Ex Vivo Mercury Release from Dental Amalgam after 7.0-T and 1.5-T MRI

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This study was approved by the Kirikkale University Clinical Research Ethics Committee. Written informed consent was obtained from patients for the use of extracted teeth in this project.

Materials and Methods

The use of dental amalgam fillings remains popular despite the controversy surrounding its potential effects on human health (1–4). The American Dental Association has reported that 100 million amalgam filling procedures are performed every year in the United States (5). However, since 2008, the use of amalgam fillings has been forbidden or restricted in Sweden, Norway, Denmark, and Germany (1). In addition, the European Parliament has adopted a ban on the use of amalgam in clinical practice for children younger than 15 years and pregnant or lactating women, effective by 2018.

The oropharyngeal region is an area in which metals are often used for dental applications. These dental materials often contain precious (gold, silver, platinum) and nonprecious (chromium, cobalt, molybdenum, nickel) metals, amalgam, pure gold, titanium, and titanium alloys (6,7). Dental implants and surgical reconstruction materials are mostly made of titanium, stainless steel, and vitallium (7). Studies that are conducted to characterize the MRI properties of these materials for patient safety purposes use in vitro testing methods (7,8). Dental amalgam has been in use for the past 200 years and consists of approximately 50% mercury. The release of mercury from amalgam fillings occurs through metal ions (mercury ions) and evaporation of mercury (elemental). Various conditions that occur during and after the restoration process, such as chewing, brushing, and corrosion, result in mercury discharge. Although approximately 40% of the mercury released from amalgam passes into the saliva in the form of metal ions and enters the gastrointestinal system (10% is absorbed), 60% is released as mercury vapor and is either inhaled and enters the circulation in the lungs or is exhaled. It has been suggested that release of mercury into the environment during the application or removal of amalgam may also have some potentially detrimental effects on the body (2,9).

Several previous studies have examined amalgam-filled teeth in terms of translational interaction, heating rates, and microleakage after MRI (8,10,11). To our knowledge, no previous study has tested the effects of 7.0-T MRI on mercury release from amalgam fillings, and we hypothesized that 7.0-T MRI can trigger mercury release. The aim of this study was to investigate the mercury release into artificial saliva from amalgam-filled teeth exposed to 7.0-T MRI and microleakage in an ex vivo setting.

Materials and Methods

This study was approved by the Kirikkale University Clinical Research Ethics Committee. Written informed consent was obtained from patients for the use of extracted teeth in this project.

Sample Preparation

Human teeth that had been extracted for various reasons (eg, orthodontic procedures, third-molar extractions, and periodontal hypermobility) were used for this study. The study included 60 caries-free molar or premolar teeth that had been extracted for clinical indications. Consenting patients were asked to sign and return the written informed consent. This research was approved by the Clinical Research Ethics Committee of the Kirikkale University. This study was supported by the Kirikkale University Scientific Research Projects Coordination Unit (project no. 2017/36). The authors evaluated 60 caries-free molar or premolar teeth that had been extracted for clinical indications. Two-sided cavities were opened in each tooth and amalgam fillings applied. After 9 days, two groups of 20 randomly selected teeth were placed in 20 mL of artificial saliva immediately followed by 20 minutes of MRI exposure at 1.5 or 7.0 T. A control group of teeth was placed in artificial saliva without undergoing MRI exposure. The teeth were removed from the artificial saliva 24 hours later, and the saliva was analyzed for mercury content by using inductively coupled plasma mass spectrometry. One-way analysis of variance was used to compare the mean mercury values among the three independent groups, and the Tukey test was used for multiple comparisons of the mean values.

Results:

The mean mercury content of the artificial saliva was 673 µg/L ± 179 in the 7.0-T MRI group, 172 µg/L ± 60 in the 1.5-T MRI group, and 141 µg/L ± 152 in the control group. The mercury content in the 7.0-T group was greater than that in both the 1.5-T group \((P < .001; 95\% \text{ confidence interval: } 368 \mu g/L, 633 \mu g/L)\) and the control group \((P < .001; 95\% \text{ confidence interval: } 416 \mu g/L, 648 \mu g/L)\). There was no statistically significant difference in mercury content between the 1.5-T and control groups \((P = .84; 95\% \text{ confidence interval: } -164 \mu g/L, 110 \mu g/L)\).

Conclusion:

In an ex vivo setting, mercury was released from amalgam fillings after exposure to 7.0-T MRI but not 1.5-T MRI.
Ex vivo Mercury Release from Dental Amalgam after 7.0-T and 1.5-T MRI

Summary
Nine days after dental restoration, exposure to 7.0-T MRI was associated with mercury release from dental amalgam in an ex vivo experimental setting.

Implications for Patient Care
- Nine days after restoration of human teeth with dental amalgam containing mercury, exposure to 7.0-T MRI was associated with mercury release in artificial saliva in an ex vivo setting.
- In the same ex vivo setting, no mercury release was observed after exposure of amalgam-restored teeth to 1.5-T MRI.
- Further studies of mercury amalgam at 7.0-T MRI may be warranted to evaluate the relationship between high-field-strength MRI and release of mercury from dental amalgam.

Results
The mean mercury values were 673 μg/L ± 180 in the 7.0-T MRI group, 172 μg/L ± 60 in the 1.5-T MRI group, and 141 μg/L ± 152 in the control group (Fig 3). One-way analysis of variance revealed a statistically significant difference in mean mercury values among the three groups (P < .001) (Table).

7.0-T MRI Group
MRI was performed with a 7.0-T MR unit (Magnetom Trio; Siemens Healthineers, Erlangen, Germany) by applying a head imaging protocol (axial T1-weighted thin-section imaging before and after the administration of contrast material, axial T1- and T2-weighted fast spin-echo imaging, T1-weighted imaging, magnetization-prepared rapid acquisition gradient-echo imaging, T2-weighted imaging, T2-weighted fluid-attenuated inversion-recovery imaging, and T2-weighted coronal and sagittal fast spin-echo imaging) with a head coil (Nova 1Tx/32Rx, Siemens Healthineers) and exposure to a static and varying magnetic field for approximately 20 minutes. Twenty-four hours after imaging, the teeth were removed from the tubes and the artificial saliva was stored in a closed container for analysis.

1.5-T MRI Group
A 1.5-T MR unit (Achieva; Philips Medical Systems, the Netherlands) was used to perform MRI for approximately 20 minutes with the same protocol used for 7.0-T imaging. Twenty-four hours after imaging, the teeth were removed from the tubes and the artificial saliva was stored in a closed container for analysis.

Control Group
The teeth in the control group were placed into artificial saliva 9 days after the fillings were placed. After 24 hours, the teeth were removed from the tubes and the artificial saliva was stored in a closed container for analysis.

Mercury Concentration Analysis
To determine the concentration of mercury in the artificial saliva, inductively coupled plasma mass spectrometry (Spectro Analytical Instruments, Kleve, Germany) was performed in the Kirikkale University Central Research Laboratories. The sample tubes were numbered, and the laboratory technician was not aware of group assignment. Three separate 0.5-mL samples were obtained from the 20-mL artificial saliva within the tubes. The mean mercury values from the three analyses were used for statistical comparison.

Statistical Methods
The power analysis was performed with software (G*power, version 3.1.9.2; developed by Franz Faul, Universität Kiel, Germany) and indicated that a total sample size of 60 subjects would provide greater than 88% power (actual power = 0.88) to detect significant differences with an effect size of 0.40 at α of .05. Mean mercury values were determined with 95% confidence intervals. A one-way analysis of variance test was used to compare the mean mercury values among the three independent groups. The Tukey test was used for multiple comparisons of the mean values among the groups. Descriptive statistics were expressed as means ± standard deviations for numeric variables. Software (SPSS for Windows, version 24.0; IBM, Armonk, NY) was used for statistical analysis, and P < .05 was considered to indicate a statistically significant difference.

Figure 1: Sample tooth with amalgam filling routinely used in clinical practice.
According to the Tukey multiple comparison test, the mercury content in the 7.0-T group was significantly greater than that in both the 1.5-T group ($P < .001$; 95% confidence interval: 368 µg/L, 633 µg/L) and the control group ($P < .001$; 95% confidence interval: 416 µg/L, 648 µg/L). However, there was no statistically significant difference in mercury content levels between the 1.5-T and control groups ($P = .84$; 95% confidence interval: $-164$ µg/L, 110 µg/L).

**Discussion**

In our study, the mean mercury concentrations released into artificial saliva from amalgam fillings 24 hours after 7.0- and 1.5-T MRI were 673 µg/L and 172 µg/L, respectively. We concluded that, 9 days after dental restoration, exposure to 7.0-T MRI was associated with mercury release from dental amalgam in an ex vivo experimental setting.

In the literature, two studies examined the effects of MRI on dental amalgam fillings (12,13). The first study, performed in 1996 by Müller-Miny et al (12), used 1.5-T MRI. They exposed amalgam-filled dental models to a static magnetic field for 24 hours and to a gradient-echo sequence for 60 minutes. In both situations, they found no significant increase in mercury levels (maximum level, 2.5 µg/L mercury). In the second study, performed in 2014, Kursun et al (13) carried out a temporomandibular joint MRI protocol at 1.5 T and exposed amalgam disks to the magnetic field for approximately 30 minutes. They reported that MRI had no effect on mercury release from dental amalgam (mean, 9.1 µg/L mercury). In the current study, we observed higher levels of mercury in the 1.5-T group (mean, 172 µg/L mercury). Differences in absolute levels of mercury may depend on the age of the amalgam and the conditions of its preparation. The samples in our study were not stored in routinely refreshed saline solution, which may cause corrosion and reduce the amount of mercury in the filling material. Our samples were stored in dry, closed boxes until imaging.

Figure 2: Sample tubes containing, top, tooth with dental amalgam in artificial saliva in preparation for testing and, bottom, artificial saliva only. Tube had previously undergone MRI, and the tooth was removed 24 hours after imaging.

After trituration and insertion of amalgam into a patient’s tooth, mercury continues to release while setting (hardening or amalgamation) for 48 hours. After completion of the amalgamation, the main source of mercury is the matrix in the $\gamma$-1 phase. Over time, this phase gradually transforms into the $\beta$-1 phase, which contains less mercury, and this conversion causes the release of mercury (14). In addition to this sustained mercury release, other factors affecting the release process include dismantling of the filling, wear from mechanical stimuli (chewing, consumption of carbonated drinks, functional movements such as brushing of the teeth, and parafunctional habits such as bruxism), galvanic corrosion, electrochemical corrosion, and oral conditions (temperature, pH level, and negative air pressure) (3,4,15,16). Previous studies have measured the amounts of mercury released due to these factors (5,17–19). The World Health Organization estimates that the daily absorbed dose from amalgam is 122 µg mercury, and the Environmental Protection Agency provides a reference concentration of 0.3 µg/m³ for inhalation. In the present study, the dissolved amount of mercury was observed to be in the range of 325–1000 µg/L mercury after 7.0-T MRI. An important point of discrimination concerning safety and hazard to human health is the amount of mercury that is absorbed by the vital tissues.

In a set amalgam, phase transformation is accelerated by an increase in temperature (20). The details of this transformation phenomenon are not completely understood (21,22). We believe that the mercury release after 7.0-T MRI might be caused by phase changes stimulated by high-field-strength imaging. Studies examining the effect of the magnetic field on alloys have shown that high magnetic fields have an effect on phase transformation, recrystallization, and particle structure distribution.

Figure 3: Beeswarm plot shows mercury content in artificial saliva of the three groups. Mean mercury values of artificial saliva were 673 µg/L ± 180 in 7.0-T MRI group, 172 µg/L ± 60 in 1.5-T MRI group, and 141 µg/L ± 150 in control group.
In conclusion, the results of our study indicated that 7.0-T MRI (but not 1.5-T MRI) is associated with mercury release 9 days after placement of dental amalgam fillings in ex vivo human teeth. Further studies of mercury amalgam with 7.0-T MRI may be warranted to evaluate the relationship between high-field-strength MRI and release of mercury from dental amalgam.

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