Electric toothbrushes are widely used because of their convenience. However, they have also been reported to produce low-frequency electromagnetic fields, which could cause problems, e.g., interference with pacemakers \(^1,2\). In low-frequency magnetic fields (MFs), the strength of the induced electric current is thought to be more important than the strength of the MF itself in affecting the health of living bodies \(^3\). Many home electrical appliances generate low-frequency MFs that could induce electric currents in the human body and within any metallic objects or devices worn in or on the body \(^2,4\). Previous reports showed that MFs from electric toothbrushes could induce alternating electric currents in metallic dental appliances and teeth \(^5,6\). Electric currents in oral appliances, e.g., galvanic currents, could cause discomfort for the user and corrosion of metallic dental appliances \(^7,8\). Induced currents by electric toothbrushes were also thought to cause some problems in the oral condition of patients. However, the currents induced by the toothbrushes are unlike galvanic currents \(^8\). Galvanic currents, which are direct currents, exhibited high voltages (several tens to hundreds of mV) with low currents (several tens to hundreds of nA), whereas the electric currents induced by electric toothbrushes were of the order of µA to mA with a voltage range of µV to mV \(^9\). These findings seemed to indicate that the galvanic currents were one of the causes of metal corrosion, whereas the electric currents induced in dental appliances should not be a direct cause of metal corrosion. However, there were some reports about metallic corrosion caused by induced alternating current (AC). Rapid geomagnetic variation was known to induce electric currents in power lines and pipelines, which could lead to the destruction of power transmission systems and the corrosion of pipelines \(^9\). In stray-current corrosion caused by alternating currents, the induced current occurred in embedded metal objects parallel to high voltage AC power lines or to the transportation routes of alternating current electric railways, which caused corrosion of the embedded metal objects \(^10\). We show here that the currents induced in metallic dental appliances by MF exposure from electric toothbrushes corroded stainless steel appliances but not titanium appliances.

**MATERIALS AND METHODS**

**Materials**

Five identical electric toothbrushes (Philips Sonicare HX9340/02, Philips Oral Healthcare Inc., Bothell, WA, USA, all from Lot no. 59 114303 1 881934202461), acting as the magnetic field (MF) sources, were prepared for this investigation based on the results of previous reports \(^5,6\).

We also prepared three orthodontic wire materials (SUS304, Suzuki stainless steel wire, Mitsuba Ortho
Supply Inc., Tokyo, Japan; β-titanium (β-Ti, Ti-11.5Mo-6Zr-4.5Sn)\(^{11}\), Bendalloy, Rocky Mountain Morita Inc., Tokyo, Japan; and nickel-titanium (NiTi), Sentalloy, Tomy International Inc., Tokyo, Japan). The cross-sectional sizes of these wires were approximately 0.43×0.64 mm (0.017×0.025 inches). Stainless steel (SUS) orthodontic brackets (SUS304, SuperMesh Bracket medium twin bondable for mandible incisors, Tomy International Inc., Tokyo, Japan) were also prepared. Because each SUS orthodontic bracket was 0.068±0.001 g (\(n=5\)) when weighed with an electronic balance (Mettler type AE240-S, Siber Inc., Zurich, Switzerland) with readability of 0.01 mg placed on a suitable mounting (Vibro-Absorbing Mount VAM-I, Murakami Koki Inc., Osaka, Japan), the SUS wire length was determined to be 3.0 cm by having the same weight as the brackets (0.068±0.001 g, \(n=5\)). Based on these results, the wires made from the other materials were used in 3.0 cm lengths (β-Ti wire: 0.046±0.002 g; NiTi wire: 0.053±0.001 g: \(n=5\)). Each orthodontic wire was tied to the brackets with elastomeric modules (polyurethane elastic ligature tie, Shofu Inc., Tokyo, Japan). The solution used for immersion was Fusayama-Meyer artificial saliva (AS), with content as follows: 0.4 g of KCl, 0.4 g of NaCl, 0.795 g of CaCl\(_2\)
\(\cdot\)2H\(_2\)O, 0.78 g of NaHPO\(_4\)
\(\cdot\)2H\(_2\)O, 0.005 g of Na\(_2\)S•9H\(_2\)O, and 1 g of NH\(_2\)CONH\(_2\) (all reagents were purchased from Wako Pure Chemical Industries Inc., Tokyo, Japan) in 1 L of deionized distilled water (DDW), with pH of 5.3\(^{12}\).

For exposure of the orthodontic appliances to the MFs of the electric toothbrushes, we created five experimental sets for the five prepared electric toothbrushes (Fig. 1). We created acrylic stages, plaster tube racks and silicon toothbrush racks with the same shapes and sizes by using silicon counter-dies. Turntables (battery type turntable, MM Kobo Inc., Shizuoka, Japan) driven by a single AAA battery were used for the rotation of the electric toothbrushes at 5×10\(^{-2}\) Hz (3 rpm). The electromagnetic fields from the turntables could not be detected at the positions of the orthodontic appliances (data not shown here).

**Measurement of MFs generated by electric toothbrushes**

The MFs produced by the electric toothbrushes and their frequencies were detected and evaluated using a spectrum analyzer (SPECTRAN NF-5035, Aaronia AB

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**Fig. 1** Schematic representation and time schedules of experiments for exposure of orthodontic appliances to MFs.
Inc., Euscheid, Germany)\(^5,6\). We estimated the MFs within the 1–2000 Hz frequency range, in keeping with the preliminary study and with the previous literature, which stated that this was the appropriate range to monitor\(^2,5,6\). The MFs were estimated at 2 cm distances from the front, back, and right and left sides of activated or inactive electric toothbrushes\(^5\).

**Measurement of electric currents induced in dental appliances by electric toothbrushes**

The electric currents induced in dental appliances were estimated using a digital multimeter (7351 A/E, ADC Corporation, Tokyo, Japan) in AC+DC mode (i.e. voltage=(ACV\(^2\)+DCV\(^2\))\(^{1/2}\), and current=(ACI\(^2\)+DCI\(^2\))\(^{1/2}\)). Because the electric current induced by electric toothbrushes was ostensibly known to be alternating current from the results of previous studies\(^4,5\), its value when measured in the AC+DC mode was practically identical to that in the AC mode. The induced electric current was estimated for a distance of 2 cm between the front of the toothbrush and the appliance immersed in AS in plastic culture dishes. We also estimated the electric current induced between only the connecting anode and the cathode in the AS (i.e. with no orthodontic appliance), and confirmed that no electricity was detected from electric toothbrushes at a distance of 2 cm (data not shown here). The induced electric voltages and currents in the appliance that were estimated in this study are shown in Fig. 2.

**MF exposure of orthodontic wires combined with orthodontic brackets immersed in AS**

For exposure of orthodontic appliances to the MFs from electric toothbrushes, four specimens immersed in 8 mL of AS solutions in 15 mL plastic tubes were set in the plaster tube racks on each acrylic stage. Each electric toothbrush was set in the silicon toothbrush racks on the electric turntable (Fig. 1). During exposure to the MFs from the electric toothbrushes, the turntables were rotated at 5×10\(^{-2}\) Hz. The specimens were exposed to the MF from each electric toothbrush for 24 min/day, and a total of 120 min exposure from the five toothbrushes (24 min each) was accomplished by five day exposure for each specimen. In a questionnaire survey of the tooth brushing habits of 1,200 Japanese people (600 males and 600 females, aged from teens to sixties), 52.5% of respondents cleaned their teeth twice a day, and 48% of them had brushing times of 1–3 min\(^1\). From these reports, the average Japanese person’s brushing time for one month was estimated to be 120 min (2 min×2 times/day×30 days). We thus deduced that the exposure time of specimens to MFs from the electric toothbrushes was a total of 120 min, e.g. 24 min/day×5 times (4 days).

**Measurement of pH of AS after immersion of orthodontic appliances**

Immersion solutions containing metal appliances that had been exposed to MFs from electric toothbrushes and that had been incubated at 37°C in air were collected (Fig. 1), and their pH values were measured with a pH meter (F-12, Horiba Inc., Kyoto, Japan). Before the measurements were taken, the pH meter was calibrated using three types of standard pH solution, e.g. pH4, 7 and 10 solutions (MJ-PH4, MJ-PH7, MJ-PH10, Sato Shouji Inc., Kanagawa, Japan).

**Detection of metallic elution from orthodontic appliances using the inductively coupled plasma-optical emission spectrometer (ICP-OES)**

ICP-OES measurements (ICP-OES model iCAP 6300 Duo, Thermo Fisher Scientific, Waltham, MA, USA) for specimens collected as shown in Fig. 3 were taken. Briefly, AS solutions containing metal appliances were incubated at 37°C for 3 h (day 0) or for 24 h (days 1–4) in air, and exposed to the MF for 24 min. After that, the solutions were collected for the ICP-OES measurements. The ICP-OES instrument was optimized before the

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**Fig. 2** Electric current induced in orthodontic appliance immersed in AS by the Sonicare HX9340/02 at a distance of 2 cm between the electric toothbrush and the appliance.

a. Induced voltage; b. induced current.
Fig. 3 Measurement area and lines of brackets and wires for surface roughness measurement by 3D laser confocal microscope.

Upper left: 3D laser confocal micrograph of wing of orthodontic bracket; upper right: 3D laser confocal micrograph of SUS wire at a distance of 8.0 mm from the center of the bracket; and lower: photograph of orthodontic appliance (bracket+3 cm of wire+elastomeric module) used in this study. The area surrounded by the dotted line was the measurement area, and the horizontal solid line was the measurement line for evaluation of the surface roughness of the appliance. White lines in the micrographs represented 100 µm.

Table 1 Detection and determination limits at each detection wavelength for each element in AS by ICP-OES

<table>
<thead>
<tr>
<th>Element</th>
<th>Detection wavelength (nm)</th>
<th>Detection limit (µg)</th>
<th>Determination limit (µg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr</td>
<td>205.552</td>
<td>0.011</td>
<td>0.047</td>
</tr>
<tr>
<td>Fe</td>
<td>239.562</td>
<td>0.017</td>
<td>0.071</td>
</tr>
<tr>
<td>Ni</td>
<td>216.556</td>
<td>0.028</td>
<td>0.118</td>
</tr>
<tr>
<td>Sn</td>
<td>189.989</td>
<td>0.033</td>
<td>0.141</td>
</tr>
<tr>
<td>Ti</td>
<td>308.802</td>
<td>0.006</td>
<td>0.026</td>
</tr>
</tbody>
</table>

measurement process by using standard solutions of Cr, Fe, Ni, Sn and Ti normally used in atomic absorption spectrometry (Kanto Chemical Co. Ltd., Tokyo, Japan), and was operated according to the manufacturers’ instructions. The spectrometer was used with the following parameters: radiofrequency (RF) power of 1.15 kW, frequency of 27.12 MHz, a demountable quartz torch containing Ar/Ar/Ar, plasma gas (Ar) flow of 16.5 L/min, auxiliary gas (Ar) flow of 0.5 L/min, nebulizer gas (Ar) flow of 0.7 L/min, nebulizer pressure of 0.15 MPa, a glass spray chamber according to the method of Scott (cyclone chamber, Fisher Scientific Inc., Waltham, MA, USA), with a sample pump flow rate of 1.8 mL/min, an integration time (45 s), replication capability (5 times), and the wavelength range of a monochromator (166–847 nm). First, standard curves for the AS, with or without Cr, Fe, Ni, Sn and Ti were created, and then each of the detection limits (3.3δ/slope) and determination limits (10√2δ/slope) were obtained (Table 1). The elution volumes of the metallic ions in the immersion solutions were shown as concentrations (ppb/ppm), so that these values could be converted to the eluted metal weight (µg) for easier understanding (Table 1). Selected metal ions were measured at wavelengths of 205.552 nm for Cr, 239.562 nm for Fe, 216.556 nm for Ni, 189.989 nm for Sn and 308.802 nm for Ti from the results of each standard curve (Table 1). The metallic elution values were shown as converted values (±determination limit), +(determination values<values<determination limit) or –(<determination limit) (Tables 2, 3). All reagents used were of analytical and spectral purity grade.

Detection of surface roughness of orthodontic appliances by three-dimensional laser confocal microscope

The surface roughnesses of the appliances were measured using a 3D laser confocal microscope (LEXT OLS4000, Olympus Inc., Tokyo, Japan) and estimated as Ra (the arithmetic average of the absolute value, \( Ra = \frac{1}{n} \sum |Y_i| \) (i=1–n)), Rz (the highest peaks (Rp) and lowest valleys (Rv) over the entire sampling length, \( Rz = Rp + Rv \)), and Sa (the arithmetic average of the 3D roughness (areal roughness)) by the Lext software package (Olympus Inc.) on a workstation computer (MB-P5300X-WS, Mouse Computer Inc., Tokyo, Japan). Preparation of the specimens for surface roughness estimation was performed as follows: 1) discard immersion AS; 2) wash appliances twice with distilled water (DW); 3) ultrasonicate appliances in DW for 15 min twice; 4) wash appliances twice with DW; and 5) dry the appliances in air. Estimation of the surface roughness was performed about the labial surfaces of the wires at a distance of 8 mm from the horizontal central point of the brackets (the 500 µm mesiodistal line of the center of the wires, and the 200×500 µm area of the wire surfaces), and the labial flat part of the wing surfaces of the bracket (the 500 µm mesiodistal line, and the 500×500 µm area of the flat surfaces) (Fig. 3).

Experimental conditions, data and statistical analysis

All experiments were performed in the laboratory, which was maintained at a temperature of 22±1°C. Data were obtained from each experiment, and six data out of a total of eight data were used, which meant that the maximum and minimum data were removed. These six data were calculated and represented as means±standard deviations. The data were analyzed by Mann-Whitney’s U test to determine which of the differences were statistically significant.
Table 2  Elution amount of each element (μg) from the appliances (bracket+wire+elastomeric module) to AS

<table>
<thead>
<tr>
<th></th>
<th>SUS MF (-)</th>
<th>SUS MF (+)</th>
<th>β-Ti MF (-)</th>
<th>β-Ti MF (+)</th>
<th>Ni-Ti MF (-)</th>
<th>Ni-Ti MF (+)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr</td>
<td>–</td>
<td>+</td>
<td>–</td>
<td>+</td>
<td>–</td>
<td>+</td>
</tr>
<tr>
<td>Fe</td>
<td>0.20±0.012</td>
<td>1.39±0.067*</td>
<td>0.12±0.011**</td>
<td>0.80±0.044***</td>
<td>0.11±0.014**</td>
<td>0.70±0.067***</td>
</tr>
<tr>
<td>Ni</td>
<td>–</td>
<td>+</td>
<td>–</td>
<td>+</td>
<td>–</td>
<td>+</td>
</tr>
<tr>
<td>Sn</td>
<td>na</td>
<td>na</td>
<td>–</td>
<td>–</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>Ti</td>
<td>na</td>
<td>na</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

n=6 for each experimental condition. SUS: stainless steel wire; β-Ti: β-titanium wire; NiTi: nickel titanium wire; MF: magnetic field; +: detection values≦values<determination limit; –: values<detection limit; and na: not available. Data were analyzed by Mann-Whitney’s U test to define the differences that were statistically significant. Superscript asterisks denote statistically significant differences (p<0.05) within each appliance compared to *MF(−), and within each MF exposure compared to **SUS and ***β-Ti.

Table 3  Elution amount of each element (μg) from the brackets to AS

<table>
<thead>
<tr>
<th></th>
<th>MF (-)</th>
<th>MF (+)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr</td>
<td>–</td>
<td>+</td>
</tr>
<tr>
<td>Fe</td>
<td>0.11±0.018</td>
<td>0.71±0.082*</td>
</tr>
<tr>
<td>Ni</td>
<td>–</td>
<td>+</td>
</tr>
<tr>
<td>Sn</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Ti</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

n=6 for each experimental condition. MF: magnetic field; +: detection values≦values<determination limit; and –: values<detection limit. Data were analyzed by Mann-Whitney’s U test to define the differences that were statistically significant. Superscript asterisks denote statistically significant differences (p<0.05) within each row compared to *MF(−).

RESULTS

Electric current induced in orthodontic appliances by low-frequency MFs from electric toothbrushes

In this study, electric toothbrushes acting as MF sources were set on a turntable rotating at 5×10^{-2} Hz, so that the appliances were exposed to the MFs from every side of the toothbrushes (Fig. 1). First, the MFs from the front, right, left and back sides of the toothbrushes were estimated. Typical MF profiles from every side of the toothbrushes exhibited the same pattern; however, the ranking order of these fields was: right>left>back>front side (Fig. 4).

The results for the currents induced in appliances with a distance of 2 cm between the front of the toothbrush and the appliance immersed in AS in plastic culture dishes are shown in Fig. 5. The voltage and current in each appliance that faced toward the electric toothbrush, which was switched off, when immersed in AS were 0.02±0.01 mV and 0.02±0.01 mA in the SUS wire+SUS bracket, 0.02±0.01 mV and 0.03±0.02 mA in the β-Ti wire+SUS bracket, and 0.02±0.01 mA in the NiTi wire+SUS bracket, respectively. The induced voltages among the SUS, β-Ti and NiTi wire groups exhibited almost the same values; however, the currents were dramatically different between the SUS and titanium groups. The ranking order of the induced currents is for SUS brackets with wires composed of NiTi>β-Ti>SUS, as shown in Fig. 5.

Measurement of pH of AS after immersion of orthodontic appliances

The pH changes in the immersion AS samples are shown in Fig. 6. The pH of incubated AS samples containing appliances showed lower values than that of AS without appliances. No pH differences between the non MF-exposed and MF-exposed groups were observed.

Metallic elution from orthodontic appliances by MF exposure from electric toothbrushes

First, the standard curves of AS with and without metallic elements, e.g. Cr, Fe, Ni, Sn and Ti, were created, and then the detection limit, the determination limit and the appropriate wavelength for the detection of each element were obtained (Table 1). The elution volumes of the metallic ions in AS were shown as concentrations (ppb/ppm), so that these values could be converted into eluted metal weight/appliance (μg) for easier understanding (Table 1). Fe was detected in AS with no MF exposure for each combination (Table 2). In the titanium wires combined with the SUS brackets, the elution amounts of Fe were approximately half that of the SUS wires with the SUS bracket group in both the MF-exposed and unexposed groups. Elution of the elements in the SUS brackets without any wires was also investigated (Table 3). The Fe elution amounts in the bracket-only group were approximately half the values for the SUS wires with SUS brackets group.
Fig. 4  Low-frequency MFs produced by the electric toothbrush. MFs (1–2,000 Hz) produced by the Sonicare HX9340/02 were estimated at a distance of 2 cm between the electric toothbrush and the front/right/left/back sides of the appliance with a spectrum analyzer.

Fig. 5  Electric voltage and current induced in orthodontic appliances immersed in AS by electric toothbrushes. *n=6 for each experimental condition. Br: bracket; SUS: stainless steel wire; β-Ti: β-titanium wire; NiTi: nickel-titanium wire; V: induced voltage; and C: induced current. The data were analyzed by Mann-Whitney’s U test to define the differences that were statistically significant. Asterisks denote the statistically significant differences (*p<0.05) within the induced voltages or current compared to *Br+SUS wire and **Br+β-Ti wire.

Fig. 6  pH changes in AS used to immerse the appliances, with or without exposure to MFs from electric toothbrushes. *n=6 for each experimental condition. non: artificial saliva with no appliances; Br: bracket; SUS: stainless steel wire; β-Ti: β-titanium wire; NiTi: nickel-titanium wire; and MF: magnetic field. The data were analyzed by Mann-Whitney’s U test to define the differences that were statistically significant. Asterisks denote the statistically significant differences (*p<0.05) within the groups with appliances compared to *non; **Br+SUS; ***Br+β-Ti; and within each appliance when compared to ****MF(−).
in both the MF-exposed and the unexposed groups. The Fe elution amount in the bracket-only group also showed almost the same values as those of the titanium wires with SUS brackets groups in both the MF-exposed and unexposed groups (Tables 2 and 3). MF exposure dramatically increased Fe elution from the appliances (Table 2). Cr and Ni were also detected in the MF-exposed groups for each appliance. Ti could not be detected after MF exposure of the groups of titanium wires with SUS brackets (Table 2).

**Surface roughness of orthodontic appliances caused by exposure to MFs from electric toothbrushes**

The 3D laser confocal micrographs of the surfaces of the wires and the brackets in each combination were represented in Figs. 7 and 8. The surface roughnesses of the appliances as measured and calculated by the 3D laser confocal microscope as Ra (arithmetic average of the absolute value), Rz (highest peaks and lowest valleys over the entire sampling length), and Sa (the arithmetic average of the 3D roughness) are shown in Fig. 9. These results revealed that MF exposure made the surfaces of the SUS wires and the SUS brackets uneven; however, little or no effect was observed from the MF exposure of the surfaces of the titanium wires (Fig. 9). In the micrographs, the surfaces of the intact appliances were seen not to be entirely smooth, so that the surface changes and roughness caused by MF exposure were difficult to judge, especially in the titanium wires (Figs. 7 and 8).

![Fig. 7](image_url)

**Fig. 7** 3D laser confocal micrographs of the wire surfaces immersed in AS with or without exposure to the MFs from electric toothbrushes (×20). White lines in the micrographs represented 100 µm.
Fig. 8  3D laser confocal micrographs of the bracket surfaces immersed in AS with or without exposure to the MFs from electric toothbrushes (×10). White lines in the micrographs represented 200 µm.

DISCUSSION

There has been considerable recent interest in the effects of electromagnetic fields, such as those near electrical transmission lines, on human health, and the International Agency for Research on Cancer (IARC), the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the World Health Organization (WHO) have each established guidelines and criteria outlining the roles and risks of MFs in carcinogenesis\textsuperscript{16-18}). Previous studies have demonstrated that alternating electric currents can be induced not only in fixed dental appliances (including orthodontic appliances), but also in human teeth by electromagnetic fields generated by electric toothbrushes and curing lights\textsuperscript{5,6}). Galvanic corrosion caused by weak galvanic currents, which are direct currents, can occur in various combinations of dental materials, and can cause various human health problems, including metal allergies and poisoning\textsuperscript{7,8}). Some reports have also described metallic corrosion caused by electromagnetic field-induced AC\textsuperscript{15,16}). Alternating electric currents induced in dental appliances by electromagnetic fields may therefore also affect the corrosion of these appliances.

The MFs from the front, right, left and back sides of toothbrushes were found to have the same profiles in five identical electric toothbrushes with the same lot number. The MFs from every side of these toothbrushes showed the same patterns with the ranked order of right>left>back>front side (Fig. 4). These differences in MFs may be caused by the structure, including the electrical circuits, of the electric toothbrush. Induced
Fig. 9 Surface roughnesses of brackets and wires immersed in AS with or without exposure to MFs from electric toothbrushes.

\( n = 6 \) for each experimental condition. Br: bracket; SUS: stainless steel; \( \beta \)-Ti: \( \beta \)-titanium; NiTi: nickel-titanium; and MF: magnetic field. Ra represents the arithmetic average of the absolute value, Rz represents the highest peaks and lowest valleys over the entire sampling length, and Sa represents the arithmetic average of the 3D roughness (areal roughness). The data were analyzed by Mann-Whitney’s U test to define the differences that were statistically significant. Asterisks denote the statistically significant differences \(( p < 0.05 )\) within each measurement item of each appliance group when compared to *non, and **MF(−).

Metallic elution from orthodontic appliances under MF exposure from electric toothbrushes was detected by the ICP-OES. The obtained element concentrations in the AS (ppb/ppm) were converted into eluted metal weight/appliance (μg) for easier understanding (Table 1). From the results of the standard curves for AS when facing an electric toothbrush that is switched off, the galvanic current between SUS and NiTi, which could not be detected, must have no relationship to this phenomenon.

Currents in appliances in AS when exposed to the above MFs were detected (Fig. 5). The induced voltages among the SUS, \( \beta \)-Ti and NiTi wire groups had almost the same values; however, the current showed dramatic differences between the SUS and titanium wire groups (Fig. 5). These values were not in proportion to their electrical resistivity, which were 70–80 Ωm for SUS304 and 80–100 Ωm for NiTi. One of the reasons for this phenomenon might be the combination of the NiTi wire with the SUS bracket. From the measured results for the induced voltage and current in each appliance in AS when facing an electric toothbrush that is switched off, the galvanic current between SUS and NiTi, which could not be detected, must have no relationship to this phenomenon.

Fig. 9 Surface roughnesses of brackets and wires immersed in AS with or without exposure to MFs from electric toothbrushes.
limit (3.3δ/slope), the determination limit (10,2δ/slope) and the appropriate wavelength were obtained for each element (Table 1). An approximately seven-fold increased concentration of Fe was detected in AS after MF exposure for each combination when compared to each of the no-MF-exposure group (Table 2). In each MF exposure group, Cr and Ni were also detected, with values that varied between the detection values and the determination limit. In titanium wires combined with SUS brackets, the Fe elution amount was approximately half that of the SUS wires with SUS bracket group in both the MF-exposed and non-MF-exposed groups, which almost matched the values of the bracket-only group. These results suggested that the Ni eluted by MF exposure could be derived from the SUS brackets, but not from the NiTi wires (Tables 2 and 3). In titanium wires combined with the SUS brackets in AS under MF exposure, Ti and Sn could not be detected, indicating a strong resistance against corrosion by electric current for the titanium alloy in comparison to SUS.

The surface roughness of each wire and bracket measured by the 3D laser confocal microscope as Ra, Rz and Sa supported the metallic elution measurement results (Fig. 9). MF exposure made the surfaces of the SUS wires and SUS brackets uneven; however, little or no effects of MF exposure on the surfaces of the titanium wires could be found (Fig. 9). As the surfaces of the intact appliances were not completely smooth, the surface changes caused by MF exposure were difficult to see, but the roughness, including corrosion pits, could be found by detailed observation (Figs. 7 and 8). These changes are likely to be caused by the small amount of metallic elution, which was approximately 1/1000 of the weight of the appliances (Tables 2 and 3).

In contrast to the evidence of the surface roughness for the occurrence of metallic elution, no pH differences were observed between the non-MF-exposed and MF-exposed groups (Fig. 6). The pH values were lowered by the immersion of each of the appliances; however, these pH values, which did not reach the depassivation pH, could not have eroded these alloys. These results suggested that pH changes in the AS have no relation to the MF-induced SUS corrosion.

In this study, we have shown that the low-frequency MFs induced by electric toothbrushes promote the corrosion of orthodontic SUS appliances without pH changes by inducing electric currents through an evaluation of the metallic elution when the appliances are immersed in AS, and from the roughness of the metal surfaces. These results suggested the possibility that low-frequency MFs around the oral cavity that originated from electronic equipment such as electric toothbrushes induce electric currents in intraorally installed metals (especially in SUS), prostheses and appliances, and promote metallic elution which is likely to be one of the causes of metallic allergies. We must be careful when using electric toothbrushes, especially when metal prostheses and/or appliances are worn in our mouths. However, it is very difficult to protect ourselves from low-frequency MFs because they can pass through human tissues and most other materials, including glass, plastics, metals and concrete. The only viable way to limit exposure to low-frequency electromagnetic fields is thought to be the elimination of their generation by home electrical appliances and dental devices. Further studies are necessary to clarify exactly how they affect human oral health, and whether countermeasures, including standardization, can be developed to negate their effects.

CONCLUSION

We examined the possibility of metallic corrosion caused by exposure to the MFs from electric toothbrushes via induced currents. The results obtained in this study are as follows:

1. Exposure of orthodontic appliances to MFs from electric toothbrushes induced currents in the appliances when they were immersed in AS.
2. SUS appliances were corroded by exposure to the MFs from electric toothbrushes.
3. Metal elution caused by exposure to the MFs from electric toothbrushes could not be detected in two types of titanium wire.
4. The pH values of the solutions used for the immersion, with or without MF exposure, exhibited no statistical significance.

We concluded that corrosion of SUS appliances, but not titanium appliances, occurred under exposure to MFs from electric toothbrushes via induced currents, but not through pH changes.

REFERENCES