How Do Different Physical Stressors' Affect the Mercury Release from Dental Amalgam Fillings and Microleakage? A Systematic Review

Marzieh Keshavarz[1], Jamshid Eslami[2], Razzagh Abedi-Firouzjah[3], Seyed Alireza Mortazavi[4], Samaneh Abbasi[5], Ghazal Mortazavi[6]*

[1]MSc, Department of Nursing, School of Nursing, Larestan University of Medical Sciences, Larestan, Iran
[2]PhD, Department of Anesthesiology, School of Nursing, Shiraz University of Medical Sciences, Shiraz, Iran
[3]MSc, Cellular and Molecular Research Center, Yasuj University of Medical Sciences, Yasuj, Iran
[4]MD, School of Medicine, Shiraz University of Medical Sciences, Shiraz, Iran
[5]MSc Student, Department of Medical Physics, School of Medicine, Shiraz University of Medical Sciences, Shiraz, Iran
[6]DDS, School of Dentistry, Shiraz University of Medical Sciences, Shiraz, Iran

ABSTRACT

Background: Approximately 50% of dental amalgam is elemental mercury by weight. Accumulating body of evidence now shows that not only static magnetic fields (SMF) but both ionizing and non-ionizing electromagnetic radiations can increase the rate of mercury release from dental amalgam fillings. Iranian scientists firstly addressed this issue in 2008 but more than 10 years later, it became viral worldwide.

Objective: This review was aimed at evaluating available data on the magnitude of the effects of different physical stressors (excluding chewing and brushing) on the release of toxic mercury from dental amalgam fillings and microleakage.

Material and Methods: The papers reviewed in this study were searched from PubMed, Google Scholar, and Scopus (up to 1 December 2019). The keywords were identified from our initial research matching them with those existing on the database of Medical Subject Headings (MeSH). The non-English papers and other types of articles were not included in this review.

Results: Our review shows that exposure to static magnetic fields (SMF) such as those generated by MRI, electromagnetic fields (EMF) such as those produced by mobile phones; ionizing electromagnetic radiations such as X-rays and non- Ionizing electromagnetic radiation such as lasers and light cure devices can significantly increase the release of mercury from dental amalgam restorations and/or cause microleakage.

Conclusion: The results of this review show that a wide variety of physical stressors ranging from non-ionizing electromagnetic fields to ionizing radiations can significantly accelerate the release of mercury from amalgam and cause microleakage.

Keywords

Amalgam; Mercury; Magnetic Resonance Imaging; Microleakage; Radiation; Electromagnetic; Radiofrequency

Introduction

Despite the wide application of mercury in industry and medicine, it has known toxic effects. Methylmercury (MeHg), mercury vapor (Hg^0), and ethylmercury (EtHg) are the three main forms of mercury which are the origin of concerns to human populations non-occupationally exposed to this toxic element [1]. Scientists' effort for increasing human knowledge about the risks linked to mercury exposure is complicated due to its variable environmental fate as well as

*Corresponding author: Ghazal Mortazavi
Doctor of Dental Surgery, School of Dentistry, Shiraz University of Medical Sciences, Shiraz, Iran
E-mail: qaz.mortazavi@gmail.com

Received: 4 September 2020
Accepted: 12 December 2020

the key role of environmental, biological, and socioeconomic factors [2]. Substantial data suggests that mercury causes a wide variety of physiological and adverse health effects ranging from bioaccumulation in the central nervous system (CNS), liver and kidney as its major targets to promoting carcinogenesis, immunotoxicity, kidney damage that leads to nephrotoxicity, declined neurological capacity, and neurobehavioral function, changed the functioning of 3 main endocrine axes, and impaired reproduction quality and altered offspring quality [3-24]. Due to the ability of inhaled mercury vapor which can cross the blood-brain barrier, it can cause serious damage to the CNS [11].

Today, exposure of humans to mercury is a major public health concern. These exposures can be due to a wide variety of sources ranging from industrial processes, occupational and household uses of mercury, mercury-containing vaccines, dental amalgams, and consumption of fish [25]. The problems can be appeared differently over 250 symptoms in the clinical picture, involving many systems other than the immune system (e.g. neurological, renal, respiratory, gastrointestinal, cardiovascular, hepatic, and reproductive),), along with fetotoxicity and genotoxicity [25, 26].

Among the humans, children are believed to have a greater risk of developing detrimental neurological effects of mercury. The case of a 3-month-old infant reported in a study demonstrated that Hg causes poisoning and finally, it developed pneumothorax and respiratory failure. These kinds of cases highlight that Hg exposure should be considered as a crucial issue [27].

Hg vapor inhalation is the major route of contamination and dental amalgam fillings (~ 50% Hg), are also a significant source of mercury in general population [25].

Several studies have reported that magnetic resonance imaging (MRI) [28], chewing and brushing in an artificial mouth [29], Nd:YAG laser pulse energy [30], radiofrequency radiation sources including Wi-Fi routers, smartphones, light-curing tools [31] and also X-rays [32] might change the rate of evaporation of mercury from amalgam fillings. Iranian scientists firstly addressed this issue in 2008 [33] but more than 10 years later, it became viral worldwide [34].

In a study, the authors investigated the urinary mercury from dental amalgam fillings in MRI-exposed and control groups and reported a significant difference between these groups [28]. Moreover, in another study, electromagnetic radiation from Wi-Fi routers and mobile phones could increase the concentration of mercury released from amalgam restorations [31]. Furthermore, the level of mercury vapor release was significantly linked to the pulse energy of Nd:YAG laser [30]. Recently, it has been suggested that exposure of women with dental amalgam fillings to electromagnetic fields may may increase the risk of autism due to higher release of mercury from dental amalgam [35]. A literature review shows that over the past years many publications have been reported to be adversely affected by the key shortcoming of ignoring the role of static magnetic fields or electromagnetic radiation in accelerating the release of mercury from amalgam and microleakage [36-38]. In the current study, the main purpose is to review physical stressor impact on mercury release and amalgam microleakage.

Material and Methods

This study was performed as a systematic review. Figure 1 briefly illustrates the process of data collection and analysis.

Search strategy

The papers reviewed in this study were searched from PubMed, Google Scholar, and Scopus (up to 1 December 2019). The keywords were identified from our initial research matching them with those existing on the database of Medical Subject Headings (MeSH) managing by the US National Library of Med-

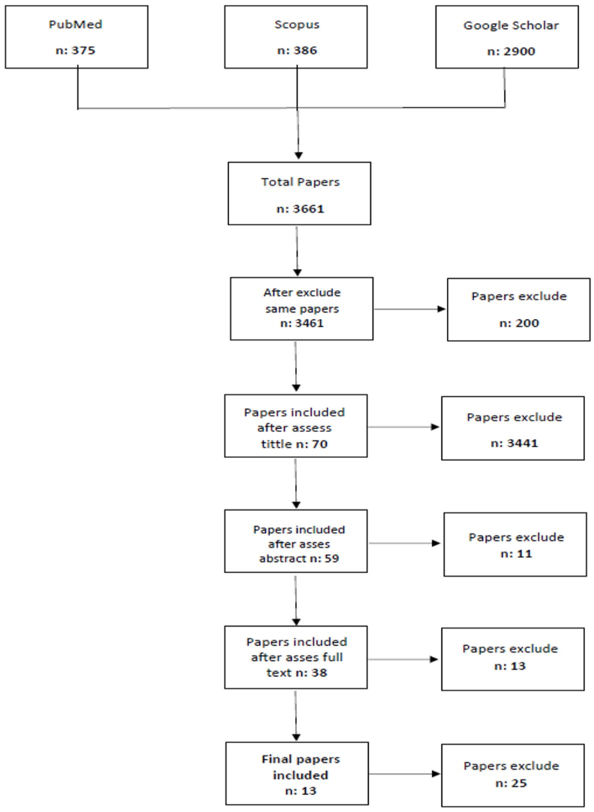

Figure 1: Data collection and analysis process used in this study

icine. Furthermore, to improve the quality of searches, we got helped by an expert who worked in the Medical Branch libraries. The search strings were selected MeSH, title, abstract, and keywords based on "amalgam" "or "microleakage" or "mercury release" or "electromagnetic field".

Inclusion and exclusion criteria

The original articles were chosen based on inclusion criteria, by contrast, the non-English papers, and any types of articles related to the review papers, letters, etc. were considered as exclusion criteria.

Selection process

At the first sage, the papers were screened by a reviewer in the point of titles and abstracts views and then they were classified into three sets completely; the first step was included the papers with certain inclusion criteria, the second one has contained the papers without the clear inclusion criteria from reviewers, and the third one, set referred to the papers with no inclusion criteria which were not appropriate and then excluded from the screening.

Data extraction

Four variables for responding to the research questions were extracted in this phase contained mercury release, amalgam microleakage, electromagnetic fields, and radiofrequency wave.

Results

The data extracted from the 13 articles reviewed are shown in Table 1. The fourth variables of the selected papers are represented in the Table 1. As presented in the fourth column of the Table 1, a wide variety of physical stressors were studied. Our review shows that exposure to:

1. Static magnetic fields (SMF) such as MRI
2. Electromagnetic fields (EMF) such as mobile phones
3. Ionizing Electromagnetic Radiation such as X-rays
4. Non- Ionizing Electromagnetic Radiation such as lasers, and light cure devices can significantly increase the mercury release from amalgam fillings and/or cause microleakage.

Mercury release or amalgam microleakage applies in physical stressors study

As shown in the fifth column of Table 1, mercury release and amalgam microleakage have been applied in physical stressors. The fifth and sixth columns of the Table 1 demonstrate the method of various studies and the effects of different physical stressors on mercury release and amalgam microleakage, respectively.

Discussion

Currently it seems unlikely that dental amal-

Table 1: Summary of the data extracted from 13 articles finally included in our review

	Study	End point	Physical stressor	Method	Outcome summery
1	Unal Erzurumlu 2019 [39]	Micro-leakage of amalgam restorations	MRI	Using extracted molar teeth, various groups exposed to 1.5 or 3-T MRI.	Microleakage was higher in the gingival region compared to occlusal region in all groups. The strength of the magnetic field directly determined the level of microleakage.
2	Yilmaz et al. 2018 [40]	Mercury release from dental amalgam	MRI	Extracted caries-free molar or premolar teeth were exposed to 1.5 or 0.7 T MRI.	While mercury was released from amalgam fillings after exposure to 0.7 T, 1.5-T MRI did not change the release.
3	Hosseini et al. 2018 [41]	Mercury release from dental amalgam	Wi-Fi and X-Ray radiation	Extracted premolars were divided into five groups; control, CT, "CT+Wi-Fi", "Wi-Fi+CT", and "Wi-Fi only". Mercury level was measured 24 and 48 hours after exposure.	The mercury released from teeth exposed to Wi-Fi and CT scan (ionizing radiation) was higher.
4	Paknahad et al. 2016 [42]	Mercury release from amalgam restorations	Radiofrequency radiation from Wi-Fi devices	Non-carious extracted human premolars were exposed to Wi-Fi..	Conventional Wi-Fi routers could increase the release of mercury from amalgam fillings.
5	Mortazavi et al. 2016 [43]	Dental amalgam microleakage	Radiofrequency electromagnetic radiation	Investigation of the mechanisms behind the accelerated microleakage of amalgam after exposure to electromagnetic fields.	Multiple reflections of the radiofrequency radiation on the inner walls of the tiny spaces between amalgam and teeth and their interferences produces some "hot spots", then rapid expansion of the gas bubbles lead to increase in the micro-leakage of amalgam (the so-called Triple M" effect).
6	Mortazavi et al. 2016 [44]	Microleakage of amalgam restorations	Radiofrequency electromagnetic fields of dental light cure devices and mobile phones	Identical class V cavities were prepared on the buccal surfaces of 60 non-carious extracted human teeth, exposed to dental light cure devices and smartphones.	Both light cure devices and mobile phones can increase the microleakage of amalgam restorations meaningfully.

	Study	End point	Physical stressor	Method	Outcome summery
7	Kursun et al. 2014 [32]	Mercury release from dental amalgam	X-rays and MRI	Amalgam capsules were molded into discs. The samples were exposed to X-rays or MRI in a soft tissue-equivalent material.	Increased release of mercury was observed in X-ray group; while no change was seen in MRI group.
8	Marti Akgun et al. 2014 [45]	Microleakage of amalgam restorations	MRI	Permanent molar teeth (class II cavities with gingival margins ending 1 mm below the cementoenamel junction were exposed to MRI.	No difference found in surface microleakages in MRI and control samples.
9	Savadi Oskoee et al. 2013 [30]	Mercury vapor release from the dental amalgam	Nd:YAG laser pulse energy	Aamalgam samples in sealed containers were exposed to Nd:YAG laser (pulse energies of 50, 150, and 250 mJ at a distance of 1mm from the surface of amalgam for 4 seconds).	A significant increase was observed in the of release of mercury vapor.
10	Shahidi et al. 2009 [46]	Microleakage of amalgam restorations	MRI	Eextracted premolar teeth were divided into 3 groups. Three high-copper amalgams were used to restore standard class V. MRI was randomly applied.	Increased micro-leakage was reported in MRI-exposed teeth. The authors believed that thermo-electromagnetic convection caused the enhancement of the diffusion process, grain boundary migration, and vacancy formation that finally resulted in microleakage.
11	Mortazavi et al. 2008 [33]	Mercury release from dental amalgam	MRI and following mobile phone	Stimulated saliva samples from 30 patients were collected just before and after 0.23-T MRI. Thirty patients were investigated. In the second phase of the study, fourteen female healthy university students who had not used mobile phones before the study and did not have any previous amalgam restorations, were studied. In this phase urine sample was studied.	Both MRI and mobile phone radiation could significantly increase the mercury release from amalgam.
12	Berglund A et al. 1998 [47]	Intra-oral release of mercury vapor from amalgam restorations.	Low frequency magnetic fields	Subjects with amalgam fillings were exposed to magnetic fields (flux densities of 20 μT at 30 kHz and 500 μT at 50 Hz).	No increase was found in the mercury release from dental amalgam fillings.
13	Muller-Min et al. 1996 [48]	Mercury dissolution from dental amalgam fillings	MRI	Dental cavities were filled with amalgam and the mercury release was measured for 2 weeks in a nonmagnetic condition. Then, the samples were divided into two groups; i.e. exposed to a static magnetic field and exposed to a repetitive gradient-echo sequence.	There was no difference in mercury release between the groups.

MRI: Magnetic resonance imaging, CT: Computed tomography gams can lead to health problems in majority large proportion of humans. However, specific groups such as pregnant women, children, elderly people and hypersensitive individuals may be in risk [33]. Figure 2, shows studies conducted to date that indicate exposure to different physical stressors can lead to accelerated mercury release from amalgam and microleakage. According to several articles were mentioned in this study, magnetic resonance field has an increasing effect on mercury release. However, the study conducted by Muller-Miny et al., failed to show significant increase in mercury release after MRI [48]. Kursun et al., reported that magnetic resonance field (1.5 T) did not change the level of mercury release from dental amalgam [32]. Akgun et al., reported no statistically significant differences in microleakage in groups with or without exposureto MRI [45]. Exposure to pulsed electromagnetic fields (PEMF) exposure generated by Helmholtz coil, as reported by Mortazavi et al., could not increase the microleakage of amalgam restorations. However, in their experiments, X-ray exposure significantly increased the microleakage of amalgam. In their stydy, intraoral radiography increased microleakage of amalgam fillings [49]. Amalgam microleakage was not significantly different in the light cure-exposed group or those exposed to mobile phone radiation with that of the control group [44]. Akgun et al., reported that MRI cannot change the microleakage of bonded or nonbonded amalgam fillings [45]. Moreover, laser beams (Nd:YAG) with the pulse energies of 50, 150, and 250 mJ increased the mercury vapor release, that was dependent on the Nd:YAG laser pulse energy [30]. However, Pioch et al., showed that CO_2 laser, no signs of amalgam ablation or mercury vapor release were observed [50]. In Figure 3 a possible mechanism that can be involved in accelerated microleakage of amalgam after exposure to radiofrequency radiation is demonstrated.

Mortazavi et al., have previously introduced “Triple M effect”. According to Triple M” effect, in hot spots, increased amalgam microle-

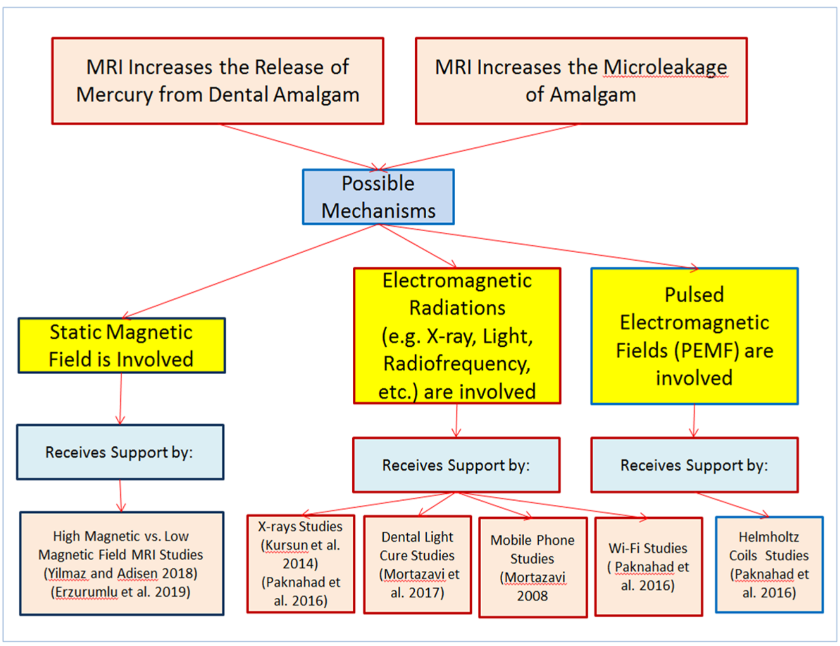

Figure 2: Studies conducted so far show that a wide variety of physical stressors can induce the accelerated release of mercury from dental amalgam fillings and microleakage.

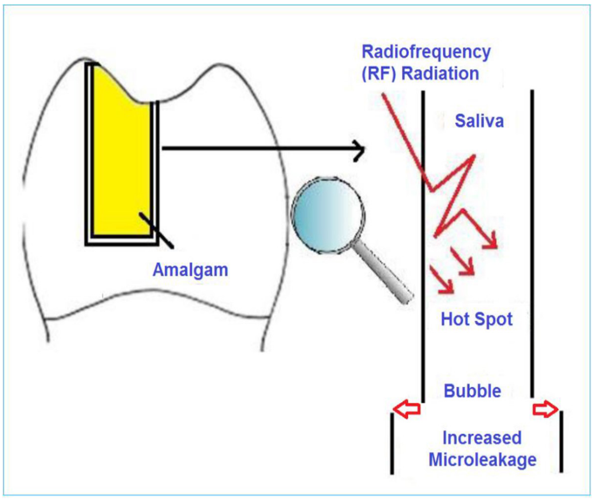

Figure 3: Demonstration of a possible mechanism that can be involved in accelerated microleakage of amalgam after exposure to radiofrequency radiation as a major physical stressor. (Originally from Mortazavi et al, [43] modified and reproduced with permission)

akage after exposure to radiofrequency electromagnetic fields increases the temperature in saliva-filled tiny spaces between amalgam fillings and teeth. Reflection of radiofrequency radiation on the inner walls of these tiny spaces, and their interferences produce specific "hot spots" in these areas. High temperature and fast expansion of the bubbles is responsible for accelerated microleakage of amalgam. Appropriate experiments are needed to verify the validity of this theory [43].

Hypersensitive People and Pregnant Women Issues

Although what we know about mechanisms of hypersensitivity to the damaging effects of mercury is very limited, genetic factors can be involved in this phenomenon [51]. Studies conducted so far reveals that a proportion of any population may show hypersensitivity to mercury. Besides hypersensitive people, children and pregnant women with dental amalgam fillings require special attention. Regarding the pregnant women, it's worth noting that the strong link between maternal and cord blood mercury levels are reported previously. Thus, in order to decrease the toxic effects of mercury in their fetuses, pregnant women with amalgam restorations are requested to limit their exposures (both exposure time and exposure intensity) to electromagnetic radiation.

Conclusion

In this paper, we systematically reviewed the physical stressor impact on mercury release and amalgam microleakage. The results of this investigation show that physical stressors such as Electromagnetic fields, MRI and laser, just to name a few, have an effect on mercury release and amalgam microleakage. Furthermore, it shows a new view in providing protections against mercury release and amalgam microleakage.

Conflict of Interest

None

References

1. Branco V, Caito S, Farina M, Teixeira da Rocha J, Aschner M, Carvalho C. Biomarkers of mercury toxicity: Past, present, and future trends. *J Toxicol Environ Health B Crit Rev.* 2017;**20**(3):119-54. doi: 10.1080/10937404.2017.1289834. PubMed PMID: 28379072. PubMed PMCID: PMC6317349.
2. Diaz Barriga F. Modulators of mercury risk to wildlife and humans in the context of rapid global change. *Ambio.* 2018;**47**(2):170-97. doi: 10.1007/s13280-017-1011-x. PubMed PMID: 29388128. PubMed PMCID: PMC5794686.
3. Hawley DM, Hallinger KK, Cristol DA. Compromised immune competence in free-living tree swallows exposed to mercury. *Ecotoxicology.* 2009;**18**(5):499-503. doi: 10.1007/s10646-009-0307-4. PubMed PMID: 19322655.
4. Lewis CA, Cristol DA, Swaddle JP, Varian-Ramos CW, Zwollo P. Decreased immune response in zebra finches exposed to sublethal doses of mercury. *Arch Environ Contam Toxicol.* 2013;**64**(2):327-36. doi: 10.1007/s00244-012-9830-z. PubMed PMID: 23229191.
5. Hu XF, Eccles KM, Chan HM. High selenium exposure lowers the odds ratios for hypertension, stroke, and myocardial infarction associated with mercury exposure among Inuit in Canada.

Environ Int. 2017;**102**:200-6. doi: 10.1016/j.envint.2017.03.002. PubMed PMID: 28279481.

6. Zhang QF, Li YW, Liu ZH, Chen QL. Exposure to mercuric chloride induces developmental damage, oxidative stress and immunotoxicity in zebrafish embryos-larvae. *Aquat Toxicol.* 2016;**181**:76-85. doi: 10.1016/j.aquatox.2016.10.029. PubMed PMID: 27821350.
7. Crowe W, Allsopp PJ, Watson GE, Magee PJ, Strain JJ, Armstrong DJ, Ball E, McSorley EM. Mercury as an environmental stimulus in the development of autoimmunity–A systematic review. *Autoimmunity Reviews.* 2017;**16**(1):72-80. doi: 10.1016/j.autrev.2016.09.020. PubMed PMID: 27666813.
8. Tchounwou PB, Ayensu WK, Ninashvili N, Sutton D. Environmental exposure to mercury and its toxicopathologic implications for public health. *Environ Toxicol*. 2003;**18**(3):149-75. doi: 10.1002/tox.10116. PubMed PMID: 12740802.
9. Steuerwald U, Weihe P, Jørgensen PJ, Bjerve K, Brock J, Heinzow B, Budtz-Jørgensen E, Grandjean P. Maternal seafood diet, methylmercury exposure, and neonatal neurologic function. *J Pediatr.* 2000;**136**(5):599-605. doi: 10.1067/mpd.2000.102774. PubMed PMID: 10802490.
10. Basu N, Stamler CJ, Loua KM, Chan HM. An interspecies comparison of mercury inhibition on muscarinic acetylcholine receptor binding in the cerebral cortex and cerebellum. *Toxicol Appl Pharmacol.* 2005;**205**(1):71-6. doi: 10.1016/j.taap.2004.09.009. PubMed PMID: 15885266.
11. Clarkson TW, Magos L. The toxicology of mercury and its chemical compounds. *Crit Rev Toxicol*. 2006;**36**(8):609-62. doi: 10.1080/10408440600845619. PubMed PMID: 16973445.
12. Scheuhammer AM, Sandheinrich MB. Recent advances in the toxicology of methylmercury in wildlife. *Ecotoxicology*. 2008;**17**(2):67-8. doi: 10.1525/california/9780520271630.003.001.
13. Depew DC, Basu N, Burgess NM, Campbell LM, et al. Toxicity of dietary methylmercury to fish: derivation of ecologically meaningful threshold concentrations. *Environmental Toxicology and Chemistry.* 2012;**31**(7):1536-47. doi: 10.1002/etc.1859.
14. Bridges KN, Soulen BK, Overturf CL, Drevnick PE, Roberts AP. Embryotoxicity of maternally transferred methylmercury to fathead minnows (Pimephales promelas). *Environ Toxicol Chem.* 2016;**35**(6):1436-41. doi: 10.1002/etc.3282. PubMed PMID: 26471903.
15. Landler L, Painter MS, Coe BH, Youmans PW, Hopkins WA, Phillips JB. High levels of maternally transferred mercury disrupt magnetic responses of snapping turtle hatchlings (Chelydra serpentina). *Environ Pollut*. 2017;**228**:19-25. doi: 10.1016/j.envpol.2017.04.050. PubMed PMID: 28501632.
16. Wada H, Cristol DA, McNabb FA, Hopkins WA. Suppressed adrenocortical responses and thyroid hormone levels in birds near a mercury-contaminated river. *Environ Sci Technol.* 2009;**43**(15):6031-8. doi: 10.1021/es803707f. PubMed PMID: 19731714.
17. Hopkins BC, Willson JD, Hopkins WA. Mercury exposure is associated with negative effects on turtle reproduction. *Environ Sci Technol.* 2013;**47**(5):2416-22. doi: 10.1021/es304261s. PubMed PMID: 23360167.
18. Tartu S, Lendvai ÁZ, Blévin P, Herzke D, et al. Increased adrenal responsiveness and delayed hatching date in relation to polychlorinated biphenyl exposure in Arctic-breeding black-legged kittiwakes (Rissa tridactyla). *Gen Comp Endocrinol*. 2015;**219**:165-72. doi: 10.1016/j.ygcen.2014.12.018. PubMed PMID: 25796954
19. Woods JS, Heyer NJ, Russo JE, Martin MD, et al. Genetic polymorphisms of catechol-O-methyltransferase modify the neurobehavioral effects of mercury in children. *J Toxicol Environ Health A*. 2014;**77**(6):293-312. doi: 10.1080/15287394.2014.867210. PubMed PMID: 24593143. PubMed PMCID: PMC3967503.
20. Woods JS, Heyer NJ, Russo JE, Martin MD, Farin FM. Genetic polymorphisms affecting susceptibility to mercury neurotoxicity in children: Summary findings from the Casa Pia Children's Amalgam Clinical Trial. *Neurotoxicology*. 2014;**44**:288-302. doi: 10.1016/j.neuro.2014.07.010. PubMed PMID: 25109824. PubMed PMCID: PMC4176692.
21. Suzuki T, Imura N, Clarkson TW. Advances in mercury toxicology. Springer Science & Business Media; 2013.
22. Hartwig A, Asmuss M, Ehleben I, Herzer U, et al. Interference by toxic metal ions with DNA repair processes and cell cycle control: molecular mechanisms. *Environ Health Perspect*. 2002;**110**(Suppl 5):797-9. doi: 10.1289/ehp.02110s5797.9. PubMed PMID: 12426134. PubMed PMCID: PMC1241248.
23. Morales ME, Derbes RS, Ade CM, Ortego JC, et al. Heavy metal exposure influences double strand break DNA repair outcomes. *PLoS One*. 2016;**11**(3):e0151367. doi: 10.1371/journal.pone.0151367. PubMed PMID: 26966913. PubMed PMCID: PMC4788447.

24. Nersesyan A, Kundi M, Waldherr M, Setayesh T, et al, Barcelos GR, Knasmueller S. Results of micronucleus assays with individuals who are occupationally and environmentally exposed to mercury, lead and cadmium. *Mutat Res*. 2016;**770**(Pt A):119-39. doi: 10.1016/j.mrrev.2016.04.002. PubMed PMID: 27894681.
25. Andreoli V, Sprovieri F. Genetic aspects of susceptibility to mercury toxicity: an overview. *Int J Environ Res Public Health*. 2017;**14**(1):93. doi: 10.3390/ijerph14010093. PubMed PMID: 28106810. PubMed PMCID: PMC5295343.
26. McGuire T. Chronic mercury poisoning and mercury detoxification. *Townsend Letter: The Examiner of Alternative Medicine*. 2007;**287**:96-106.
27. Gao Z, Ying X, Yan J, Wang J, Cai S, Yan C. Acute mercury vapor poisoning in a 3-month-old infant: A case report. *Clin Chim Acta*. 2017;**465**:119-22. doi: 10.1016/j.cca.2016.12.019. PubMed PMID: 28027882.
28. Mortazavi SMJ, Neghab M, Anoosheh SM, et al. High-field MRI and mercury release from dental amalgam fillings. *Int J Occup Environ Med*. 2014;**5**(2):101-5. PubMed PMID: 24748001. PubMed PMCID: PMC7767616.
29. Berdouses E, Vaidyanathan TK, Dastane A, Weisel C, Houpt M, Shey Z. Mercury release from dental amalgams: an in vitro study under controlled chewing and brushing in an artificial mouth. *J Dent Res.* 1995;**74**(5):1185-93. doi: 10.1177/00220345950740050701. PubMed PMID: 7790596.
30. Oskoee SS, Bahari M, Kimyai S, Rikhtegaran S, Puralibaba F, Ajami H. Effect of Nd: YAG laser pulse energy on mercury vapor release from the dental amalgam. *Photomed Laser Surg*. 2013;**31**(10):480-5. doi: 10.1089/pho.2013.3549. PubMed PMID: 24053716.
31. Mortazavi SMJ, Mortazavi G. Ex Vivo Mercury Release from Dental Amalgam. *Radiology.* 2018;**289**(1):273-74. doi: 10.1148/radiol.2018181576. PubMed PMID: 30179106.
32. 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 Radiology*. 2014;**30**(2):142-6. doi: 10.1007/s11282-013-0154-0.
33. Mortazavi SMJ, Daiee E, Yazdi A, Khiabani K, Kavousi A, Vazirinejad R. Mercury release from dental amalgam restorations after magnetic resonance imaging and following mobile phone use. *Pak J Biol Sci.* 2008;**11**(8):1142-6. doi: 10.3923/pjbs.2008.1142.1146. PubMed PMID: 18819554.
34. BBC. Metal fillings 'leak mercury after scan' - BBC News. BBC; 2018.
35. Mortazavi G, Haghani M, Rastegarian N, Zarei S, Mortazavi SMJ. Increased release of mercury from dental amalgam fillings due to maternal exposure to electromagnetic fields as a possible mechanism for the high rates of autism in the offspring: introducing a hypothesis. *J Biomed Phys Eng*. 2016;**6**(1):41-6. PubMed PMID: 27026954. PubMed PMCID: PMC4795328.
36. Mortazavi SMJ, Mortazavi G, Paknahad M. Mercury transmitted from mother's with amalgam dental fillings to fetus. *J Matern Fetal Neonatal Med*. 2017;**30**(5):594. doi: 10.1080/14767058.2016.1180359. PubMed PMID: 27090019.
37. Mortazavi SMJ, Mortazavi G, Paknahad M. Dental metal-induced innate reactivity in keratinocytes. *Toxicol in Vitro.* 2016;**33**:180-1. doi: 10.1016/j.tiv.2016.02.016. PubMed PMID: 26928047.
38. Mortazavi SMJ, Mortazavi G, Paknahad M. Quantification of Hg excretion and distribution in biological samples of mercury-dental-amalgam users and its correlation with biological variables. *Environ Sci Pollut Res Int*. 2017;**24**(9):8889-90. doi: 10.1007/s11356-017-8530-7. PubMed PMID: 28160179.
39. Unal Erzurumlu Z, Guler C, Uslu Cender E, Cakıcı EB, Cankaya S. The effect of 1.5 T and 3 T magnetic resonance imaging on microleakage of amalgam restorations. *Microsc Res Tech.* 2019;**82**(11):1878-83. doi: 10.1002/jemt.23355. PubMed PMID: 31368622.
40. Yilmaz S, Adisen MZ. Ex vivo mercury release from dental amalgam after 7.0-T and 1.5-T MRI. *Radiology.* 2018;**288**(3):799-803. doi: 10.1148/radiol.2018172597. PubMed PMID: 29944087.
41. Hosseini MA, Mehdizadeh AR, Sanipour L, Afrasyabi MR, Shiravani MH, Asmarian N, Zamani A. The assessment of mercury released from dental amalgams after exposure to Wi-Fi and X-Ray radiation in artificial Saliva. *Eurasian J Anal Chem.* 2018;**13**(2):em08. doi: 10.29333/ejac/84805.
42. Paknahad M, Mortazavi SMJ, Shahidi S, Mortazavi G, Haghani M. Effect of radiofrequency radiation from Wi-Fi devices on mercury release from amalgam restorations. *J Environ Health Sci Eng.* 2016;**14**:12. doi: 10.1186/s40201-016-0253-z. PubMed PMID: 27418965. PubMed PMCID: PMC4944481.
43. Mortazavi G, Mortazavi SAR, Mehdizadeh AR. "Triple M" Effect: A Proposed Mechanism to Explain Increased Dental Amalgam Microleakage af-

ter Exposure to Radiofrequency Electromagnetic Radiation. *J Biomed Phys Eng*. 2018;**8**(1):141-6. PubMed PMID: 29732349. PubMed PMCID: PMC5928305.

44. Mortazavi SMJ, Nazhvani AD, Paknahad M. Synergistic Effect of Radiofrequency Electromagnetic Fields of Dental Light Cure Devices and Mobile Phones Accelerates the Microleakage of Amalgam Restorations: An in vitro Study. *J Biomed Phys Eng*. 2019;**9**(2):227-32. PubMed PMID: 31214528. PubMed PMCID: PMC6538905.
45. Akgun OM, Polat GG, Illca AT, Yildirim C, Demir P, Basak F. Does magnetic resonance imaging affect the microleakage of amalgam restorations? *Iran J Radiol*. 2014;**11**(3):e15565. doi: 10.5812/iranjradiol.15565. PubMed PMID: 25763074. PubMed PMCID: PMC4341166.
46. Shahidi SH, Bronoosh P, Alavi AA, Zamiri B, et al. Effect of magnetic resonance imaging on microleakage of amalgam restorations: an in vitro study. *Dentomaxillofac Radiol*. 2009;**38**(7):470-4. doi: 10.1259/dmfr/30077669. PubMed PMID: 19767518.
47. Berglund A, Bergdahl J. Influence of low frequency magnetic fields on the intra-oral release of mercury vapor from amalgam restorations. *Eur J Oral Sci*. 1998;**106**(2 Pt 1):671-4. PubMed PMID: 9584915.
48. 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**(1):258-60. doi: 10.1002/jmri.1880060146. PubMed PMID: 8851439.
49. Paknahad M, Nazhvani AD, Jarideh S, Mozdarani H, et al. Increased Mercury release due to exposure to electromagnetic radiation as a limiting factor for using dental amalgam. *Int J Radiat Res*. 2016;**14**(4):355-9. doi: 10.18869/acadpub.ijrr.14.4.355.
50. Pioch T, Matthias J. Mercury vapor release from dental amalgam after laser treatment. *Eur J Oral Sci*. 1998;**106**(1):600-2. doi: 10.1046/j.0909-8836..t01-3-.x. PubMed PMID: 9527362.
51. Austin DW, Spolding B, Gondalia S, Shandley K, et al. Genetic variation associated with hypersensitivity to mercury. *Toxicol Int*. 2014;**21**(3):236-41. doi: 10.4103/0971-6580.155327. PubMed PMID: 25948960. PubMed PMCID: PMC4413404.