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Assessment of medical laboratory waste management in Bam City in 2025

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ABSTRACT

Effective adherence to medical waste management protocols in clinical diagnostic laboratories is crucial for safeguarding public health and preventing the transmission of pathogens and environmental pollution. This descriptive cross-sectional study, conducted in 2025, evaluated waste management practices across all nine active clinical laboratories in Bam City, Iran, using a census method. Data were collected through direct on-site observation, structured interviews with laboratory technical supervisors, and a standardized checklist approved by the Ministry of Health and Medical Education. Daily and monthly waste quantities by category were also obtained from laboratory managers, with analysis performed using Microsoft Excel. Findings revealed an average waste generation of 0.19 kg per patient per day, with the nine laboratories collectively producing 106.48 kg/day and 2,875 kg/month. Compliance with national regulations varied significantly across domains: the highest adherence was recorded in waste collection and segregation (82.54%), whereas the lowest rates were observed in decontamination procedures (66.67%) and training/supervision (59.26%). The overall mean compliance rate across all laboratories was 71.56%, indicating moderate performance with considerable room for improvement. To enhance waste management standards, policymakers should implement continuous professional training programs, provide laboratories with standardized decontamination equipment, establish proper temporary storage infrastructure, and enforce regular supervisory audits by environmental health experts. Adopting a systemic, integrated approach throughout the entire waste management cycle—from generation to final disposal—is critical to ensuring safety and regulatory compliance.

Highlights

- Average medical lab waste generation was 0.19 kg per patient per day in Bam City labs.
- Nine labs produced 106.48 kg/day and 2,875 kg/month of waste in total combined.
- Waste collection and segregation compliance was highest, reaching 82.54% across all labs.
- Decontamination procedures had the lowest compliance rate at just 66.67% of required steps.
- Overall mean compliance was 71.56%, showing moderate performance with room to improve.

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1. Introduction

Amalgam has been the most commonly used dental filling material for over 200 years (Tibau & Grube, 2022). One of its main components, mercury, is of particular concern due to its potential adverse effects on humans and the environment (Joy & Qureshi, 2020). It is estimated that the annual consumption of mercury for dental applications is 3-4% worldwide (approximately 300 metric tons of mercury) (Chin et al., 2000; Khwaja et al., 2014). Although the use of amalgam as a restorative material has recently declined, amalgam restorations and their release into the environment continue to be a widely used dental restorative material. According to recent studies, dental clinics are responsible for a significant amount (10–70%) of daily mercury entering the environment through wastewater treatment plants (Jamil et al., 2016; Molina et al., 2014).

Mercury may bioaccumulate in fish and other organisms and therefore can impose an environmental mercury burden on the entire food chain (Gupta & Yadav, 2024; Qu et al., 2022). Among the groups directly exposed to mercury are dentists and their patients, who have been reported to have significantly increased plasma mercury concentrations compared with controls (Manyani et al., 2021; Warwick et al., 2019). On the other hand, people and the environment are indirectly exposed to this element through mercury emissions from waste incinerators and mercury in wastewater from dental clinics and households (Cheng & Hu, 2012). Several studies have shown that mercury exposure may lead to several health complications, such as disruption of the developing central nervous system, pulmonary and nephritic damage, and impaired osmoregulation functions (Fernandes Azevedo et al., 2012). These complications are usually attributed to the strong affinity of mercury for sulfur and sulfhydryl groups within living organisms (Houston, 2014).

Increased knowledge about the risk of toxic effects from anthropogenic accumulation of mercury in ecosystems has led to increased pressure to reduce the discharge of mercury waste into the environment. As a result, the problem of mercury waste in dental clinics has received increasing attention, and restrictions on the transport and disposal of contaminated waste have been imposed in several countries. Studies show that mercury emissions from dental clinics can be reduced by improved waste disposal system design, the use of high-pressure water cleaning, and frequent replacement of amalgam separators and filters (Eshrati et al., 2024; Musliu et al., 2021). For example, it was reported that the use of mercury separators reduced the mercury content in the wastewater of some dental clinics from 270 mg mercury per dentist per day to only 35 mg mercury per dentist per day. As a result, many countries such as Switzerland, Germany, Sweden, and Denmark have introduced mandatory installation of amalgam separators in dental clinics (Arenholt-Bindslev and Larsen 1996; Arenholt-Bindslev 1998). However, the use of these separators in dental clinics in Iran is still uncommon. Furthermore, despite the fact that a large part of the recycled wastewater is reused for irrigation, it is necessary to investigate the amount of mercury discharged into the wastewater collection system.

Therefore, this study aimed to quantitatively assess the mercury load in wastewater from some dental clinics. The results of this project will contribute to the Ministry of Health's efforts to reduce mercury concentrations in wastewater by providing new measures for the handling and disposal of mercury-containing waste from dental clinics.

2. Materials and Methods

An atomic absorption spectrometer (Spectra AA 220 FS, Varian) equipped with a vapor generation accessory (VGA-77, Varian) and a T-shaped quartz absorption cell was used for mercury determination.

2.1 Reagents and Solutions

All chemicals were of analytical grade. All water used was obtained from a Milli-Q reagent system (EC= 18.2 MΩ cm, Millipore, Bedford, MA, USA). All plastic and glassware were soaked in 4 M nitric acid for at least 12 h, washed with distilled water, and finally rinsed with Milli-Q water before use.

Nitric acid (68.0-70.0%) and sodium chloride (99.5%), sulfuric acid (GPR), hydrochloric acid (37.0%), hydroxylamine hydrochloride (99.0%) and stannous chloride (98.0%), potassium permanganate (99.5%), potassium persulfate (98.0%), mercury (for calibration, solution of 1001 ± 1001 mg/L in 2 mol/L HNO3) were purchased from Merck and Sigma.

2.2 Sample Collection

The samples were collected in acid-washed glass containers from two clinics (each clinic, 15 samples) in Tehran. The samples were collected after a variety of treatments, including amalgam restorations, composite fillings, root canal treatment, cavity preparation plus temporary filling, glass ionomer filling, pulpotomy, scaling plus polishing, fissure sealants, and cementation. Each sample was collected directly from the dental chair exits into collection containers at the end of each treatment.

2.3 Sample Preparation and Testing

The collected samples were stored in HNO_3 (concentrated acid was added to each sample container to obtain a final acid concentration of 1% and stored in a refrigerator at 4°C until analysis). The samples were digested according to USEPA Method 245.1. Briefly, the sample containers were shaken vigorously before taking subsamples for analysis. 50.0 mL of the filtered sample (gravity filtration using Schleicher & Schuell 595 filter papers) was placed in a clean 150 mL plastic bottle, and then 5.0 mL of H_2SO_4, 2.5 mL of HNO_3, 5.0 mL of $K_2S_2O_8$ (5%), and 5 mL of $KMnO_4$ (5%) were added. Then, each sample was kept in an oven at 95°C for 2 hr. After cooling to room temperature, hydroxylamine hydrochloride (12% in 12% NaCl) was added dropwise to each bottle until the $KMNO_4$ color disappeared. If the $KMNO_4$ color reappeared before 15 min after the first addition, more hydroxylamine hydrochloride was added. Approximately 1 mL of hydroxylamine hydrochloride was sufficient to completely reduce the excess $KMNO_4$. Finally, water was added to each bottle to obtain a volume of 100.0 mL. Total mercury was determined using cold vapor atomic absorption spectrometry (CV-AAS).

3. Results and Discussion

The mercury concentration in the wastewater of two dental clinics is given in Table 1. This table also includes the types of treatments provided to each patient. The dental treatments performed are classified into 3 different categories: one is "amalgam restoration only". The second is "amalgam restoration with other types of treatment", and the third is "no amalgam restoration". From Tables 1 and 2, it is clear that the wastewater samples of Clinic 1 have relatively higher mercury than those of Clinic 2. This can be easily explained by the release of mercury from the amalgam itself during the dental treatment or afterwards from amalgam particles deposited inside the drainage pipes. The highest mercury content measured in the effluent was from Clinic 1 (Sample 2), where there were 25 patients, nine of whom had undergone amalgam restorations, and the mercury content was 125.67 µg/L. In addition, in cases treated without amalgam, the mercury content was very low, so that in many cases of treatment without amalgam, the mercury content was below the detectable level. The reason for the higher mercury content in the samples of the second treatment mode compared to the third treatment mode is the use of amalgam, which contains high levels of mercury, while in the third treatment mode, the possible mercury content was very low. Nevertheless, the mercury content in the effluent was higher than the permissible mercury content in the environment according to the EPA recommendation (0.002 mg/l) (Mirlean et al., 2003; Nevado et al., 2003; Vandeven & Mcginnis, 2005). The mean, standard deviation, and range of mercury concentration in the samples versus treatment type are shown in Table 3.

Table 1 Mercury concentration in wastewater samples collected from dental clinics, along with the type of treatment performed

Sample	Type of Treatment	Total No. of patients treated	Treated with amalgam	Hg (µg/L)
1	2	30	7	98.32
2	2	25	9	125.67
3	2	27	6	78.44
4	2	32	5	80.62
5	2	21	6	83.54
6	٣	26	0	3.25
7	2	28	8	114.67
8	2	21	3	31.92
9	2	23	2	19.87
10	2	27	4	43.22
11	2	22	6	75.41
12	2	27	5	71.33
13	3	26	0	1.16
14	3	20	0	ND
15	3	37	0	ND
16	3	39	0	0.84
17	2	35	7	60.42
18	2	32	6	45.63
19	2	40	8	93.74
20	2	42	7	71.23
21	2	48	8	88.55
22	2	46	6	65.92
23	2	39	5	42.25
24	3	40	0	ND
25	3	42	0	0.54
26	3	44	0	n.d.
27	2	43	4	19.95
28	2	37	6	63.64
29	3	43	0	1.29
30	3	41	0	0.21

Table 2 Mean, (standard deviation), maximum, and minimum mercury levels by type of dental treatment

	Type of Treatment	n	Min.	Max.	Mean	SD
Clinic 1	2	11	19.87	125.67	74.82	32.74
	3	4	0	3.25	1.11	1.53
Clinic 2	2	9	19.95	93.74	61.26	23.02
	3	6	0	1.29	0.48	0.51

According to Table 3, the mercury content in treatment mode 2 was higher than in treatment mode 3, and the type of treatment also had a significant relationship with the mercury content. The reason is that most of the mercury in the wastewater of dental clinics comes from amalgam, which is used a lot in treatment mode 2, while amalgam is not used in treatment mode 3 (Mukherjee et al., 2004; Vandeven & Mcginnis, 2005).

Table 3 Relationship between treatment type and mercury content based on *t*-test

Type of Treatment	n	Hg (µg/L)	SD	F	Sig	df
2	20	68.72	28.9	15.64	0.0001	28
3	10	0.73	1.02			19.09

4. Conclusion

This study confirms that wastewater effluent from sampled dental clinics in Tehran contains mercury concentrations substantially exceeding permissible environmental limits, with levels directly correlated to the use of dental amalgam. The findings demonstrate that procedures involving amalgam restorations release significant quantities of mercury into clinic wastewater, whereas treatments that do not utilize amalgam result in negligible, often undetectable, mercury levels. This stark contrast underscores amalgam as the primary source of mercury pollution within this setting. The environmental and public health implications are considerable, given mercury's persistence, capacity for bioaccumulation, and toxicity. The discharge of such contaminated wastewater into municipal systems poses a risk of wider environmental contamination, ultimately affecting ecosystems and human health through indirect exposure pathways. Consequently, these results underscore the urgent need for the widespread adoption and strict enforcement of mitigation measures in Iranian dental practices. Mandatory installation and maintenance of efficient amalgam separators are essential first steps, alongside the implementation of best management practices for amalgam waste. Furthermore, the development and enforcement of specific national regulations for dental effluent are crucial to significantly reduce this preventable source of mercury pollution. Future research should expand the scale of monitoring to quantify the total national mercury load from dental clinics and rigorously evaluate the real-world efficacy of available separator technologies in diverse clinical environments.

Statements and Declarations

Ethical considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the author.

Data availability

Data will be made available on request.

Conflicts of interest

The author declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author contribution

M.H. Abbasi; F. Ahmadizadeh: Investigation, Writing the main Draft; N. Shams-Aldini; N. Fazli: Conceptualization; Writing – Review & Editing.

AI Use Declaration

During the preparation of this manuscript, the authors used ChatGPT for language translation. All content has been carefully reviewed and revised by the authors, who take full responsibility for the final version of the manuscript.

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