, Ispringen, Germany) as stainless steel wire, Bioforce Sentalloy(Tomy, Tokyo, Japan) as NiTi wire in same size with S32050, and TMA(Ormco, Glendora, USA) in size of 0.017 × 0.025 inch as beta-Ti wire, and Tomy standard edgewise bracket(Tomy, Tokyo, Japan) in slot size of 0.018 inch as stainless steel bracket were used to compare with S32050 wire and bracket. Elastic O-ring(Ormco, Glendora, USA) was used to ligate bracket and wire. Chemical compositions of orthodontic brackets and wires are presented in Table 1 and 2, respectively. And constituents of an artificial saliva used for electrochemical measurement and metal ion release test in this study are shown in Table 3.

To investigate the corrosion properties of each wire, The potentiodynamic test was performed in artificial saliva solution, at temperature of 37 (1℃, using the potentiostat (EG&G Model 263A, Perkin Elmer Instruments, Connecticut, US). The length of all the samples was 3 cm. Each was then ultrasonically cleaned in acetone and ethylalcohol solution for five minutes, then rinsed in distilled water, and dried. The potential scanning rate was 60 mV/min, scan range, -600 mV ~ 1600 mV and a saturated calomel electrode (SCE) was used as the reference electrode.

Table 1. Chemical composition of orthodontic brackets (weight %)

Type	Code	C	Si	Ni	Cr	Mo	N	Fe
S32050	SB	0.03	0.80	21.23	22.69	6.21	0.28	Bal.
Stainless steel	TB	-	2.38	9.42	20.36	3.04	-	Bal.

Table 2. Chemical composition of orthodontic wires(weight %)

Type	Code	C	Si	Ni	Cr	Mo	N	Fe
S32050	SRW	0.03	0.80	21.23	22.69	6.21	0.28	Bal.
Remanium	RW	0.11	1.13	8.29	18.75	-	-	Bal.

Type	Code	Ti	Ni	Sn	Cu	Mo	Zr	-
NiTi	NW	42.68	48.75	-	8.57	-	-	-
TMA	TW	78.85	-	5.28	-	9.35	6.53	-

Table 3. Composition of artificial saliva

Constituent	Concentration(g/l)
NaCl	0.40
KCl	0.40
$CaCl_2.2H_2O$	0.80
$Na_2S.5H_2O$	0.01
$CO(NH_2)_2$(Urea)	1.00
Distilled Water	1000ml

Table 4. Classification of bracket-wire groups

Group	Bracket	Wire
1 group	Tomy bracket	0.016 × 0.022 S32050 wire
2 group		0.016 × 0.022 Remanium wire
3 group		0.016 × 0.022 NiTi Bioforce sentalloy wire
4 group		0.017 × 0.025 TMA wire
5 group	S32050 bracket	0.016 × 0.022 S32050 wire
6 group		0.016 × 0.022 Remanium wire
7 group		0.016 × 0.022 NiTi Bioforce sentalloy wire
8 group		0.017 × 0.025 TMA wire

Metal ion release test was performed for each bracket and wire, and the ligated bracket and wire in 37℃ artificial saliva. The wire size was 5 cm, both ends of the wire were mounted by epoxy resin. All samples were provided by triple sets with the same type and immersion time and divided into 8 groups as presented in Table 4. Each sample was immersed in separate screw top polyethylene bottle containing 50 ml artificial saliva, and was kept at 37 ℃ in an incubator. On immersion times of 1 day(1D), 3 day(3D), 1 week(1W), 2 week(2W), 4 week(4W), 8 week (8W) and 12 week(12W), each bottle was removed from the incubator and then each sample was removed from the bottle for subsequent nickel and chromium analyses, which were carried out by graphite furnace atomic absorption spectroscopy(6601 model, Shimadzu Co Ltd., Japan).

Corrosion behavior and site of each sample removed from the polyethylene bottle according to the immersion time were investigated using optical microscopy. Statistical analysis was performed using the student's t test, the significant difference was accepted at the 95% confidence interval. And the significant difference on the amount of ions released from each group according to immersion time and at each immersion time was decided by Kruskal-Wallis test.

3. Results and discussion

3.1 Corrosion resistance

The orthodontic appliances consist of bracket, wire, ligature wire, band etc, and metallic orthodontic appliances are widely used. However, when they corrode they can release metallic ions into the oral cavity. Therefore, it is necessary to investigate the corrosion properties of these metallic orthodontic appliances. Many researchers have studied the topic and reported upon this corrosion of metallic orthodontic appliances, but these reports have been largely inconsistent. To date, no severe problems of the human body have been attributed to the use of metallic orthodontic appliances, but because there is always the possibility of adverse effect on the human body by corrosion, this point should not be passed over lightly.

Fig. 1 shows anodic polarization curves of each wire in artificial saliva. SRW showed low passive current density of approximately 1 $\mu A/cm^2$ and pitting corrosion did not occurred with the increase of potential. But RW, which was conventionally used stainless steel wire(type 302 stainless steel), showed narrow passive region and high passive current density of about 10 $\mu A/cm^2$ and pitting corrosion occurred at about 250 mV(SCE), also its corrosion potential was the lowest of the wires used in this study. NW showed high passive current density of about 10 $\mu A/cm^2$ and unstable passivity. TW had the lowest passive current density of approximately 1 $\mu A/cm^2$ and stable passivity to high potential.

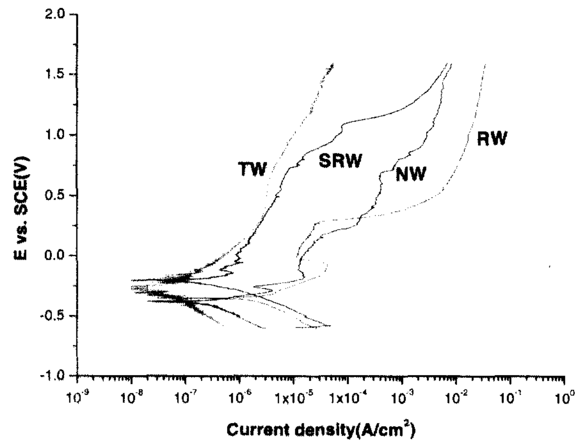

Fig. 1. Anodic polarization curves of wires used in this study.

Although each constituent of orthodontic appliances have been made of materials with high corrosion resistance, the possibility of corrosion may be raised when the constituents of these appliances are combined for orthodontic treatment in the oral cavity. When the bracket and wire are combined with ligature wire or an elastomeric O-ring, crevice and galvanic corrosion can occur in the oral cavity, and when the bracket is soldered onto the metal band, many types of corrosion can occur. Pitting corrosion can occur on orthodontic appliances by aggressive Cl^- ion attack in saliva or from food or drink. In an environment with a high chloride concentration and with different oxygen concentration from the neighbor region, and the pH is low. Under these circumstances, the passive film of stainless steel tends to be unstable and this allows pitting and crevice corrosion to occur more easily. This environment is similar to the salivary solution that exists in the oral cavity under conditions of low pH, the presence of dental plaque, and a high chloride concentration. Because nickel and chromium ions released by corrosion can induce the adverse effects on the human body, it is very important that we pay attention to the minimization of these corrosion factors.

3.2 Metal ion release

Nickel and chromium are two metals often used in the construction of various parts of most orthodontic appliances. Their predominant systemic effects in humans are allergies, dermatitis, and asthma. Nickel plays an important role in human health as a toxin, an allergen, and as a candidate essential element. Nickel is one of the most common causes of allergic contact dermatitis, especially in women[5),6)] However, exposure to this metal is virtually inescapable. Despite the fact that nickel is used to produce stainless steel alloys, most nickel-sensitive patients are able to tolerate these materials without difficulty. The crystal lattice of the alloys generally binds the nickel so that it is not free to react. Furthermore, the protective film of stainless steel, called the passive film, can inhibit the release of metallic ions.

From the results of the amount of nickel ion released from the wires presented in Fig. 2, the released nickel ion from SRW was 1.0943 ppb in one-day immersion time and 2.9141 ppb in 12-week immersion time, but there was no significant difference between the release amounts of nickel ion according to immersion time. The released nickel ions from RW increased from one day to 8-week immersion time, but there was not significantly different according to immersion times, however, they increased with significant difference in 12-week immersion time. The released nickel ions from NW increased continuously in the range of 1.2887~2.6493 ppb to 12-week immersion time, but not significantly different. In terms of chromium ion release amount, that from SRW and RW was very little and not significantly different according to immersion time.

Fig. 3 shows the released amount of nickel ions from the brackets. Amounts of nickel ions released from TB and SB with immersion time were not significantly different and there was not significant difference between the amounts released from TB and SB brackets in each immersion time. The released amount of nickel ion from SB was in the range of about 1.28 ~ 2.48 ppb and that from TB, about 1.50 ~ 3.68 ppb. The released amount of chromium ion from TB and SB was not significantly different according to immersion time.

Fig. 4 shows the released amount of nickel ion from the ligated appliances of each wire and TB bracket. The first group(TB-SRW) showed the increased amount of nickel ion release from 8-week immersion time with significant difference, and the most released amount of 9.1851 ppb nickel ion in 12-week immersion time. The second group(TB-RW) showed the increased amount from 4-week immersion time with significant difference, and the most released amount of 11.8991 ppb nickel ion in 12-week immersion time of all groups. The third group (TB-NW) released even less the amount of nickel ion than the first and second groups for all immersion time and nickel ion release amount from it increased from 4-week immersion time with significant difference. The released amount of nickel ion in the fourth group(TB-TW) was not significantly different with immersion time. Fig. 5 shows the released amount of nickel ion from the ligated

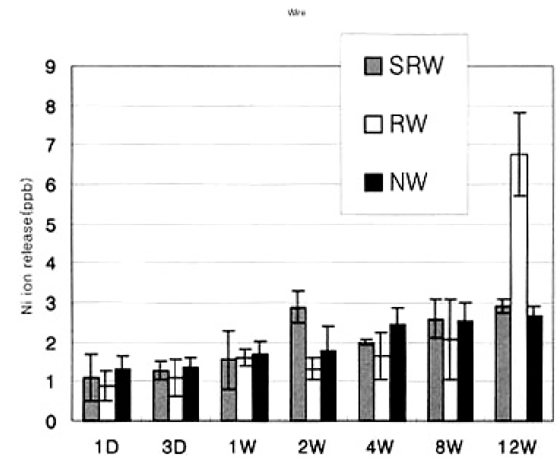

Fig. 2. Amount of Ni ion released from wires with immersion time(ppb unit).

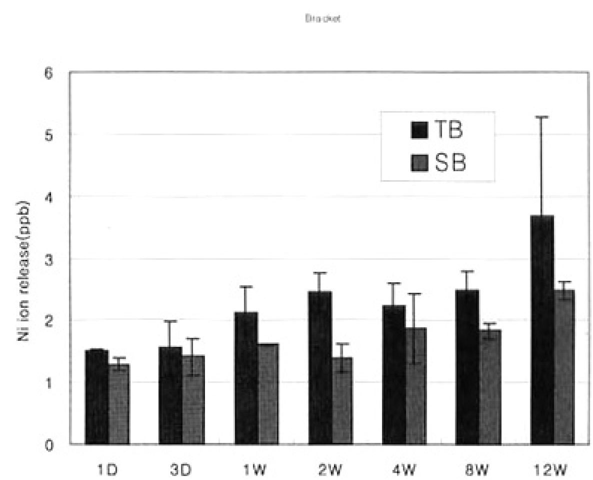

Fig. 3. Amount of Ni ion released from brackets with immersion time(ppb unit).

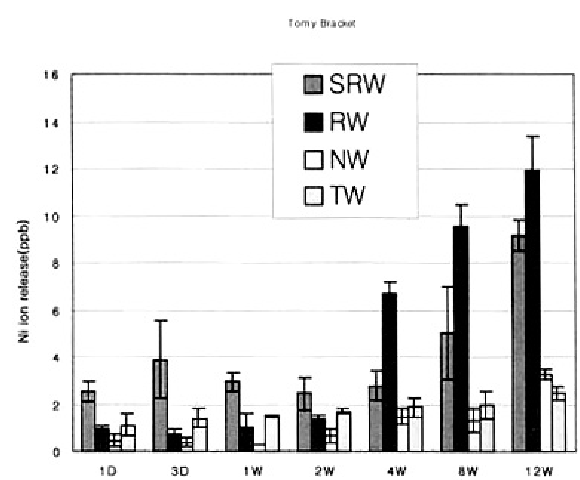

Fig. 4. Amount of Ni ion released from bracket-wires with immersion time(ppb unit): Tomy bracket.

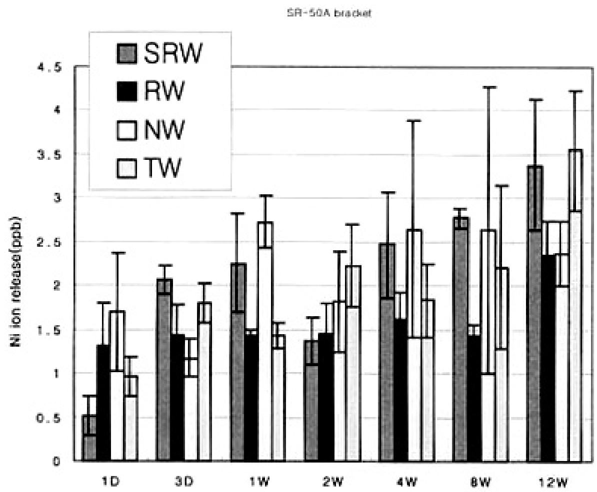

Fig. 5. Amount of Ni ion released from bracket-wires with immersion time(ppb unit): S32050 bracket.

appliances of each wire and SB bracket. The fifth group (SB-SRW) did not show significant difference in the released amount according to immersion time. In the sixth group(SB-RW), there was not significant difference between the released amounts of nickel ion to 8-week immersion time, but there was significant difference between them in only 12-week immersion time(2.3539 ppb). In the seventh and eighth group, there was no significant difference for all immersion time. Amount of chromium ion released from each group was very little in the range of about 0.1 ppb below.

Nickel and chromium are normally present in foods. The dietary intake of nickel has been reported to be around 300 to 500 μg per day, while chromium intake varied from 5 to more than 100 μg per day depending on diet.[20] Park and Shearer's experiment[1] measured nickel and chromium release from one quadrant of a simulated full-mouth appliance, their results showed a release of 40 μg nickel and 36 μg chromium per day for a simulated full-mouth appliance. These values are thus well below the normal daily intake of these two metals and may not be of clinical significance in most patients. However, the clinician should be aware that the release of metal ions might cause a local hypersensitivity reaction in oral soft-tissue sites. Contact stomatitis with characteristic lesions, such as loss of taste, numbness, burning sensations, and soreness of the involved area, itching and contact dermatitis can be provoked. Moreover, severe gingivitis associated with orthodontic therapy may be a manifestation of not only poor oral hygiene but also a contact hypersensitivity reaction to nickel and/or chromium ions released during the corrosion of stainless steel. Therefore, using materials with high corrosion resistance should minimize the formation probability of these lesions owing to metal ion release.

3.3 Surface morphology on the corroded appliances

Fig. 6 and 7 shows surface morphologies of the orthodontic appliances after 8 and 12 week immersion, respectively. Corrosion phenomenon on most of samples in artificial saliva to 12-week immersion time was hardly observed visually and optical microscopy. But in the second group(TB-RW), corrosion products were observed on the ligated part of bracket and wire with O-ring from 8 week immersion time, and corrosion site was extended from the ligated part to the bracket wing in the 12 week immersion time.

4. Conclusions

1) S32050 wire(SRW) and NiTi wire(NW) didn't show significant difference of Ni ion release with immersion time, meanwhile, Remanium wire(RW) showed significant difference in 12 weeks. Cr ion release didn't show any significant difference in all wires.

2) Ni ion released from the brackets didn't show any significant difference with immersion time and between SB and TB. The released Cr ion didn't show any significant difference with immersion time.

3) Ni ion released from TB-SRW showed significant difference in 12 weeks, Ni ion released from TB-RW showed significant difference from 4 weeks later and the highest release among all groups in 12 weeks. TB-NW showed little Ni ion release during all immersion time and significant difference from 4 weeks later, TB-TW(TMA wire) showed significant difference in 12 weeks. Cr ion release of all groups were measured within 0.1 ppb and showed rarely difference.

4) SB-SRW didn't show any significant difference and SB-RW showed significant difference in 12 weeks, but lower compared with TB group. SB-NW and SB-TW didn't show any significant difference. Cr ion release from all groups were measured within 0.05 ppb and showed no significant difference.

5) Corrosion products didn't be observed in mostly groups during the immersion time, except that in TB-RW, they were observed on the bracket surface between O-ring and wire from 8 weeks later. Super stainless steel wire had good corrosion resistance compared with stainless steel wire, and it is believed that it can be used as orthodontic material for bracket and wire.

Acknowlegement

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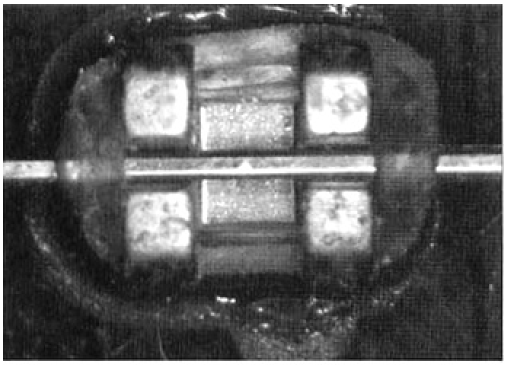
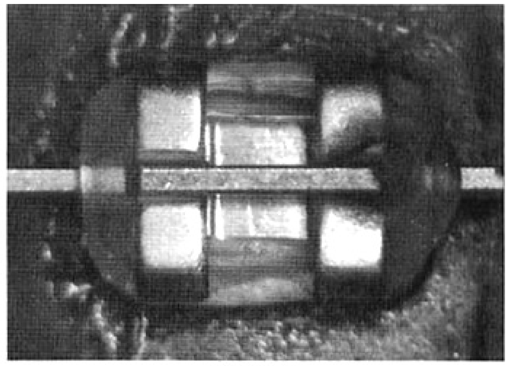
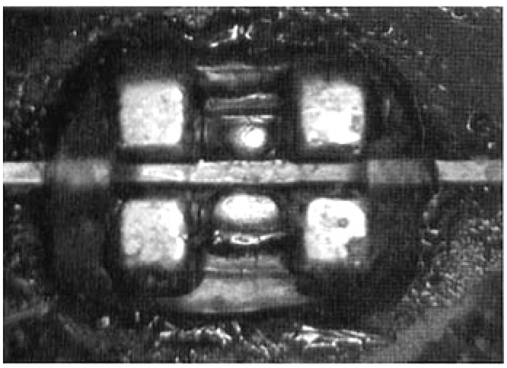


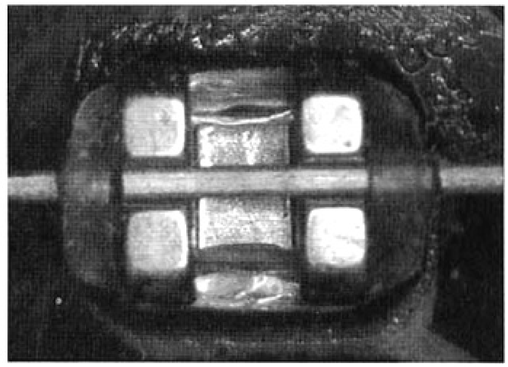
TB-SRW



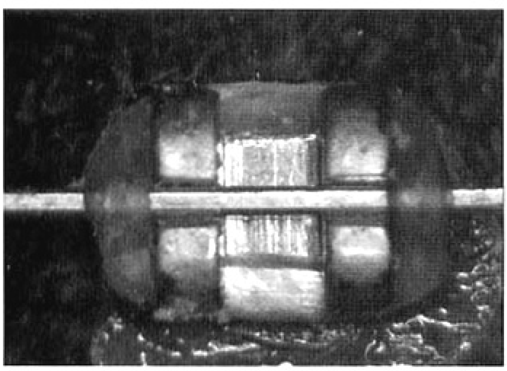
TB-RW



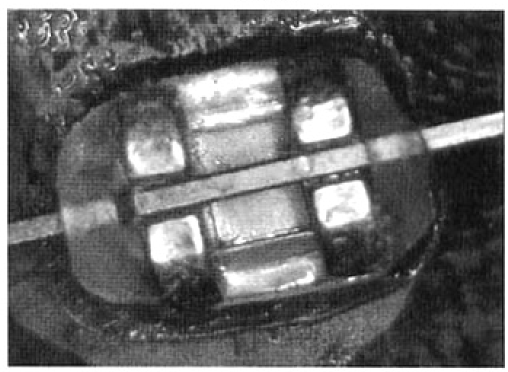
TB-NW



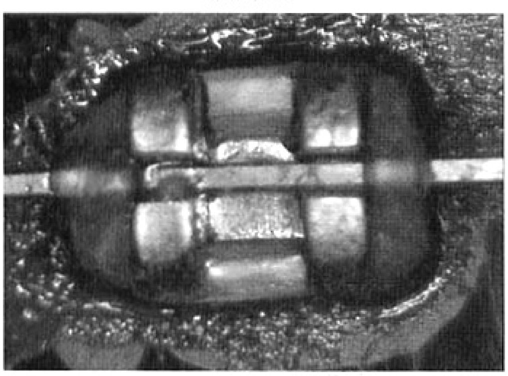
TB-TW



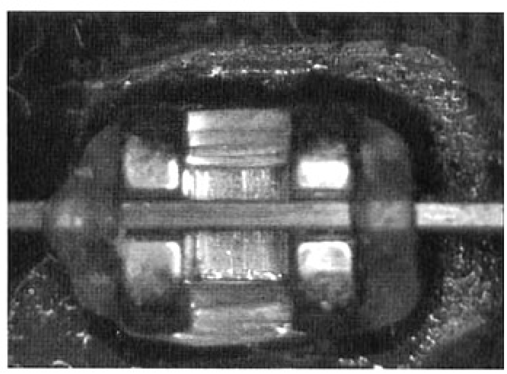
SB-SRW



SB-RW



SB-NW



SB-TW

Fig. 6. Photographs of bracket-wires after 8-week immersion.

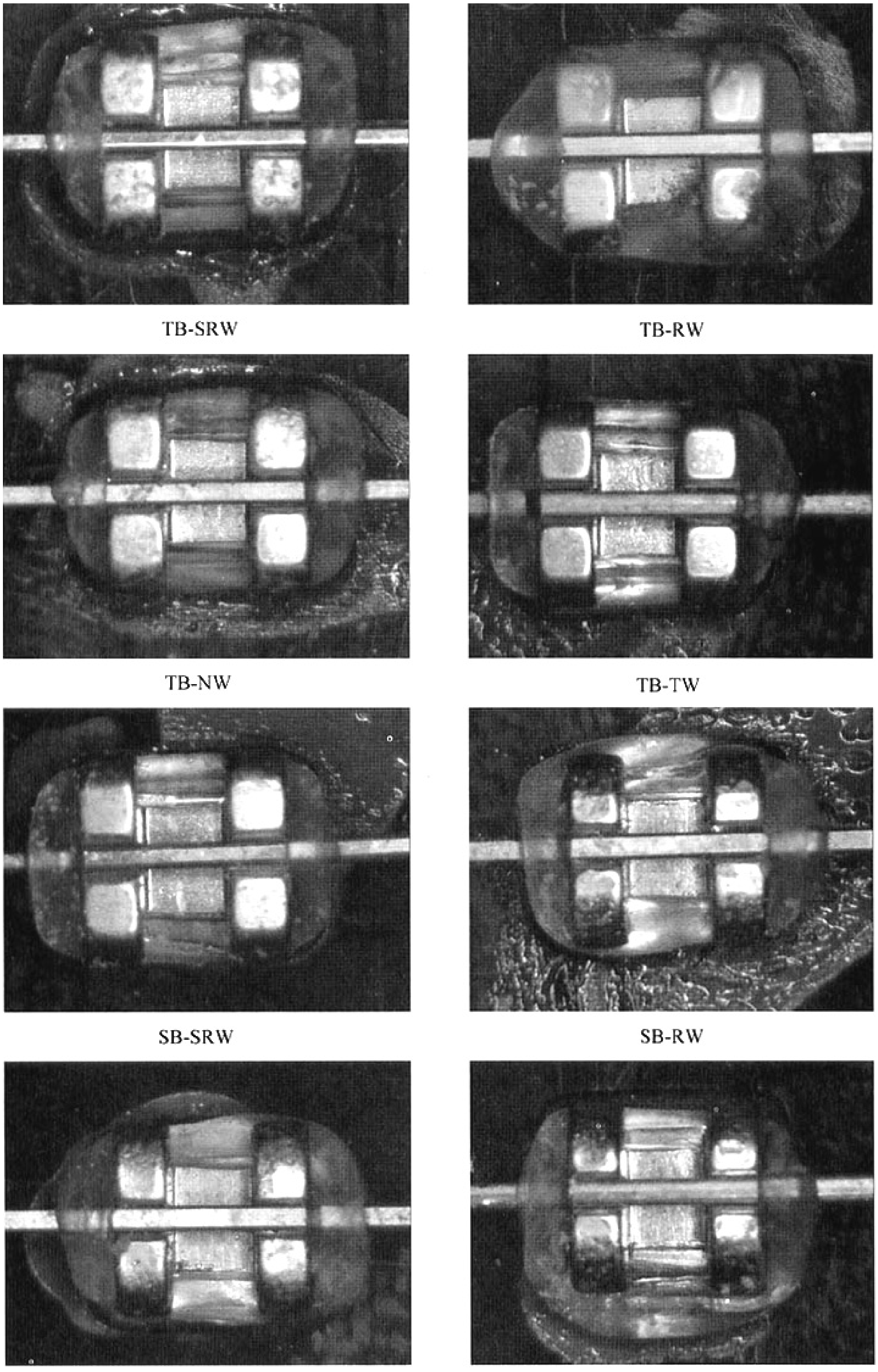


Fig. 7. Photographs of bracket-wires after 12-week immersion.

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