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Mercury Release from Dental Amalgam Restorations after Magnetic Resonance Imaging and Following Mobile Phone Use

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ABSTRACT

Background: Mercury or Hydrargyrum (Hg) is the most non-radioactive toxic element. Dental amalgam is made up of 50% mercury. Exposure to electromagnetic fields of magnetic resonance imaging (MRI) and microwave radiation emitted from mobile phone use may increase the emission of mercury from dental amalgam fillings. It was thus aimed to study the effects of exposure to MRI and mobile phone use on the mercury release from dental amalgam restorations.

Materials and Methods: Following approval of the University Medical Ethics Committee and the informed consents of the subjects, two different studies were undertaken. **A-MRI: -** Thirty patients (27F,3M) aged 18 to 48 years who had been referred to MRI department of Ali-ebn Abitaleb Teaching Hospital and had at least four amalgam restorated teeth , were investigated. Five ml stimulated saliva was collected just before and after MRI. The magnetic flux density was 0.23 T, and the duration of exposure of patients to magnetic field was 30 minutes. **B-Mobile phone Use:** Fourteen female healthy University students aged 19-23years, who had not used mobile phones before the study and did not have any previous amalgam restorations but had decays in at least four teeth were investigated. Their urine samples were collected before amalgam restoration, and at days 1, 2, 3 and 4 after restoration. Dental amalgam restoration was performed for all 14 students (2 molars on one side, one class I and one class II restorations with identical volume and surface area of the amalgam fillings). The students randomly divided into two equal groups. The test group students were exposed

to microwave radiation emitted from a Nokia 3310 mobile phone (SAR=0.96 W kg^{-1}) that was operated in talk mode for 15 min every day at days 1-4 after restoration. The other seven female age matched students who served as controls sham exposed to microwave radiation.

For each subject, a questionnaire regarding their possible sources of exposure to electromagnetic fields, occupation, medical history and life style was filled out. Salivary and urinary Hg concentrations were measured by cold vapor (Mercuric Hydride System) of an atomic absorption (Perkin Elmer, Model 3030) spectrometry. Relevant statistical tests (paired and independent Student-t, and ANOVA) were performed using SPSS at $p<0.05$ as the significant level.

Results: A-MRI: The mean ± SD saliva Hg concentrations of the patients before and after MRI were 8.6 ± 3.0 and 11.3 ± 5.3 μg L^{-1}, respectively ($p<0.01$). **B-Mobile phone Use**: A statistical significant ($p<0.05$) higher concentration was observed in the students used mobile phone. The mean± SE urinary Hg concentrations of the students who used mobile phones were 2.43±0.25, 2.71±0.27, 3.79±0.25, 4.8± 0.27 and 4.5±0.32 μg L^{-1} before the amalgam restoration and at days 1, 2, 3 and 4 respectively. Whereas the respective Hg concentrations in the controls, were 2.07±0.22, 2.34±0.30, 2.51±0.25, 2.66± 0.24 and 2.76±0.32 μg L^{-1}.

Conclusion: It appears that MRI and microwave radiation emitted from mobile phones significantly release Hg from dental amalgam restoration. Further research is needed to clarify whether other common sources of electromagnetic field (EMF) exposure may cause alterations in dental amalgam and accelerate the release of mercury.

Keywords: Mobile Phone, MRI, Microwave Radiation, Mercury, Dental amalgam

Introduction

Humans are surrounded daily with electric and magnetic fields. Natural magnetic field originates from earth's molten core and the electric field comes from thunderstorm activity in the atmosphere. The earth's natural magnetic field is about 0.5 Gauss on the surface. Natural magnetic fields are not as intense or environmentally disruptive as the magnetic fields emitted from man-made sources. The use of technology in medicine, communication, entertainment, industry and science has improved the quality of life. In spite of this, the detrimental effects of the electric and magnetic fields associated with this technology are not well understood. Man made sources of magnetic fields include emissions from cathode ray tubes (CRTs), radio and television towers, cellular telephones and their base stations, weather and air traffic control radar, military and commercial communications systems, household and industrial remote control devices, and intrusion detection equipment. Early experiments on undersea welders showed that electromagnetic fields might alter the evaporation of mercury from dental amalgam restorations (Ortendahl *et al.* 1988).

Magnetic resonance imaging (MRI), as an efficient medical diagnostic procedure, is increasingly used. During MRI patients are exposed to static and gradient magnetic fields as well as electromagnetic radiation in radiofrequency range (Formica and Silvestri 2005). The introduction of MRI as a clinical modality dates back to approximately 20 years ago. Over the past 2 decades, this technology had a rapid continuous evolution. Nowadays, MRI systems utilize stronger static magnetic fields, faster and stronger gradient magnetic fields, and more powerful radiofrequency (RF) transmission coils (Shellock and Crues 2004). Although, more

than 150 million MR examinations have been performed to date, only few major incidents have occurred (Schenck 2001, Zaremba 2001, FDA 2002, Shellock 2003). In spite of this, potential hazards associated with MRI systems and procedures have been extremely controversial over the past decade (Formica and Silvestri 2004). Heating and induction of electrical currents may present risks to patients with implants or external devices (Shellock 2002, Dempsey and Condon 2001). The majority of MRI related accidents have been originated from metallic objects, implants, and biomedical devices (Sawyer-Glover A and Shellock 2000, Ho 2001).

Radiofrequency (RF) waves have long been used for different types of information exchange. Increasingly larger numbers of people rely on mobile telephone technology. Radio and television broadcast waves have exposed populations to RF for more than 50 years. Mobile phones which have come into widespread uses, generate potentially harmful radiofrequency electromagnetic radiation. While it was predicted that in 2005 there would be 1.6 billion mobile phone users worldwide (Yeolekar and Sharma 2004), now there are more than 2.4 billion cellphone users, with more than 1,000 new customers added every minute. The point worth consideration is that 59 percent of these 2.4 billion people using cellphones, live in developing countries. In this light, this is the first telecommunications technology in history to have more users in developing countries than in the developed world (MIT 2007).

No doubt, this drastically increased number of users has lead to large numbers of base station to provide widespread availability of service to large populations (Valberg et al. 2007). Rapidly increasing use of wireless communication systems has caused a growing public concern about

possible health effects of EMFs (Markova´ et al.,2005) , particularly because the mobile phones operate in close proximity to brain. An increasing number of people report subjective symptoms and hypersensitivity to a wide variety of electromagnetic sources such as power lines, radio and TV broadcasting stations, cellular phones and their base stations, computer monitors (cathode ray tubes or CRTs) and electrical home appliances (Sandstrom et al., 1997; Hocking, 1998; Lyskov et al. 2001). On the other hand, Mortazavi et al. (2007) found no association between the exposure to some major sources of electromagnetic fields and self-reported illness symptoms. In this light, there is still a great public concern about the safety of mobile phones.

Although, human exposure to the vapor of metallic mercury dates back to antiquity, it still exists in occupational settings and dental amalgam fillings (Clarkson and Magos 2006). As reported by some investigators, mercury is still an "element of mystery" (Clarkson and Magos 2006). Mercury, in particular mercury vapor, is assumed to be the most toxic nonradioactive element, and is toxic even in very low doses (Mutter et al. 2007). Dental amalgam that is one of the most commonly used materials in restorative dentistry, has been used in dentistry for more than150 years. It consists of around 50 % elemental mercury and a mixture of silver, tin, copper and zinc. As individuals with dental amalgam restorated teeth have 2-12 times more mercury in their body tissues compared to those without amalgam. Dental amalgam is believed to be the main source of human total mercury body burden (Mutter et al. 2007). Amalgam fillings release mercury at a low level ranging 2-5 micrograms/day in an adult (Spencer 2000). The half-life of mercury deposits in brain and bone tissues ranges from several years to decades, and this is the reason that mercury accumulates over time of exposure (Mutter et al. 2007). In spite of the widespread use of amalgam, most dentists and doctors are still unaware of its health effects

(Pleva 1994). Studies which indicate that amalgam fillings are safe for human beings seem to have considerable methodological flaws (Mutter et al. 2007).

Dental amalgams have long been assumed to be of little importance as contributors to the overall body burden of mercury. However, more recent studies indicating considerable elemental mercury vapor release from dental amalgams have raised renewed concern about amalgam safety (Reinhardt 1992). It has been reported that mercury vapour is more neurotoxic than methyl-mercury in fish. New studies suggests that mercury from dental amalgam may lead to nephrotoxicity, neurobehavioural changes, oxidative stress, autism, skin and mucosa alterations or non-specific symptoms and complaints (Mutter et al. 2005). Lungs absorb about 80% of the inhaled mercury vapor and enter it to the bloodstream rapidly. Following distribution by blood circulation, mercury can enter and accumulate in certain tissues for long periods of time. The primary target organs of concern for mercury are the central nervous system and kidneys (Reinhardt 1992).

The aim of the present study was to assess the potential alterations in the release of mercury from human dental amalgam restorations after exposure to electromagnetic fields produced by conventional MR imaging and microwave radiation emitted by using mobile phones.

Materials and Methods

Following approval of the University Medical Ethics Committee in Rafsanjan and the informed consents of the subjects, two different studies were undertaken.

A-MR imaging: In this natural experiment, studied population was consisted of individuals with at least 4 teeth with amalgam restorations. The time passed from the last restoration was

not more than one week. The sample size was calculated after conducting a pilot study. The confidence interval, power and effect size were 95%, 80% and 0.5%, respectively. Thirty persons (27F, 3M; aged 18 to 48 years), who met all the inclusion criteria for our research and were referred by their own physicians to MRI department of Ali-ebn Abitaleb Teaching Hospital for performing brain scans, were investigated. As inter-individual variations is usually a major confounding factor in these studies, mercury level in each individual's saliva before MRI was compared to that of himself/herself after MRI. Following interview,5 ml stimulated saliva was collected just before and after MRI for Hg determination.. The MRI scanner used in this experiment was an electromagnet type Bruker (Tomikon R 23, Bruker Medizintechnik, Karlsruhe) that is the first MRI facility installed in IR Iran. The magnetic flux density was 0.23 T, and the duration of exposure of patients to magnetic field was 30 minutes.

B-Mobile phone Use- Fourteen female healthy University students aged 19-23 years who had not used mobile phones before the study and did not have any previous amalgam restorations but had more than 4 teeth decayed were investigated. Their urine samples were collected before amalgam restoration, and one hour after mobile phone use at days 1, 2, 3 and 4 after restoration. Dental amalgam restorations were performed for all 14 students (2 molars on one side, one class I and one class II restorations with identical volume and surface area of the amalgam fillings). They all were asked not to use sea food, canned food, and hot tea/coffee from one week before the study to final sampling at day 4 after amalgam restoration. The students were randomly divided into two equal groups. The test group students were exposed to microwave radiation emitted from a Nokia 3310 mobile phone (SAR=0.96 W kg^{-1}) that was operated in talk mode

for 15 min every day at days 1-4 after restoration. The other seven female age matched students who served as controls, sham exposed to microwave radiation.

For each subject of the two studies, a questionnaire regarding their possible sources of exposure to electromagnetic fields or microwave radiation, occupation, medical history and life style was filled out.

After freezing, the samples were sent to the Toxicology Laboratory of Imam Reza Hospital (Mashhad, Iran) and mercury concentrations in samples were measured by cold vapor (Mercuric Hydride System) of an atomic absorption (Perkin Elmer, Model 3030) spectrophotometer.

Relevant statistical tests (paired and independent Student-t, and ANOVA) were performed using statistical package for social sciences (SPSS,version 13.0) at $p<0.05$ as the significant level.

Results

A-MRI- The overall mean age of the studied participants was 30.70±11.80 (mean±SD) years. The participants mean age for males and females were 29.23, and 40.66 years, respectively. Age and sex distributions of the studied patients are shown in Table 1. More than 50% of them were in the age range 30-49 year. The chief complaints for which participants were referred to MRI department were headache and vertigo (68.96%), hypophys gland problems (13.79%) and other causes including MS, cerebrovascular accidents, driving accidents and vision problems (17.24%). MRI procedure for all participants took 30 minutes and the number of slices was 57.

The oral cavity of participants were carefully examined by a dentist and the number of teeth with amalgam restoration was recorded. The minimum, maximum and mean numbers of teeth with amalgam fillings were 4, 11 and 6.4., respectively. The minimum, maximum and mean numbers of amalgam-filled surfaces were 4, 23, and 10.5, respectively.

Mean ± SD sliva Hg concentrations of of the patients before and after MRI were 8.6 ± 3.0 and 11.3 ± 5.3 μg L^{-1} (micg/L), respectively ($p<0.01$). Mercury saliva concentrations of the studied participants before and after MRI are shown in Figure 1. The mercury saliva concentrationsbefor MRI ranged from 5.0 to 15.0 μg /L, but after MRI, it ranged from 5.0 to 25.0 μg /L.

Table 1

Figure 1

B-Mobile phone Use: As shown in Table 2, an elevated urinary mercury concentration released from dental amalgam fillings was observed after exposure to microwave radiation emitted from mobile phones. The (mean ±SD) urinary Hg concentrations in the test group students were 2.43±0.66, 2.71±0.72 , 3.79±0.65 , 4.8± 0.71 and 4.5±0.85 μg L^{-1} before the amalgam restoration and at days 1, 2, 3 and 4, respectively. Whereas the respective figures in the controls were 2.07±0.33, 2.34±0.64, 2.51±0.44, 2.66± 0.41 and 2.76±0.72 μg L^{-1}.

Table 2

Discussion

Application of EMF has been increased rapidly over the past decades. This is of great concern regarding the possible risks of such exposures. In a recent report published by Mortazavi et al. (2007) no association could be detected between the exposure to some major sources of electromagnetic fields and self-reported illness symptoms. In IR Iran, general public and even physicians are less familiar with hypersensitivity to electromagnetic fields. This may be due to lack of the interest of mass media to the possible hazards of exposure to electromagnetic fields.

Although the amount of released mercury from dental amalgam is not sufficient for causing a toxic effect in humans, potential toxicity due to exposure to mercury vapor (Hg) from dental amalgam fillings is still the subject of current public health debate in many countries (Echeverria et al. 1998). Despite there is no evidence that dental amalgams cause health problems in the majority of the population, the effects of dental amalgam on specific groups, including pregnant women, small children, elderly and people who are especially sensitive to mercury is not clearly known. As some people tend to be more sensitive to the effects of exposure to any chemical substance in their environment, National Health and Medical Research Council (NHMRC 2002) in Australia has recommended the use of new tooth-coloured materials in children where cavities are small. Further research is needed to clarify whether MRI exposure may cause alterations in dental amalgam.

It has been reported that contact between gold and dental amalgam restorations in the oral environment may cause sensitivity from galvanic current flow between the two restorations

(Walker et al. 2003). In an early report published by Snyder?? Ref?, the incidence of painful oral electrogalvanism from a variety of dissimilar metals was 0.4 percent of restorations. Factors such as the physiological condition of the tooth (Anusavice and Phillips 1996), electromotive force between the two metals (Mumford 1960), patient's pain threshold (Mumford 1957), salivary electrolyte concentration, shape of dental amalgam and relative size of the restorations (von Fraunhofer and Staheli 1972) determine the magnitude of electrogalvanism due to a variety of dissimilar metals. In a recent study conducted by Sutow et al (2004) it was shown that galvanic currents were influenced by restoration age and total surface area of the galvanic couple.

A-MRI:- Magnetic fields may interfere with ferromagnetic material and cause serious risks such as projectile effects, twisting, burning, artifacts and malfunction in some special device. However, other health effects of MR imaging have not been clearly known yet. In present study a significant relationship was observed between the mercury level in saliva and exposure to MRI. This finding confirms previous reports regarding the increased release of mercury from dental amalgam restorations in undersea welders. As in MRI the exposure to the magnetic field exceeds by far the exposure from undersea welding/cutting, these findings are expected. However, our findings are in contrast with the results reported in an in vitro study. (Müller-Miny et al. 1996). As far as we know, our study is the first to investigate the effect of MR imaging *in vivo* on the release of mercury from dental amalgams and the only other study that is previously performed in vitro, is the study performed by Müller-Miny et al.(1996). These investigators examined the mercury release for typical MRI conditions, separated for both the

static and the variable magnetic fields in a 1.5 T MR-unit. They could not demonstrate any significant increase in mercury release due to MRI. Their in vitro study showed no evidence of an increased mercury release from a non-gamma-2 amalgam during magnetic field exposure by MRI. The main difference observed between the results of our study and those reported by Müller-Miny and co-workers (1996) can simply explained by the in- vivo condition used in this study. It should be noted that saliva is a good electrolyte and may increase the release of mercury from dental amalgam due to induction of galvanic currents (Huggins and Levy 1999). Amalgam fillings produce electrical currents which accelerate the release of mercury vapor. As saliva acts as an electrolyte, negatively charged fillings or crowns push electrons into the oral cavity. These currents are measured in micro amperes, with some measured at over 4 micro amps.

A point worth consideration is that the Bruker MRI device used in this experiment was the first MRI facility installed in IR Iran and the magnetic flux density was only 0.23 T. Needless to say, modern MRI scanners use magnets as strong as 0.5 to 2 T. In this light, it can be suggested that further studies should be performed on this topic by modern MR imaging systems.

B-Mobile phone Use: In recent years, the widespread use of mobile phones has lead to a public debate about possible detrimental effects on human health. As mobile phones are a relatively new technology, scientists do not yet have long-term follow-up on their possible health effects (Frumkin et al. 2001). In this study a significant relationship was detected between the mercury levels in urine samples and exposure to microwave radiation emitted from mobile phones. This finding is in agreement with previous reports regarding the increased release of mercury from dental amalgam restorations in undersea welders. Nowadays, in some developed countries, the

number of patients reporting health complaints associated with electromagnetic fields is rapidly increasing (Sandstrom et al. 1997, Gobba 2002, and Leitgeb et al. 2003). However in developing countries such as Iran, people are usually less familiar with the health effects of exposure to electromagnetic fields.

Concluding Remarks: Electromagnetic radiation in radiofrequency (RF) region has long been used for different types of information exchange. Despite it is widely believed that MRI does not present any biological risk for humans, its components (static magnetic field, gradient magnetic fields, and RF pulses) may cause some risks for patients. On the other hand, the dramatic increase in the use of cellular phones has generated great concerns about all potential adverse effects. Lack of ionizing radiation and the low energy level emitted from cell phones has led to this public perception that mobile phone use is safe. Results obtained in this study show a significant increase of the mercury release in urine after mobile phone use. Theses findings confirm early reports that showed an increased release of mercury from dental amalgam restorations in undersea welders. Further research is required to clarify whether other common sources of EMF exposure may cause alterations in dental amalgam and accelerate the release of mercury. However, further studies are needed to make a general conclusion.

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Table 1. Age distribution of the MRI studied participants

Age (Year)	Gender				Total	
	Female		Male			
	No.	%	No.	%	No.	%
<20	3	11.1	0	0	3	10
20-29	14	51.9	0	0	14	46.7
30-39	3	11.1	2	66.7	5	16.7
>40	7	25.9	1	33.3	8	26.7
Total	27	100	3	100	30	100

Table 2. The (mean ±SE) urinary Hg concentrations of students with (test group) and without using mobile phone (controls) after dental amalgam restoration.

Time / Urine Hg (micg/L)	Day 0	Day 1	Day 2	Day 3	Day4	P-Value (ANOVA)
Controls	2.07±0.58	2.34±0.80	2.51±0.67	2.66±0.64	2.76±0.84	NS
Test Group	2.43±0.66	2.71±0.72	3.79±0.65	4.80±0.71	4.50±0.85	P<0.001
P-Value (Student's t-test)	NS	NS	P<0.001	P<0.001	P<0.001	

Mercury Level (µg/L) NS: Non Significant

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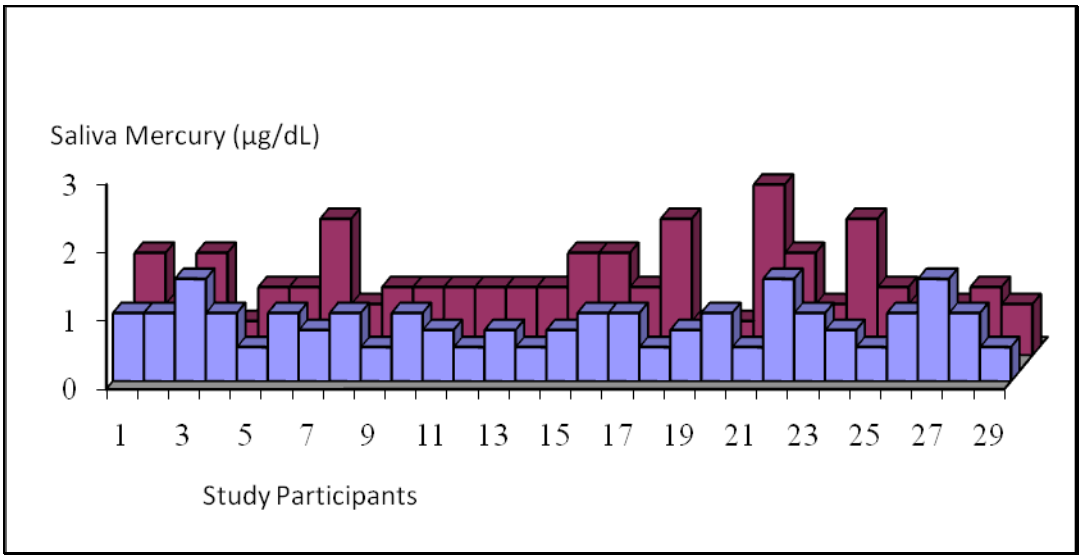

Figure 1. Mercury saliva concentrations of the studied participants before and after MRI