Frontiers in Dentistry

Radiofrequency-Induced Heating of Amalgam Restorations and Dental Implants During 1.5T Magnetic Resonance Imaging

Maryam Paknahad[1], Iman Khaleghi[2], Seyed Mohammad Javad Mortazavi[3,4*]

1. Department of Oral and Maxillofacial Radiology, School of Dentistry, Shiraz University of Medical Sciences, Shiraz, Iran
2. Department of Operative Dentistry, School of Dentistry, Shiraz University of Medical Sciences, Shiraz, Iran
3. Ionizing and Non-Ionizing Radiation Protection Research Center (INIRPRC), Shiraz University of Medical Sciences, Shiraz, Iran
4. Department Medical Physics and Medical Engineering, School of Medicine, Shiraz University of Medical Sciences, Shiraz, Iran

Article Info

Article type:
Original Article

Article History:
Received: 10 Apr 2023
Accepted: 30 Sep 2023
Published: 27 Apr 2024

**** Corresponding author:***
Department Medical Physics and Medical Engineering, School of Medicine, Shiraz University of Medical Sciences, Shiraz, Iran

Email: mmortazavi@sums.ac.ir

A B S T R A C T

Objectives: This study aimed to evaluate radiofrequency-induced heating of different amalgam restorations and dental implants during 1.5T magnetic resonance imaging (MRI).

Materials and Methods: Standardized class I cavities (5 mm long, 3 mm wide, and 3 mm deep) were prepared on the occlusal surface of 45 extracted human third molars. The samples were restored by three different types of amalgam including Cinalux amalgam (non-gamma-2, spherical), GS-80 (non-gamma-2, admix), and GK-110 amalgam (non-gamma-2, admix in silver). As a separate intervention group (G4), five titanium mini drive-lock implants with 2mm diameter and 10mm length were also selected and mounted to the base of the Eppendorf tube with 3mm of the implants extending above the mounting putty. The box containing the specimens was placed parallel to the long axis of the standard head and neck coil of the MRI device (64MHz radio-frequency energy with 25kW amplifier, 1.5T). Temperature fluctuations of the metallic materials in each group were monitored during MRI scans using a calibrated thermometer. One-way ANOVA was used to compare temperature changes among the amalgam groups ($P<0.05$).

Results: Temperature elevations ranged from 0.21°C to 0.70°C in amalgam restorations and from 0.35 to 0.47°C in dental implants. The temperature changes among the three amalgam agents were not statistically significant.

Conclusion: According to our findings, the radiofrequency-induced heating of amalgam restorations and dental implants during MRI examination can be considered within acceptable ranges. Therefore, amalgam restorations and dental implants can be categorized as "MR safe" in terms of radiofrequency-induced heating during 1.5 T MRI.

Keywords: Dental Amalgam; Dental Implants; Magnetic Resonance Imaging

➢ **Cite this article as:** Paknahad M, Khaleghi I, Mortazavi SMJ. Radiofrequency Induced Heating of Amalgam Restorations and Dental Implants During 1.5 T Magnetic Resonance Imaging. *Front Dent.* 2024:21:15.

INTRODUCTION

Magnetic resonance imaging (MRI) is an increasingly efficient imaging modality that can play an important role in the diagnosis, treatment planning, and treatment process. Moreover, it is a significant technique used for controlling head and neck diseases, particularly those involving soft tissues, such as the entire mucosal extent, intracranial invasion, orbital extension, marrow infiltration, or peri-neural tumor spread [1,2]. In recent decades, the indication of MRI in different branches of dentistry has evolved, including prosthodontics, endodontics, and orthodontics [3].

During the procedure, the patients are exposed to static, gradient, and radio-frequency (RF) electromagnetic fields that may affect the magnetic substances inside the body [4]. The RF irradiation during clinical MRI procedures can be converted to heat within the human body which may cause severe tissue damage and burn accidents [5]. Nowadays, various dental alloys, including denture frames, osseointegrated implants, orthodontic brackets, crowns, bridges, and amalgams are widely used in clinical practice; hence, they may pose hazards to the safety of patients [6]. Most dental metal objects cannot be removed before an MRI examination and remain in situ. Therefore, it is critical to assess the MR safety of these objects, especially the thermal effects of the RF radiation.

The RF-induced heating of some dental materials has been previously investigated [7-12]. Our lab at the Non-Ionizing Department of the Ionizing and Non-Ionizing Radiation Protection Research Center, Shiraz University of Medical Sciences, Shiraz, Iran has performed experiments on the health effects of exposure to different sources of electromagnetic fields, such as cellular phones [13-21], mobile base stations [22], Wi-Fi [23,24], mobile phone jammers [25,26], laptop computers [27], radars [14], dentistry cavitrons [28], MRI [19,29], and Helmholtz coils [30,31].

Dental amalgam has been the predominant tooth-filling material in posterior teeth restorations in the past. However, its use today as a restorative material has decreased due to various problems, such as improper color and the possibility of releasing mercury from its composition after being set. Nevertheless, there are still many people who have old restorations in their oral environment. The challenge that arises today is whether it is appropriate to replace old amalgam restorations with a composite restorative material. Various studies have examined different aspects of this issue [32-34]; however, no previous studies have evaluated the thermal heating of the amalgam restorations caused by MRI.

Moreover, in the composition of amalgam, the most and least thermal conductivity among its constituent elements are related to tin or silver and mercury, respectively [35]. Regarding this issue and the matter that the percentage of these elements is different in various amalgam brands, this study aimed to focus on the evaluation of the induced heating in three brands of amalgam with different elements composition.

To date, numerous studies have evaluated the effect of electromagnetic waves on dental implants [1,8,9,35]. However, these studies have reported different and sometimes contradictory results, which may be due to different experimental conditions and methods. Some previous studies have indicated that the increasing temperature did not exceed 1°C at the point of the extremity of dental implants after MRI exposure [1,8,9]. Nevertheless, results of another study have shown a higher temperature increase in dental implants following MRI [36].

The null hypotheses of the present study were: (1) MRI does not cause enough induced heating in dental implants and amalgam restorations to damage the bone surrounding implants and dental pulp adjacent and (2) the difference in induced heating among different types of dental amalgams is not statistically significant. Therefore, the present study aimed to evaluate the effect of the electromagnetic environment caused by MRI on increasing the temperature in the different types of amalgam restoration and dental implants.

MATERIALS AND METHODS

Ethical Considerations

The present study was approved by the Ethics Committee (IR.SUMS.REC.1397.18) and conducted according to all ethical principles and guidelines set by the Declaration of Helsinki.

Preparation of specimens

In total, 45 non-caries human third molars without periapical lesions, according to radiographic images before extraction, were transferred into the saline solution and stored for 3 months. All samples were evaluated with a magnifying glass and the teeth with cracks were excluded. After surface debridement of the teeth with a hand scaling instrument and cleaning them with a rubber cup and slurry of pumice, a standardized box-type Class I cavity (5 mm long, 3 mm wide, and 3 mm deep) was prepared on the occlusal surfaces of the teeth with the pulpal floor ending at mid-coronal dentin.

The preparations were made using no. 329 carbide bur (SS White Burs, Lakewood, NJ, USA) and a high-speed handpiece with air-water spray using a template. A separate bur was used after every six cavity preparations to ensure cutting efficiency. The teeth were randomly divided into three groups that were equal in number. Each group was restored with a different type of amalgam agent including Cinalux (non-gamma-2 and spherical amalgam by Faghihi Dental, Tehran, Iran), GS-80 (non-gamma-2 and admix amalgam by SDI, Victoria, Australia), and GK-110 (non-gamma-2 and admix in silver amalgam by Pishva Trading Co., Tehran, Iran) amalgams. The composition of each amalgam brand is mentioned in Table 1.

Table 1. Composition of the three different amalgam materials used in this study

Amalgam	Composition
Cinalux	Ag 42.6%, Sn 31.4%, Cu 26%*
GS-80	Ag 40%, Sn 31.3%, Cu 28.7%, Hg 47.9%
GK-110	Ag 43%, Sn 32%, Cu 25%*

*No data in the manufacturer's instruction about Hg percentage

The amalgams were triturated using an amalgamator (Farazmehr, Esfahan, Iran) according to the instructions of the manufacturer. Afterward, they were condensed incrementally towards the cavity walls using small condensers (Small 1.1-1.4 mm, Smart Instru-Conical Condenser, Dena Pooya, Iran). Subsequently, carving, burnishing, and polishing were performed by the same clinician using a discoid-cleoid Carver (4/5, Hu-Friedy Mfg Co Inc, Chicago, IL, USA), ovoid shape burnisher (B29/31, Smart Instru, Dena Pooya, Iran), and small flame amalgam polisher (Amalgam Polisher Flame, Toboom, Iran), respectively.

Moreover, for evaluation of RF-induced heating of dental implants, five titanium Mini Drive-Lock (MDL® IMPLANTS, Intra lock, USA) implants, with 2.0 mm diameter and 10 mm length, were selected and categorized as a separate intervention group (G4). The implants were mounted at the bottom of the Eppendorf tube by Coltene Speedex putty; accordingly, 3 mm of implants were left above the mounting putty (Figure 1).

Fig. 1. Preparation of dental implants for radio-frequency-induced heating measurement

Magnetic resonance imaging exposure

Each restored tooth and mounted MDL implants were placed in artificial saliva. The specimens were placed parallel to the long axis of the Eppendorf tubes in a container filled with water. The box containing the specimens was placed parallel to the long axis of the coil of the MRI device. The metallic material in the container was placed in the center of the transmit head coil, where the strength of the RF field was assumed to be the maximum (the container of the implants and the static magnetic field coincided). The container was left in the MR scanning room one day before the experiment to equalize its temperature with ambient temperature, which was artificially maintained between 20˚C and 21˚C. This temperature was considered the reference temperature for the evaluation of temperature changes.

The specimens were scanned in the MR scanning room with a standard head and neck coil, and the specimens and plastic containers were placed on the bench of the 1.5 T MRI device for the imaging process (64 MHz RF energy with 25kW amplifier). They were scanned with T2-weighted turbo spin echo (TSE) sequences in the axial and coronal planes, T1-weighted inversion recovery TSE-based sequences, and T1-3D sequences in the sagittal plane. All scans were acquired in the first level controlled operating mode.

Assessment of radio-frequency-induced heating

The temperature of the metallic material was measured for 6 minutes with 30s intervals during image acquisition and 10-minute intervals between each of the sequences. After the completion of all MRI sequences, the container was removed from the MR scanner, and the temperature of the samples was recorded immediately outside the Eppendorf tubes. The temperature changes in metallic materials during image acquisitions of a 1.5T MRI scanner (Avanto, Siemens, Germany) were measured using a recently calibrated K-type thermometer (Lutron TM-903, Taiwan). In amalgam restorations, the temperature was measured in the central fossa of the restoration. In the implants, this temperature was assessed from the marginal third of the restoration, which was outside the putty.

Statistical analysis

The data were analyzed using SPSS software (SPSS Inc., Chicago, IL). A one-way analysis of variance test was used to identify any statistically significant differences between temperature changes among the three different groups filled with three different materials. A P value of less than 0.05 was considered statically significant.

RESULTS

The mean, standard deviation, and minimum and maximum temperature changes in each group are presented in Table 2.

Table 2. Minimum (Min), maximum (Max), and mean ±standard deviation (SD) of temperature rise during magnetic resonance imaging

Amalgam	Temperature rise (˚C)		
	Min	Max	Mean±SD
Cinalux	0.26	0.45	0.36±0.06
GS-80	0.21	0.7	0.40±0.1
GK-110	0.35	0.59	0.42±0.05
Dental implants	0.35	0.47	0.41±0.04

Temperature increases were detected in all groups; however, none of the groups showed excessive heating. The maximum temperature increase did not exceed 1°C in all the studied specimens. Among the teeth filled with various amalgam agents; the maximum temperature rise was observed in the GK-110 amalgam restorations. No significant difference in RF-induced heating was found among the three groups filled with different materials (P=0.11). The mean temperature increase in dental implants was 0.41±0.04 °C.

DISCUSSION

Excessive RF-induced heating of metallic devices in the body during MRI examination is a matter of concern [12]. The findings of the present study showed that different amalgam restorative materials and dental implants that are commonly used for restorations do not cause risks for the patients during 1.5 T MRI. Only minor temperature changes occurred in implants and amalgams with different metallic compositions during and following MRI.

Amalgam composition includes mercury (50%), silver (~22-32%) tin (~14%), copper (~8%), and other trace metals. In the simulation procedure, amalgam fillings consisting of mercury (50%), silver (28%), tin (14%), and copper (8%) were studied. Among all these elements, the highest amount of electrical conductivity was related to tin (8.70e+006S/m) and silver had the highest thermal conductivity (429 W/K/m). However, the lowest values of electrical and thermal conductivity were related to mercury with values of 1.04e+0.06S/m and 8.30W/K/m, respectively [35]. These two properties in dental amalgam depend on the percentage of constituent elements and the properties of each element. No reports have been found in the literature on the potentially harmful temperature elevations of amalgam restorations during MRI procedures conducted at 1.5T.

Although burn accidents from RF irradiation during MR procedures have been reported [36], most previous investigations on different types of bio-implants have found only minor temperature rises during MRI examinations. Previously, the thermal effects of various dental metal-based materials, such as orthodontic appliances, different wires, dental implants, and fixed partial dentures induced by the magnetic field of MRI scanners have been evaluated [6,8-12]. The majority of previous studies have indicated that the increasing temperature did not exceed 1°C after MRI exposure [1,8,9].

Results of previous studies that have tested fixed orthodontic materials manufactured from different metallic alloys have indicated only minor temperature changes during MR procedures [11,12]. Similar to the results of the present research, other studies [8,9] found a temperature elevation of less than 1°C in all the studied configurations and locations of dental implants during 3T MRI examinations. They suggested that dental implants do not present a thermal risk from RF overheating [8].

Ayyıldız et al. [6] observed minor temperature changes in fixed partial dentures (single crowns and bridges) fabricated from CO-Cr, Ni-Cr, and Zirconia during 3T MRI. They evaluated the heating of partial dentures after each sequence. However, in the present study, the temperature changes were recorded following all sequences used for clinical diagnosis. We only found one study in the literature that showed RF over-heating above the industrial standard in orthodontic appliances [10]. The authors suggested that wires should be removed from brackets in orthodontic patients undergoing MRI examination.

The RF field energy absorbed by metal objects is predominately converted to heat. Such local temperature increases near the implants are termed "hotspots" [5]. Two mechanisms have been suggested for the heating effect during MRI examinations. The first is electromagnetic induction heating which occurs due to RF induction voltage in conductive media which can lead to circulating currents and ohmic heating. The other theory suggests that the occurrence of resonating RF waves in the metallic object may cause heating due to the "Antenna Effect" [7].

The International Commission on Non-Ionizing Radiation Protection has proposed that the safety limit of the temperature increase in the center of the human body is up to 1°C for a healthy subject and drops to 0.5°C for infants, pregnant women, and people with cardio-vascular diseases . Overheating of amalgam restorations may lead to pulpal injury, especially in patients with large amalgam restorations and a thin layer of residual dentin remaining after tooth restoration. Temperature rises between 5°C and 7°C in the pulp chamber can increase the capillary permeability which is the first evidence of pulpal damage. Ottl and Lauer reported that an elevation of 5.6°C in pulpal tissue can cause pulp necrosis in 15% of cases [37]. The temperature increase in this study was far below the safety limit of 5.6 °C for the pulpal tissue.

Eriksson and Albrektsson suggested that an increase in temperature up to 44-47°C for 1 minute may lead to alveolar bone necrosis [38]. According to the industrial standard (CENELEC standard pr EN 45502-2-3), the elevation of 2°C for all medical implants leads to tissue damage and patient discomfort. Therefore, elevations shown in this study did not affect the pulpal or mucosal health of tissues in the oral cavity.

The degree of temperature increase during MRI examination depends on various factors, such as size, shape, composition, and quality of materials as well as orientation, the relationship between the metal object and thermometer probe, the specific absorption rate (SAR) value of each sequence, and the duration of the scanning time. The degree of temperature rises in tissues also depends on factors such as the thermal diffusion mechanism of the body, the RF pulse duration, and duty cycles. Oriso et al. [35] showed minimal temperature changes up to 0.8°C in dental implants with 7-13mm lengths, which was significantly less than the temperature elevation of much longer implants with 50mm lengths (up to 1.5°C).

In the present study, all the prepared cavities and dental implants were of similar shape and size to control this confounding factor. The American Society for Testing and Materials has suggested that the RF-induced heating of metallic objects with a size of less than 2cm is not clinically significant, which is in agreement with the findings of the present research. In this study, it was demonstrated that the results of RF-induced heating of the tested amalgam restorations with different chemical compositions and different structures of the elements included in the dental amalgams were not significantly different.

SAR is the rate of tissue energy absorption following interaction with an RF magnetic field [9]. In other words, it is an index for measuring RF exposure dose and shows the amount of energy deposited by RF irradiation per unit mass in the human body that can turn into heat [5,8]. SAR is the best indicator of RF-induced heating [8] and is considered the current standard routinely used for the characterization of the thermogenic aspects of this electro-magnetic field . It depends on the type of RF pulses, repetition time, type of RF coil, and Larmor frequency as well as the type and volume of tissue within the coil . However, Miyata et al. [9] have found that the console-reported SAR is not a reliable index of RF-induced heating of implants and believe that the use of this index as an indicator for the establishment of implant safety may be dangerous.

The maximum temperature rise produced during an MRI session with a given specific absorption rate can be calculated using the following formula: $T: (SAR \times t)/CH$; where T is the temperature rise in degrees Celcius, SAR is the specific absorption rate (W/kg), t is the duration of exposure (s), and CH is the heat capacity of the sample (J/kg°C). As to this equation, if we assume an SAR of 2W/kg, an effective CH of 300J/kg°C for the restorative material, and t=100 seconds, T can be calculated as, $T: (2 \times 100)/300 = 0.67$ °C.

Muranaka et al. [5] evaluated the dependence of RF heating on variations in the angle between implants and the static magnetic field. They observed greater RF-induced heating when the implants were placed parallel to the static magnetic field. Therefore, in the present study, the direction of the specimens was set parallel to the static magnetic field to measure the maximum RF heating by preparing the most unfavorable condition for its assessment. The immersion of the restored teeth and dental implants in artificial saliva applied in this study to simulate the intraoral environment of a patient and the convective properties of the natural saliva may be necessary to avoid underestimation of the temperature rises.

An increase in the MRI field strength is likely to generate greater potentially harmful RF-induced heating than reported in the present study for 1.5T systems since the heating effect is proportional to the square of the static magnetic field. Additional investigations are warranted to examine the effect of RF-induced heating on MR systems operating at higher field strengths. Furthermore, the present study was an in vitro investigation. One of the limitations of the in vitro tests is that they do not exactly simulate the clinical environmental conditions during the examination of a patient. The RF-induced heating is influenced by body weight and height, electrical properties, and the blood flow of the organs [5]. Therefore, the results of these tests should be applied in clinical situations only after substantiation of in vivo studies. Moreover, in the current investigation, the thermal changes in the mentioned metallic materials were evaluated. However, future studies are recommended to assess the temperature increase in the dental pulps or the surrounding bone.

CONCLUSION

The greatest temperature rise observed in amalgam restorations and dental implants was less than 1˚C, which was regarded as tolerable. The findings of the present study showed that the thermal elevations of the tested amalgam restorations and dental implants during 1.5T MRI examinations do not seem to be a safety concern.

CONFLICT OF INTEREST STATEMENT

None declared.

REFERENCES

1. Kajima Y, Takaichi A, Tsutsumi Y, Hanawa T, Wakabayashi N, Kawasaki A. Influence of magnetic susceptibility and volume on MRI artifacts produced by low magnetic susceptibility Zr-14Nb alloy and dental alloys. Dental Materials Journal. 2020 Mar 27;39(2):256-61.
2. Reda R, Zanza A, Mazzoni A, Cicconetti A, Testarelli L, Di Nardo D. An update of the possible applications of magnetic resonance imaging (MRI) in dentistry: a literature review. Journal of imaging. 2021 Apr 21;7(5):75.
3. Tymofiyeva O, Vaegler S, Rottner K, Boldt J, Hopfgartner AJ, Proff PC, et al. Influence of dental materials on dental MRI. Dentomaxillofac Radiol. 2013;42(6):20120271.
4. Shellock FG, Woods TO, Crues JV 3rd. MR labeling information for implants and devices: explanation of terminology. Radiology. 2009 Oct;253(1):26-30.
5. Muranaka H, Horiguchi T, Ueda Y, Tanki N. Evaluation of RF heating due to various implants during MR procedures. Magn Reson Med Sci. 2011;10(1):11-9.
6. Ayyıldız S, Kamburoğlu K, Sipahi C, Murat S, Görgülü S, Pişkin B. Radiofrequency heating and magnetic field interactions of fixed partial dentures during 3-tesla magnetic resonance imaging. Oral Surg Oral Med Oral Pathol Oral Radiol. 2013 Nov;116(5):640-7.
7. Nordbeck P, Fidler F, Weiss I, Warmuth M, Friedrich MT, Ehses P, Geistert W, Ritter O, Jakob PM, Ladd ME, Quick HH, Bauer WR. Spatial distribution of RF-induced E-fields and implant heating in MRI. Magn Reson Med. 2008 Aug;60(2):312-9.
8. Marincas C, Mada M, Rotaru H, Carpenter A, Ciupa R. The thermal effect of radio frequency waves near dental implants during MRI examination at 3 tesla. Acta Electrotehnica. 2013 Jan 1;54(1):66-71.
9. Miyata K, Hasegawa M, Abe Y, Tabuchi T, Namiki T, Ishigami T. Radiofrequency heating and magnetically induced displacement of dental magnetic attachments during 3.0 T MRI. Dentomaxillofac Radiol. 2012 Dec;41(8):668-74.
10. Hasegawa M, Miyata K, Abe Y, Ishigami T. Radiofrequency heating of metallic dental devices during 3.0 T MRI. Dentomaxillofac Radiol. 2013;42(5):20120234.
11. Görgülü S, Ayyildiz S, Kamburoglu K, Gökçe S, Ozen T. Effect of orthodontic brackets and different wires on radiofrequency heating and magnetic field interactions during 3-T MRI. Dentomaxillofac Radiol. 2014;43(2):20130356.
12. Regier M, Kemper J, Kaul MG, Feddersen M, Adam G, Kahl-Nieke B, et al. Radiofrequency-induced heating near fixed orthodontic appliances in high field MRI systems at 3.0 Tesla. J Orofac Orthop. 2009 Nov;70(6):485-94. English, German.
13. Mortazavi SM, Motamedifar M, Namdari G, Taheri M, Mortazavi AR, Shokrpour N. Non-linear adaptive phenomena which decrease the risk of infection after pre-exposure to radiofrequency radiation. Dose Response. 2013 Jul 18;12(2):233-45.
14. Mortazavi SM, Taeb S, Dehghan N. Alterations of visual reaction time and short term memory in military radar personnel. Iran J Public Health. 2013 Apr 1;42(4):428-35.
15. Movahedi MM, Golpaygani AT, Safari A, Amani S. Effects of short-term exposure to electromagnetic fields emitted by 3G and 4G mobile phones on reaction time and short-term memory. Iranian Journal of Medical Physics. 2019;16(3):250-4. 16. Mortazavi SM, Erfani N, Mozdarani H, Azmoonfar R, Shokrpour N. Induction of apoptosis by 900 MHz radiofrequency radiation emitted from a GSM mobile phone simulator in bystander Jurkat cells.
16. Mortazavi, S. M. J., SHIRAZI MA MOSLEH, A. R. Tavassoli, M. Taheri, Z. Bagheri, R. Ghalandari, S. Bonyadi, M. Shafie, and M. Haghani. A comparative study on the increased radioresistance to lethal doses of gamma rays after exposure to microwave radiation and oral intake of flaxseed oil Iran. J. Radiat. Res., 2011; 9(1): 9-14
17. Mortavazi S, Habib A, Ganj-Karami A, Samimi-Doost R, Pour-Abedi A, Babaie A. Alterations in TSH and Thyroid Hormones following Mobile Phone Use. Oman Med J. 2009 Oct;24(4):274-8.
18. Mortazavi SM, Daiee E, Yazdi A, Khiabani K, Kavousi A, Vazirinejad R, et al. Mercury release from dental amalgam restorations after magnetic resonance imaging and following mobile phone use. Pak J Biol Sci. 2008 Apr 15;11(8):1142-6.
29. Baliatsas C, Bolte J, Yzermans J, Kelfkens G, Hooiveld M, Lebret E, van Kamp I. Actual and perceived exposure to electromagnetic fields and non-specific physical symptoms: an epidemiological study based on self-reported data and electronic medical records. International journal of hygiene and environmental health. 2015 May 1;218(3):331-44.
20. Mortazavi SM, Motamedifar M, Namdari G, Taheri M, Mortazavi AR. Counterbalancing immunosuppression-induced infections during long-term stay of humans in space. J Med Hypotheses and Ideas. 2013 Jan 1;7(1):8-10.
21. Mortazavi SM. Safety issues of mobile

phone base stations. J Biomed Phys Eng. 2013 Mar 1;3(1):1–2.
22. Mahmoudi R, Mortazavi S, Safari S, Nikseresht M, Mozdarani H, Jafari M, et al. Effects of microwave electromagnetic radiations emitted from common Wi-Fi routers on rats' sperm count and motility. Int J Radiat Res. 2015;13:363–8.
23. Paknahad M, Mortazavi SM, Shahidi S, Mortazavi G, Haghani M. Effect of radiofrequency radiation from Wi-Fi devices on mercury release from amalgam restorations. J Environ Health Sci Eng. 2016 Jul 13;14:12.
24. Parsanezhad ME, Mortazavi SM, Doohandeh T, Jahromi BN, Mozdarani H, Zarei A, Davari M, Amjadi S, Soleimani A, Haghani M. Exposure to radiofrequency radiation emitted from mobile phone jammers adversely affects the quality of human sperm. Int J Radiat Res. 2017;15(1):63.
25. Mortazavi S, Parsanezhad M, Kazempour M, Ghahramani P, Mortazavi A, Davari M. Male reproductive health under threat: Short term exposure to radiofrequency radiations emitted by common mobile jammers. J Hum Reprod Sci. 2013 Apr;6(2):124-8.
26. Mortazavi SM, Tavassoli A, Ranjbari F, Moammaiee P. Effects of laptop computers' electromagnetic field on sperm quality. J Reprod Infertil. 2010 Dec 1;11(4):251–8.
27. Mortazavi SM, Vazife-Doost S, Yaghooti M, Mehdizadeh S, Rajaie-Far A. Occupational exposure of dentists to electromagnetic fields produced by magnetostrictive cavitrons alters the serum cortisol level. J Nat Sci Biol Med. 2012 Jan;3(1):60-4.
28. Mortazavi SM, Neghab M, Anoosheh SM, Bahaeddini N, Mortazavi G, Neghab P, et al. High-field MRI and mercury release from dental amalgam fillings. Int J Occup Environ Med. 2014 Apr;5(2):101-5.
29. Haghnegahdar A, Khosrovpanah H, Andisheh-Tadbir A, Mortazavi G, Saeedi Moghadam M, Mortazavi S, et al. Design and fabrication of helmholtz coils to study the effects of pulsed electromagnetic fields on the healing process in periodontitis: preliminary animal results. J Biomed Phys Eng. 2014 Sep 1;4(3):83-90.
30. Paknahad M, Shahidi S, Mortazavi SMJ, Mortazavi G, Moghadam MS, Nazhvani AD. The effect of pulsed electromagnetic fields on microleakage of amalgam restorations: an in vitro study. Shiraz E-Med J. 2016;17(2):e32329.
31. Louopou RC, Trottier H, Arbuckle TE, Fraser WD. Dental amalgams and risk of gestational hypertension in the MIREC study. Pregnancy Hypertens. 2020 Jul;21:84-89.
32. Rahat S, Kashetsky N, Bagit A, Sachdeva M, Lytvyn Y, Mufti A, Maibach HI, Yeung J. Can we separate oral lichen planus from allergic contact dermatitis and should we patch test? A systematic review of chronic oral lichenoid lesions. Dermatitis. 2021 Jun 1;32(3):144-50.
33. Ishida Y, Aoki H, Miyasaka T, Aoyagi Y, Miura D, Shinya A. Effects of Removal Conditions on Mercury Amount Remaining in the Oral Cavity and inside Drainage System after Removing Dental Amalgams. International Journal of Environmental Research and Public Health. 2021 Dec 13;18(24):13135.
34. Zigar D, Hederić Ž, Sokolović D, Marković V, Dunjić M, Cvetanović S, Vučković L. Modelling and Simulation of Electromagnetic Radiation Effects of Mobile Phones on Teeth with an Amalgam Filling. Tehnički vjesnik. 2020 Dec 19;27(6):1754-60.
35. Oriso K, Kobayashi T, Sasaki M, Uwano I, Kihara H, Kondo H. Impact of the Static and Radiofrequency Magnetic Fields Produced by a 7T MR Imager on Metallic Dental Materials. Magn Reson Med Sci. 2016;15(1):26-33.
36. Knopp MV, Essig M, Debus J, Zabel HJ, van Kaick G. Unusual burns of the lower extremities caused by a closed conducting loop in a patient at MR imaging. Radiology. 1996 Aug;200(2):572-5.
37. Ottl P, Lauer HC. Temperature response in the pulpal chamber during ultrahigh-speed tooth preparation with diamond burs of different grit. J Prosthet Dent. 1998 Jul;80(1):12-9.
38. Eriksson AR, Albrektsson T. Temperature threshold levels for heat-induced bone tissue injury: a vital-microscopic study in the rabbit. J Prosthet Dent. 1983 Jul;50(1):101-7.