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Evaluation of mercury release from dental amalgam after cone beam computed tomography and magnetic resonance imaging with 3.0-T and 1.5-T magnetic field strengths

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Objectives. This in vitro study aimed to investigate leakage of mercury from amalgam restorations after cone beam computed tomography (CBCT) and magnetic resonance imaging (MRI) examinations.

Study Design. In total, 238 amalgam disks were prepared and placed in saline solution. The samples were allocated randomly to 7 groups, with 34 samples in each group. CBCT imaging was performed for 4 groups with different imaging parameters (narrow/wide field of view [FOV]; standard/high-resolution). MRI procedures were performed with 3.0-T and 1.5-T magnetic field strengths. No imaging was performed for the samples in the control group. The amalgam samples were removed from the tubes 24 hours after imaging and submitted for plasma mass spectrometry analysis. Kruskal-Wallis and Dunn's tests were performed to compare data. A *P* value less than .05 was accepted as statistically significant.

Results. The highest mean mercury value was found in the 3.0-T MRI group, whereas the lowest mean value was found in the narrow FOV, standard-resolution CBCT group. There were no significant differences between the control group and the experimental groups ($P \geq .338$) or between the experimental groups ($P > .05$).

Conclusions. CBCT and MRI procedures similar to those used in patient care caused no significantly different mercury release compared with nonexposed samples. (Oral Surg Oral Med Oral Pathol Oral Radiol 2020;130:603−608)

Concerns have been raised recently about potential health problems resulting from the use of cone beam computed tomography (CBCT) and magnetic resonance imaging (MRI) in patients with conventional metallic dental materials.[1,2] These materials are tested for safety, especially with MRI, because of their metallic components.[2] Many metals, such as titanium, palladium, gold, copper, tin, and chrome−nickel alloys, are used to formulate restorative materials.

Amalgam is widely used in restorative dentistry and contains mercury, which is a highly toxic environmental pollutant. Humans are primarily exposed to metallic mercury through consumption of fish and shellfish or through inhalation. Mercury and its compounds, especially methyl mercury, pose a major risk for human health.[3] Other compounds of mercury, such as phenylmercury acetate and ethyl mercury, are commonly used as fungicides, antiseptics, and disinfectants; some medicines and vaccines also contain mercury as a preservative.[4,5] Although global health organizations have not determined a reliable threshold of risk for mercury-related disease, the U.S. Environmental Protection Agency (EPA) provides a reference concentration of 0.3 $\mu g/m^3$ for inhalation.[6]

Amalgam is triturated and placed in a tooth, after which mercury can be released from the restoration. However, after complete hardening, the outer amalgam surface is sealed with an oxide layer, allowing only small amounts of mercury leakage.[1,7,8] Factors that increase leakage include removal of the restoration, mechanical stimuli (chewing; functional movements, such as tooth brushing; and parafunctional habits, such as bruxism); drinking carbonated beverages; galvanic corrosion; and electrochemical corrosion.[9,10] Despite its nonaesthetic appearance, amalgam is still used by dentists in many countries for restoration of carious teeth because it is durable, inexpensive, and easily applied.[11,12] Studies on the toxic effects of mercury contained in amalgam restorations have been conducted, and some investigators propose that these fillings can lead to harmful effects on health as a result of the release of mercury.[1,13-15] A recent study showed that mercury was released from amalgam restorations exposed to a high-field-strength MRI device.[1]

Although some researchers have investigated mercury release secondary to conventional radiographic exposure and 1.5-T MRI, no studies have examined the effects of

Statement of Clinical Relevance

Release of mercury from amalgam restorations is a health concern because of the known toxic effects of this element. It is important to understand how the commonly used imaging analyses with cone beam computed tomography and magnetic resonance imaging are associated with mercury release.

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CBCT and 3.0-T MRI devices on mercury release from amalgam.[1,16,17] The objective of this in vitro study was to compare leakage of mercury from amalgam in specimens exposed to CBCT radiation in 4 protocols, MRI at 2 magnetic field strengths, and control restorations with no exposure to x-rays or MRI. The null hypothesis stated that the leakage of mercury would not be significantly different in any of these conditions.

MATERIALS AND METHODS

This study was approved by the Clinical Research Ethics Committee of Pamukkale University (No: 60116787-020/391).

Sample preparation

Amalgam containing a standard proportion of mercury and alloy (i.e., 47.9% mercury [GS-80]; SDI, Bayswater, Australia) was triturated by using an amalgamator (SYG-200; Hangzhou Sifang Medical Apparatus, Beijing, China). After trituration, the samples were condensed into standard round plastic templates with 4 mm height and 4 mm diameter, according to the manufacturer's instructions. In total, 238 of these amalgam cylindrical disks were prepared. All disks were placed in separate Falcon tubes (SuperClear; Labcon, Petaluma, CA) in saline solution 48 hours after sample preparation (Figure 1). The reason for this waiting period is that after trituration, mercury continues to be released while setting (hardening) for 48 hours.[1]

The samples were allocated randomly to 7 groups, with 34 samples in each group. CBCT imaging was performed for 4 groups, and MRI was performed for 2 groups. One group served as the control, and no imaging protocol was used for these samples (Table I).

Fig. 1. One of the prepared samples. The cylindrical disk of amalgam is depicted at the bottom of the tube.

Imaging protocols

CBCT imaging was performed with a supine-position pulsed x-ray unit (Newtom 5 G XL; QR, Verona, Italy). For the 4 CBCT groups, 4 different imaging protocols were used, with tube voltage of 110 kVp, tube current of 8.3 or 11.4 mA, exposure time of 5.4 or 9 seconds, and scanning time of 26 seconds. The field of view (FOV) ranged from 6 × 6 cm to 21 × 19 cm and the voxel size was 100 or 200 μm^3 (see Table I). For this device, the standard resolution was acquired with 6 × 6 cm and 21 × 19 cm FOVs, whereas high-resolution settings were acquired at 6 × 6 cm and 12 × 8 cm FOVs.

MRI was executed with 2 different units. The first MRI group was imaged by using a 3.0-T MRI unit (Magnetom Trio; Siemens, Erlangen, Germany), employing a head imaging protocol (axial T2 turbo spin echo, T2 fluid-attenuated inversion recovery [FLAIR], T2 FLAIR axial hemo, axial T1 spin echo, diffusion, sagittal FLAIR, coronal FLAIR, axial T1 spin-echo fat-sat, sagittal T1 MPRAGE, coronal T1 spin-echo) with a Nova 32-channel head coil (Nova 1 Tx/32 Rx; Nova Medical, Wilmington, MA). The samples were exposed to the static and varying magnetic fields for approximately 30 minutes.

The second MRI group was imaged with a 1.5-T MRI (Magnetom Essenza; Siemens, Erlangen, Germany) with the same head imaging protocol. The same type of head coil was used, and the total magnetic field exposure was approximately 30 minutes.

Mercury concentration analysis

Various devices and methods are used to determine the mercury concentration released from amalgam restorations in fluids. These techniques include inductively coupled plasma−mass spectrometry (ICP-MS); cold vapor atomic absorption spectrometry (CVAAS); and inductively coupled plasma optical emission spectrometry (ICP-OES).[16,18,19] ICP-MS can analyze specimens faster compared with CVAAS but is more expensive.[20]

Table I. Sample groups and imaging protocols

Groups (n = 34)	*Imaging protocol*
Control	No imaging
CBCT-1	Tube voltage: 110 kV; tube current: 8.3 mA; exposure time: 5.4 seconds; scanning time: 26 seconds. Narrow FOV (6 × 6 cm); standard resolution setting (200 μm^3 voxel size)
CBCT-2	Tube voltage: 110 kV; tube current: 11.4 mA; exposure time: 9.0 seconds; scanning time: 26 seconds. Narrow FOV (6 × 6 cm); high-resolution setting (100 μm^3 voxel size)
CBCT-3	Tube voltage: 110 kV; tube current: 8.3 mA; exposure time: 5.4 seconds; scanning time: 26 seconds. Wide FOV (21 × 19 cm); standard resolution setting (200 μm^3 voxel size)
CBCT-4	Tube voltage: 110 kV; tube current: 11.4 mA; exposure time: 9.0 seconds; scanning time: 26 seconds. Wide FOV (12 × 8 cm); high-resolution setting (100 μm^3 voxel size)
MRI-1	3.0-T MRI head imaging protocol
MRI-2	1.5-T MRI head imaging protocol

CBCT, cone beam computed tomography; *FOV,* field of view; *MRI,* magnetic resonance imaging.

However, ICP-MS can perform more accurate measurements compared with the other two techniques.[21,22] Because of these benefits, we used ICP-MS for chemical mercury analyses in our study.

The amalgam samples were removed from the tubes 24 hours after the CBCT and MRI procedures. Research indicates that significantly more mercury is released over a 24-hour period after exposure to x-rays or MRI compared with shorter periods (1 or 2 hours).[17] Therefore, as in the recent study by Yılmaz et al.,[1] we kept the samples for 24 hours after imaging. The tubes containing isotonic saline were numbered and submitted for chemical analysis. All samples were analyzed by using an ICP-MS device (NexION 2000 B; PerkinElmer Inc., Shelton, CT) in the Advanced Research Laboratories of our university. The mean of the measurements was recorded by performing 3 readings for each sample.

Statistical analysis

The power analysis was determined by using G*power software, (version 3.1.9.2; Heinrich Heine Universität, Düsseldorf, Germany). The minimum number of samples required to find a statistically significant difference in mercury concentration between the groups was 34 in each group ($\alpha = 0.05$; $1 - \beta = 0.80$; actual power = 0.81). Statistical analysis was performed with SPSS for Windows, version 21.0 (SPSS Inc., Chicago, IL). The normality of the distribution of continuous variables was evaluated by using the Shapiro-Wilk test. Because the data were not distributed normally, Kruskal-Wallis and Dunn's multiple comparison tests were performed to compare the data from several independent groups. Differences between mercury levels were calculated by subtracting the level in the control group from the levels in each of the experimental groups and analyzed statistically. Mean mercury values were determined with 95% confidence intervals. Statistical significance was established at P value less than .05.

RESULTS

The mean mercury levels of all groups are shown in Table II. The highest mean value (150.08 μg/L) was detected in the 3.0-T MRI group, whereas the lowest mean value (142.85 μg/L) was observed in the CBCT-1 group (Figure 2). There were no significant differences ($P \geq .338$) between the control group and the other groups (see Table II). In addition, no statistically significant differences ($P > .05$) were found among the 6 experimental groups.

DISCUSSION

Corrosion is the degradation of materials by electrochemical attack. It is a concern when metallic implants, prostheses, intracoronal restorations, or orthodontic appliances are placed in the electrolytic environment provided by oral tissues. Saliva is a hypotonic solution containing bioactonate, chloride, potassium, sodium, nitrogenous compounds, and proteins. The pH of saliva varies from 5.2 to 7.8. Small galvanic currents associated with electrogalvanism are continually present in

Table II. Mercury levels (μg/L) of the groups and comparison between the control group and the experimental groups

Group comparisons	*Mercury level ± SD*	*Mean difference*	*P value*	*95% confidence interval*
Control group	144.53 ± 12.78	–	–	–
Versus CBCT-1	142.85 ± 9.68	−1.68	.995	−9.43 to 6.08
Versus CBCT-2	145.47 ± 9.54	0.94	1.000	−6.81 to 8.70
Versus CBCT-3	145.38 ± 10.33	0.85	1.000	−6.90 to 8.61
Versus CBCT-4	148.53 ± 9.41	4.00	.725	−3.76 to 11.76
Versus MRI-1	150.08 ± 12.01	5.55	.338	−2.20 to 13.32
Versus MRI-2	149.44 ± 11.06	4.91	.494	−2.84 to 12.6

CBCT, cone beam computed tomography; *MRI,* magnetic resonance imaging; *SD,* standard deviation.

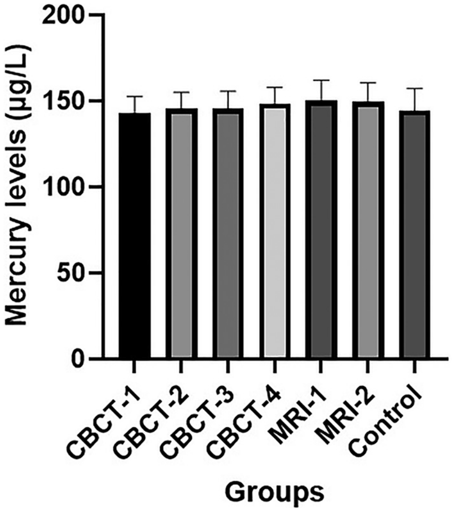

Fig. 2. Amount of released mercury in the experimental and control groups.

the oral cavity. On the basis of the hypothesis that MRI can create microcurrents that can increase corrosion, we used isotonic saline solution instead of salivary components, which may have affected the magnitude of the corrosion process.

The studies that examined corrosion of dental materials used Ringer's solution, 0.9% sodium chloride solution, and artificial saliva.[23-26] The content of the solution and its interaction with the sample can change the corrosion rate and products. In previous investigations of mercury release from amalgam, saline solution or artificial saliva was used as the liquid environment for the amalgam specimens.[1,16,17] In the present study, we preferred saline solution because it is less costly and easier to use, and mercury dissolution in saline solution is the same as in artificial or natural saliva.[16,27]

We studied 2 imaging techniques with different energy types. x-rays are a form of ionizing radiant energy. The interaction between x-rays and amalgam and the subsequent release of mercury was examined by Kursun et al.[17] In that study, samples were exposed to x-rays by using a conventional intraoral dental x-ray device at 70 kV and 8 mA for 0.4 second, with a 25-cm target-to-image distance. The results of that investigation showed significantly greater release of mercury in the x-ray−exposed group compared with the control group. Kursun et al. suggested that this was related to the ionization of the amalgam alloy with the high energy x-ray photons, which caused chemical changes in the metallic bonds in the amalgam alloy structure.[17]

Three-dimensional CBCT imaging is now widely used in dentistry for various diagnostic purposes. The exposure parameters can be changed according to different conditions.[28] One of the exposure parameters affecting the radiation dose is FOV.[29] The effective dose in adults varies by 46 to 1073 μSv for wide, 9 to 560 μSv for medium, and 5 to 652 μSv for narrow FOVs.[29] Radiation doses for the same FOV can vary up to 15-fold between low- and high-resolution modes.[30] On the basis of this information, we used 4 different sets of imaging parameters: narrow and wide FOVs, and normal- and high-resolution modes. In our study, mercury released as a result of CBCT exposure was not significantly different from that in the control samples. These findings differ from the results of the study by Kursun et al., in which x-ray exposure increased the release of mercury.[17] The number of exposures was not mentioned in that study. Thus, a higher number of exposures may have resulted in greater radiation exposure in that study than in the present investigation, even though the CBCT photons in our project had greater energy than the x-rays generated in the intraoral device used by Kursun et al.

The other imaging technique used in the present study, MRI, involves radiofrequency (RF) energy and a magnetic field. MRI is a safe and useful imaging modality that creates sectional images and allows high-quality visualization of soft tissues.[31] These devices are categorized according to their magnetic field strength as conventional (1.0−1.5-T); high-field (3.0−4.0-T); and ultra-high-field ($\geq$ 7.0-T) systems.[32] For maxillofacial imaging, with its demands for high resolution, 3.0-T systems are generally preferred over 1.5-T systems.[33] The exposure of the RF pulse chain in diagnostic MRI is higher than the recommended limits for occupational RF exposures.[34] The greater magnetic field requires higher RF energy for transverse magnetization. The static magnetic field interacts with the human body at the molecular, cellular, tissue, and organ levels. When the body moves through the main magnetic field, electric currents are expected to occur.[35] RF energy also induces currents in the body and can cause tissue heating. This deposited power, which varies with the intensity of the electric field, is expressed in a specific absorption rate (SAR) and measured in units of watts per kilogram.[36]

Three studies[1,16,17] examined the effects of MRI on dental amalgam fillings. All 3 included 1.5-T magnetic field and RF exposure results, and 1 study also used a 7.0-T magnetic field and RF exposure. The majority of units in clinical practice operate with either 1.5-T or 3.0-T field strength. Müller-Miny et al.[16] found a statistically insignificant increase in mercury levels (maximum level, 4.1 μg/L mercury) working with a 1.5-T MRI device, in which some of the amalgam specimens were exposed to a static magnetic field, whereas other specimens received pulsed sequences. Kursun et al.[17] revealed that 1.5-T MRI, when used in a temporomandibular joint protocol, did not significantly affect mercury release (mean 9.1 μg/L). Yilmaz et al.[1] found an insignificant increase in the release of mercury (mean 172 μg/L) after 1.5-T MRI, compared with the values in the control group. Our study found that the change in mercury release in amalgam exposed to 1.5-T MRI compared with the control sample and the other experimental groups was not statistically significant, similar to the 2 previous 1.5-T MRI studies mentioned. However, Yilmaz et al.[1] found a statistically significant increase in mercury release (mean 673 μg/L mercury) in amalgam exposed to 7.0-T MRI, an ultra-high magnetic field. Use of these devices is attractive because they produce a high signal-to-noise ratio, leading to increased spatial and temporal image resolution.[37] Because of the power storage of the RF pulse that is used with the increased magnetic field strength, the SAR value is quite high compared with that of conventional devices.[38] A high SAR value may warp the tissue, but there is no study showing its effect on the amalgam alloy. The mechanisms by which mercury release occurs from amalgam are not yet understood. Researchers should investigate whether the change in mercury occurs in the phases during which it is attached in the alloy and whether this causes liberation. At the same time, movement occurring in the magnetic field creates microcircuits, the impact of which on alloys is still unknown.

We did not find a study that examined the field of 3.0-T MRI. No statistically significant differences in mercury release were found in the 3.0-T MRI compared with the other groups in this study, the results of which add to those of previous research. However, our results revealed a mean mercury release of 149 μg/L, which is higher than that reported in previous 1.5-T MRI studies.[16,17] We believe that the reason for this numerical difference is that MRI was performed with a longer exposure time in our study, and experimental conditions were different from those of the other investigations. Methodologic differences may include the volume and type of amalgam, the volume and type of solution, the devices used in chemical analysis, and the method of statistical analysis. Future investigations may use various experimental conditions, such as different volumes and numbers of amalgam specimens.

The fact that the imaging methods used in our study did not have a significant effect on the release of mercury suggests that CBCT, as well as the 3.0-T and 1.5-T MRI devices, used in clinical applications can be considered safe in terms of the risk of mercury-induced toxic effects in patients with amalgam restorations in their teeth, in concurrence with the results of previous research.[1,17]

Various studies[1,16,17] have been conducted to assess the potential harmful effects of mercury. However, it is not clear how much mercury exposure results from the presence of amalgam restorations or from the placement or removal of the amalgam material. Mercury is released from amalgam restorations through 2 mechanisms: evaporation and liquid dissolution. In our study, only the amount dissolved was detected. To determine the total amount of mercury to which the patient may be exposed, it is necessary to know the entire bioburden of mercury in the patient. Further studies are needed to address these issues.

CONCLUSIONS

The results of this study showed no significant differences in the levels of mercury released from amalgam as observed after CBCT, 3.0-T MRI, or 1.5-T MRI exposure compared with the levels in the control samples, and no significant differences were found between the CBCT and MRI protocols.

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PRESENTATION

This study was presented and awarded the third best oral presentation at the 2nd International Meandros Dental Congress, November 22−24, 2019, Kusadasi, Turkey.

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