Necmettin Erbakan Üniversitesi Diş Hekimliği Dergisi
Necmettin Erbakan University Dental Journal (NEUDentJ)
DOI: 10.51122/neudentj.2023.72

Cilt:5 Sayı:3 Yıl:2023 | Araştırma Makalesi / Research Article | E-ISSN: 2687-5535

Effect of 14.1T MRI on Mercury & Amalgam: A Study by ICP-MS and XRD

14.1T MRG'nin Cıva ve Amalgama Etkisi: ICP-MS ve XRD Çalışması

Samed ŞATIR[1]
samedsatir@yahoo.com

Selmi YARDIMCI*[2]
selmiyard@gmail.com

ABSTRACT

Aim: The aim of this study was to evaluate the effect of electromagnetic effects of magnetic resonance imaging (MRI) on the release of mercury (Hg) and on the possible amalgam phase change in amalgam with 14.1T MRI.

Material and methods: 60 amalgam discs with 4 mm diameter and 4 mm height were prepared. 30 were selected as the control and 30 as MRI group. They were placed in the Fusayama-Meyer solution. MRI group were exposed to 14.1T ultra-high-field magnetic resonance imaging (UHF-MRI) system (EPFL, Lausanne, Switzerland). 2, 12 and 24 hours after MRI, all discs were removed from the solutions. Inductively coupled plasma-mass spectroscopy (ICP-MS) analysis was performed to the solutions. X-ray diffractometry (XRD) was performed to amalgam discs. Differences and interactions between groups were evaluated by two-way ANOVA.

Results: The concentration of Hg released from the amalgams to the solution in the MRI group was significantly higher than the control group (p=0,026; F=5,253). The peak intensity of the amalgam in the MRI group obtained by XRD was significantly lower than the control group (p = 0.000).

Conclusion: UHF-MRI increases the release of Hg in the amalgam due to the strength of the magnetic field and appears to have a debilitating effect on the crystal structure of the amalgam within the period of exposure to the magnetic field.

Keywords: Amalgam, Magnetic Resonance Imaging, Mercury, Inductively coupled plasma-mass spectroscopy, X-ray diffractometry

Received: 12.05.2023 **Accepted:** 26.07.2023 **Published:** 27.12.2023

ÖZ

Amaç: Bu çalışmanın amacı, Manyetik Rezonans Görüntülemenin (MRG) elektromanyetik etkilerinin cıva (Hg) salınımı ve olası amalgam faz değişimi üzerindeki etkisini 14.1T MRG ile değerlendirmektir.

Gereç ve Yöntemler: 4 mm çapında ve 4 mm yüksekliğinde 60 adet amalgam disk hazırlandı. 30'u kontrol ve 30'u MRG grubu olarak seçildi. Diskler Fusayama-Meyer solüsyonuna yerleştirildi. MRG grubu 14.1T Ultra Yüksek Alanlı Manyetik Rezonans Görüntüleme (UYA-MRG) sistemine (EPFL, Lozan, İsviçre) maruz bırakıldı. MRG'den 2, 12 ve 24 saat sonra tüm diskler solüsyonlardan çıkarıldı. Solüsyonlara İndüktif eşleşmiş plazma-kütle spektroskopisi (ICP-MS) analizi yapıldı. Amalgam disklere X-ışını difraktometresi (XRD) uygulandı. Gruplar arasındaki farklılıklar ve etkileşimler çift yönlü ANOVA ile değerlendirildi.

Bulgular: MRG grubunda amalgamlardan solüsyona salınan Hg konsantrasyonu kontrol grubuna göre anlamlı derecede yüksekti (p=0,026; F=5,253). XRD ile elde edilen MRG grubundaki amalgamın pik seviyesi kontrol grubuna göre anlamlı derecede düşüktü (p=0.000).

Sonuç: UYA-MRG, manyetik alanın gücünden dolayı amalgamdaki Hg salınımını arttırmaktadır ve manyetik alana maruz kalma süresi içinde amalgamın kristal yapısı üzerinde zayıflatıcı bir etkiye sahip olduğu görülmektedir.

Anahtar Kelimeler: Amalgam, Manyetik Rezonans Görüntüleme, Cıva, İndüktif eşleşmiş plazma-kütle spektroskopisi, X-ışını difraktometresi

Geliş: 12.05.2023 **Kabul:** 26.07.2023 **Yayın:** 27.12.2023

Atıf/ Citation: Şatır S., Yardımcı S., Effect of 14.1T MRI on Mercury & Amalgam: A Study by ICP-MS and XRD, NEU Dent J. 2023;5:158-66.

* Sorumlu Yazar/Corresponding Author

1. Asst. Prof. Karamanoglu Mehmetbey University, Faculty of Dentistry, Oral and Maxillofacial Radiology, Karaman, Türkiye
2. Assoc. Prof. Akdeniz University, Faculty of Dentistry, Oral and Maxillofacial Radiology, Antalya, Türkiye

INTRODUCTION

Magnetic resonance imaging (MRI) is an effective and safe method for imaging soft tissues and used in maxillofacial radiology to determine the pathologies and their extensions of the head and neck region.[1-3] Visualization of body structures is performed by a static magnetic field and radio wave energy. The magnetic field generated by the magnets is defined as the unit of Tesla (T).[4] Devices have 1.5T and more magnetic field are called high-field MRI devices, while devices have 7T and more are defined as ultrahigh-field magnetic resonance imaging (UHF-MRI) system. With the use of UHF-MRI devices, it is aimed to obtain a clearer image and to differentiate the anatomical and pathological structures easier.[5]

The distribution of mercury (Hg) on earth became anthropogenic with the effects of the industrial revolution in the 18th and 19th centuries.[6] Dental amalgam is shown as the primary source of Hg exposure in today's societies.[7] The most important factor limiting the use of amalgam is its possible harmful effects on human health due to biochemical reactions derived by Hg in its structure.[8,9] However, it has also been shown that there is insufficient evidence to prohibit the use of amalgam.[10]

Atomic absorption spectroscopy (AAS), inductively coupled plasma-optical emission spectroscopy (ICP-OES) and inductively coupled plasma-mass spectroscopy (ICP-MS) are techniques used to measure Hg concentration.[11-13] Different methods and devices are used to measure the concentration of Hg released in a variety of liquids. ICP-MS is a new technique than AAS.[14] ICP-MS is a more expensive system compared to AAS, but it can perform analysis faster. Therefore, AAS may be preferred for a small number of sample analyses.[15] AAS technique was used in 54 of 62 studies measured Hg concentration from dental amalgams that were published in PubMed and Web of Science databases until 2018, whereas the ICP-MS technique was used in only eight studies. More than half of the 54 studies using the AAS technique were published before 2005 and all eight studies using the ICP-MS technique were published after 2006. Following the literature, this situation shows that the ICP-MS technique is a new method than the AAS technique and suggests that it may be less preferred because of its higher cost.

The X-ray diffractometry (XRD) allows molecular structure analysis of crystalline materials such as composites and metals. Changes in the phases or crystal structures of various dental materials examined under physical or chemically modified conditions can be determined by XRD. Mostafa and Aboushelib[16] used XRD to compare the success of osteointegration of implants which their surface coated with and without hydroxyapatite (HA) crystal. Amalgam phase change may effect released Hg amount and phase analysis of amalgam restorations can be performed using XRD.[17] In a study examining the changes in phase structure of amalgam restorations with MRI applications, it was found that the phase structure of amalgam did not change compared to control group and according to magnetic field strength.[18]

The resulting interactions between new MRI systems and materials present in the human body are tested in the context of safety. This study is planned to ensure personnel and future patient safety of 14.1T UHF-MRI applications, a technology not yet used in human studies, and to observe possible Hg leakage. The aim of this study was to evaluate the effect of electromagnetic effects of MRI on the release of Hg and on the possible amalgam phase change in amalgam restorations with 14.1T UHF-MRI.

MATERIAL AND METHODS

Preparation of amalgam discs

Amalgam samples to be used in the experiment was prepared as capsule form mercury and amalgam powder (%59 Ag, %28 Sn, %13 Cu, %42,5 Hg, Tytin, Kerr, Michigan, USA) that tiruated by a mixing machine. 60 discs condensed to a standard template of 4 mm height and 4 mm diameter according to the manufacturer's instructions. Consistent with clinical practice, burnishing process was repeated for each sample. After shaping, the samples were left at room temperature for 48 hours for setting process, in a dry environment. Then all samples were incubated in 500cc isotonic serum solution (0.9% NaCl) for 72 hours. And all samples were resuspended in renewed 500cc isotonic serum solution for 72 hours again. Each sample was placed separately in 10 ml capped tubes containing Fusayama-Meyer (FM) solution (Ph: 7.1; NaCl, KCl, $CaCl_2.H_2O$, $NaH_2PO_4.2H_2O$, $Na_2S.9H_2O$, urea) 30 minutes prior to MRI protocol (Figure 1). MRI protocol was applied for 30 amalgam discs and 30 discs were included in the study as control group.

The discs in both the MRI group and the control group were divided into three equal subgroups and removed from Fusayama-Meyer solution after 2, 12 and 24 hours after the MRI protocol.

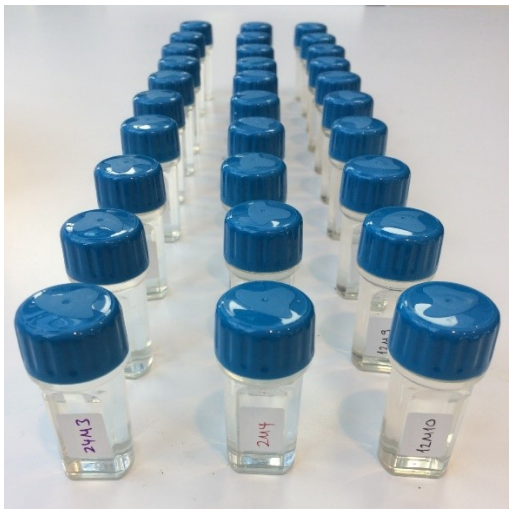

Figure 1. *Fusayama-Meyer solution in capped tubes*

MRI protocol

14.1T UHF-MRI device [The Center for Biomedical Imaging (CIBM), École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland] was used in the study. The MRI protocol [name of sequence: Fast Spin Echo Multi-slice Imaging sequence, effective TE: 20ms, TR: 4000ms, turbo factor: 4 (center of echo: 1), matrix size: 128*128, slice thickness: 1mm (30 slices), field of view: 19.2*19.2mm, scan time: 6 min 30 s (total 15 min in magnetic), coil: single channel transmit and receive surface coil] was created in accordance with the routine procedure.

Since the bore diameter of the 14.1T UHF-MRI device was 260 mm and the length of the active using area was approximately 100 mm, the tubes containing the amalgams in the study group were included in the MRI protocol in three equal parts (Figure 2).

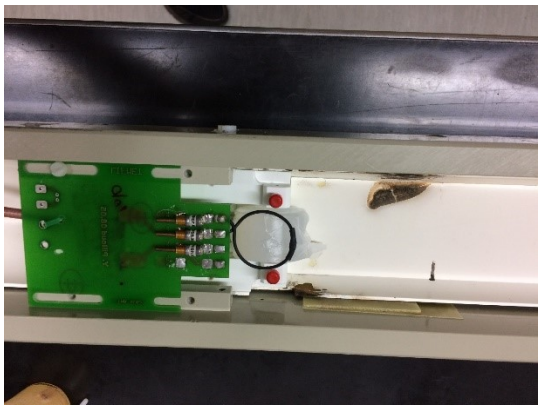

Figure 2. *Active field of 14.1T UHF-MRI device and ring-shaped coil*

ICP-MS analysis

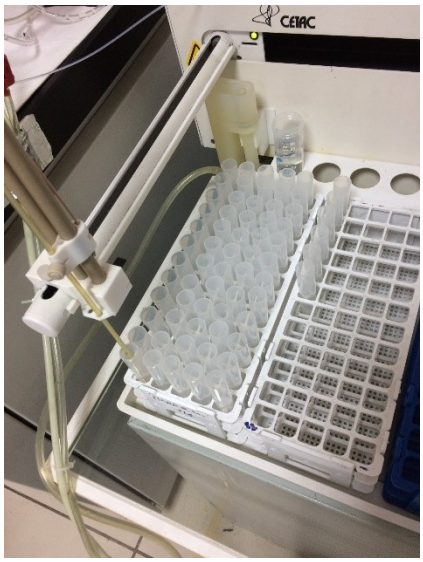

Figure 3. *ICP-MS device when reading samples*

The disc-shaped amalgam samples that underwent MRI were removed from their FM solution after 2, 12 and 24 hours since the MRI. The solutions containing Hg dissolved in the closed tubes were delivered to the laboratory where the Hg concentrations were analyzed together with the control groups. ICP-MS analysis was performed with the ICP-MS device (ELAN DRC-e, PerkinElmer, Massachusetts, USA) in the laboratory of The Center of the Food Safety and Agricultural Research at. 1 ml of FM solution without Hg was taken and 100 ppb stock Hg standard was added with 2% and 5% HNO_3 to make to total volume 15 ml with pure water and HNO_3. After 24 hours, recovery studies were performed to obtain Hg concentration at 0.2, 0.5 and 2 ppb levels. Since the recovery values in the results were not at the desired level, it was waited for 24 hours by adding 65% HNO_3 and stock Hg standard to 1 ml FM solution with make to final volume 15 ml with pure water and HNO_3 and recovery results found in the range of 96% -99%. Thus, the preparation protocol for the ICP-MS analysis of FM solutions containing Hg released from the amalgam was determined. For analysis, the most common isotope number 202 of Hg in earth was selected. Calibration controls were repeated after every 20 sample readings at 2.5 ppb. In addition, 5% HNO_3 washing was performed after every two sample readings in order Hg residues that may remain in the device path after sample reading not to affect the new sample results. Three simultaneous readings were made for each sample, and the numerical data obtained were recorded in units of µg/L, multiplying by 15,

since the samples were diluted 15-fold in preparation (Figure 3). The arithmetic mean of the three readings was accepted as the result data. All readings were performed at 18°C to prevent evaporation of Hg ions in the samples. A total of 3 samples (1 from MRI group and 2 from control group) were excluded from the study due to various problems during transportation, preparation and analysis of samples.

XRD analysis

XRD device (Bruker, D8 Advance, Germany) which in Technology Application and Research Center was used for X-ray diffractometer analysis. It was aimed to analyze a total of 40 amalgam discs in the control and MRI group extracted 2 and 24 hours after FM solution after MRI protocol. A total of 8 amalgam discs were randomly selected from each of the four groups in the MRI and control groups to test the accuracy of the analysis results. As a result of the preliminary analysis, the remaining discs (total 32 amalgam discs) were included in the study as four different groups (n = 8) in the MRI and control groups after 2 and 24 hours. Amalgam discs were placed on the holder of the XRD device and 2Θ scanned between the 20° and 90° angles (Figure 4). XRD analysis results were interpreted with DIFFRAC.EVA XRD (2001) program. For each sample, angles of 2Θ were determined and peak intensities were recorded numerically. For the angles in which peak intensity was observed and phase analysis was performed, statistical analysis was performed between the MRI and control groups and 2 and 24 hour groups.

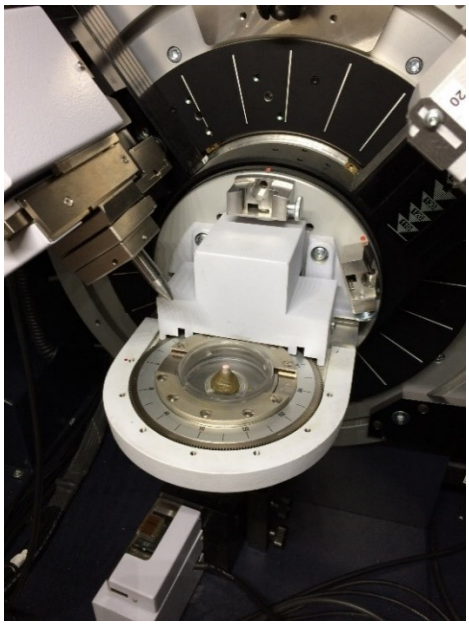

Figure 4. *A disc in the XRD device holder*

Statistical Analysis

The differences and interactions between the control and MRI groups with the solutions from which amalgam was removed after 2, 12 and 24 hours for ICP-MS and amalgam discs removed from solution after 2 and 24 hours for XRD were performed by two-way ANOVA.

RESULTS

The concentration of Hg released from the dental amalgams to the solution in the MRI group was significantly higher than the control group (p=0,026; F=5,253). When Hg concentrations were compared according to the 2, 12 and 24 hour periods, time did not make a significant difference between the MRI and control groups (p=0,107; F=2,337). Similarly, there was no significant difference or interaction between MRI and control according to time differences (p=0,751; F=0,289) (Table 1). Homogeneity and normality tests were applied to the data in the statistical analysis process. In order to meet the minimum requirements of parametric analyzes, all data were converted to logarithmic data and interpreted in the converted form. The mean values and standard deviations of the original data and logarithmic data are shown in Table 2.

Table 1. Significant differences and interactions with time differences between MRI and control groups (two-way ANOVA test)

	F	*p*	Observed power
Group	5.253	.026	.093
Time	2.337	.107	.084
Group.Time	0.289	.751	.011

The X-ray diffraction pattern was obtained for each of the 32 amalgam discs undergoing XRD. When the diffraction patterns of all samples were examined, it was found that there was no difference between angles which observed the peak. In order to reveal the differences and interactions between MRI and control groups, peak intensity raw data were transformed logarithmically. According to statistical results; when the peak intensity observed in XRD was compared, the peak intensity of MRI group was found to be significantly lower than the control (p=0,000; F=43,798) (Figure 5). Without discrimination between the MRI and the control group, significant reduction was detected in peak intensity over time when 2 and 24 hour time periods were compared (p=0,000; F=15,316). Significant differences were found between MRI and

control groups when comparing the 2 and 24 hour time periods. The peak intensity decreased with time in the control group whereas increased with time in the MRI group (p=0,000; F=50,043) (Table 3).

Table 2. The raw data (µg / L) and the logarithmic data obtained as a result of ICP-MS analysis of mercury concentrations of artificial saliva

	Raw data (µg / L)	Logarithmic data	
Time&Group	**Mean (s.d.)**	**Mean (s.d.)**	**Sample number (n)**
MRI 2 hours	9,9750 (7,95591)	0,9122 (0,37594)	10
MRI 12 hours	14,8815 (14,06678)	1,0584 (0,38753)	10
MRI 24 hours	20,4433 (20,86413)	1,1930 (0,34921)	9
MRI total	14,9157 (15,06195)	1,0497 (0,37672)	29
Control 2 hours	6,6383 (9,46836)	0,7101 (0,35987)	9
Control 12 hours	9,2625 (6,56724)	0,9292 (0,28913)	10
Control 24 hours	8,9283 (8,62516)	0,8932 (0,29955)	9
Control total	8,3116 (8,02350)	0,8472 (0,31982)	28
Total 2 hours	8,3945 (8,62684)	0,8164 (0,37280)	19
Total 12 hours	12,0720 (11,06653)	0,9938 (0,33931)	20
Total 24 hours	14,6858 (16,58192)	1,0431 (0,35128)	18
Total	11,6716 (12,47255)	0,9502 (0,36154)	57

Table 3. Interaction and differences of XRD analysis results between MRI and control groups according to angles (two-way ANOVA test)

	F	p	Observed power
Group	43,798	0,000	0,048
Time	15,316	0,000	0,017
Group.Time	50,043	0,000	0,055

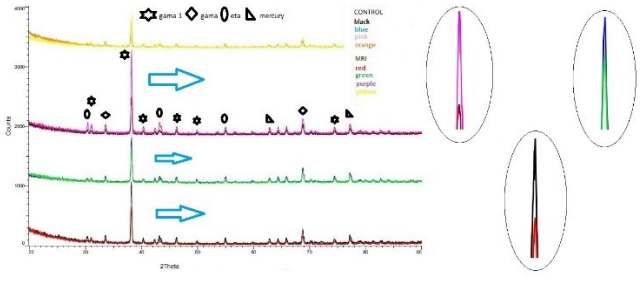

Figure 5. *Graph showing the diffraction patterns and detected phases obtained from the amalgams in the MRI and the control group*

DISCUSSION

It can be concluded that UHF-MRI increase the amount of Hg leakage from amalgam. In order to observe this release of Hg concentration changes over time; solution samples analysed at 2, 12 and 24 hours after MRI. It was found that there was no significant difference between the MRI and control groups but the effect size was found to be high (*F*=2.337). These results show that the release of Hg after MRI continues similarly with the control. This similarity can be explained by the solution saturation, which is a chemical principle. There was no effect of removal time of amalgam discs extracted from solutions at mercury concentration between groups. It can be interpreted that the effect of MRI on the amount of Hg released depends on the duration of the magnetic field.

In the present study, we set an experiment to test the mentioned dental material in extended limits. Food and Drug Administration (FDA) approved 7T devices in 2017 for clinical use.[19] The emerging interactions between new MRI systems and materials that exist in the human body are tested in the context of safety. Amalgam was considered safe until testing this material in ultra-high magnetic field. 14.1T UHF-MRI is a technology that has not been used in human studies yet. Hereby for the safety of staff working with UHF-MRI, as well as future patients, this study was performed with 14.1T to observe possible Hg leakage.

The increasing of released Hg concentration from amalgam discs exposed to a magnetic field for a total of 15 minutes, which is chosen like present neuroimaging protocols with the 14.1T UHF-MRI device that is consistent with the literature. Considering the duration of exposure to magnetic field in Yılmaz and Adisen[20] and our study, it can be said that UHF-MRI have a significant increase effect on the amount of Hg released. Although the duration of exposure to the magnetic field in the study of Müller-Miny et al[11] was quite long compared to the preferred periods in 14.1T UHF-MRI, 1.5T MRI did not have a significant effect on Hg release.

Only a few studies have been conducted to investigate the effect of temperature changes on dental materials in the oral cavity or the effect of these materials on image quality by UHF-MRI.[21-23] Considering the studies examining the physical, chemical and behavioural changes of metal-containing dental materials that may occur by using UHF-MRI, our study evaluated Hg release of amalgam with 14.1T UHF-MRI device that may contribute to the literature as it presents new results.

The aim of some of the studies is to investigate the changes in the amount of Hg released under varying

conditions. However, it may be useful for researchers planning a new study for a similar purpose to examine the similar methods and results of the relevant literature to determine the appropriate method for their studies and to interpret the reliability of the results (Table 4). According to the table, various variable factors seem to be effective on the numerical data obtained. Also, it can be said that the difficulty in making comparisons between the data of previous studies may be related to the inadequate presentation of the method and data. The numerical data we found in our study are given in unit of µg/L and are consistent with the numerical ranges in the literature. However, the values obtained in our study were closer to zero because all samples were diluted with isotonic serum solution for 6 days at the beginning of the study. With this dilution process, it was aimed that both the ICP-MS device was not exposed to high concentrations of Hg to create technical problems and to obtain samples which containing the appropriate Hg concentration determined before the detection limits. It was mentioned in the study conducted by Al-Salahi[26] that, the standard deviation among the samples within the group showed wide fluctuations and it was stated that the calibration of ICP-MS device was taken care of to indicate that this was not related to the reliability of the data obtained. Similarly, Gurgan et al[13] stated that the standard deviation was higher than the mean value in the ICP-MS, and argued that this result may be due to using of the relatively small number of samples compared to similar studies in the literature. In our study, the standard deviation in the raw data was found to be quite close to the average value as a result of ICP-MS. This result may be due to the relatively small number of samples included in the study and difficulties in measuring ion concentrations. In addition, the difficulty of obtaining a microscopically homogeneous mixture during the formation of amalgam discs used in the study may lead to a high standard deviation.

Table 4. Studies examining mercury released from prepared amalgam disc

	Planning/ sample number	Preparation of samples	Solution	Numerical data (lowest & highest)	Unit	Analysis technic / protocol	Istatistical method	Results
Al-Salehi et al, 2006 [24]	%10 and %0 carbamide peroxide (CP)/ **20 samples**	10mm diameter, 2mm height, 20ml solution, 37°C, **24 hours**	**Distilled water**	0 – 0,8	**µg cm^{-2}**	**ICP-MS /** Acidification with HNO_3 or HCl	**One-way ANOVA**	No significant difference in Hg ion release between %10 CP and %0 CP (p>0.05).
Al-Salehi et al, 2007 [25]	%0, %1, %3, %10, %30 hydrogen peroxide (HP)/ **25 samples**	10mm diameter, 2mm height, 20ml solution, 37°C, **24 hours**	**Distilled water**	2,70 ± 0,92 1428 ± 882,59	**µg/L**	**ICP-MS /** Calibration before each measurement, acidification with HNO_3 or HCl	**One-way ANOVA**	Difference in Hg ion release between %0 HP and all concentrations is statistically significant. For Hg, there is a significant difference in ion release between %30 and each of %1 and %3 HP.
Gurgan et al, 2007 [13]	%16 and %30 CP/ **56 samples**	10mm diameter, 2mm height, 10ml solution, 37°C, **24 hours**	**Distilled water**	9,46 ± 4,49 61,87 ± 44,19	**ppt**	**ICP-MS**	**Mann-Whitney U test**	The CP resulted in a significant release of Hg (p<0.05). There is no significant difference in the release of Hg between the %16 and %30 CP (p>0.05).
Al-Salehi, 2009 [26]	%0, %3.6, %6, %30 HP/ **65 samples**	10mm diameter, 2mm height, 10ml solution, 37°C, **1-8-48-156 hours**	**Distilled water**	0 - 1000	**µg/L**	**ICP-MS /** Calibration before each measurement, acidification with HNO_3 or HCl	**One-way ANOVA**	There are statistically significant differences in Hg ion release values between water and all HP concentrations at all exposure times (p<0.05).
Kursun et al, 2014 [27]	X-ray and MRI/ **84 samples**	10mm diameter, 3mm height, 100ml solution, **1-2-24 hours**	FM solution	0,54 – 10,36	ppb	**AAS**	**Two-way ANOVA**	A significant increase in mercury was detected in the X-ray-exposed group versus the control (p≤0.05). No significant difference was found in released mercury between the MRI-exposed group and the control.
Present study	MRI/ **60 samples**	4mm diameter, 4mm height, 10ml solution, **2-12-24 hours**	FM solution	6,63 ± 9,46 20,44 ± 20,86	**µg/L**	**ICP-MS** / Acidification with HNO_3, calibration on every 20 samples, washing between every 2 measurements	**Two-way ANOVA**	The concentration of Hg released in the MRI group is significantly higher than in the control (p=0.026). According to 2, 12 and 24 hour periods, no significant difference was found between MRI and control (p=0.107). There is no significant difference or interaction between MRI and control groups according to time differences (p=0,751).

In the X-ray diffraction patterns obtained from the amalgams in the MRI group and the control group, the observed peak angles were not different. Based on this result it can be said that MRI do not have an effect that may create new phases in the structure of amalgam. The peak intensity in the diffraction patterns obtained from the MRI group was significantly lower than the control. This suggests that MRI do not cause any phase change, but it causes change in the crystal structure. In comparison with 2 and 24 hour time periods without any distinction between MRI and control group, significant decrease of peak intensity over time can be interpreted as crystal structure of amalgam may change with the effect of solution. Alkurt et al[18] used 0.2T and 1.5T MRI and could not find any difference between the MRI and control groups in the phase angles and between the peak intensity in the determined phases according to the control group and the magnetic field strength used. In our study, although the peak intensity decreased in the control group, the peak intensity increased after 24 hours in the MRI group. This result suggests that MRI applications cause a non-permanent change in the crystal structure of the amalgam and that the crystal structure of the amalgam tends to return to the state before the MRI application.

By using diffraction patterns obtained by XRD, the determination of the phases of the crystalline materials, as well as the change of peak intensity at the determined angles in the diffraction pattern under the effect of various conditions can be evaluated. Toledano et al[28] examined the change of HA crystal structure on the surface of caries affected dentin layer which has high remineralization ability according to the zinc content of amalgam applied to the surface for treatment. After removal of zinc-free amalgam, XRD showed that the intensity of HA phase peak intensity of intact dentin was greater at each diffraction angle than HA phase peak intensity of caries affected dentin. According to these results, the researchers concluded that zinc-containing amalgams had a higher remineralization effect on the dentin surface than those without zinc. Park et al[29] used the XRD to evaluate the phase structure of the new material, in a study aimed at strengthening the structure of hydroxyapatite, which is the preferred bioceramic material because of its biocompatibility in the treatment of bone defects. They aimed to cover titanium surfaces with HA produced by using multi-walled carbon nano-tubes (MWCNT) at different concentrations. XRD showed that the peak intensity in HA phase increased with increasing MWCNT concentration in diffraction patterns. Based on this result, researchers concluded that HA crystallization developed with increasing concentration of MWCNT. Considering the results of these two studies, a significant difference between peak intensity in the XRD results of MRI and the control group can be explained by the change in crystallization of amalgams. The fact that the peak intensity of the discs in the MRI group was less than the discs in the control group suggests that MRI may weaken the crystal structure of amalgam.

XRD is a preferable method for determining the corrosion of metal containing materials in various liquids. Lee et al[30] evaluated the effect of aluminum-zinc coating of steel materials used in marine equipment on corrosion resistance by XRD. As a result, the formation of Simonkolleite which is known as a protective and slightly soluble corrosion product that adheres to the material in water is supported by the idea of aluminum-zinc coated materials have high corrosion resistance. According to result of the XRD, the researchers stated that the peak intensity in the aluminum and zinc phases in the product held in solution was lower than in the aluminum and zinc phases before being placed in the solution. Researchers have argued that this result is related to the formation of corrosion. In our study, the time-dependent reduction of peak intensity obtained in the XRD diffraction pattern of amalgam discs without distinction between control and MRI groups was consistent with the XRD results of Lee et al.[30] Considering these results, it can be said that the crystal structure of amalgam may be affected by the residence in FM solution independent of MRI.

In the present study, the amount of mercury dissolved in FM solution from amalgam was investigated. However, the release of mercury from amalgam is in the form of both evaporation and corrosion products. Not to measure the mercury vapour value is a limitation of this study and to make an accurate assessment, it is necessary to add the evaporating value to the dissolved value to know the total released amount.

CONCLUSIONS

In conclusion, UHF-MRI increases the release of mercury in the amalgam fillings due to the strength of the magnetic field. XRD analysis revealed that 14.1 T MRI did not cause any change in metallurgical phases in amalgam restorations. Besides, UHF-MRI appears to have a debilitating effect on the crystal structure of the amalgam within the period of exposure to the magnetic field.

Abbreviations

AAS: Atomic Absorption Spectroscopy, CIBM: The Center for Biomedical Imaging, CP: Carbamide Peroxide, EPFL: École Polytechnique Fédérale de Lausanne, FDA: Food and Drug Administration, FM: Fusayama-Meyer, HA: Hydroxyapatite, Hg: Mercury, HP: Hydrogen Peroxide, ICP-MS: Inductively Coupled Plasma-Mass Spectroscopy, ICP-OES: Inductively Coupled Plasma-Optical Emission Spectroscopy, MRI: Magnetic Resonance Imaging, MWCNT: Multi-Walled Carbon Nano-Tubes, T: Tesla, UHF-MRI: Ultrahigh-Field Magnetic Resonance Imaging, XRD: X-ray diffractometry.

Acknowledgements

Thanks to Deniz Ozel Erkan for the support of professional statistical analysis. Thanks to Ting Yin and Ozlem Ipek for their support in the UHF-MRI application.

Ethics approval and consent to participate

This research was conducted in accordance with the Helsinki Declaration and does not contain any studies with human or animal subjects performed by the any of the authors. Ethical approval is not applicable because this study is an in-vitro.

Authors' contributions

Design: SY, Data collection or data processing: SS, Analysis and comment: SY, SS, Literature search: SS, Writing: SS.

Competing interests

The authors declare that they have no competing interests.

Funding

This study funded by Akdeniz University Scientific Research Projects Coordination Unit (Project No: TDH-2018-3157).

REFERENCES

1. Klatkiewicz T, Gawriołek K, Pobudek Radzikowska M, Czajka-Jakubowska A. Ultrasonography in the diagnosis of temporomandibular disorders: a meta-analysis. Med Sci Monit. 2018; 24: 812-7.
2. Grossmann E, Poluha RL, Iwaki LCV, Santana RG, Filho LI. Predictors of arthrocentesis outcome on joint effusion in patients with disk displacement without reduction. Oral Surg Oral Med Oral Pathol Oral Radiol. 2018; 125: 382-8.
3. Apajalahti S, Kelppe J, Kontio R, Hagström J. Imaging characteristics of ameloblastomas and diagnostic value of computed tomography and magnetic resonance imaging in a series of 26 patients. Oral Surg Oral Med Oral Pathol Oral Radiol. 2015; 120: e118-30.
4. Westbrook C, Kaut C (1998) MRI in Practice, 2nd Edn, Blackwell Publishing Company, Oxford, UK.
5. Moser E. Ultra-high-field magnetic resonance: why and when? World J Radiol. 2010; 2: 37-40.
6. Risher JF. Elemental mercury and ınorganic mercury compounds: human health aspects. World Health Organization, 2003.
7. Skare I. Mass balance and systemic uptake of mercury released from dental amalgam fillings. Water Air Soil Pollut. 1995; 80: 59-67.
8. Counter SA, Buchanan LH. Mercury exposure in children: a review. Toxicol Appl Pharmacol. 2004; 198: 209–30.
9. Clarkson TW, Magos L, Myers GJ. The toxicology of mercury – current exposures and clinical manifestations. N Engl J Med. 2003; 349: 1731–7.
10. Patini R, Spagnuolo G, Guglielmi F, Staderini E, Simeone M, Camodeca A, Gallenzi P. Clinical effects of mercury in conservative dentistry: a systematic review, meta-analysis, and trial sequential analysis of randomized controlled trials. Int J Dent. 2020: 8857238.
11. Müller-Miny H, Erber D, Möller H, Müller-Miny B, Bongartz G. Is there a hazard to health by mercury exposure from amalgam due to MRI? J Magn Reson Imaging. 1996; 6: 258-60.
12. Ahn HJ, Song KB, Lee YE, Lee JT, Cho SA, Kim KH. Surface change of dental amalgam after treatment with 10% carbamide peroxide. Dent Mater J. 2006; 25: 303-8.
13. Gurgan S, Kiremitci A, Yalcin F, Alpaslan T, Yazici E. Effect of carbamide peroxide treatments on the metal-ion release and microstructure of different dental amalgams. Oper Dent. 2007; 32: 476-81.
14. Shabani MB, Shiina Y, Kirscht FG, Shimanuki Y. Recent advanced applications of AAS and ICP-MS in the semiconductor industry. Mater Sci Eng. 2003; 102: 238-46.

15. Zhang ZW, Shimbo S, Ochi N Eguchi M, Watanabe T, Moon CS, Ikeda M. Determination of lead and cadmium in food and blood by inductively coupled plasma mass spectrometry: a comparison with graphite furnace atomic absorption spectrometry. Sci Total Environ. 1997; 205: 179-87.

16. Mostafa D, Aboushelib M. Bioactive-hybrid-zirconia implant surface for enhancing osseointegration: an in vivo study. Int J Implant Dent. 2018; 4: 20.

17. Talik E, Babiarz-Zdyb R, Dziedzic A. Chemical characterization of selected high copper dental amalgams using XPS and XRD techniques. J Alloys Compd. 2005; 398: 276-82.

18. T. Alkurt M, Sadik E, Peker I, Cakmak M. Effect of magnetic resonance applications on dental amalgam phase changes. Curr Med Imaging Rev. 2016; 12: 59-66.

19. https://www.fda.gov/news-events/press-announcements/fda-clears-first-7t-magnetic-resonance-imaging-device.

20. Yilmaz S, Adisen MZ. Ex vivo mercury release from dental amalgam after 7.0-T and 1.5-T MRI. Radiology. 2018; 288:799-803.

21. Noureddine Y, Bitz AK, Ladd ME Thürling M, Ladd SC, Schaefers G, Kraff O. Experience with magnetic resonance imaging of human subjects with passive implants and tattoos at 7 T: a retrospective study. MAGMA. 2015; 28: 577-90.

22. Beau A, Bossard D, Gebeile-Chauty S. Magnetic resonance imaging artefacts and fixed orthodontic attachments. Orthod Fr. 2017; 88: 131-8.

23. 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 ımager on metallic dental materials. Magn Reson Med Sci. 2016; 15: 26-33.

24. Al-Salehi SK, Hatton PV, Miller CA, Mcleod C, Joiner A. The effect of carbamide peroxide treatment on metal ion release from dental amalgam. Dent Mater. 2006; 22: 948-53.

25. Al-Salehi SK, Hatton PV, McLeod CW, Cox AG. The effect of hydrogen peroxide concentration on metal ion release from dental amalgam. J Dent. 2007; 35: 172-6.

26. Al-Salehi SK. Effects of bleaching on mercury ion release from dental amalgam. J Dent Res. 2009; 88: 239-43.

27. Kursun S, Öztas B, Atas H, Tastekin M. Effects of X-rays and magnetic resonance imaging on mercury release from dental amalgam into artificial saliva. Oral Radiol. 2014; 30: 142.

28. Toledano M, Aguilera FS, Osorio E, Cabello I, Toledano-Osorio M, Osorio R. Mechanical and chemical characterisation of demineralised human dentine after amalgam restorations. J Mech Behav Biomed Mater. 2015; 47: 65-76.

29. Park JE, Jang YS, Bae TS, Lee MH. Biocompatibility characteristics of titanium coated with multi walled carbon nanotubes-hydroxyapatite nanocomposites. Materials (Basel). 2019; 12: 224.

30. Lee HS, Singh JK, Ismail MA, Bhattacharya C, Seikh AH, Alharthi N, Hussain RR. Corrosion mechanism and kinetics of Al-Zn coating deposited by arc thermal spraying process in saline solution at prolong exposure periods. Sci Rep. 2019; 9: 3399.