Original Article

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Orthodontic Materials Interacting with Fifth Generation (5G) Electromagnetic Waves

Ortodontik Malzemelerin Beşinci Nesil (5G) Elektromanyetik Dalgalarla Etkileşimi

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ABSTRACT

Objective: Public exposure to radiofrequency (RF) fields from fifth generation (5G) and other sources is known to be below human exposure limits. The interaction of RF fields with the human body has been widely documented, with tissue heating being the primary consequence for RF fields above 100 kHz. This study aimed to reveal possible harm to orthodontic patients associated with 5G electromagnetic waves. The possibility of individuals with orthodontic appliances (metallic braces, porcelain braces, thermoplastic appliances) being more affected by 5G was investigated.

Methods: Sixty extracted human teeth were divided into 5 groups. Different types of brackets, arch, and ligature wires were applied to each group. Each group was exposed to 5G electromagnetic waves (3.6 GHz of frequency) for 60 minutes. Temperature measurements were made inside the canine root canals and in saline solution.

Results: Exposure to a 5G electromagnetic field increased the temperatures of the root canal of the tooth and sodium chloride (NaCl) solution surrounding samples. Temperature increase in the canals were as follows; metal self-ligating braces > mini metal braces > porcelain braces > clear aligner > control. The temperature change in the NaCl solution at the 60th minute was close to each other in the self-ligating braces and mini metal braces groups. The temperature rise of the NaCl solution in the control group was also minimal.

ÖZ

Amaç: Normal şartlarda beşinci jenerasyon (5G) ve diğer kaynaklardan gelen radyo frekans (RF) dalgalarına maruziyetin, insanlar için belirlenmiş sınırlarının altında olduğu bilinmektedir. RF dalgaların insan vücudu üzerine etkileri ile ilgili yapılan çalışmalar 100 kHz'in üzerindeki RF alanları için dokular üzerindeki birincil sonucun ısınma olduğunu göstermiştir. Çalışmamızda, 5G elektromanyetik dalgaların ortodonti hastalarına olası etkilerini ortaya çıkarmak amaçlanmıştır. Farklı ortodontik apareyleri (metal braketler, porselen braketler, termoplastik plaklar) olan bireylerin normal bireylere göre 5G'den daha fazla etkilenme olasılığı araştırılmıştır.

Yöntemler: Altmış adet çekilmiş insan dişi 5 gruba ayrıldı. Her gruba farklı tipte braket, ark ve ligatür telleri uygulandı. Her grup 60 dakika boyunca 5G elektromanyetik dalgalara (3,6 GHz frekanslı) maruz bırakıldı. Sıcaklık ölçümleri köpek diş kök kanallarının içinden ve dişin etrafında bulunan salin solüsyonunda yapıldı.

Bulgular: 5G elektromanyetik alana maruz kalan dişlerin kök kanalı ve çevreleyen sodyum klorür (NaCl) solüsyonunun sıcaklıkları kontrol grubuna göre artış gösterdi. Kanallardaki sıcaklık artışı sıralaması metal self-ligating braket > mini metal braket > porselen braket > şeffaf plak > kontrol şeklindeydi. Altmışıncı dakikada NaCl solüsyonundaki sıcaklık değişimi kendinden bağlanan braket ve mini metal braket gruplarında birbirine yakındı. Kontrol grubundaki NaCl çözeltisinin sıcaklık artışı ise minimum düzeydeydi.

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ABSTRACT

Conclusion: The hypothesis that orthodontic materials alter electromagnetic waves is supported by temperature increases. The ferromagnetic density of the orthodontic materials used was shown to be closely connected to temperature increase.

Keywords: Electromagnetic field, ferromagnetic, orthodontic materials, radiofrequency, telecommunication, 5G

ÖZ

Sonuç: Ortodontik materyallerin elektromanyetik dalgaların yoğunluğunu değiştirdiği hipotezi sıcaklık artışları ile desteklenmektedir. Kullanılan ortodontik materyallerin ferromanyetik yoğunluğunun sıcaklık artışı ile yakından ilişkili olduğu gösterilmiştir.

Anahtar Sözcükler: Elektromanyetik alan, ferromanyetik, ortodontik materyaller, radyofrekans, telekomünikasyon, 5G

Introduction

As has been observed in every area in recent years, the volume of mobile phone use and the numbers of base stations have increased with the development of technology in the field of mobile telecommunications. The increasing use of radio frequency (RF) fields above 6 GHz, particularly for the fifth generation (5G) cellular network, has raised public concerns about its potential adverse effects on human health. Public exposure to RF fields from 5G and other sources is below the human exposure limits set by the International Commission on Non-Ionizing Radiation Protection (1). It has been demonstrated that RF electromagnetic waves emitted from mobile phones and base stations might cause health problems like headaches and further increase the risk of developing brain tumours in humans (2). Many concerns have been raised regarding the possible effects of radiation emitted by these devices that are used by people of all ages. In the study conducted by Ionescu et al. (3), it was shown that there was a temporary decrease in pH values of saliva when people were exposed to electromagnetic waves of mobile phones; and these values decreased even further to lower values in the presence of orthodontic wires and braces. In another study conducted, it was discovered that there were temperature changes and electric currents induced by low-frequency magnetic fields generated by electric toothbrushes and dental curing light devices (1-2000 Hz) on tooth surfaces with or without braces. This study concluded that electric current was induced in tooth tissue, irrespective of whether such teeth were bonded to stainless steel or zirconia braces (4).

Many research claims that 5G RF is of higher frequency and more harmful than 4.5G (LTE) that we have used so far and investigating its possible effects on human health emphasize that the effects of 5G have not been investigated enough yet (5,6). 5G technology is planned to be used in every field of our lives worldwide soon. The 5G system expected to bring forth revolutionary developments is intended to be used not only in mobile phones but also in devices requiring high processing power such as driverless vehicles, home internet, virtual reality, smart security cameras, physical and rehabilitation devices, etc. (7). When this system is deployed after the preparation of its infrastructure, exposure to this electromagnetic field will become inevitable for all individuals.

With this study, it was aimed to examine the fifth-generation electromagnetic waves (frequency 3.6 GHz) of mobile telecommunication systems, which was currently a bone of contention due to the insufficient investigation of its possible effects particularly on human health today, in terms of their interaction with orthodontic materials such as metallic braces, porcelain braces and thermoplastic appliances.

Methods

The study was conducted with 60 human teeth (10 molars, 20 premolars, 10 canines, and 20 anterior teeth) extracted in the Department of Oral and Maxillofacial Surgery at Bezmialem Vakıf University Faculty of Dentistry Hospital. Teeth with impaired enamel integrity, or hypoplastic, decalcified, or cracked teeth, which were not suitable for putting braces, were excluded. Patients were informed about the purpose of the study and their written consent was obtained for participation in this study. The ethics committee approval required for the study was received from the Non-Invasive Clinical Research Ethics Board of Bezmialem Vakıf University (approval number: E-54022451-050.05.04-15499, date: 27.04.2021).

Teeth were put in a jar filled with normal saline [0.9% isotonic sodium chloride (NaCl) solution] and stored in a cabinet protected from light until the tests were performed. Sixty teeth were divided into 5 different groups. To simulate the right amount of ferromagnetic effect, each group of 12 teeth included 2 molars, 4 premolars, 2 canines, and 4 anterior teeth. The pink wax was heated and formed into a box shape; and then, the teeth were fixed with a few drops of pink wax in contact with each other.

The boxes were filled with auto-polymerized acrylic resin (STEADY-RESIN S Polymer, SCHEU-DENTAL GmbH, Germany) around the roots, thus leaving the crowns of the teeth exposed. Following polymerization, the acrylic block was removed from the box to make it ready for the application of orthodontic materials. The following groups were prepared:

1st group: Active Self Ligating metal braces (YES metal self-ligating braces, 022 slot size, HUBIT Co., Ltd, Korea), 0.014” NiTi, bands in molars (American Orthodontics, Sheboygan, Wisconsin, USA).

2nd group: Metal braces (mini diamond metal, 0.018” slot size, Ormco, USA), 0.014” Ni-Ti arch wire, SS wire ligature, bands in molars (American Orthodontics).

3rd group: Porcelain braces (Inspire ICE, 0.022” slot size, Ormco, USA), 0.014” Ni-Ti arch wire, SS wire ligature (American Orthodontics).

4th group: 0.030” essix thermoplastic appliance (Dentsply Raintree Essix, York, Pennsylvania., Keystone Industries, USA).

5th group: Control group, did not receive any orthodontic material (Figure 1).

The blocks prepared were placed in a glass box filled with %0.9 isotonic NaCl solution at 22°. All materials and devices to be used in the study were placed in the Electromagnetic Diagnostic and Measurement Laboratory in İstanbul Technical University Technical University, Electrical and Electronic Engineering Faculty. The temperature of the unreflecting room was controlled by the control unit and a constant room temperature of 22 degrees was achieved. The samples were kept at constant 22 degrees for 24 hours before the experiment and homogeneous heat was provided in the samples.

The signal source was an analog signal generator (Agilent Technologies E8257D PSG, 250 kHz-20 GHz, Colorado Springs, USA). High-frequency magnetic fields radiated from the horn antenna (Double Ridged Broadband Horn Antenna, 3.6 GHz- SCHWARZBECK BBHA 9120 A Schönau, Germany), were measured with a spectrum analyzer (Agilent Technologies E7405A EMC ANALYZER, 100Hz-26.5 GHz, California, USA) (Figure 2). Thus, the temperature changes induced in the tooth groups with different orthodontic materials applied were measured using a thermometer (EXTECH SDL200: 4-Channel Datalogging Thermometer, New Hampshire, USA).

In our research, the inputs to the signal source were as follows: Frequency: 3.6 GHz (Start Frequency: 3 GHz, Stop Frequency: 4 GHz), output power: 16.00 dBm. Each group of teeth was exposed to electromagnetic waves for 60 minutes (Figure 3). During such exposure, the thermometer was inserted into the root canals of the canine teeth, which were accessed through the apex in the experimental groups. These tips were placed to measure the temperature increase inside the root canals of the teeth during exposure (Figure 4). Another tip of the thermometer was placed in the saline solution containing the experimental group at a certain level that would be flush with the top of the teeth.

The values measured with the thermometer for each group were recorded for 60 minutes. Thus, it was possible to monitor temperature changes from the first to the last minute of the exposure of teeth to electromagnetic waves. Although the temperature change was fixed for around half an hour for all groups, it was waited in all groups until the 60th minute to ensure that the temperatures were stable.

Results

Exposure to a 5G electromagnetic field increased the temperatures of the root canal of the teeth and NaCl solution surrounding samples. There were gradually increasing temperature changes observed in each group. A total temperature increases of 1.5 °C was measured at the 60th minute inside the root canal of the teeth in group 1 applied with self-ligating metallic braces with the highest metallic content. However, the temperature increases inside the canals were measured as 0.2 °C at the 60th minute in the control group with no orthodontic materials applied (group 5),

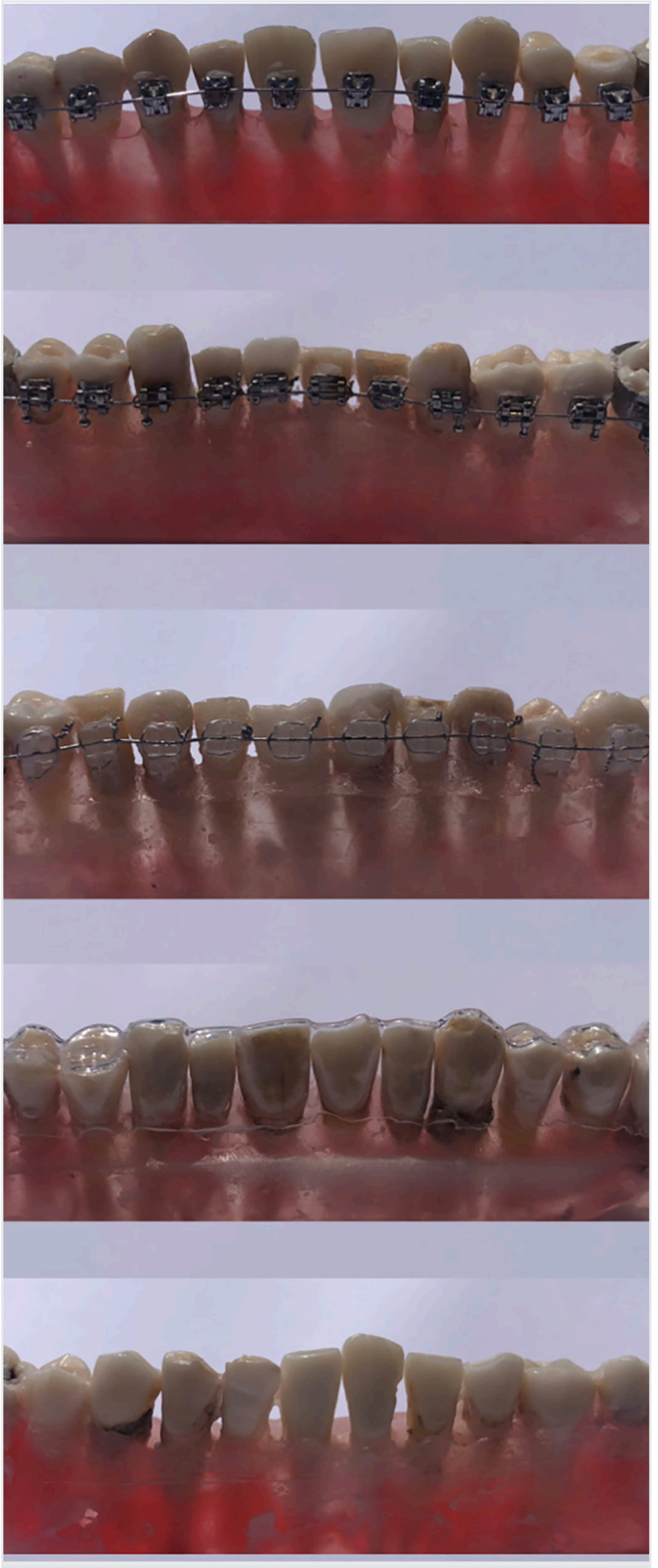

Figure 1. Subject groups (from top to bottom: 1st, 2nd, 3rd, 4th, 5th group)

which reflected the lowest temperature increase measured among all groups. The groups were listed from the group displaying the highest total temperature increase to the group with the lowest temperature increase as follows; group 1 > group 2 > group 3 > group 4 > group 5. The temperature change in the NaCl solution was close to each other for group 1 and group 2 at the 60th minute. The temperature increase of the NaCl solution in the control group was also minimal. Temperature changes of all groups at the 60th minute are given in (Table 1).

Discussion

While the benefits of 5G have been well discussed, and there is no disputing the fact of the need for faster and more reliable wireless communication systems, the implementation of this new technology is raising concerns about the potential health and safety risks associated with exposure to the electromagnetic field emitted by 5G systems (8). The increased use of RF fields above 6 GHz, particularly for the 5G mobile phone network, has sparked public concern about potential health risks. The public's exposure to RF fields from 5G and other sources is below the International Commission on Non-Ionizing Radiation Protection's human exposure limits (ICNIRP). Many researchers have investigated the biological and health effects of RF fields above 6 GHz at exposure levels below the ICNIRP occupational limits (1). But the effects of 5G technologies, which are widely regarded as safe for the public, have never been studied in orthodontic patients. During orthodontic treatment, materials with different ferromagnetic properties are used together in the mouth and the supplier usually does not know the content of

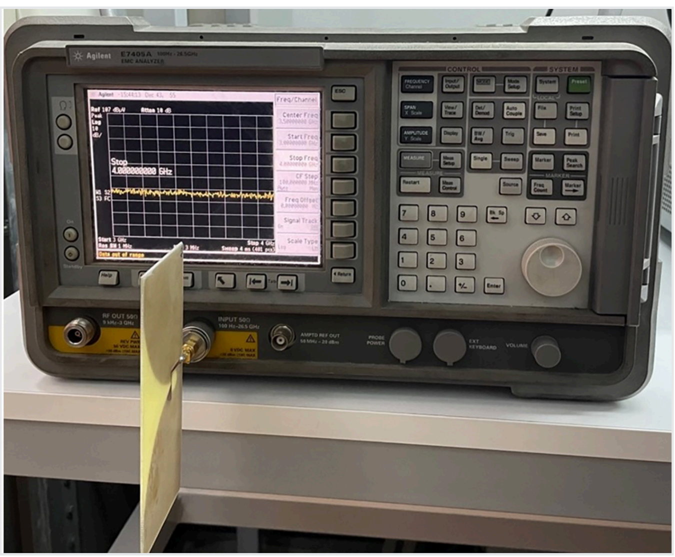

Figure 2. Spectrum analyzer and measurement device

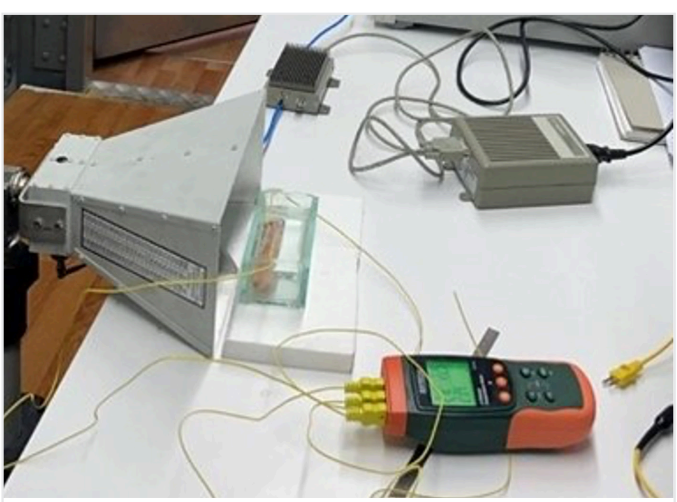

Figure 3. Working system

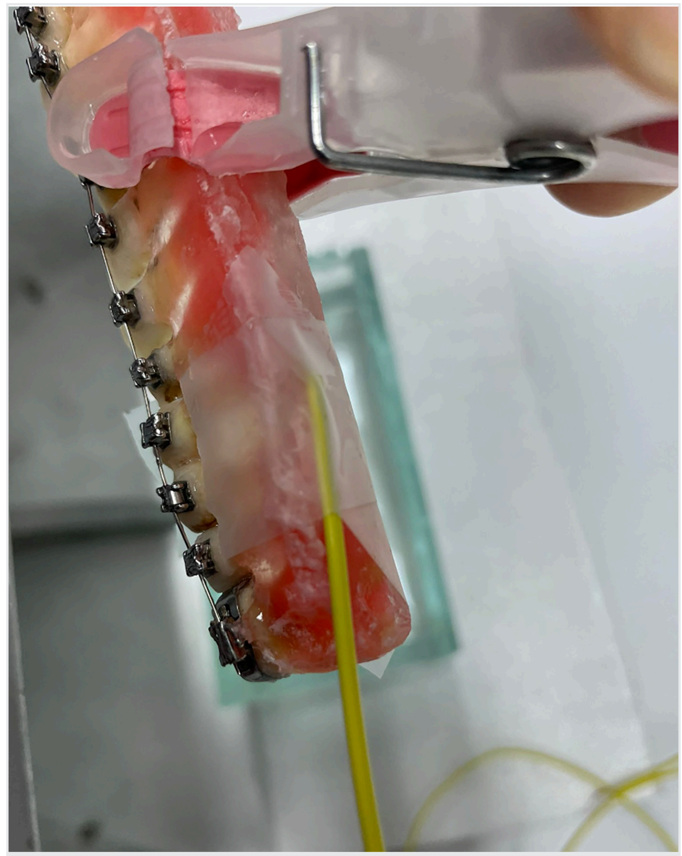

Figure 4. Thermometer tip placement within the root

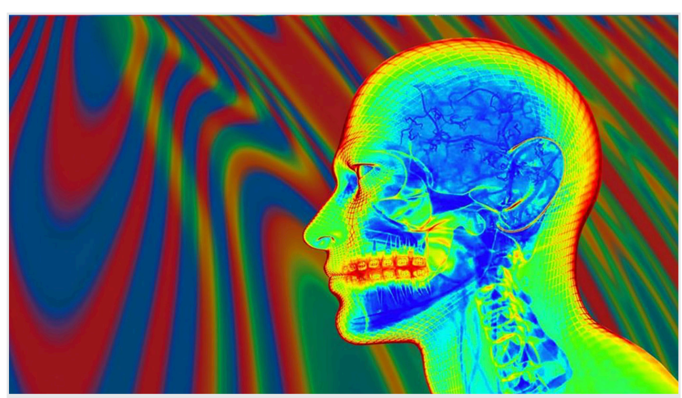

Figure 5. The proposed illustration of a person with braces under RF waves

RF: Radiofrequency

Table 1. Temperature changes of groups

	Group's content	Temperature increase in root canal	Temperature increase in NaCl
Group 1	Self-ligating metal brackets + molar bands + 0.014" NiTi	1.5 °C	1.6 °C
Group 2	Mini metal brackets+ molar bands+ 0.014" NiTi	1.3 °C	1.7 °C
Group 3	Porcelain brackets+ 0.014" NiTi	1.2 °C	0.8 °C
Group 4	0.030" Essix	0.8 °C	1.3 °C
Group 5	Control	0.2 °C	0.4 °C

NiTi: Nickel-titanium, NaCl: Sodium chloride

each material used. The orthodontist may also use components from different vendors combining them on a patient (9). Although stainless steel orthodontic appliances are the most commonly used materials. Titanium, ceramic, and composite materials are also used. Electromagnetic radiation can pass through the structure thanks to the braces' metallic component and the archwire connecting to the various braces. The use of the entire metallic body of orthodontic braces as a radiating antenna element is investigated, and the results have shown that it is a viable option (10). It is shown that residents living near mobile base station antennas experience more headaches, memory changes, tremors, dizziness, depressive symptoms, and sleep disturbance than controls (11).

The temperature increase that occurred in our study was within safe limits (12). However, the effect of ferromagnetic materials working as antennas and altering electromagnetic waves for 24 hours has never been evaluated. during orthodontic treatment, patients take very hot or cold water which shows large differences in the intra-oral temperature and leads to corrosion on archwires (13). The increase in the temperature rises in this study may be more dangerous than those induced by hot nutrients taken in daily life. The heat generated is not due to the balancing of the heat coming from a material taken from outside, but due to constant RF scattering and absorption modified by orthodontic materials. Since the room temperature was kept constant at 22 degrees, the heat produced by the absorption and scattering of RF waves might decrease by the room heat until the heat produced by RF waves reached the equilibrium point and then remained constant. This explained the reason why the intra-root temperature was higher than the saline temperature even though the samples were in an unreflecting room with constant room temperature. At first, the heat increased rapidly. However, the heat increases started to slow down and stabilized after approximately half an hour to 45 minutes, depending on the groups. Therefore, the final values after the stabilization of the heat increases were used. This type of heat increase is commonly referred to as "asymptotic heat increase" and is typically observed in industrial or laboratory environments. In this study, instead of conducting statistical analysis on measurements taken at different times, the decision was made to use the final stabilized value of the heat increases based on the shape and nature of the measured heat increases.

The thermal effect is the most important component in RF exposure over 100 kHz (14). Due to the *in vitro* character of the study, the temperature increase could not be one-to-one with real life. Individuals of all ages will be exposed to 5G for most of each 24 hours. In real life, the penetration depth in soft tissues is minimal (e.g., around 0.85 mm at 30 GHz and 0.5 mm at 60 GHz in cutaneous tissues), thus electromagnetic power absorption is known to be mostly restricted to the skin (15-17). Multilayer skin models have been created to characterize energy absorption and the associated temperature rise (15-18). While these basic models are useful for assessing RF exposure, they do not take into consideration the possibility of children or elderly people wearing metal braces. The thermal time constant of a developing child with a low body mass index wearing an orthodontic appliance containing a high amount of ferromagnetic material, such as a Herbst appliance, may differ from standard animal and human subjects. Our study was the first to draw attention to the question of whether orthodontic treatment patients should be considered a vulnerable population if 5G technologies became widespread (Figure 5).

The findings obtained indicate the interesting fact that the density of the ferromagnetic content of materials is directly proportional to the RF absorption and scattering. This study substantiates the emphasis laid in the literature on the fact that the oral environment with orthodontic appliances is more affected by RF and these interactions should be studied further (4,19,20). This study also showed that the experimental groups with ferromagnetic orthodontic materials were more affected in terms of temperature increase. It has already been shown that cell phone radiations can cause ion release from the appliances of patients undergoing fixed orthodontic treatment and reduce pH levels of saliva (19,20).

Many studies have shown that temperature increase may lead to corrosion; however, the experimental temperatures used are generally above the maximum temperature increase measured in this study (13,21). Radiofrequency may increase the temperature of the surrounding tissues and thus cause dysfunction of facial nerves; the salivary flow rate is increased and there is an alteration of the cytokine expression profile of the salivary gland in heavy cell phone users; and patients with metallic (orthodontic) appliances or restorations should be more cautious as there is the risk of leaching of metallic ions or mercury (19). The mentioned study emphasizing that further human and epidemiological studies are required to evaluate the long-term effect of cell phones on the health of the individual is also justified with the results obtained in this study.

Very few studies regarding the effects of RF on human health were conducted with high frequencies such as 5G (22-24); and most of these studies reached these conclusions by examining quite lower frequency ranges. The conclusion reached in the study indicating that the higher RF planned to be used in the future might cause a temperature increase in tissues was also in line with the results of this study (22). It seems that exposure levels in areas open to the public will continue to be substantially below the exposure limits defined by organizations that develop worldwide guidelines and standards. The study findings yet do not support a conclusion that harmful health impacts are related to RF exposures, including those from 5G systems. Still, it is also pointed out that future studies should take the necessary safety steps to increase validity (25).

In our study, we tried to simulate the amount of materials affecting the RF waves realistically. The main purpose here is not the amount of heating in the root canal, but to demonstrate whether the behaviour of RF waves causes any change in the heat amount, considering the type of existing appliance. In real life, RF waves deflected by ferromagnetic materials will be absorbed or scattered by the skin, eyes, and brain tissue. In dentistry we can measure this with orthodontic materials because most of the materials are attached to the teeth and they are kept in the mouth for long periods. Although the results obtained are limited, it is the first wet lab study that draws attention to the subject, and the data given here can provide the basis for further dry lab and *in vivo* studies.

Conclusions

Although the temperature increases that were found in the teeth were within the safe ranges considered in the literature, it should be noted that the test was performed *in vitro* in a room with a constant temperature of 22 °C. It was concluded that further *in vitro* and *in vivo* studies were warranted to obtain scientific data on keeping 5G frequencies within reliable limits for patients undergoing orthodontic treatment.

Ethics

Ethics Committee Approval: The ethics committee approval required for the study was received from the Non-Invasive Clinical Research Ethics Board of Bezmialem Vakıf University (approval number: E-54022451-050.05.04-15499, date: 27.04.2021).

Informed Consent: Informed consent was obtained from all participants included in this study.

Authorship Contributions

Surgical and Medical Practices: B.K., H.Y.Ü., E.E., Concept: B.K., H.Y.Ü., E.E., Design: B.K., H.Y.Ü., E.E., Data Collection or Processing: B.K., H.Y.Ü., E.E., Analysis or Interpretation: B.K., H.Y.Ü., E.E., Literature Search: B.K., H.Y.Ü., E.E., Writing: B.K., H.Y.Ü., E.E.

Conflict of Interest: No conflict of interest was declared by the authors.

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