Original Article

Determination of Mercury, Silver, Tin, and Copper Discharged to the Municipal Wastewater Collection Network in Kermanshah through Dental Units in 2015

Mohammad Ahmadian[1], Meghdad Pirsaheb[2], Hiwa Hossaini[2], Shoeib Rahimi[3], Boshra Ahmadian[3], Niloofar Balkani[3], Afshin Darsanj[3]

[1]Department of Environmental Health Engineering, School of Public Health, Bam University of Medical Sciences, Bam, Iran, [2]Research Center for Environmental Determinants of Health (RCEDH), Kermanshah University of Medical Sciences, Kermanshah, Iran, [3]Students Research Committee, Kermanshah University of Medical Sciences, Kermanshah, Iran

Abstract

Aim: Dental amalgam contains 50% mercury, with the remaining 50% comprising metals such as tin, silver, copper, and titanium. This study aimed to determine the content of mercury, silver, tin, and copper discharged into the municipal wastewater collection network in Kermanshah, Iran through dental units. **Methods:** A questionnaire was prepared and completed by dentists for two working weeks. The total amalgam and the amounts of silver, mercury, copper, and tin metals discharged into the sewage through the studied units, and then the total units in the city per year, were determined. **Results:** The results showed that, in Kermanshah, 125330.14 amalgam units were emptied to the sewer per year. Furthermore, on average, 52.26, 27.84, 14.07, and 12.06 kg of mercury, silver, tin, and copper, respectively, entered the Kermanshah wastewater collection network through dental units. **Conclusion:** If all dental units are equipped with amalgam separators, the quantity of amalgam entering the sewer will be reduced from 105.5 to 17.78 kg per year.

Keywords: Amalgam, dentistry, Kermanshah, municipal wastewater

Introduction

Amalgam is a metal restorative made of an alloy of silver, tin, copper, and mercury, introduced in the United States in 1830. Amalgam restorations were initially made by dentists who ground silver coins and mixed their chips with mercury to form a paste-like mass and placed it inside the defective tooth. Globally, about 10,000 tons of mercury are extracted annually, and it is estimated that about 3%–4% of it is used as an amalgam compound in dentistry. Due to the dangers posed by this compound, considerations have been made during previous decades, and the amount of this material in amalgam has decreased.[1,2]

Dental amalgam contains 50% mercury, and the remaining 50% alloy contains metals such as tin, silver, copper, and titanium. The silver content in dental amalgam ranges from 40% to 70%, depending on the type.[3,4] New types of recently used alloys contain 40%–70% silver, 12%–30% tin, 12%–24% copper, which may also include 0%–4% indium, 0.5% palladium, and 1% zinc.[5,6] Global studies show that direct contact with mercury or inhalation of its vapors can cause a variety of disorders, including autoimmune disorders, kidney failure, infertility, adverse effects on the fetus, and neurobehavioral problems.[7-9] Mercury has adverse effects on aquatic ecosystems by disrupting the function of phytoplankton, as one of the important sources of oxygen production in the oceans and, in turn, upsetting the global balance of aquatic organisms. Some of the mercury released into the air gradually seeps into water bodies and then finds its way into the food chain; it is assumed that all or part of the mercury released into the air or surface water is stored in fish. For these reasons, the US

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Address for correspondence: Dr. Hiwa Hossaini, Department of Environmental Health Engineering, School of Public Health, Kermanshah University of Medical Sciences, Kermanshah, Iran. E-mail: hiwa_hossaini@yahoo.com

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Environmental Protection Agency (EPA) has identified it as the second major pollutant of lakes and natural waters.[10,11] With the entry of this substance into rivers, the life of aquatic organisms is endangered, and with the accumulation in the bodies of fish, the potential risk of its pathogenicity in humans increases.[11,12]

Silver ions are considered to be the most toxic form of silver in aqueous environments.[13] The inhibitory effect of silver ions on several biological events, such as cell membrane attachments, is manifested by the uptake of Gram-negative bacteria into the cell wall and changes in their membrane permeability, by the production of free oxygen species and the inactivation of cellular enzymes. They may negatively affect health and the environment and lead to high toxicity.[14] The results of the study by Arenholt *et al*. (1995) on "silver concentration in human tissue, its relationship with dental amalgam and other factors" showed that the average concentration of this chemical element in the liver and brain of adult women was about twice that of men. In addition, the concentration of silver, particularly in the brain, depends on age. There was a statistically significant relationship between the number of restorative teeth and amalgam and the concentration of silver in the cortex and liver, though this was not the case for the kidneys.[15]

Although tin is not a very toxic and dangerous metal, its high concentration (about 0.1–1 g/L) affects the taste of food and causes gastrointestinal disorders and diarrhea over time. Furthermore, some studies suggest that tin interferes with iron metabolism, and its long-term absorption may result in complications such as anemia, growth retardation, and liver dysfunction.

Between 30% and 60% of the copper entering the body is absorbed through the intestines and transported to the liver, kidneys, heart, and brain. Prolonged absorption of copper in the body causes destruction of liver cells, liver cirrhosis, and anemia and may have fatal consequences.[16] Moreover, high levels of copper in water lead to diseases such as anemia, bone abnormalities, high cholesterol, and green hair in the body and sometimes lead to death.[17]

A study by Kawas *et al*. (2008) in the United Arab Emirates found that 0.25–0.146 mg per 100 g of amalgam used was discharged into the sewer system.[18] In another study conducted in Canada, 1880.32 kg of amalgam was consumed and about 1128 kg of it was discharged into the wastewater system.[19] Malekipour Esfahani *et al*.'s research, which examined several heavy metals, including mercury, in the inlet and outlet water of dental clinic units, dental wastewater was at an unfavorable level in terms of heavy metals.[20] Similarly, Benaïssa *et al*.'s study indicated high concentrations of heavy metals such as mercury, nickel, and zinc in the effluent of dental units.[21] Therefore, the purpose of this study was to determine the content of mercury, silver, tin, and copper discharged into the municipal wastewater collection network in the city of Kermanshah through dental units in 2015.

Materials and Methods

Study area and sampling size

This cross-sectional descriptive study was performed in the spring of 2015 on dental units in the city of Kermanshah, Iran. First, a list of all private dentists was obtained from the health center of Kermanshah province. Next, the number of dental units was estimated, and the Morgan table was used to determine the sample size.[22]

Preparation of the questionnaire

The questionnaire included the number of working days per week, the number of working hours per year, the number of teeth emptied in 2 weeks, the amount of amalgam used per level, the type and brand of amalgam used, and whether the unit was equipped with an amalgam separator under the ISO license.

Completion of the questionnaire by dentists

The questionnaires were completed by the dentists over two working weeks. Based on the number of channels emptied per week and the number of teeth emptied, the total amalgam and the amounts of silver, mercury, copper, and tin metals discharged into the wastewater were determined for the units studied and for all the units in the city per year. The questionnaire used in this study was extracted from the previously published article.[23]

Sample analysis and calculation

To calculate working days in the year, Equation 1 was used.

$$\text{Number of working days per year} = \frac{\text{Number of working weeks per year}}{2} \times \text{Number of working days monitored in two weeks} \quad (1)$$

Furthermore, to calculate the percentage of emptied teeth, considering that the amount of amalgam in the emptied tooth depends on the number of teeth, first, the total number of teeth No. 5, No. 6, No. 7, and No. 8 were calculated together. Next, according to the average amalgam unit emptied from each tooth (based on the comments of the referred unit dentists), the amount of amalgam was calculated.

To convert the amalgam unit to the mass unit (g), the mass of each amalgam unit was determined, and the average mass of the discharged amalgam was calculated based on equations 2 and 3.

$$\mathrm{Wt} = \Sigma_{\mathrm{surface\,1}}^{\mathrm{surface\,4}} \mathrm{Wt}_{\mathrm{isurface}} \quad (2)$$

$$\mathrm{Wt}_{\mathrm{isurface}} = \sum_{\mathrm{tooth\,1}}^{\mathrm{toothj}} N_{\mathrm{1surface}} \times Hg_{\mathrm{1surface}} \quad (3)$$

In the above equations, Wt is the weight of amalgam discharged from all teeth from one level to four levels, $N_{1sufarce}$ is the number of single-level amalgams discharged from each toot, $Hg_{1sufarce}$ is the weight of the discharged amalgam at the desired level (based on tooth numbers from one to four levels), and tooth 1-j represents cuspid, premolar, mandibular, and maxillary.

The percentage of mercury, tin, silver, and copper was obtained according to the specifications set by the manufacturer. Next, the averages of silver, mercury, tin, and copper were calculated. Moreover, the amount of discharged amalgam per unit was calculated per year and multiplied by the average percentages of silver, mercury, tin, and copper to determine their amounts in grams. From the total units, the total mercury, silver, copper, and tin discharged per year were determined.

Results

The city of Kermanshah has a total of 197 dentists. Using the Morgan (1970) sampling method, 98 dentists were selected to complete the questionnaire. Among these, 72 were general dentists and 26 were specialists.

The number of working days was asked from the dentists and entered into the questionnaire. The maximum number of working days per week was 7, and the minimum was 2, with an average of 5.41 days per week. It was found that in 1 week, the total number of working days for the sample of dental units was 530 days (98 dentists × 5.41 days). According to the questionnaire responses, the minimum working weeks per year was 20, the maximum was 50, and the average was 42.235 weeks per year per dentist. Therefore, the total number of working days for 98 dentists in a year was 22,384 days (530 days × 42.235 weeks).

The frequency of teeth extractions from the dental unit over a 2-week period has been shown in Figure 1. The frequency of extractions for tooth number 5 over 2 weeks has been indicated in Figure 2. The frequency of extractions for tooth number 6 over 2 weeks is presented in Figure 3. Figure 4 shows the number of extractions for tooth number 7. Figure 5 shows the quantity of tooth number 8 extracted from the dental unit in 2 weeks.

Moreover, 83.7% of the dentists had extracted between 0 and 3 instances of tooth number 8 within 2 weeks, and 2% had extracted between 8 and 11 instances. None of the dentists reported extracting more than 11 instances of tooth number 8. The average amount of discharged amalgam, according to tooth number, is shown in Figure 6. According to the dentists, the highest and lowest amounts of discharged amalgam were related to tooth number 8 (3.31 units) and tooth number 5 (2.02 units), respectively. The results of the research on amalgam discharge over different periods are shown in Table 1. In the population under study, 62,346.98 units of amalgam were discharged annually. The findings revealed that only 31% of the dental units had amalgam separators, while 69% did not. Considering the 87% efficiency of amalgam separators, it can be estimated that out of 68.072 kg of amalgam discharged annually, 52.481 kg was released into the sewage collection network.

To determine the amount of mercury, silver, copper, and tin metals discharged through the dental units, the number of used brands of amalgam was first recorded by referring to the dental

Table 1: Amalgam discharged during different times

Items	Value
The entire amalgam discharged	2976 (unit/2 weeks)
Total amalgam discharged	292 (unit/day)
The amount of amalgam discharged	2.97 (unit/day/dentist)
The amount of amalgam discharged	62,346.98 (unit/year)
The amount of amalgam discharged	68.072 (kg/year)
The amount of amalgam discharged into municipal sewage	52.481 (kg/year)
Average of amalgam discharged	636.19 (unit/year/dentist)
Average of amalgam discharged	30.3637 (unit/2 weeks/dentist)

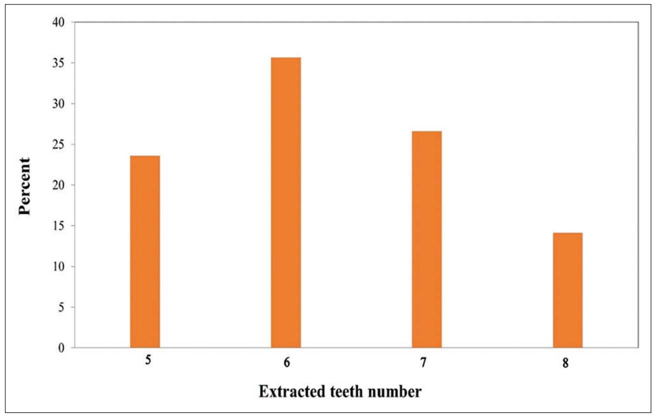

Figure 1: Frequency of extracted teeth number from the dental unit in 2 weeks

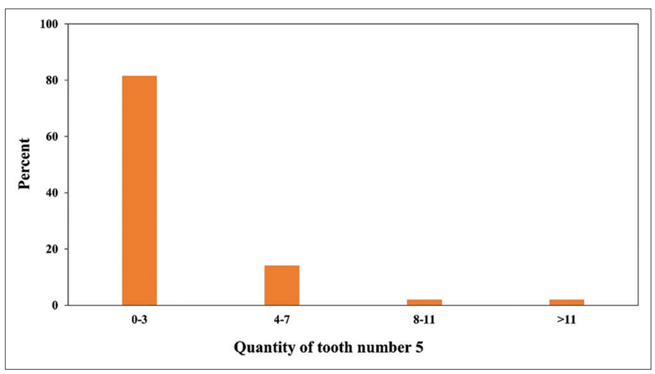

Figure 2: The quantity of tooth number 5 extracted from the dental unit in 2 weeks

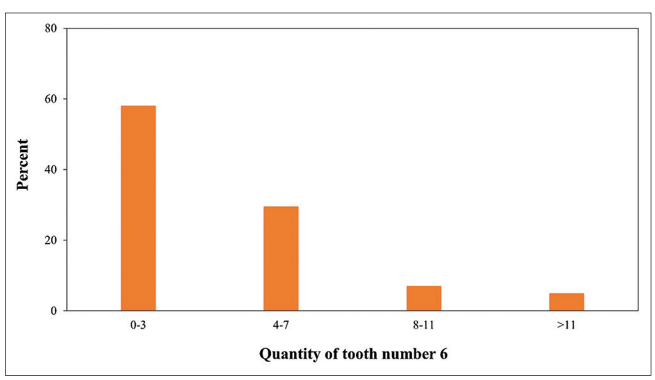

Figure 3: The quantity of tooth number 6 extracted from the dental unit in 2 weeks

units [Figure 7]. According to Figure 7, the most frequently used amalgam brand was ANA® (31.6%), whereas the least used brand was Densplay® (2%). The percentages of mercury, silver, copper, and tin in different types of amalgam are shown in Table 2. Typically, mercury constitutes between 43% and 54.5% of the weight of the amalgams used. The estimated amounts of mercury, silver, copper, and tin that entered the sewage system of Kermanshah through the studied units, measured in grams per year, are provided in Table 3.

Table 2: The mean and standard deviation of mercury, silver, copper, and tin metals in different brands of amalgam (average±standard deviation)

Brands (country)	Hg (%)	Ag (%)	Cu (%)	Sn (%)
ANA 2000 (Sweden)	51±0.6	21.5±2	12.8±0.2	14.8±0.2
Septodont (UK)	54.5±1.5	19.5±0.5	11.5±0.5	14.5±0.5
Cookson Aristaloy 21 (Pakistan)	54.5±1.8	20.2±0.6	11±0.6	14.3±0.6
SDI (Australia)	42.9±0.3	26±0.1	14.2±0.1	16.9±0.1
Ardent (Sweden)	50±1.2	22±0.4	12±0.4	15±0.4
Dentsply (USA)	50±0.9	23±0.3	13±0.3	14±0.3
Cinalux (Iran)	50±2.4	25±0.8	10±0.8	15±0.8

SDI: Southern Dental Industries

Table 3: The estimated amount of mercury, silver, copper, and tin entered the sewage

	Copper	Tin	Silver	Mercury
Amount (g/year)	25,935.6	13,856.61	7087.81	5586.83

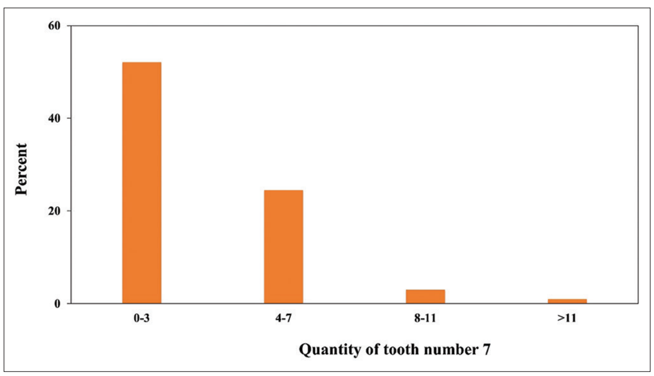

Figure 4: The quantity of tooth number 7 extracted from the dental unit in 2 weeks

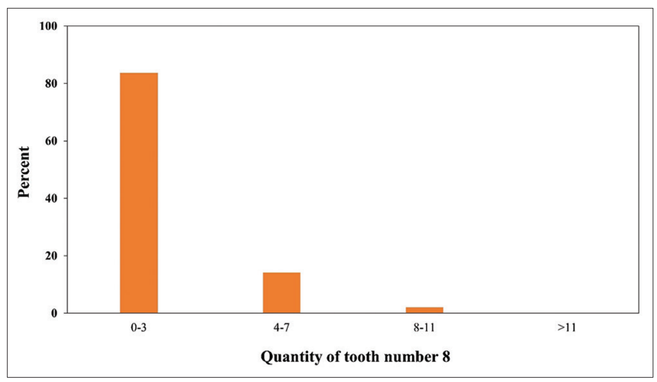

Figure 5: The quantity of tooth number 8 extracted from the dental unit in 2 weeks

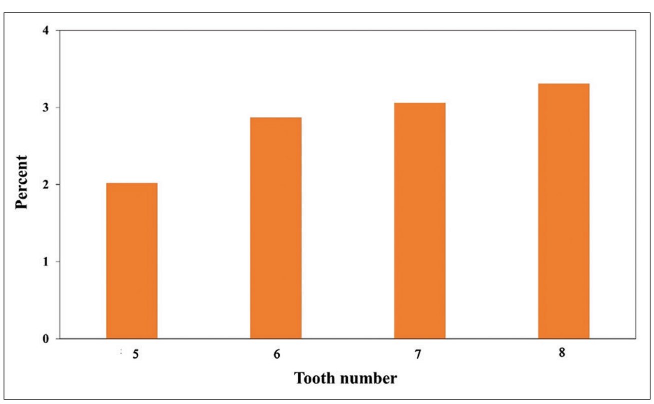

Figure 6: The average of discharged amalgam, according to tooth number (%)

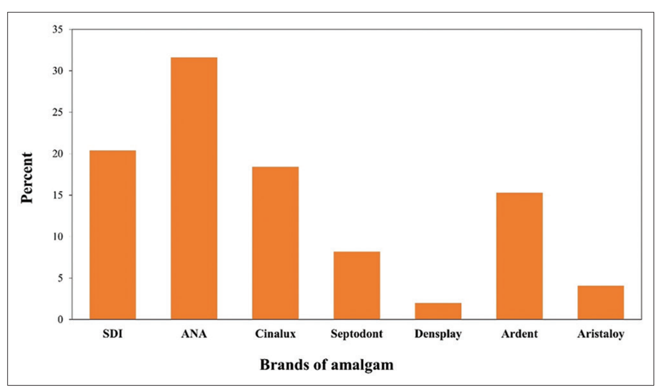

Figure 7: Frequency of different brands of amalgam used in the units under study

Discussion

According to the results presented in Table 1, the total amalgam discharged by 98 dental units in the current study was 292 units. Therefore, the average discharge of amalgam per dental unit was calculated to be 2.9795 units. Multiplying this by the total number of dental clinics in Kermanshah (197 units), the total amalgam produced in 1 day is 586.97 units. With an average of 5.41 working days per week, this equates to 10.82 working days in 2 weeks. Thus, the expected number of discharged units in 2 weeks should be 6351. However, based on the questionnaire responses and considering closures due to illness or leave, the actual number of units discharged in 2 weeks is 5,982.36, which equals 125,330.14 units per year. It was also found that out of 136.83 kg of amalgam discharged in Kermanshah, 105.5 kg entered the sewage network, and 31.3 kg is separated through a separator. Unfortunately, the separated amalgam is disposed of with domestic solid waste, and no proper management is in place.

The high discharge of amalgam into sewer systems is due to the fact that most dental units do not have an amalgam separator. In a study by Al Kawas *et al.* (2008) in the United Arab Emirates, the amount of discharged amalgam in the effluent of three dental clinics showed that on average, from every

1 kg of material used, about 14.6–25 mg/day was discharged into the sewage system.[20] The findings of Benaïssa *et al*. showed that approximately 184 tons of amalgam is consumed annually in the United States.[21] Furthermore, Drummond *et al*. (2003) reported that in Chicago, about 2763 kg of amalgam is discharged into the environment annually.[22]

The observations of the present study illustrated that an average of 52.26, 27.84, 14.07, and 12.06 kg of mercury, silver, tin, and copper, respectively, entered the Kermanshah wastewater collection network through dental units, which is consistent with the results reported by similar studies. For instance, according to a 2010 study by Mumtaz *et al*., New Delhi releases 51 kg of mercury annually through amalgam waste disposal from hospitals and dental clinics.[24] In the study by Bahramian *et al*. in 2016, which investigated the characteristics and management of dental wastewater in Tehran, including five dental centers in Region 6, it was found that dental clinics mainly do not use amalgam and pre-treatment systems. As a result, a significant amount of heavy metals is discharged into urban sewage in the form of solutions or particles.[25] In a 2010 study in Norway, it was estimated that the use of mercury in dental fillings had decreased significantly over the years. Primary sources indicate that the use of mercury for new dental fillings was 2000 kg per year in 1985. By 1995, this had reduced to 840 kg, and following the public ban in 2008, it gradually decreased to almost zero.[26]

The Danish EPA estimated that approximately 1200 kg of mercury was used in dental restorations in 2001. Of this amount, it was estimated that between 190 and 269 kg of mercury was dumped into the sewage.[27]

Based on previous studies, the amount of amalgam removal in units equipped with separators is estimated to be 87%.[28] Therefore, if all dental units in Kermanshah were equipped with separators, the amount of amalgam discharged into the wastewater would decrease from 105.5 to 17.78 kg per year. Consequently, the amounts of mercury, silver, tin, and copper discharged into the wastewater would be reduced to 6.79, 3.61, 1.82, and 1.56 kg per year, respectively. A study by Bender *et al*. (2008) in the United States indicated that the installation of separators in dental clinics reduced the discharge of amalgam by about 80%–90%.[29] The amount of amalgam consumed in Canada was 1880.32 kg. Without mercury separation devices, about 1128 kg of this could be discharged into the sewage. However, it is estimated that only 12.41 kg is actually discharged into the sewage.[30]

Lawrence (2020) reported in a study in Australia that approximately 210 kg of mercury was discharged annually from dental clinics into the sewage system of Victoria City. The study predicted that with the installation of separators in dental offices over a 3-year program, this amount would be reduced to 33 kg (an 84% decrease) within the next 3 years.[31]

One of the control methods of amalgam is its collection by filter and recycling, which is rarely done in Iran. Although the mercury in amalgam is stable, it should not be disposed of as regular solid waste. In many countries, amalgam wastes can now be recycled if it is separated from other wastes. Moreover, the mercury in them can be separated by a process of distillation and purification and used in new products. The American Dental Association considers recycling the best way to manage amalgam debris and highly recommends it for dental clinics.[8,11,32]

Due to the dangerous toxic substances in amalgam, care must be taken regarding its disposal. Part of this material is vaporized by dentists while working, and another part is implanted in damaged dental cavities. In addition, part of amalgam enters wastewater through its use in dental clinics to repair damaged teeth.

Amalgam poses serious challenges for treatment due to its toxicity, and the costs of treatment are also high. This material is usually either incinerated with medical wastes or buried in landfills with other municipal wastes, posing hazards such as leakage into the leachate and infiltration into groundwater and soil resources.[1,12] Environmental pollution caused by the release of heavy metals from dental amalgam is a major concern, but it is currently receiving international attention and is expected to be eliminated in the foreseeable future.[27] However, in Iran, amalgam is still used as the main material in tooth filling and restoration, and its use is increasing. There is a need for a comprehensive research program in Iran to investigate the nature, magnitude, and impact of pollution caused by the release of amalgam through sewage and dental waste into the environment.

Conclusion

According to the results, huge quantities of mercury, silver, tin, and copper enter the sewage collection network of the city of Kermanshah through dental units every year. Based on the results obtained in the present study, the amount of amalgam discharged per day is 2.97 units per dentist, resulting in 68,072 kg of amalgam being discharged by Kermanshah dentists annually. Of this amount, 52.481 kg enters the sewage collection system due to the lack of proper management by health officials. It was also found that by installing a separator in dental units, the amount of amalgam discharge can be reduced from about 17%. It is recommended that policymakers and officials implement regulatory standards and laws to control the discharge of amalgam into sewers to prevent environmental pollution.

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Nil.

Ethical issues

The ethics code of this study is KUMS.REC.1395.34.

Conflicts of interest

There are no conflicts of interest.

Authors' contributions

Meghdad Pirsaheb: Project administration; Hiwa Hossaini: Project administration, Methodology; Shoeib Rahimi: Conceptualization, Data collection; Boshra Ahmadian: Data collection; Niloofar Balkani: Data collection; Afshin Darsanj: Data collection; Mohammad Ahmadian: Writing - review and editing;

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