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ORTHODONTIC ARCHWIRES AND BRACKETS MAY INTERACT WITH MOBILE PHONES IN CLOSE PROXIMITY

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Mobile phones are the most popular one-to-one communication method in world. Many concerns have been raised regarding the possible effects of radiations emitted by these devices. We tested whether orthodontic wires may conflict with electromagnetic waves generated by mobile phones and what are the potential effects on saliva. We ware interested in the differences between two types of orthodontic appliances, namely between the NiTi wires/NiTi brackets and NiTi wires/ceramic brackets. In this study we measured the pH average values in the presence of electromagnetic fields generated by mobile phones in 9 groups of patients. We used 10 patients in each group (90 people in total). For pH measurements we used a PL-600 Lab pH-meter. In our study we have observed a temporary decrease in pH values of saliva in patients exposed to GSM 900-MHz. The average pH value under normal conditions was 7.02 (SD=0.48). When the mobile phone was used, the average pH value decreased to 6.88 (SD=0.48). When the mobile phone was used in combination with NiTi round orthodontic wires of 0.014mm and ceramic brackets the average pH value decreased to 6.81 (SD=0.53). In the presence of NiTi rectangular orthodontic wires of 0.021mm × 0.025 mm and NiTi brackets, the average pH value decreased even further to 6.73 (SD=0.5).

Key words: orthodontic archwires, mobile phones, pH values, saliva, brackets, alloys.

INTRODUCTION

In recent years, orthodontists have started questioning whether the materials they use actually have a sufficient degree of biocompatibility. For studies made on biological processes involving metal dental aids, the oral cavity provides a diverse environment. Materials used in orthodontics interact continuously with physiological fluids in the oral cavity. Saliva (pH range of 5.2 to 7.8) is a hypotonic solution component of oral fluid, containing bioactonate, chloride, potassium, sodium, nitrogenous compounds and proteins[1,2]. Compared to other parts of the human body, teeth are also exposed to extreme temperature variations (*i.e.* ice cold temperatures of 0˚C or 60˚C of soup of hot coffee) which further participate to an unpredictable environment[3-6]. The complex interplay between different factors, such as temperature, pH, quality and quantity of saliva, enzymes, physicochemical properties of solids and liquids or dental plaque, may influence corrosion processes[2]. Accordingly, when the orthodontic appliances are placed in a hostile electrolytic environment the degradation of materials by electrochemical attack is of particular importance[7]. In the active environment of saliva the ions and non-electrolytes constantly flow against wires, brackets and bands. Galvanic differences between metal alloys and physiological fluids in the oral cavity can trigger electrochemical reactions which can further lead to corrosion. Generally, corrosion processes occur from the progressive dissolution of a surface film or loss of metal ions directly into solution.

A critical factor that determines the biocompatibility of alloys used in orthodontics is their resistance to corrosion[8,9]. In order to correct irregularities in the position of the teeth, a constant stress is created within periodontal ligament. This is usually obtained trough the orthodontic archwire conforming to the alveolar or dental arch linked to dental braces. In order to apply specific forces and move the teeth into a desirable alignment, orthodontic wires are shaped into various configurations.

Ultimately, the bracket performs the transmission of forces from the orthodontic wire to the periodontal ligament tissues in order to effect the tooth movement. Thus, changes in the distribution of the circulatory system at the periodontal level caused by applied forces induce drastic biological responses, leading to bone remodeling. Generally, the bone tissue is reabsorbed by osteoclast cells in the direction of the applied force and generated by osteoblast cells in the opposite direction. Also, the end result of the treatment requires a period of contention in order to stabilize teeth in their new position (generally a short thin wire on the back teeth is applied). Duration of contention period varies depending on age, type of anomaly and medication.

In practice, several types of materials are commonly used, such as precious (Au, Ag, Pt) and non-precious alloys (Cr, Co, Mo, Ni), titanium and titanium alloys[10].

Orthodontic archwires and brackets used in malocclusion treatment may be fabricated from several alloys, most commonly from stainless steel, nickel-titanium alloys (NiTi), β-titanium alloys (composed primarily of titanium and molybdenum) and cobalt-chromium-nickel alloys[11]. Except precious metals such as pure gold and platinum, titanium and titanium based alloys have the greatest corrosion resistance. The osseointegration property and other biocompatibility qualities of titanium (ie. non- toxicity) made it a favorite in the medical industry, from prosthetics up to dental implants. Moreover, patients with titanium implants can be examined with magnetic resonance imaging (MRI) due to a non-ferromagnetic property of titanium. In contrast, metal components of used alloys, like iron, nickel or cobalt are common ferromagnetic metals.

Although safe for the patient, artifacts in magnetic resonance imaging have been reported due to metallic dental objects[12]. According to their *magnetic susceptibility*, all substances placed in a magnetic field are magnetized to a certain degree[13-16].

However, regardless of the chosen metal alloy, very little has been investigated about the impact of high frequencies generated by mobile phones on orthodontic wires. The cell phone is the most popular one-to-one communication method in world. Nevertheless, many concerns have been raised regarding the possible effects of radiations emitted by these devices.

Our hypothesis was that radio-frequency magnetic fields from mobile phones may interfere in various ways with the orthodontic treatment. The orthodontic apparatus may stay in the oral cavity for many years, especially in the case of older patients. Then, the effects of induction may be even more radical for corrosion processes of orthodontic metal alloys or for the outcome of the treatment.

A radio-frequency (RF) magnetic field can transfer energy by means of electromagnetic induction in the surrounding areas. A radio-frequency alternating current passed through a coil of wire (*i.e.* the mobile phone antenna) acts as the transmitter, while a second coil (*i.e.* or any conducting object) can act as the receiver. Shortly, the current flow through the first coil induces a voltage across the ends of the second coil (*i.e.* orthodontic wire) through electromagnetic induction.

Although they are low-powered radiofrequency transmitters, mobile phones are operating at frequencies between 450 MHz and 2700 MHz. Essentially, the RF energy that is radiating from the antenna of the mobile phone seeks to communicate to the nearest cell phone relay tower. Thus, depending upon the distance to the nearest relay tower, mobile phones can change their power output in the range of 0.1 watts up to 2 watts. As the phone gets closer to the relay tower (the good reception areas), the transmitter output power is diminishing automatically. Consequently, long distances from the relay tower increase the power output of the phone transmitter. Signal penetration losses inside buildings also increase the power output of the phone transmitter. The reported measurements for the average penetration losses are between 7.6 dB and 16.4 dB depending upon building materials and the operation frequency[17-20].

As the radiofrequency signals may interfere with other electronic devices (*i.e.* electro-medical or navigation systems), turning cell phones “off” is often a mandatory request in places with a high security risk, such as hospitals or airplanes.

Therefore, the aim of this study was to assess the hypothesis whether there is a direct relationship between radio-frequency magnetic fields generated by mobile phones and the orthodontic wires/brackets.

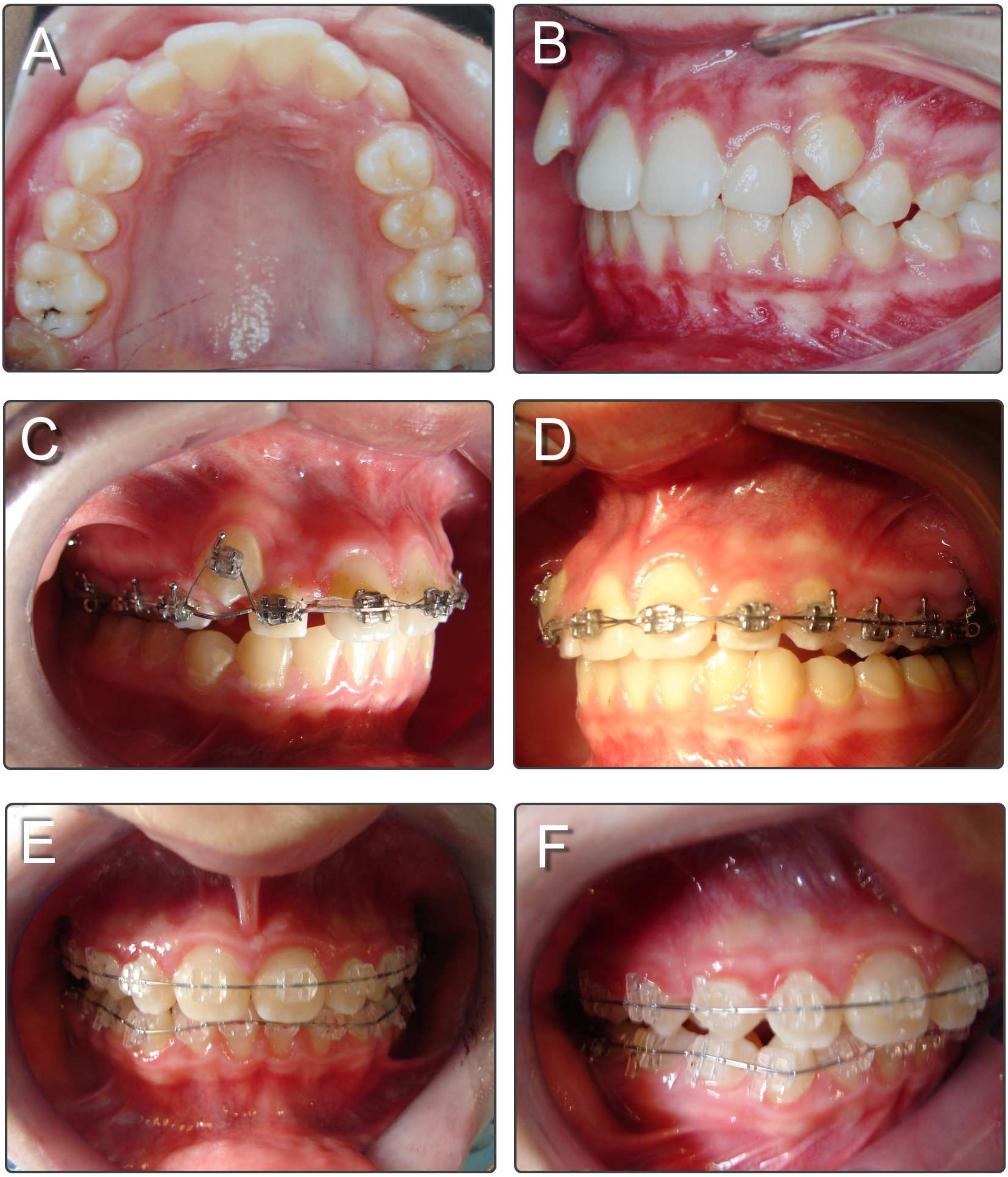

Fig. 1. Common materials used in orthodontics. (**A**,**B**) classic example of malocclusion, (**C**,**D**) metallic orthodontic wires and metalic brackets, (**E**,**F**) metallic orthodontic wires and ceramic brackets.

MATERIALS AND METHODS

GSM is a digital mobile phone standard used in Europe and other countries. The 900 MHz spectrum is commonly used because is advantageous for mobile network operators (when compared with the 1800 MHz spectrum bands and 2100 MHz), as electro-magnetic properties of the lower frequencies allow greater geographical coverage, which is an important factor especially in the less populated areas.

In this study we measured the pH average values in the presence of electromagnetic fields generated by mobile phones in 9 groups of patients. We used 10 patients in each group (90 people in total). The average age of the entire lot was 22 years.

We used NiTi round orthodontic wires of 0.014mm and NiTi rectangular orthodontic wires of 0.021mm × 0.025mm (Fig. 2E). NiTi round orthodontic wires for lingual orthodontic appliances (Fig. 2D) or special cases such as the loops (Fig. 2B) formed for the initial adjustments early in the treatment or the anchoring bracelets (Fig. 2A), were also considered (see results).

We ware interested in the differences between two types of orthodontic appliances, namely between the NiTi wires/ NiTi brackets and NiTi wires/ceramic brackets. For pH measurements we used a PL-600 Lab pH meter (Fig. 3B). All pH measurements of saliva ware taken inside the oral cavity (Fig. 3A).

Measurements were made as follows:

I. NCP/NWB (no cell phone/no wire or brackets) case. The pH values of saliva have been measured without the presence of orthodontic appliances or cell phone radiation exposure (Fig. 1A,B and Fig. 3A).

II. CP/NWB (cell phone/no wire or brackets) case. The patients were exposed to GSM 900-MHz for about 10 minutes and the pH values of saliva have been measured.

III. CP/WCB (cell phone/NiTi wires and ceramic brackets) case. The provisional orthodontic appliances containing NiTi wires and ceramic brackets have been assembled (Fig. 1E,F). Thus, the patients were exposed to GSM 900-MHz for about 10 minutes and the pH values of saliva have been measured.

IV. CP/WNB (cell phone/NiTi wires and NiTi brackets) case. The provisional orthodontic appliances containing NiTi wires and NiTi brackets have been assembled (Fig. 1C,D). Thus, the patients were exposed to GSM 900-MHz for about 10 minutes and the pH values of saliva have been measured.

RESULTS

In our study we observed a temporary decrease in pH values of saliva in patients exposed to GSM 900 MHz. The average pH value under normal conditions (no cell phone/no wire or brackets case) has been 7.02 (SD=0.48) (Table 1).

When the mobile phone was used (cell phone/no wire or brackets case), the average pH value decreased to 6.88 (SD=0.48). When the mobile phone was used in combination with NiTi round orthodontic wires of .014mm and ceramic brackets (Fig. 2E) the average pH value decreased to 6.81 (SD=0.53) (cell phone/NiTi wires and ceramic brackets case). In the presence of NiTi rectangular orthodontic wires of 0.021mm × 0.025mm (Fig. 2E) and NiTi brackets (cell phone/NiTi wires and NiTi brackets case), the average pH value decreased even further to 6.73 (SD=0.5).

In the case of NiTi round orthodontic wires for lingual orthodontic appliances the pH value behaved relatively similar to those found in NiTi rectangular orthodontic wires of 0.021 mm × 0.025 mm and NiTi brackets.

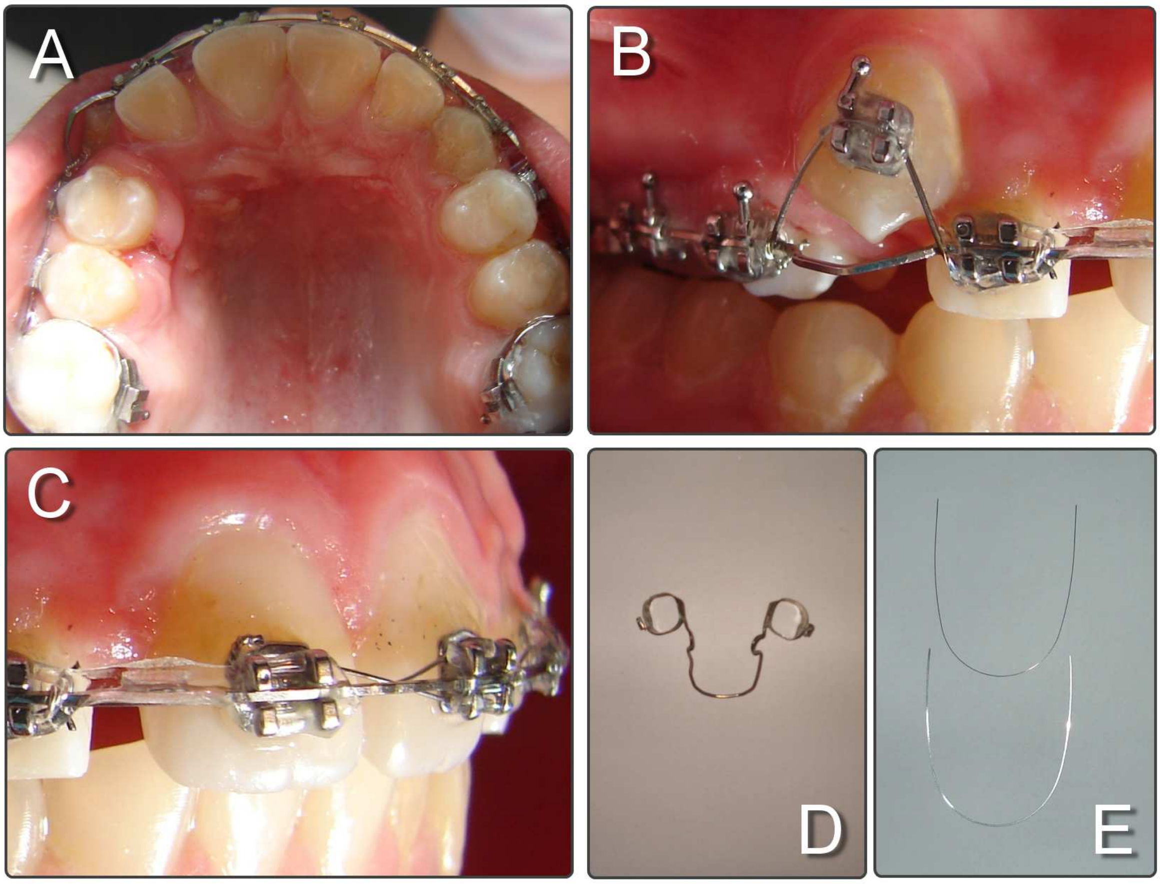

Fig. 2. Common orthodontic appliances used in this study. (**A**) orthodontic appliance fixed to the upper arch teeth, (**B**) loops made for the initial adjustments early in the treatment, (**C**) brackets installation close up, (**D**) NiTi round wires (1.2 mm) for lingual orthodontic appliances, (**E**) NiTi round orthodontic wires of 0.014mm are located at the top of the pannel, while the NiTi rectangular orthodontic wires of 0.021mm × 0.025mm are located at the bottom.

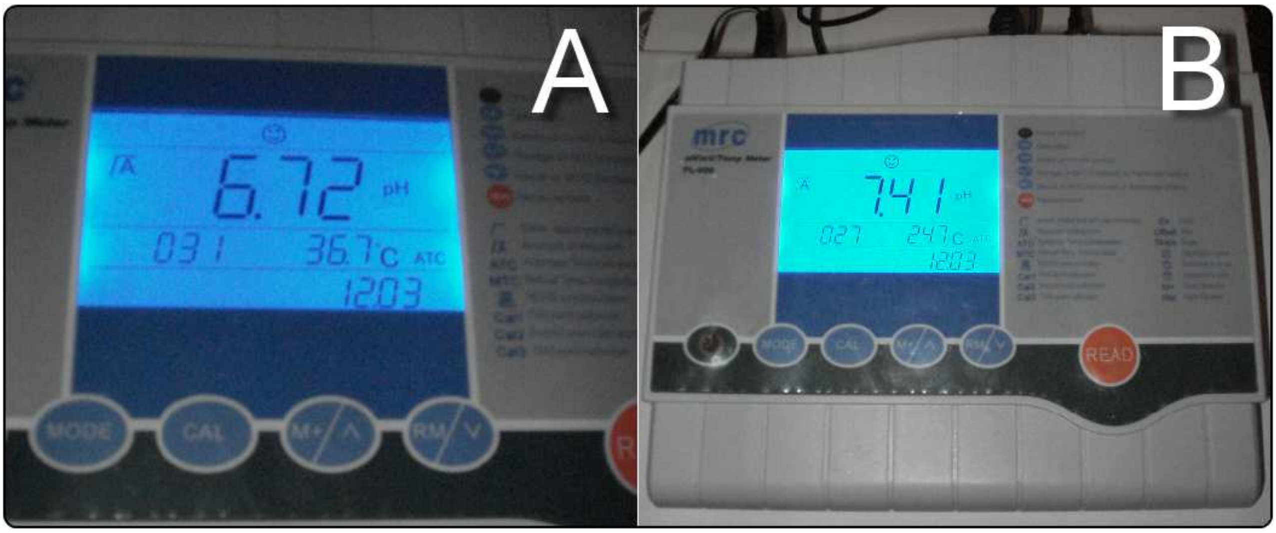

Fig. 3. PL-600 Lab pH meter sample measurements. (**A**) pH measurements of saliva taken in the oral cavity, (**B**) pH measurements of saliva taken outside the oral cavity (a different patient from A).

Table 1

The pH values measured in the oral cavity under the given circumstances

	NCP/NWB	CP/NWB	CP/WCB	CP/WNB
1	6.7	6.3	6.22	6.16
2	7.8	7.29	7.26	7.23
3	7.61	7.26	7.28	7.15
4	6.7	6.44	6.2	6.28
5	6.33	6.4	6.3	6.19
6	7.2	7.39	7.29	7.09
7	7.11	7.25	7.24	7.18
8	6.58	6.37	6.28	6.2
9	7.22	7.29	7.23	7.11
	7.02	6.88	6.81	6.73

Our results suggest that the pH average values in the presence of mobile phones and orthodontic appliances behave almost linearly (Fig. 4B).

It appears to be a direct correlation between the amount of metal in the oral cavity and the temporary decrease of pH in the presence of mobile phones (Fig. 4A,B). One can observe a lower impact on pH of NiTi wires and ceramic brackets in the presence of mobile phones. These results were not verified with other types of pH meters.

DISCUSSION

In the last two decades, scientific research has been focused on the impact of electromagnetic radiation on living matter in general. Daily, artificial RF fields are produced by devices such as mobile phones, microwaves ovens, computers, radio transmitters or radars.

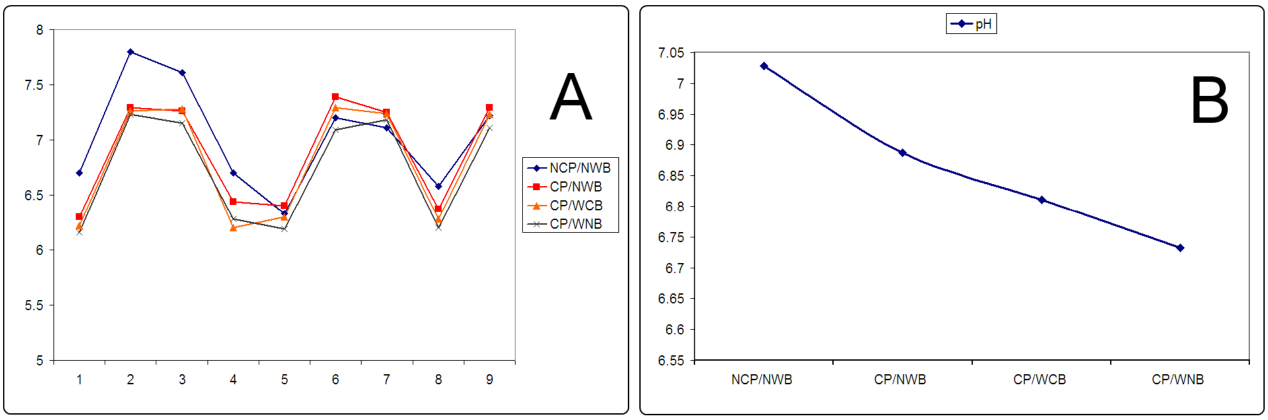

Fig. 4. The pH values measured in 9 groups of patients under the given circumstances. We used four general situations, namely NCP/NWB (no cell phone/no wire or brackets) case, CP/NWB (cell phone/no wire or brackets) case, CP/WCB (cell phone/NiTi wires and ceramic brackets) case, and CP/WNB (cell phone/NiTi wires and NiTi brackets) case. (**A**) pH average values for each group. (**B**) general pH average values for each situation.

Taking into account the frequency-dependent effects, the electromagnetic energy has been classified into non-ionizing and ionizing radiation. Radio frequencies which lack of sufficient energy for ionization, produce mechanical vibration of atoms (ie. agitation of polar molecules) which is further expressed as thermal energy.

Cell phone radiation is too weak to heat biological tissues at dangerous levels or to break chemical bonds. Nevertheless, the radio waves they emit may still change cell behavior.

Non-thermal effects of RF fields on biological tissues were also observed. Accordingly, in the presence of an electromagnetic field, the biological tissue is considered as a medium with losses (absorbance)[25-28]. People using cell phones absorb some of the transmitted energy in their bodies.

Among non-thermal effects, questions related to the direct action of electric and magnetic fields on biological tissues or some other resonance mechanisms, are in a constant focus in the scientific community.

An old example of RF inductive transfer is the crystal radio (a radio without batteries or other power sources) which uses the radio signal itself to power the speaker. Therefore, RF field levels are expressed in watts per square metre (W/m^2). The ICNIRP (International Commission for Non-ionizing Radiation Protection) exposure guidelines[29] are presented in Table 2.

Table 2

The ICNIRP exposure guidelines

	European power frequency		**Mobile phone base station frequency**		**Microwave oven frequency**
Frequency	50 Hz	50 Hz	900 MHz	1.8 GHz	2.45 GHz
	Electric field (V/m)	Magnetic field (μT)	Power density (W/m^2)	Power density (W/m^2)	Power density (W/m^2)
Public exposure limits	5 000	100	4.5	9	10
Occupational exposure limits	10 000	500	22.5	45	

In Europe, the digital mobile telephony uses two distinct frequencies, GSM 900 MHz and DCS 1800 MHz systems. However, both frequencies use the same pulse repetition frequency of 217 Hz. Therefore, both frequencies include microwave carrier frequencies pulsed on extremely low frequencies (ELF). Accordingly, some studies have shown that pulsed electromagnetic field stimulation (PEMF) of MG63 osteoblast-like cells affects differentiation and local factor production[30,31]. Also, currently available experimental studies have shown that radio frequency electromagnetic radiation (RF-EMR) from GSM (0.9/1.8 GHz) mobile phones induces oxidative stress (particularly via the Fenton reaction[32]) on heart, lung, testis and liver tissues[33-35]. Low-intensity ELF and RF exposures on long periods of time that increase free radical production may be considered a plausible biological mechanism for carcinogenesis. Free radicals can damage cells (up to apoptosis) by altering macromolecules, such as DNA, proteins or by breaking parts of the cells membrane.

The impact of radio frequency electromagnetic radiation on DNA integrity it is also a widely accepted phenomena[36-39].

Magnetic field interactions of orthodontic wires during magnetic resonance imaging (MRI) or the effects of a static magnetic field on bone formation around a SLA treated titanium implant were also studied[40,41].

Genetically, higher levels of radio frequency electromagnetic radiation (0.9/1.8 GHz) triggers stress response mechanisms inside the cells closer to the emission source. The stress response is a natural defence mechanism that involves the activation of stress genes as well as the activation of genes that correct DNA or protein mutations.

Probably the most important genetic factor for the orthodontic treatment is the behavior of the osteoblast and osteoclast cells under radio frequency electromagnetic radiation.

Furthermore, capacitively coupled electric fields (CCEF) must also be considered in the orthodontic treatment, since they accelerate proliferation of osteoblast-like primary cells and increase bone extracellular matrix formation in vitro[42]. Exposure of confluent osteoblast-like primary cells to electric fields resulted in enhanced synthesis and secretion of extracellular matrix-related proteins.

CONCLUSIONS

In this paper we have shown that the effects of Radio Frequency (RF) microwave and consequently ELF electromagnetic fields may represent a risks and partially affect the orthodontic treatment.

In this regard, our study shows the temporary pH behavior of saliva in patients exposed to GSM

900-MHz from a clinical point of view. Nevertheless, the biochemical mechanisms regarding these results are unknown.

Studies made in the last 20 years regarding Radio Frequency (RF) microwave and ELF electromagnetic fields, have suggested many adverse biological effects, such as evidence for stress response, effects on gene expression, genotoxic effects or changes in intracellular ionic concentrations. Other more general biological effects include changes in the nervous system and brain function, changes in cell proliferation rates or changes in the reproductive capacity of animals.

In the future we also wish to consider the capacitively coupled electric fields (CCEF) in the orthodontic treatment, because there is sufficient evidence showing an accelerate proliferation of osteoblast-like primary cells and an increase in bone extracellular matrix formation.

REFERENCES

1. de Almeida Pdel V, Grégio AM, Machado MA, de Lima AA, Azevedo LR. *Saliva composition and functions: a comprehensive review*. J Contemp Dent Pract. 2008, 9(3):72-80.
2. Martinez, J.R. and Barker, S. *Ion transport and water movement*. Arch.Oral Biol. 1987, 32, 843-847.
3. Iijima M, Endo K, Ohno H, Yonekura Y, Mizoguchi I. *Corrosion behavior and surface structure of orthodontic Ni-Ti alloy wires*. Dent Mater J. 2001, 20(1):103-13.
4. Iijima M, Endo K, Yuasa T, Ohno H, Hayashi K, Kakizaki M, Mizoguchi I. *Galvanic corrosion behavior of orthodontic archwire alloys coupled to bracket alloys*. Angle Orthod. 2006, 76(4):705-11.
5. Maijer R, Smith DC. *Corrosion of orthodontic bracket bases*. Am J Orthod Dentofac Orthop. 1982, 81:43–48.
6. Maijer R, Smith DC. *Biodegradation of the orthodontic bracket system*. Am J Orthod Dentofac Orthop. 1986, 90:195–198.
7. House K, Sernetz F, Dymock D, Sandy JR, Ireland AJ. *Corrosion of orthodontic appliances--should we care?*. Am J Orthod Dentofacial Orthop. 2008, 133(4):584-92.
8. Jones TK, Hansen CA, Singer MT, Kessler HP. *Dental implications of nickel hypersensitivity*. J Prosthet Dent. 1986, 56(4):507-9.
9. Schmalz G, Garhammer P. *Biological interactions of dental cast alloys with oral tissues*. Dent Mater. 2002, 18(5):396-406.
10. Hubálková H, Hora K, Seidl Z, Krásenský J. *Dental materials and magnetic resonance imaging*. Eur J Prosthodont Restor Dent. 2002, 10:125-30.
11. Brantley WA. *Orthodontic wires.* In: Brantley WA, Eliades T, eds. *Orthodontic Materials: Scientific and Clinical Aspects*. Stuttgart: Thieme; 2001:77–103.
12. Costa AL, Appenzeller S, Yasuda CL, Pereira FR, Zanardi VA, Cendes F. *Artifacts in brain magnetic resonance imaging due to metallic dental objects*. Med Oral Patol Oral Cir Bucal. 2009, 14(6):E278-82.
13. Gray CF, Redpath TW, Smith FW, Staff RT. Advanced imaging: *Magnetic resonance imaging in implant dentistry*. Clin Oral Implants Res. 2003, 14:18-27.
14. Bellon EM, Haacke EM, Coleman PE, Sacco DC, Steiger DA, Gangarosa RE. *MR artifacts: a review*. AJR Am J Roentgenol. 1986, 147:1271-81.
15. Czervionke LF, Daniels DL, Wehrli FW, Mark LP, Hendrix LE, Strandt JA, *et al.*, *Magnetic susceptibility artifacts in gradient-recalled echo MR imaging*. AJNR Am J Neuroradiol.1988, 9:1149-55.
16. Shellock FG, Kanal E. *Aneurysm clips: evaluation of MR imaging artifacts at 1.5 T*. Radiology. 1998, 209:563-6.
17. T. S. Rappaport and S. Sandhu. *Radio Wave Propagation For Emerging Wireless Personal Communication Systems*, IEEE Antennas and Propagation Magazine, 1994, vol. 136, no. 5.
18. A. M. D. Turkmani and A. F. Toledo. *Propagation into and within Buildings at 900, 1800, and 2300 MHz*, in IEEE Vehicular Technology Conference, 1992.
19. J. M. Durante. *Building Penetration Loss at 900 MHz*, in IEEE Vehicular Technology Conference, 1973.
20. E. H. Walker. *Penetration of Radio Signals into Buildings in Cellular Radio Environments*, in IEEE Vehicular Technology Conference, 1992.
21. R. Boyer, G. Welsch, and E. W. Collings. *Materials Properties Handbook: Titanium Alloys*, ASM International, Materials Park, OH, 1994.
22. *Metals Handbook*, Vol. 2 – *Properties and Selection: Nonferrous Alloys and Special-Purpose Materials*, ASM International 10th Ed. 1990.
23. *Metals Handbook*, Vol. 3, *Properties and Selection: Stainless Steels, Tool Materials and Special-Purpose Metals, Ninth Edition*, ASM Handbook Committee., American Society for Metals, Materials Park, OH, 1980.
24. *Structural Alloys Handbook*, 1996 edition, John M. (Tim) Holt, Technical Ed; C. Y. Ho, Ed., CINDAS/Purdue University, West Lafayette, IN, 1996.
25. M. A. Stuchly, and S. S. Stuchly, *Dielectric properties of biological substances – tabulated*. Newspaper of Microwave Power, 1980, vol.15, no. 1, pp. 19-26.
26. H. P. Schwan. *Electrical and acoustic properties of biological materials and biomedical applications*. IEEE Trans Biomedical Eng. 1984, vol.31, no. 12, pp. 872-878.
27. H. P. Schwan, and K. R. Foster. *RF-field interactions with biological systems: electrical properties and biophysical mechanisms*. Proceedings of the IEEE, 1980, vol. 68, no. 1, pp. 104-113.
28. H. E. Bussey. *Measurement of RF properties of materials a survey*. Proceedings of the IEEE, 1967, vol. 55, no. 6, pp. 1046-1053.
29. ICNIRP, EMF guidelines, Health Physics 74, 1998, 494-522.
30. Lohmann CH, Schwartz Z, Liu Y, Guerkov H, Dean DD, Simon B, Boyan BD. *Pulsed electromagnetic field stimulation of MG63 osteoblast-like cells affects differentiation and local factor production*. J Orthop Res. 2000, 18(4):637-46.
31. Sollazzo V, Palmieri A, Pezzetti F, Massari L, Carinci F. *Effects of pulsed electromagnetic fields on human osteoblastlike cells (MG-63): a pilot study*. Clin Orthop Relat Res. 2010, 468(8):2260-77.
32. Fenton H.J.H. *Oxidation of tartaric acid in presence of iron*. J. Chem. Soc., Trans. 1894, 65 (65): 899–911.
33. Mailankot M, Kunnath AP, Jayalekshmi H, Koduru B, Valsalan R. *Radio frequency electromagnetic radiation*

(RF-EMR) from GSM (0.9/1.8GHz) mobile phones induces oxidative stress and reduces sperm motility in rats. Clinics (Sao Paulo). 2009, 64(6):561-5.

34. Esmekaya MA, Ozer C, Seyhan N. *900 MHz pulse-modulated radiofrequency radiation induces oxidative stress on heart, lung, testis and liver tissues*. Gen Physiol Biophys. 2011, 30(1):84-9.
35. Hardell L and C Sage. *Biological effects from electromagnetic field exposure and public exposure standards, Biomed Pharmacother*. 2008, 62(2):104-9.
36. Lai H & NP Singh. *Acute low-intensity microwave exposure increases DNA single-strand breaks in rat brain cells*. Bioelectromagnetics. 1995, 16(3):207-10.
37. Lai H & Singh NP. *Single- and double-strand DNA breaks in rat brain cells after acute exposure to radiofrequency electromagnetic radiation*. Int J Radiat Biol. 1996, 69(4):513-21.
38. Aitken RJ *et al.*, *Impact of radio frequency electromagnetic radiation on DNA integrity in the male germline.* Int J Androl. 2005, 28:171–179.
39. Phillips JL *et al.*, *Electromagnetic fields and DNA damage*. Pathophysiology. 2009, 16(2-3):79-88.
40. Klocke A, Kemper J, Schulze D, Adam G, Kahl-Nieke B. *Magnetic field interactions of orthodontic wires during magnetic resonance imaging (MRI) at 1.5 Tesla*. J Orofac Orthop. 2005, 66(4):279-87.
41. Leesungbok R, Ahn SJ, Lee SW, Park GH, Kang JS, Choi JJ. *The effects of a static magnetic field on bone formation around a SLA treated titanium implant*. J Oral Implantol. 2011.
42. Hartig M, Joos U, Wiesmann HP. *Capacitively coupled electric fields accelerate proliferation of osteoblast-like primary cells and increase bone extracellular matrix formation in vitro*. Eur Biophys J. 2000, 29(7):499-506.