

Mercury levels in wastewater samples at a South African dental school

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ABSTRACT

Dental amalgam is a commonly used restorative material in oral health care services in South Africa. It is composed of between 43-50% mercury. Over the past 40 years, advancing knowledge of mercury toxicity to the environment and life has led to concerns over the waste produced during the placement and removal of dental amalgam. The present study determined mercury levels in wastewater, described the application of the best management practices (BMPs) for dental amalgam use and investigated dental amalgam procurement patterns at the WITS Oral Health Centre, University of the Witwatersrand. The wastewater generated during the study period was diverted, collected and sampled. The samples were analysed for total mercury concentrations using USEPA method 245.7 – Cold Vapor Atomic Absorption Spectroscopy. A structured interview was used to investigate the application of the BMPs for dental amalgam use. The amalgam procurement records were accessed and analysed. The study found that the levels of mercury in wastewater samples ranged from 1.048mg/l to 108.762mg/l, there was an increasing procurement of dental amalgam over nine years and there was inadequate adherence to the BMPs. The mercury levels observed called for the urgent need to institute BMPs.

INTRODUCTION

Mercury is a recognised global environmental pollutant with various adverse health effects on animal and human life.¹ Mercury is released into the environment from geologic reservoirs and human activities and persistently circulates in the atmosphere, water, soil, plants and animals.² In the environment, mercury deposits in waterways and is converted to a highly toxic form of methylmercury through microbial methylation. Methylmercury ingestion in lower trophic levels leads to bioaccumulation and biomagnification in higher trophic levels of marine animals such as long-lived fish and marine mammals.³ Human consumption of methylmercury may harm the nervous, cardiovascular, respiratory, immune

and digestive systems. The developing nervous system is particularly sensitive to methylmercury, and exposure could lead to impaired neurological development.⁴ To minimise the risk of environmental mercury contamination, the mining, usage and trade of mercury and mercury-containing products are subject to control under the Minamata Convention on Mercury (MCM).⁵

Dental amalgam is a commonly used restorative material in primary oral health care provision in South Africa.⁶ Dental amalgam restorative material comprises 43-50% liquid mercury, which forms an intermetallic alloy with varying amounts of silver, tin, copper, zinc and palladium.⁷ Two standards, ISO 24234:2021⁸ and ISO 20749:2023,⁹ provide the compositional specifications, requirements and test methods for dental amalgam products. The mercury component of dental amalgam has been controversial since its introduction.¹⁰ The placement, removal and polishing of dental amalgam restorations and extraction of teeth containing dental amalgam generate mercury-containing waste in oral health care settings.¹¹ The waste is generated in an open system which, without proper waste management processes, can release up to 50% of consumed material into the environment.¹² The release of dental amalgam mercury to the environment occurs through the following pathways: atmosphere 50-70 tons/year; surface water 35-45 tons/year; groundwater 20-25 tons/year; and soil 75-100 tons per year. An estimated 40-50 tons/year of dental amalgam are recycled and 40-50 tons/year are processed through sequestration and secure disposal.¹³

In the MCM, dental amalgam is the only mercury-added product subject to a phase-down approach based on prevention, research for alternative materials and waste management practice.^{14,15} Dental amalgam is banned in Sweden, Norway and Denmark, and restrictions have been introduced in Japan, Germany, Finland, Bulgaria, Mongolia, Vietnam and Thailand.¹³ Standards, guidelines and provisions for dental amalgam use have been introduced in Canada,¹⁶ the US¹⁷ and the European Union.¹⁸ Middle- and low-income countries rely on “affordable” dental amalgam to offset unmet restorative needs in their populations.¹⁹ Dental amalgam’s contribution to environmental mercury contamination in developing countries is recognised, but information on the extent and mitigation processes is lacking. Available estimates of dental amalgam usage in South Africa indicate that 70-100kg of dental amalgam was sold annually between 2009 and 2011, with a further 50kg of non-amalgamated mercury sold to dental practitioners.²⁰ Dental amalgam was previously reported to be widely used in the training of restorative dentistry in all four dental schools in South Africa (Lombard, et al., 2009). The amount of dental amalgam procured and used by the dental schools and the potential wastewater contamination have remained unreported. The World Health Organization (WHO) has adopted best management practices (BMPs) for

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Author's contribution

1. Stephen M Sudi – conceptualisation, methodology, investigation, draft preparation (60%)
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dental amalgam use, which were previously developed by the American Dental Association.²¹ The South African Dental Association (SADA) advocated the introduction of the BMPs for dental amalgam use to prevent environmental mercury contamination.²² The extent of BMPs application in dental schools that use dental amalgam for training and treatment remains unreported.

The present study aimed (i) to determine mercury levels in wastewater, (ii) to investigate the application of best management practices for dental amalgam use, and (iii) to describe the procurement patterns of dental amalgam at the WOHC.

MATERIALS AND METHODS

Study setting

The study was conducted at the WITS Oral Health Centre (WOHC) of the School of Oral Health Sciences, University of the Witwatersrand. Ethical clearance was obtained from the Human Research and Ethics Committee of the University of the Witwatersrand (Ethics number M170908) and permission to conduct the study at the centre was obtained from the Hospital Research and Risk Committee. The WOHC provides clinical services and training through four polyclinics – P1, P2, P3 and P4 – a multi-skills technique laboratory (MSTL) and various support sections. Polyclinic supervisors managed the polyclinics and the MSTL. The restorative procedures using dental amalgam were performed in the P1, P2, P3 and occasionally in the P4 and the MSTL. The wastewater generated during operations was evacuated by four 50mm main lines connected to vacuum pumps, two each for P1, P2, P3 and MSTL. The vacuum pumps used at WOHC were Midmark, Classic-Series® CV10 Wet-Ring twin. The P4 polyclinic was excluded from the study due to the unfavourable vacuum system layout. The procurement of supplies and materials necessary for training and clinical operations was managed by the Central Procurement Section (CPS).

Study design

A cross-sectional study design was used to determine the levels of mercury in wastewater samples, dental amalgam uses and the application of best management practices for dental amalgam use at the WOHC. The dental amalgam procurement trends were obtained retrospectively.

The determination of the level of mercury in wastewater and dental amalgam use

The study period for determining levels of mercury in wastewater and dental amalgam use was seven days. Wastewater collection was facilitated by diverting the wastewater flow using a collection apparatus made of a sampling valve installed perpendicular to the main vacuum pipe, a vacuum hose with a lower ball valve, and a 20L container. Eight collection systems were installed on the four main vacuum lines proximal to the suction pump stations and trialled for collection efficiency.

During the study, the collected wastewater was poured into a plastic basin and manually agitated to obtain a uniform mixture. A 500ml test sample was obtained from the collected wastewater from the basin using a measuring jar and was kept in polyethylene bottles previously. This step was uniformly performed for each polyclinic and MSTL. The remaining wastewater was measured to determine the total amount of wastewater collected from each mainline per day.

The remaining collected wastewater was discharged to the main sewage line.

The control samples were 500ml “point-of-use water samples” collected in polyethylene bottles from the steam distillers, which provide water used for irrigation/cooling in the dental chairs at polyclinics 1, 2 and 3, and from the three-way air/water syringe in the MSTL. The total number of samples obtained was 25 test samples and 25 control samples. The obtained samples were preserved by adding 10ml of 32% hydrochloric acid, followed by storage in a refrigerator at 4°C. The equipment used for test sample collection was thoroughly washed with SteriScrub soap containing chlorhexidine and water after each collection, rinsed with de-ionised water, dried and stored ready for next-day collection.

At the end of the study period, the 50 collected samples were removed from the refrigerator, placed in a cooler box filled with ice and transported to the Council for Scientific and Industrial Research (CSIR) – Water and Environment Laboratory in Pretoria for analysis. The total mercury levels in wastewater were determined through the US EPA method 245.7 – Cold Vapour Atomic Absorption Spectroscopy using a Hydra II Mercury Analyser. The use of dental amalgam was determined by observing restorative procedures performed in polyclinics 1, 2 and 3 and the MSTL during the study period. Information on the number of dental amalgam restorations removed or placed, the number of surfaces, the number and type of dental amalgam capsules and the amount of dental amalgam used was recorded in a data collection sheet.

Best management practices for dental amalgam use

The application of best management practices for dental amalgam use was determined through a structured interview with the clinic supervisors for polyclinics 1, 2, 3 and the technician. The interview questionnaire was based on the practical guide to integrating best management practices (WHO, 2010) into dental practice, with the main areas of focus including the use of amalgam capsules, retention and storage of amalgam waste, equipment maintenance, prevention of releases and disposal of dental amalgam waste. The interview was conducted on the sixth day of the study.

Dental amalgam procurement

The records of dental amalgam procured from April 2009 to March 2018 were accessed at the procurement office and central stores of the WOHC. The number of dental amalgam boxes issued, the number of capsules – ie the clinical utilisation unit – and the amount of dental amalgam calculated were entered into the data collection sheet.

Statistical analyses

The data was captured on a spreadsheet. Descriptive statistics were used to summarise the data. Trendline analysis was used to determine procurement trends. Spearman correlation analysis using Stata 15 was used to determine the correlation between dental amalgam used and mercury levels in wastewater. The level of significance was set at $P < 0.05$.

RESULTS

Dental amalgam use and mercury levels in wastewater

The number of patients seen at P1, P2, and P3 during the study was 820, of which 163 (20%) received restorative treatment. The dental amalgam restorative material used

was the "Permite" brand, in pre-dosed capsules of one/two spill sizes with regular setting time. The number of dental amalgam procedures performed was 28, comprising the removal of 9 amalgam restorations with 17 surfaces and the placement of 19 amalgam placements with 29 surfaces. The number and type of amalgam capsules were 41 one-spill and 72 two-spill capsules. The amalgam restorative procedures were performed by the fourth- and fifth-year students.

The MSTL was used on days 1, 3, 5 and 7 of the study. Fifty-seven restorations consisting of 69 surfaces were removed, and 106 restorations with 146 surfaces were placed. The number and type of amalgam capsules used were 67 one-spill capsules and 146 two-spill capsules. The total amount of dental amalgam used at WOHC during the study period was 258.8mg, of which 85% was used in the MSTL and 15% was used in the polyclinics.

Fifty samples were submitted to CSIR for total mercury analyses. The samples comprised 25 control samples and 25 wastewater samples. The levels of mercury in all control samples were <1.0 µmg/l, while the levels of mercury from the wastewater samples ranged from a minimum of 1,048 mg/l in P2 to a maximum of 108.762mg/l in MSTL. The median mercury level in wastewater samples was 4.457mg/l, with an interquartile range of 15.804mg/l (2.303mg/l – 15,804mg/l). Table 1 summarises the amount of dental amalgam used, collected wastewater and mercury levels in the P1, P2, P3 and MSTL.

The application of best management practices

The use of dental amalgam in the form of pre-capsulated alloys of various sizes was the only BMP for dental amalgam use applied in the three polyclinics and the MSTL. Other BMPs, including the use of marked, wide-mouthed, airtight

Table 1. Dental amalgam used and mercury levels in wastewater

	Day of the study	Dental amalgam use (mg)	Wastewater collected (l)	Total mercury levels in wastewater (mg/l)
P1	1st	2304	4.6	3.130
	2nd	3068	5.7	18.843
	3rd	0	11.7	8.094
	5th	0	0.8	4.457
	6th	0	4.2	2.436
	7th	0	3.6	2.170
	P2	1st	0	6.7
2nd		5348	6.4	1.134
3rd		0	11.7	7.135
4th		0	0.8	3.342
5th		0	5.1	2.881
6th		3820	10.6	2.857
7th		2292	6.1	1.508
P3	1st	1152	4.1	3.750
	2nd	16056	7.6	4.553
	3rd	5348	6.4	9.047
	5th	0	5.3	4.509
	6th	0	6.6	1.385
	7th	0	2.4	1.048
	MSTL	1st	85868	1.9
2nd		0	0.4	17.371
3rd		32632	0.75	48.572
5th		53284	1.4	67.744
6th		0	0.5	37.943
7th		47596	1.7	108.762
Total			258768	117.05

There was a moderate correlation between dental amalgam use and mercury levels in wastewater ($r_s=0.4688$), ($p=0.0181$).

containers for storage of non-contact amalgam, used capsules, contact amalgam, extracted teeth, traps and filters, were not practised in all three polyclinics and the MSTL. Moreover, the following BMPs – using amalgam separators in the wastewater system, using disinfectants and line cleaners that do not contain chlorine or bleach, and disposing of amalgam waste with a compliant recycler – were not employed.

Dental amalgam procurement

The dental amalgam restorative material procured by WOHC was the “Permite” brand, in pre-dosed capsules of one and two spill sizes with regular setting time. The pre-dosed capsules were packaged in a box of 50 capsules. The one-spill size capsule contained 400mg alloy and 364mg mercury, while the two-spill capsule contained 600mg alloy and 552mg mercury. Over the nine years from April 2009 to March 2018, WOHC procured 454 Permite dental amalgam boxes, which contained 22700 dental amalgam capsules, of which 51.8% were two-spill capsules and 48.2% were one-spill capsules.

The pre-dosed dental amalgam capsules contained 21.91kg of dental amalgam, consisting of 11.43kg of alloy and 10.47kg of mercury. The median number of capsules procured was 700 for one-spill capsules and 1,500 for two-spill capsules. The trendline analysis revealed a slight increase in dental amalgam procured by the WOHC from the year 2009 to 2017 (0.1847, R² 0.0953) (Figure 1).

DISCUSSION

The present study aimed to determine mercury levels in dental wastewater samples, investigate the application of BMPs for dental amalgam use and describe the dental amalgam procurement patterns at WOHC. The study’s main findings were that the wastewater samples had a high mercury concentration, the BMPs for dental amalgam use were not adequately applied, and WOHC still procured and used dental amalgam for training and management of dental caries.

The mercury concentration in all wastewater samples was higher than the maximum concentration limit of 1.0mg/l allowed in any sewage, industrial effluent or other liquid discharged to the sewer by the City of Johannesburg Metropolitan Municipality Water services by-laws.²³ Discharging wastewater with a high mercury concentration harms the environment and life as it may prejudice downstream sewage effluent reuse by the municipality and water recycling/reuse. The total mercury concentration in wastewater from the WOHC was similar to that reported in a previous study: 45.2mg/l (n=13; SD=68.5) for the chair-side samples, 13.4mg/l (n=13; SD=9.8) for the 107-chair clinic and 5.4mg/l (n=12; SD=2.7) for the 30-chair clinic.²⁴

The mercury levels in wastewater samples obtained from the polyclinics were lower than the MSTL by a factor of 10. The lower mercury levels in the polyclinics could be due to lower dental amalgam use and a higher number of procedures not using dental amalgam. A study from the United Arab Emirates similarly described the lower wastewater mercury concentration in clinics not offering or with lower numbers of dental amalgam treatments compared to those that offer primarily dental amalgam treatment.²⁵ The moderate correlation between the amount of dental amalgam used in the polyclinics and the MSTL and the level of mercury in wastewater can be attributed to a limited number of samples collected and a higher settling rate of dental amalgam particles in the wastewater flow. The detection of mercury in the wastewater samples due to flushing of dental amalgam particles in the wastewater lines on days when no amalgam was used, was described as the reason for the lack of correlation between dental amalgam use and mercury concentration in dental wastewater.²⁶

The wastewater system layout at the WOHC necessitated the installation of the sampling apparatus proximal to the vacuum pump location in the main vacuum line for the polyclinics and MSTL. The wet-ring vacuum pumps used at the WOHC use water to lubricate and cool the pump housing

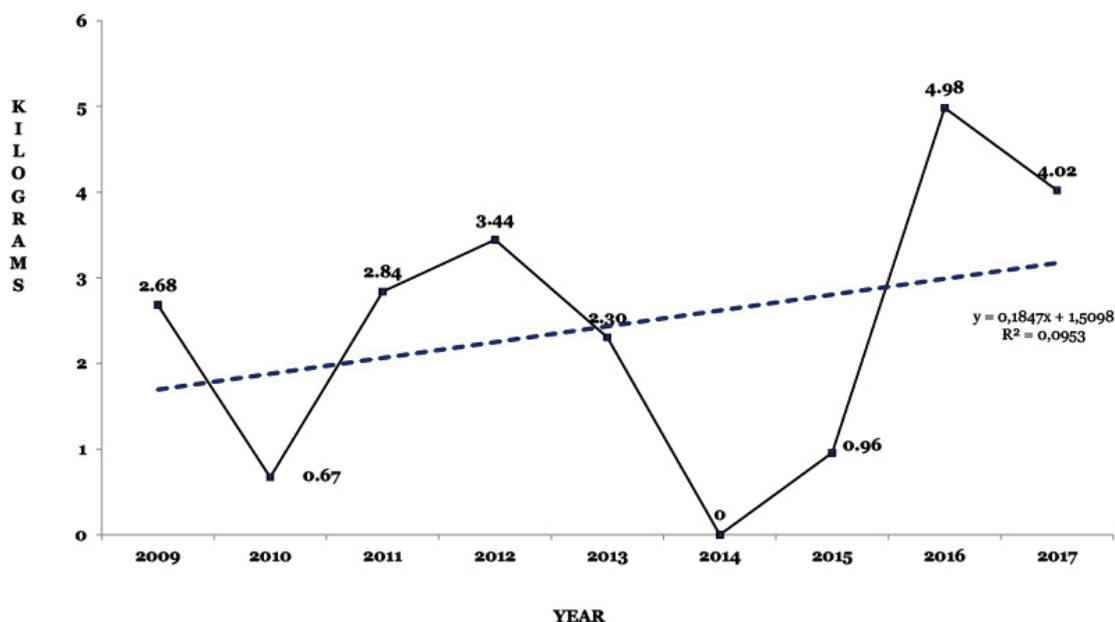


Figure 1. The amount of dental amalgam procured yearly by WOHC from 2009 to 2017.

seal and contain a trap that protects the pump from solids in the wastewater. In a typical eight-hour working day, the pump uses 1,089.6 litres of water.²⁷ The above conditions make the mercury concentration of wastewater samples collected before the wet-ring vacuum pump higher than that of wastewater entering the sewer. Previous studies have used wastewater collected directly from the dental chair,²⁵ and dental chair and settling tanks.²⁴ The different options in vacuum line layouts, sampling points and pump types used in dental clinics' design might lead to widely varying wastewater mercury levels. The national sanitation policy emphasises the importance of industries and businesses connected to the sewage system to ensure that discharge does not risk the treatment process, quality and quantity of effluent.³⁵ The South African national norms and standards for sanitation services prohibit dilution of the effluent to achieve compliance with set concentration limits.²⁸ Rising utility costs and environmental concerns have led to a shift to the more efficient dry vacuum system and recycling of wet ring pumps.²⁹ The establishment of sampling points for dental wastewater should consider the fact that dilution occurs in wet ring pumps, unlike dry vacuum pumps.

The present study found that only a partial application of BMPs for dental amalgam use was adhered to, leading to contamination of the wastewater and the environment by mercury and other dental amalgam constituents. The inadequate application of the BMP is similar to that reported in other developing countries.³⁰⁻³² This could be due to a lack of national guidelines. The current guidelines on managing healthcare risk waste in South Africa do not adequately meet the current standards in amalgam waste management.³³

The provision for separating amalgam waste into contact and non-contact waste, amalgam spill kits, specification of amalgam waste containers, measures to mitigate wastewater mercury contamination, and disposal methods is lacking. The healthcare waste management regulations in South Africa state that establishments are responsible for the waste from the point of generation until its final treatment and disposal.³⁴ Developing updated healthcare waste guidelines will facilitate proper amalgam waste management and ensure oral healthcare facilities do not contravene the country's waste management regulations.

There was a slight increase in dental amalgam procured during the study period. The increase in procurement was ascribed to an increased intake of first-year dental students, which doubled from 25 in 2011 to 50 in 2014. The variations in yearly procurement of dental amalgam observed in this study uncovered a need for accurate demand forecasting to prevent wastage and potential environmental contamination during long-term storage.

Dental amalgam restorative material continues to play an essential role in the pre-clinical training of dental students and the provision of restorative treatment at the WOH. Procuring regular setting amalgam for pre-clinical training may contribute to the high amount of dental amalgam used in the MSTL. WOH should consider the introduction of extended carving time (ECT) and slow carving (SC) dental amalgam formulations, which afford the operator a longer working time and could lower the amount of dental amalgam used for training.³⁶ There is a need for further investigations on the affordability and utility of dental amalgam restorative material, considering the cost of waste management,

disease burden, practitioner skills and treatment coverage goals related to forthcoming universal health coverage.

The limitations of the present study include its short duration due to budgetary constraints, the inability to establish different species of mercury, and the nature of mercury due to analytical incapability in laboratory services.

CONCLUSIONS

The study revealed that the wastewater samples from WOH contained total mercury levels ranging from 1.048mg/l to 108.762mg/l. The levels of mercury in wastewater were above limits allowable by the City of Johannesburg Metropolitan Municipality Water Services by-laws. The study also demonstrated an increasing procurement of dental amalgam over a nine-year period, most of which is used for training, and inadequate adherence to the BMPs for dental amalgam use was also identified.

RECOMMENDATIONS

- The Department of Health, the HCPSA, SABS and the dental community should develop, advocate and implement appropriate guidelines for managing dental amalgam waste in South Africa.
- The possibility of introducing the extended carving time (ECT) and slow carving (SC) dental amalgam formulations for restorative dentistry training should be investigated.
- An investigation on the cost-benefits analysis of dental amalgam, based on restorative treatment needs burden and the affordability through universal health coverage should be undertaken to inform the future training priorities and planning of waste management programmes.

Keywords

Dental amalgam, mercury, dental amalgam waste, best management practices for dental amalgam use

Conflict of interest

The authors declare that the research was conducted without any commercial or financial relationships that could potentially create a conflict of interest.

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