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Electric toothbrushes induce electric current in fixed dental appliances by creating magnetic fields

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Magnetic fields can represent a health problem, especially low frequency electromagnetic fields sometimes induced by electric current in metallic objects worn or used in or on the body (as opposed to high frequency electromagnetic fields that produce heat). Electric toothbrushes are widely used because of their convenience, but the electric motors that power them may produce electromagnetic waves. In this study, we showed that electric toothbrushes generate low frequency (1–2000 Hz) magnetic fields and induce electric current in dental appliances (*e.g.* orthodontic and prosthetic appliances and dental implants). Current induced by electric toothbrushes might be dependent on the quantity and types of metals used, and the shape of the appliances. Furthermore, these induced currents in dental appliances could impact upon human oral health, producing pain and discomfort.

Keywords: Electromagnetic fields, Low frequency, Orthodontic appliances, Prosthetic appliances, Dental implants

INTRODUCTION

There has been much recent interest in the effect of electromagnetic fields near electricity transmission lines *etc*. on human health, especially their effect on the development of leukemia and central nervous system tumors. The discovery of a correlation between carcinogenesis and extremely low frequency electromagnetic fields by epidemiological research prompted the International Agency of Research on Cancer (IARC) to add electromagnetic fields to their list of significant carcinogenic risks to humans in 2001[1)]. The International Commission on Non-Ionizing Radiation Protection (INCIRP) established guidelines limiting exposure to electromagnetic fields with magnetic flux densities over 2 mA/m^2 at 4–1000 Hz magnetic fields[2)]. This value is equal to the 0.5 mT at 50/60 Hz that is the Japanese commercial frequency. The World Health Organization (WHO) also established criteria for magnetic fields[3)], stating that magnetic flux densities between 1 and 10 mA/m^2 (induced by magnetic fields above 0.5–5 mT at 50/60 Hz, or 10–100 mT at 3 Hz) can have minor biological effects in humans. However, galvanic corrosion caused by weak galvanic currents can occur in various combinations of dental materials[4,5)], which cause a variety of human health problems including metallic allergy and poisoning.

Many electric home appliances generate low frequency magnetic fields[6)], including those used near the head (*e.g.* electric shavers, hair dryers and electric toothbrushes), and thus should be examined for their potential to generate electromagnetic fields[7)]. In this study, we first estimated the low frequency magnetic fields (1–2000 Hz) generated by five commercially available electric toothbrushes. We then examined whether these magnetic fields induced electric current in dental appliances (*e.g.* orthodontic and prosthetic appliances, and dental implants). We show here that, while switched on, electric toothbrushes do induce electric current in dental appliances.

MATERIALS AND METHODS

Materials

The electric toothbrushes used in this study were: Braun Oral-B (P&G Inc., Ohio, U.S.A.); GC PRINIA Slim (GC Inc., Tokyo, Japan, but produced by Panasonic Inc., Osaka, Japan), Lion VibrateCare Dental ExSystema (Lion Inc., Tokyo, Japan, but produced by OMRON Inc, Kyoto, Japan), Philips Sonicare HX6100 (Royale Philips Electronics Inc., Amsterdam, The Netherlands), and Philips Sonicare HX9100 (Royale Philips Electronics Inc., Amsterdam, The Netherlands).

For experiments investigating the induction of electric current, we used orthodontic and prosthetic appliances, and dental implants. Components of the orthodontic appliances were from Tomy International Inc., Tokyo, Japan, unless stated. We used a multi-bracket system (including brackets (SUS304×10, SuperMesh Bracket), molar tubes (SUS304×2, Single Tube), molar bands (SUS304×2, Ideal Molar Band), and wire (SUS304 × 1, Suzuki stainless steel wire (Mitsuba Ortho Supply Inc.,Tokyo, Japan)); a quadhelix expansion appliance (including molar bands (SUS304×2, Ideal Molar Band), and wire (SUS304×1, Remanium wire (Dentaurum Inc., Ispringen, Germany)); and a canine-to-canine retainer (including a pad (SUS304×2, MeshVeneerPlate, (Dentsply Sankin Inc., Tokyo, Japan))

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and wire (SUS304×1, Remanium wire (Dentaurum Inc., Ispringen, Germany)). Three types of prosthetic appliances were used: a metal core (upper left canine, 70% Ag); a full cast crown (lower left first molar, 12% Au-40% Ag-20% Pd); and a bridge (lower left second premolar to second molar, with the second premolar being a crown (12% Au-40% Ag-20% Pd), the first molar the pontic (12% Au-40% Ag-20% Pd+TEGMA (Epricord, Kuraray Inc., Tokyo, Japan)) and the second molar an MOD inlay (12% Au-40% Ag-20% Pd). Dental implants were fixtures with or without apatite (without apatite: IMZ D3.3/L1.3 (Titan, FRIATEC AG Inc., Germany); with apatite: μ-one D3.3/L10+10 (Titan+apatite, Yamahachi Dental Mfg Inc., Aichi, Japan)).

Measurement of magnetic fields generated by electric toothbrushes

Detection of magnetic fields produced by electric toothbrushes and their frequencies were evaluated using a spectrum analyzer (SPECTRAN NF-5035, Aaronia AB Inc., Euscheid, Germany). We estimated magnetic fields within the range of 1–2000 Hz, in keeping with preliminary study and previous literature stating that this was the appropriate range to monitor[6,7]. Magnetic fields were estimated at 0 cm from the front and back of activated or inactivated electric toothbrushes[6].

Measurement of electric current induced in dental appliances by electric toothbrushes

Electric current induced in dental appliances was

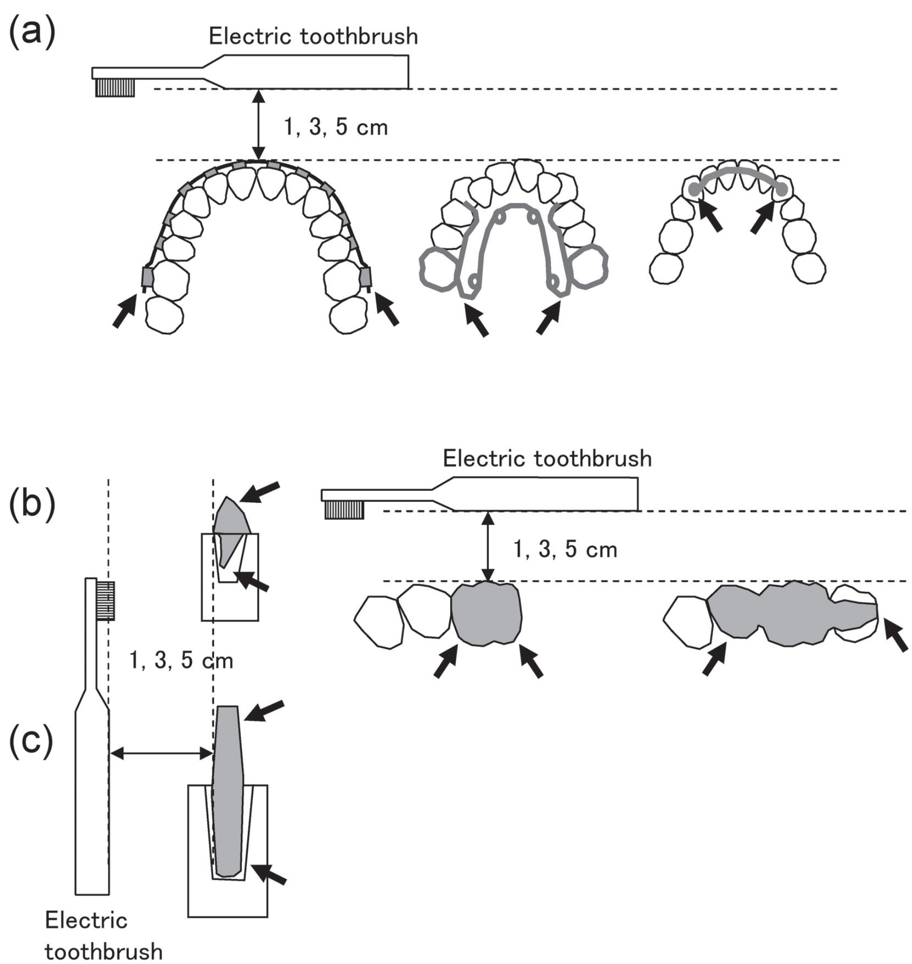

Fig. 1 Schematic representation of experiments for estimating induced electric currents.
(a): Orthodontic appliances: a multibracket system, a quadhelix expansion appliance and a canine-to-canine retainer
(b): Prosthetic appliances: a metal core, a full cast crown and a bridge
(c): Dental implant
Arrows indicate the positions of digital multimeter electrodes for estimation of voltage and current.

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 = $(ACI^2+DCI^2)^{1/2}$). From the results of preliminary study, electric current induced by electric toothbrushes was ostensibly alternating current, so its value measured in AC+DC mode was practically identical to that in AC mode. The positions of the electrodes and electric toothbrushes relative to the dental appliances are shown in Fig. 1. Induced electric current was estimated at a distance of 1, 3 or 5 cm between the front of the toothbrush and the appliance (Figs. 1a left, 1b and 1c) or central incisors (Fig. 1a, center and right). Metal core and dental implants were placed in acrylic jigs when estimated (Figs. 1b and c). Center of toothbrushes were placed parallel to appliances or central incisors of dental models. We also estimated the electric current induced between only the connecting anode and cathode (*i.e.* with no dental appliance), and confirmed that no electricity was detected from electric toothbrushes at a distance of 1, 3 or 5 cm (data not shown). Induced electric voltage and current in the appliance estimated in this study was shown in Fig. 2.

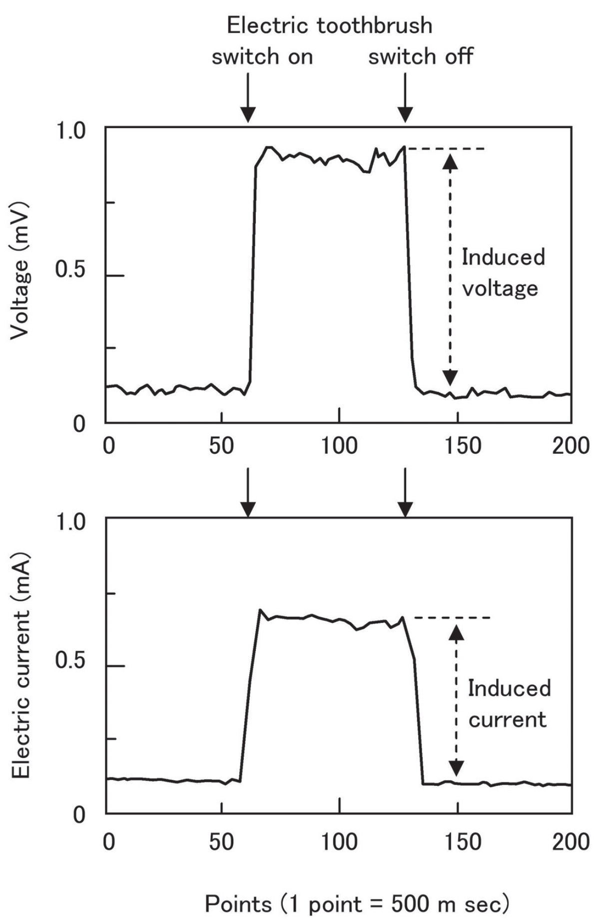

Fig. 2 Electric current induced in the multibracket system by the Sonicare HX9100 at a distance of 1 cm between the electric toothbrush and the appliance.

Experimental conditions, data and statistical analysis
All experiments were performed in a laboratory environment maintained at 22±1°C without magnetic shielding. Each experiment was repeated seven times independently, with the maximum and minimum values in each data set being removed before calculation of mean values. Data are given as the mean±standard deviation. The statistical significance of the differences within and between groups was determined with two-way ANOVA Bonferroni's post-test comparing all columns. Statistical significance was accepted at $p<0.05$.

RESULTS

Low frequency magnetic fields produced by electric toothbrushes
We estimated the magnetic fields generated by various electric toothbrushes (Braun Oral-B, GC PRINIA Slim, Lion VibrateCare Dental ExSystema, and Philips Sonicare HX6100 and HX9100 models). Preliminary experiments indicated that all electric toothbrushes generated very weak magnetic fields, but not at frequencies above 2000 Hz. We therefore estimated magnetic fields generated by electric toothbrushes at 1–2000 Hz, a range within which all electric toothbrushes generated their peak magnetic fields (Fig. 3).

A typical profile of the generated magnetic field consists of a single large peak at 4–5 Hz and several moderate-to-large peaks at 1–2000 Hz (Figs. 3a–e). In magnetic fields of 4–5 Hz, the Oral-B, PRINIA and VibrateCare models generated ~70–90 μT, whereas the Sonicare models created 40–50 μT. In contrast, at 1–2000 Hz, only Oral-B and the Sonicare brushes generated peaks of over 0.4 μT, whereas PRINIA and VibrateCare did not. Furthermore, at 0.2–1000 Hz, only the Sonicare brushes generated peaks over 10 μT. The magnetic fields from these electric toothbrushes could be detected at both their front and back surfaces.

Electric current induced by electric toothbrushes in dental appliances
The results of our experiments demonstrating the induction of electric voltage and current in dental appliances by electric toothbrushes are shown in Table 1. Magnetic fields were inversely related to the distance between the brush and the appliance, with fields decreasing in strength as distance increased. All types of appliance (orthodontic, prosthetic, and dental implants) experienced electric voltage and current induced by electric toothbrushes.

In orthodontic appliances, those with long wires experienced the highest electric voltage and current, whereas in prosthetic appliances the current induced was proportional to the amount of metal in the crown and bridge (Tables 1A and B). Coating of dental implant fixtures with apatite did not affect the induction of electric current, with both coated and uncoated fixtures experiencing current generated by the toothbrushes

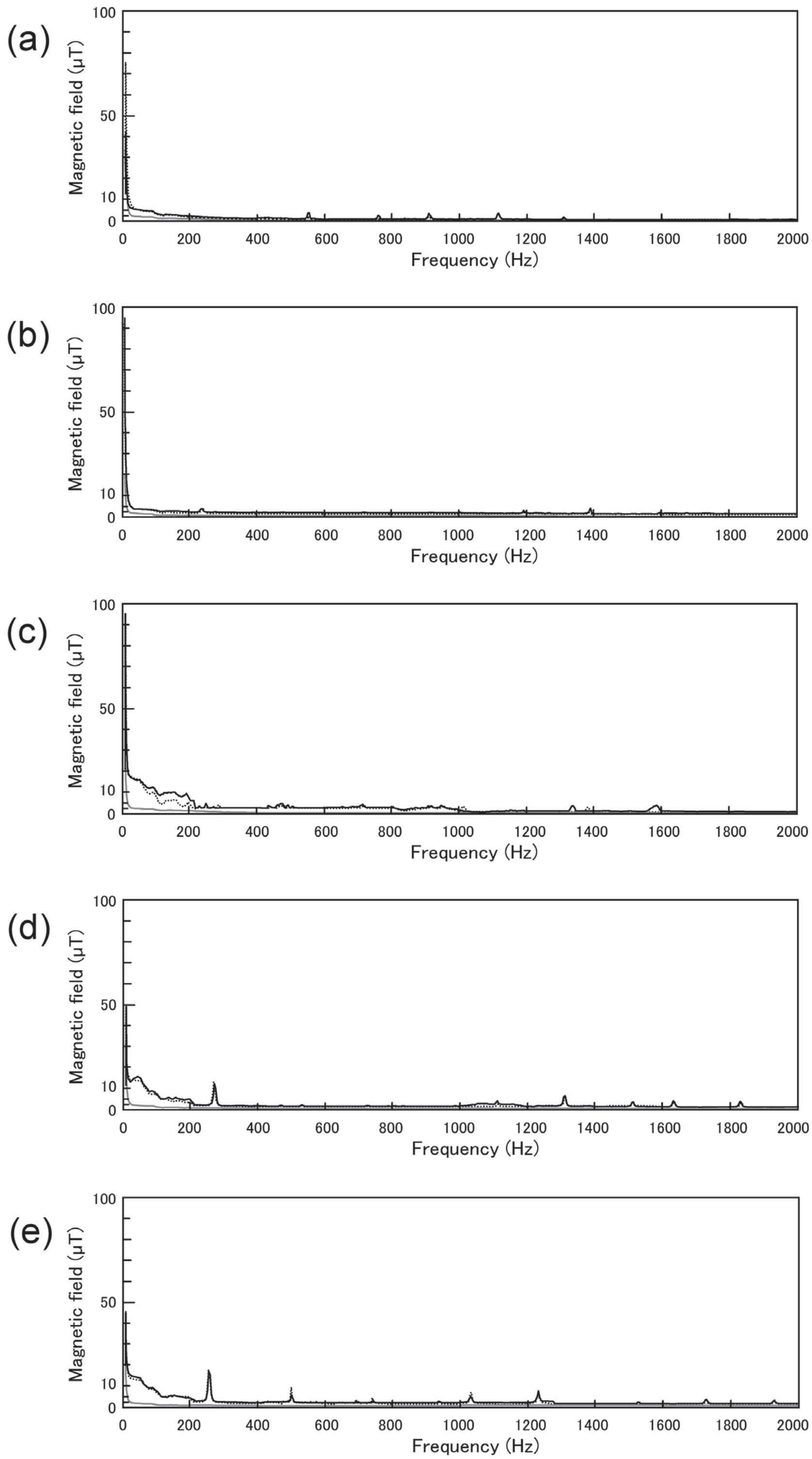

Fig. 3 Low frequency magnetic fields produced by electric toothbrushes.
(a): Braun Oral-B; (b): GC PRINIA Slim (Panasonic); (c): Lion VibrateCare Dental Ex Systema (OMRON); (d) Philips Sonicare HX6100; (e): Philips Sonicare HX9100. Black line indicates the magnetic fields measured at the front of the electric toothbrush when switched on. The dotted line indicates magnetic fields measured at the back of the brushes when switched on. The gray line denotes magnetic fields measured from toothbrushes when switched off.

Table 1 Electric voltage and current induced in dental appliances by electric toothbrushes

A. Induced voltage

Induced voltage (μV)	Distance (cm)	Brown OralB	GC PRINIA	Lion VibrateCare	Philips Sonicare HX6100	Philips Sonicare HX9100
Multibracket system	1	8±1	8±2	11±3	724±18^{a,b,c}	860±13^{a,b,c,d}
	3	6±1	6±1	6±1*	604±12^{a,b,c,*}	716±17^{a,b,c,d,*}
	5	6±1	4±1*	4±1*	541±28^{a,b,c,*,**}	625±19^{a,b,c,d,*,**}
Quadhelix	1	6±1	3±1^{a}	7±1^{b}	594±24^{a,b,c}	380±24^{a,b,c,d}
	3	4±1	3±1	5±1	164±21^{a,b,c,*}	11±2^{a,b,c,d,*}
	5	3±0*	2±1	5±1^{a,b}	88±10^{a,b,c,*,**}	3±1^{d,*,**}
Canine-to-canine retainer	1	5±1	3±1	2±1^{a}	72±7^{a,b,c}	123±13^{a,b,c,d}
	3	2±1*	2±0	1±1	31±3^{a,b,c,*}	38±6^{a,b,c,*}
	5	1±1**	1±1	1±0	13±5^{a,b,c,*,**}	16±4^{a,b,c,*,**}
Metal core	1	2±0	2±0	2±0	84±9^{a,b,c}	106±8^{a,b,c,d}
	3	1±0*	2±0	2±0	26±2^{a,b,c,*}	43±5^{a,b,c,d,*}
	5	1±0*	1±1	1±0*,**	10±1^{a,b,c,*,**}	9±2^{a,b,c,*,**}
Full cast crown	1	2±0	2±0	2±1	184±20^{a,b,c}	282±25^{a,b,c,d}
	3	2±0	1±0	1±0	38±8^{a,b,c,*}	107±11^{a,b,c,d,*}
	5	1±0*	1±1	1±0	7±1^{a,b,c,*,**}	20±5^{a,b,c,d,*,**}
Bridge	1	16±2	2±0^{a}	69±5^{a,b}	390±12^{a,b,c}	486±19^{a,b,c,d}
	3	12±1*	2±1^{a}	3±1^{a,*}	103±13^{a,b,c,*}	175±14^{a,b,c,d,*}
	5	3±1*,**	1±0^{a}	2±1*	35±5^{a,b,c,*,**}	77±9^{a,b,c,d,*,**}
Implant without apatite	1	2±1	3±1	2±1	10±2^{a,b,c}	19±1^{a,b,c,d}
	3	2±1	2±0	1±1	4±1^{a,b,c,*}	8±1^{a,b,c,d,*}
	5	1±0	1±1	1±0	2±1*	4±1^{a,b,c,*,**}
Implant with apatite	1	2±1	2±1	2±1	15±2^{a,b,c}	34±4^{a,b,c,d}
	3	2±1	2±0	2±1	8±1^{a,b,c,*}	14±0^{a,b,c,d,*}
	5	2±1	1±0**	1±0	5±1^{a,b,c,*,**}	8±1^{a,b,c,d,*,**}

B. Induced current

Induced current (μA)	Distance (cm)	Brown OralB	GC PRINIA	Lion VibrateCare	Philips Sonicare HX6100	Philips Sonicare HX9100
Multibracket system	1	16±1	5±1^{a}	3±1^{a}	487±15^{a,b,c}	537±26^{a,b,c,d}
	3	12±2	2±1^{a,*}	1±1^{a}	434±13^{a,b,c,*}	485±15^{a,b,c,d,*}
	5	10±2*	1±1^{a,*}	1±0^{a}	374±17^{a,b,c,*,**}	451±25^{a,b,c,d,*}
Quadhelix	1	70±9	66±3	52±2^{a,b}	918±22^{a,b,c}	70±9^{c,d}
	3	42±5*	53±5*	46±4	480±41^{a,b,c,*}	42±5^{b,d,*}
	5	32±3*,**	38±4*,**	40±2^{a,*}	99±13^{a,b,c,*,**}	32±3^{c,d,*,**}
Canine-to-canine retainer	1	31±8	3±1^{a}	4±2^{a}	189±12^{a,b,c}	395±25^{a,b,c,d}
	3	15±3*	2±1^{a}	2±1^{a}	143±11^{a,b,c,*}	215±26^{a,b,c,d,*}
	5	4±2*,**	1±1	1±0^{a,*}	74±10^{a,b,c,*,**}	106±8^{a,b,c,d,*,**}
Metal core	1	12±3	2±1^{a}	5±2^{a}	418±26^{a,b,c}	528±28^{a,b,c,d}
	3	6±2*	2±1	2±1^{a}	256±38^{a,b,c,*}	308±14^{a,b,c,*}
	5	3±1*	1±0^{a}	1±0^{a,*}	146±30^{a,b,c,*,**}	175±13^{a,b,c,*,**}
Full cast crown	1	10±3	17±3^{a}	7±2	691±28^{a,b,c}	952±33^{a,b,c,d}
	3	5±1*	3±1*	3±1,*	411±18^{a,b,c,*}	525±23^{a,b,c,d,*}
	5	3±1*	2±1*	1±0^{a,*,**}	220±28^{a,b,c,*,**}	272±30^{a,b,c,*,**}
Bridge	1	108±10	8±2^{a}	58±6^{a,b}	1191±14^{a,b,c}	1371±60^{a,b,c,d}
	3	43±5*	3±1^{a,*}	5±2^{a,*}	605±41^{a,b,c,*}	870±46^{a,b,c,d,*}
	5	7±1*,**	2±1^{a,*}	2±1^{a,*}	328±26^{a,b,c,*,**}	470±16^{a,b,c,d,*,**}
Implant without apatite	1	3±1	2±1	3±1	109±9^{a,b,c}	170±11^{a,b,c,d}
	3	3±1	1±1	2±1	51±7^{a,b,c,*}	108±5^{a,b,c,d,*}
	5	2±0	1±0	1±0^{a,*}	24±2^{a,b,c,*,**}	45±5^{a,b,c,d,*,**}
Implant with apatite	1	12±3	2±0^{a}	3±1^{a}	95±4^{a,b,c}	142±7^{a,b,c,d}
	3	3±1*	2±1	2±0	40±3^{a,b,c,*}	84±5^{a,b,c,d,*}
	5	1±0*,**	1±0	1±0*	16±3^{a,b,c,*,**}	35±2^{a,b,c,d,*,**}

n=5 for each experimental condition. Data were analyzed by two-way ANOVA with Bonferroni's post-test to define which differences were statistically significant. Superscript letters denote statistically significant differences (p<0.05) within each row compared to a) Braun OralB; b) GC Prinia; c) Lion VibrateCare; d) Philips Sonicare HX6100, and within each column of each appliance in each electric tooth brush group compared to *; 1cm, **3cm.

(Tables 1A and B). Voltage and current in each appliance by facing the electric toothbrush switched off, *e.g.* non-induced current, at the distance of 1cm from each appliance was 0.2±0.1μV and 0.2±0.0 μA, respectively.

The rank order with which electric toothbrushes generate electric voltage and current in dental appliances is: Sonicare HX9100>Sonicare HX6100>>Oral-B≧PRINIA≧VibrateCare.

DISCUSSION

The role of low frequency electromagnetic fields in carcinogenesis, especially of leukemia and central nervous system tumors, has been well documented. Ahlbom *et al.* demonstrated, by pooled analysis, the risk of developing childhood leukemia following exposure to 0.4 μT (*i.e.* the commercial frequency) in nine countries[8]. Floderus *et al.* also reported that occupational exposure to electromagnetic fields elevated the risk of developing leukemia[9]. Conversely, other reports have found no significant correlation between exposure to electromagnetic fields and leukemia[10,11]. Results from studies into the correlation between electromagnetic fields and the risk of central nervous system tumors are also equivocal[9,11]. IARC, ICNIRP and WHO have each established guidelines and criteria outlining the roles and risks of magnetic fields in carcinogenesis[1-3].

Electric toothbrushes produce magnetic fields at 1–2000 Hz, generating a single large peak at 4–5 Hz and several further moderate-to-large peaks at 1–2000 Hz (Fig. 3). According to a report of magnetic fields generated by electric home appliances in 2003 (which ranged between 5 and 32000 Hz), electric tooth brushes generated magnetic fields totaling 3.61 and 4.59 μT at their front and back sides, respectively (*i.e.* 3.5 and 4.31 μT at 250 Hz; 0.74 and 0.81 μT at 750 Hz; and 0.68 and 0.74 μT at 1250 Hz[6]. Except for the magnetic fields evident at 4–5 Hz, the total strength of the magnetic fields generated by the toothbrushes studied here (except the Sonicare models) were similar to these previous results. However, the frequencies at which peak magnetic field generation was detected were not consistent, and the toothbrushes were ranked, for strength of field generated, as Sonicare HX9100≧Sonicare HX6100>>Oral-B>VibrateCare≧PRINIA. At 4–5 Hz, although we experienced difficulty in estimating the magnetic fields because of limitations in the measuring range of the instrument, we found that all brushes generated much higher values than the total values reported by the Association for Electric Home Appliances in 2003[6]. Having measured these magnetic fields ten times with similar results, we believe that our measured values at 4–5 Hz, collected using a spectrum analyzer, are correct.

It is thought that magnetic fields with extremely low frequency (*i.e.* less than commercial frequency (50/60 Hz)), are closely linked to elevation of cancer risk. Many reports indicate that cancer risk begins to increase when exposure to magnetic fields at 50/60 Hz exceeds a limit of 0.4–0.5 μT[8-11]. Magnetic fields from electric toothbrushes were found to be much higher than that value. However, in contrast to the magnetic fields described in these previous reports where exposure was to the whole body and for extended periods of time, the potential health problems associated with magnetic fields generated by electric toothbrushes might be mitigated by their intermittent and brief usage[8-11].

In low frequency magnetic fields, the strength of the electric current induced is thought to be more important than the strength of the magnetic field itself in influencing the health of living bodies[12]. Many electric home appliances generate magnetic fields at low frequency[6] that could induce electric current in the human body and within metallic objects and devices worn in or on the body[7]. Electric current in oral appliances (*i.e.* galvanic current) is known to induce pain, discomfort and corrosion of metallic dental appliances[4,5]. We have shown here (Tables 1A and B) that such currents can be generated by electric toothbrushes. The Phillips Sonicare brushes were the most adept at inducing intra-appliance current, with Oral-B, PRINIA and VibrateCare generating lower currents. This rank order was almost identical to the order of strength in which these brushes produced a magnetic field. These currents were seen in all types of appliance but especially those with long metallic shapes and/or high metal content (Tables 1A and B). However, the currents produced by the brushes differ from the galvanic currents described previously, and might be due to not only electromagnetic field but also vibration of them. Firstly, the voltage values required for galvanic corrosion are very high (several tens to hundreds of mV), whereas current values in the galvanic corrosion model were very low (several tens to hundreds of nA)[4,5]. In contrast, the electric currents induced by electric toothbrushes were in the order of μV–mV and μA–mA (Tables 1A and B). Secondly, galvanic current was direct current, whereas electric current induced by electric toothbrushes was alternating current. Thirdly, galvanic current was produced whenever two different metals came into contact, whereas the electric currents induced by brushes flowed in dental appliances only during periods when the brushes were switched on (Fig. 2). Fourthly, galvanic current was one of the causes of metal corrosion, whereas induced electric current in dental appliances should not be direct cause of metal corrosion.

In this study, we have shown that the electric toothbrushes generate low frequency magnetic fields and induce electric current in dental appliances. Based on our results, we cannot speculate on how the differences between these currents and the galvanic currents described previously[4,5] will influence their relative effects on pain, discomfort and human oral health. We have attempted to decrease the magnetic fields arising from electric toothbrushes using different types of plastic, metal plates and chemical fibers, but found all of these to be ineffective (data not shown). It is very difficult to protect ourselves from low frequency magnetic fields because they are able to pass through human tissue and most other materials, including glass, plastic, metals and concrete[13]. It is thought that the only true method for defending against low frequency electromagnetic fields is to preclude their generation by electric home appliances, including electric toothbrushes. We suggest that further study is required to clarify the mechanisms by which electric currents induced by magnetic fields impact on human oral health and whether countermeasures can be developed to protect against their effects.

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