The Weight of Wastes Generated by Removal of Dental Amalgam Restorations and the Concentration of Mercury in Dental Wastewater

• Albert O. Adegbembo, BDS, DDPH, MSc •
• Philip A. Watson, DDS, MScD •
• Stanley J. Lugowski, PhD, MSc •

Abstract

Objective: *To determine the amount of amalgam entering the waste stream during removal of dental amalgam restorations.*

Methods: *Dental amalgam restorations were removed from anatomic replica teeth and natural teeth by means of a tungsten carbide bur, a high-speed handpiece and a conventional suction system. The weight of amalgam particles trapped in the primary and secondary solids separators was determined. Amalgam particles were filtered from wastewater with 15-µm filter paper and weighed. The concentration of total mercury in the effluent collected (by instantaneous flow-through) during the removal of amalgams, with and without an ISO-certified separator, was measured by means of cold-vapour atomic absorption spectrophotometry.*

Results: *About 60% by weight of the amalgam removed was found in the effluent, about a third was retained in the primary solids separator and less than 10% was retained in the secondary solids separator. The ISO-compliant separator reduced the concentration of mercury in the instantaneous flow-through discharge by 99.4%, from 31.2973 mg/L to 0.1800 mg/L.*

Conclusions: *About 60% of the waste generated during the removal of amalgams escaped the primary and secondary solids collectors and was released into the wastewater. An ISO-certified amalgam particle separator was effective in removing the amalgam from the wastewater.*

MeSH Key Words: *dental amalgam/analysis; dental waste/analysis; spectrophotometry, atomic absorption*

© J Can Dent Assoc 2002; 68(9):553-8
This article has been peer reviewed.

Particles of waste amalgam of various sizes and shapes are generated when dental amalgam restorations are removed. A conventional high-volume suction system has one solids separator at the chairside (the chairside trap) and a second separator just upstream from the pump (the pump trap). These conventional separators capture some of the waste amalgam, but the remaining wastes are discharged into the municipal sewer system. Searches of MEDLINE and the Environmental Health Information Services databases with the keywords "amalgam," "wastewater" and "mercury" (in various combinations) revealed no studies that had measured the amount of amalgam waste generated during removal of restorations or the amount of waste recoverable from conventional solids separators and wastewater. However, some studies have reported on the concentration of mercury in air and wastewater from dental clinics.[1-9]

Obenauf and Skavroneck,[3] in a report entitled *Mercury Source Sector Assessment for the Greater Milwaukee Area*, indicated that 60% by weight of the mercury from dental offices ended up in wastewater. However, the method used to calculate this figure was not reported. The Milwaukee report appears to have been one of the resources used in developing the "Canada Wide Standards for Mercury Product Fact Sheet: Dental Amalgam" contained in *Final*

Report: Inventory of Uses and Releases of Mercury During Product Life Cycles.[2]

On the basis of studies of particle-size distribution in amalgam wastewater,[10-12] O'Connor Associates Environmental Inc.[7] estimated that a conventional chairside trap with a screen pore size of 0.70 mm would trap 30% by weight of amalgam wastes and that 50% of the amalgam wastes that bypassed this trap would be captured by the second trap (the pump trap) if it had a screen pore size of 0.425 mm (#40 mesh). From these estimates, O'Connor Associates Environmental Inc.[7] concluded that conventional traps in the dental chair could capture 65% by weight of amalgam wastes.

The potential effect of mercury bound in amalgam waste from dental offices is an environmental concern that is gaining attention in North America,[3,4,6,7,9,13-16] but uncertainty about the quantity and distribution of waste generated by the removal of dental amalgams has made it difficult to establish objective policies. The aims of this study were to conduct an audit of amalgam wastes to identify the proportion of mercury retained in conventional traps and that lost to the sewage system and to determine the concentration of mercury in the resulting wastewater.

Materials and Methods

Weight of Amalgam Trapped at the Chairside and Escaping into Wastewater

Artificial replica teeth (Kilgore International Inc., Coldwater, Michigan) and natural teeth containing amalgam restorations were used for this study. The restorations in the artificial teeth had been placed by dental students at least 9 months before removal. The age of the restorations in the natural teeth, which had been placed by practising dentists, was unknown, but all of the teeth had been extracted at least 15 years before.

Five groups of artificial and natural teeth containing Class I, II, and V restorations were weighed with a model TR-602 scale (Denver Instrument Company, Arvada, Colorado; precision ± 0.01 g) before and after removal of the amalgam. The number of tooth surfaces in each group was 27, 58, 31, 36, and 42, respectively (Table 1). Before removal of restorations from each set of teeth, the dental unit was thoroughly flushed with water. All restorations were removed with a tungsten carbide friction grip bur (#271 or #245) in a water-cooled Star 430K high-speed handpiece (StarDental, Lancaster, Philadelphia) attached to a dental unit with conventional suction system; no hand instruments were used to pry restorations from cavities, and care was taken to avoid removing tooth material with the bur.

After the restorations had been removed from each set of teeth, the screen (pore size 1.34 mm) in the conventional chairside solids separator was removed and the weight of trapped particles determined from the difference in weight of the screen with and without the amalgam particles. Next, the glass container in the separator at the pump (screen pore size 0.75 mm) was removed. The contents of this container were filtered through preweighed 15-µm filter paper. The filter paper was allowed to dry for 24 hours at room temperature and was then weighed. The weight of the residue was calculated by subtracting the weight of the filter paper before use from the weight of the dried filter paper with amalgam residue. To determine if residual moisture in the filter paper affected the weights, 5 filters were weighed, soaked in water, dried for 24 hours at room temperature, and then reweighed. After drying as specified, 4 of the filter papers gained 0.04 g each and the fifth gained 0.03 g.

The experimental conditions for removal of restorations from the fifth set of teeth were modified by enclosing the working area to prevent splatter. All of the wastewater from this fifth set was collected in plastic containers and filtered, and the collected material was weighed as described previously. The quantity of amalgam that bypassed the chairside solids separators was calculated as the weight of amalgam removed from restorations minus the weights of amalgam trapped at the primary and secondary solids separators.

Concentration of Mercury in Wastewater

Samples for measurement of mercury concentration in wastewater were collected in Teflon bottles that had been

Table 1 **Weight of amalgam restorations and types of restorations removed**

Teeth	Amalgam restorations removed		Distribution of types of restorations removed (%)				Weight removed per surface (g)
	Total weight (g)	Total no. of surfaces	1 surface	2 surfaces	3 surfaces	≥ 4 surfaces	
Group 1							
Set 1	23.60	27	33	30	22	15	0.87
Set 2	35.74	58	52	28	9	10	0.62
Set 3	17.62	31	35	32	23	10	0.57
Set 4	19.64	36	36	39	14	11	0.55
Mean	**24.15**	**38**	**39**	**32**	**17**	**12**	**0.65**
Group 2							
Set 5	21.28	42	45	31	10	14	0.51

Table 2 **Separation of wastes generated during the removal of dental amalgam wastes**

Teeth	Total weight of amalgam restorations removed (g)	% of total weight of amalgam restorations recovered			% of total weight not recovered
(Column I)	(Column II)	Chairside trap (Column III)	Pump trap (Column IV)	Both traps (Column V = Columns III + IV)	(Column VI = 100 – Column V)
Group 1					
Set 1	23.60	31	10	41	59
Set 2	35.74	32	7	39	61
Set 3	17.62	31	10	41	59
Set 4	19.64	33	7	40	60
Mean (SD)	**24.15 (7.03)**	**31.8 (1.0)**	**8.5 (1.7)**	**40.2 (0.8)**	**59.8 (0.8)**
Group 2					
Set 5[a]	21.28	31	12	43	57

SD = standard deviation

[a]A further 40% (8.58/21.28 g) of the weight of amalgam removed was recovered by filtration of the 70 L of wastewater through a 15-µm filter paper.

precleaned in 30% nitric acid (trace element grade) and then cleaned according to procedures described by Lugowski and others.[17] This process was similar to the protocol of the U.S. Environmental Protection Agency (EPA),[18] but includes additional nitric acid precleaning. Samples of wastewater taken with the ISO separator (Rasch System 890, AB Dental Trends Inc., Lynden, Washington) installed in the system were preserved according to the EPA protocol[18] with high purity hydrochloric acid (Ultrex grade; 5 mL of acid per litre of sample). Mercury concentration was measured with a VGA 77 cold-vapour system and a Spectra 880 atomic absorption spectrophotometer (both from Varian Canada Inc., Mississauga, Ontario). The detection limit for these measurements was 0.1 ng/g. Standard reference material (SRM 1641d) obtained from the National Institute of Standards and Technology, Gaithersburg, Maryland, containing 1,590 ± 18 ng/g was used to validate the accuracy of the analyses. Observed values for the reference material were within the known concentration: 1,593.2, 1,600.9 and 1,596.8 ng/g.

Samples of wastewater taken without the ISO-certified[19] separator installed in the system contained a significant amount of amalgam particles. These particles were separated from the samples by sedimentation from samples of large volume (1 L) or by centrifuge for samples of small volume (100 mL). Mercury was measured in the supernatant as described previously. The sediments were digested in nitric acid and the concentration of copper was measured using atomic absorption spectrophotometry (AAS) [Varian Canada Inc., Mississauga, Ontario]. Copper was measured because it is difficult to measure high concentrations of mercury with AAS. The ratio of copper to mercury in the deposit (determined by analyzing the deposit) was used to calculate the concentration of mercury. The average baseline concentration of copper in the water used in this study (i.e., water discharged through the ISO-certified separator before the restorations were removed) was 10.4 ng/mL (range 10.2 to 10.7 ng/mL).

Results

The weight of the amalgam restorations removed from the 152 restored surfaces in the first 4 sets of teeth (group 1) was 96.60 g (Table 1). The individual restorations in the artificial teeth weighed 0.55–0.59 g and those in natural teeth weighed 0.62–0.87 g. The total weight of the restorations removed from 38 restored tooth surfaces in the fifth set of teeth (group 2) was 21.28 g or 0.65 g per restored surface removed (Table 1); 70 L of wastewater was collected during the removal of restorations from this group of teeth at a water flow rate of 1.3 L/min.

Weight of Amalgam Particles Bypassing Chairside Traps and Escaping into Wastewater

For group 1 teeth, 31.8% (range 31% to 33%) of the weight of the amalgam removed from teeth was captured by the conventional chairside trap (Table 2, column III) and an additional 8.5% (range 7% to 10%) was captured by the pump trap (Table 2, column IV). Thus, 40.2% (range 39% to 41%) of the amalgam removed was trapped by the conventional traps (Table 2, column V), and 59.8% (range 59% to 61%) bypassed both traps (Table 2, column VI).

For group 2 teeth (for the removal of which the cutting area was enclosed to prevent loss of amalgam from splatter), recovery of amalgam at the chairside trap was similar (31%), but 12% of the amalgam was recovered at the pump trap (Table 2, column IV), 3% more than for the group 1 teeth. Therefore, the average proportion of particles recovered at the chairside was 3% greater for group 2 than for group 1 teeth (Table 2, column V). An additional 8.58 g (40% of total amalgam weight) was recovered by filtration of the 70 L of wastewater. Therefore, in total, 83% of the weight of amalgam removed from group 2 teeth was

Table 3 **Concentration of mercury in dental wastewater collected without and with an amalgam separator meeting ISO specifications[20]**

Treatment and sample no.	Concentration of mercury (mg/L)	
Without ISO-certified separator	**In amalgam deposits**	**In filtrate**
1	43.00	0.0059
2	13.34	0.1677
3	37.00	0.0878
4	34.40	0.2505
5	28.00	0.2347
Mean (SD)	**31.1480 (11.3173)**	**0.1493 (0.1027)**
Combined (amalgam + filtrate)	Total 31.2973 (11.2663)	
With ISO-certified separator		
1	0.2054	
2	0.2316	
3	0.2230	
4	0.3391	
5	0.2917	
6	0.2032	
7	0.1805	
8	0.2014	
9	0.1306	
10	0.0969	
11	0.0834	
12	0.1049	
13	0.0486	
Mean (SD)	**0.1800 (0.0844)**	

recovered. The remaining 17% was assumed to have passed through the 15-µm filter paper.

Concentration of Mercury in Wastewater

A high concentration of mercury (mean 31.2973 mg/L) was found in the wastewater samples when the ISO-certified separator was not connected to the vacuum pump (Table 3). Most of this concentration was accounted for by amalgam particles; only a relatively minute quantity — 0.1493 mg/L on average — was in the filtrate. When the ISO-certified separator was connected, the concentration of mercury in the discharged wastewater was much lower, between 0.0486 and 0.3391 mg/L in individual samples (mean 0.1800 mg/L) (Table 3). This represented a 99.4% reduction in mercury concentration in the wastewater.

Discussion

In this study, the quantity of waste recovered in the chairside and pump traps and escaping in the wastewater was of the same order of magnitude for all 5 sets of teeth, approximately 30% (range 31% to 33%), 10% (range 7% to 12%) and 60% (range 57% to 61%), respectively. For the fifth set of teeth (group 2) the working area was enclosed during the removal procedures, and 3% more amalgam by weight was recovered in the pump trap than was the case for the group 1 teeth. This extra 3% may represent the fraction of particles that would have been lost in the patient's mouth and the operating environment during the removal of restorations. This finding is consistent with the results of other experiments, which have demonstrated that removal of amalgam temporarily increases the body's burden of mercury[20-23] as well as the airborne mercury in the dental operatory.[24,25]

After filtration of all of the wastewater generated during amalgam removal from the fifth set of teeth (group 2), 83% of the total weight of the restorations was accounted for; the 17% that was unaccounted for presumably passed through the 15-µm filter. This finding is consistent with that expected on the basis of the mass distribution curve of the sizes of amalgam particles as described by the ISO:[19] particles less than 15 µm in diameter constitute roughly 21% of the total mass fraction of amalgam particles. In this study about 40% of the weight of amalgam removed was recovered as solid wastes in the conventional chairside and pump traps; this is consistent with the value of 40% reported by Obenauf and Skavroneck[3] but is at variance with the 75% to 80% claimed by Westman and Tuominen[26] and the 65% calculated by O'Connor Associates Environmental Inc.[7]

The average mercury concentration in the wastewater was 0.1800 mg/L when the ISO-certified separator was connected and 31.2973 when it was disconnected from the vacuum pump; mercury in the dental wastewater was therefore reduced by 99.4% when the certified separator was connected. However, like other studies,[27-32] this one has shown that the use of a separator that meets ISO standard 11143[19] does not ensure that mercury levels in wastewater will be below 0.01 mg/L, the maximum discharge limit set in the City of Toronto's new sewer use bylaw to regulate the drainage of sewage and land drainage (By-Law No. 457-2000). The lowest mercury concentration obtained with the ISO-certified separator used in this study was 0.0486 mg/L (or 48.6 ppb), a finding very similar to those from other tests on ISO-certified separators.[27-32] However, new technologies now under investigation may be capable of reducing mercury levels in wastewater to less than 2 µg/L.[33,34]

The concentration of mercury in wastewater discharged without the ISO-certified separator ranged from 13.5077 to

43.0059 mg/L (mean 31.2973 mg/L). These concentrations are comparable to those reported by Arenholt-Bindslev and Larsen[28] for samples obtained from dental clinics without certified separators (from 9.7 ± 1 to 306 ± 30 mg/L). This wide range was expected in their study because of the large number of variables associated with field testing.

The mercury bound in dental amalgam particles and entering sewage treatment plants and private septic systems poses a risk to the environment[16] if it is released because of corrosion or other factors. Across Canada it has been estimated that 781 kg of dental-related mercury enters sewers annually.[2] The mechanism and rate of degradation of mercury in farmland and landfill sites, and the chemical forms of mercury that result, are poorly understood. What is clear is that a significant amount of dental amalgam enters the wastewater stream unless ISO-certified separators are installed. Therefore, the Canada-wide standard,[16] which includes voluntary installation of amalgam-particle separators, is a logical approach to address the concern about mercury release from dental offices in Canada. ◆

Acknowledgments: This research was supported by a grant provided by the Royal College of Dental Surgeons of Ontario.

Dr. Adegbembo is a research associate in the department of biomaterials, faculty of dentistry, University of Toronto, Toronto, Ontario.

Dr. Watson is a professor and head of the department of biomaterials, faculty of dentistry, University of Toronto, Toronto, Ontario.

Dr. Lugowski is manager of the Atomic Absorption Laboratory, Institute of Biomaterials and Biomedical Engineering, University of Toronto, Toronto, Ontario.

Correspondence to: Dr. Albert O. Adegbembo, Department of Biomaterials, Faculty of Dentistry, University of Toronto, 124 Edward St., Toronto, ON M5G 1G6. E-mail: albert.adegbembo@utoronto.ca.

The authors have no declared financial interests in any company manufacturing the types of products mentioned in this article.

References

1. Rubin PG, Yu M-H. Mercury vapor in amalgam waste discharged from dental office vacuum units. *Arch Environ Health* 1996; 51(4):335-7.

2. CC Doiron & Associates, Charles E Napier Co. Ltd. Final report: inventory of uses and releases of mercury during product life cycles. Ontario: Environment Canada ARET Secretariat, 1998.

3. Obenauf P, Skavroneck S. Mercury source sector assessment for the Greater Milwaukee Area. Milwaukee: Pollution Prevention Partnership and the Milwaukee Metropolitan Sewerage District, 1997.

4. Hinshon Environmental Consulting. Summary of activities: Mercury Minimization Task Force for Dental Facilities. Detroit: Detroit Water and Sewerage Department, 1998.

5. Hanley MJ, Pileggi J. Dental office waste management study for the Hamilton-Wentworth Region. Hamilton-Wentworth: The Regional Municipality of Hamilton-Wentworth Environmental Services Department, 1996.

6. DelConte MJ. A mercury pollution prevention study for medical & dental centers findings report. Rochester: The Monroe County Mercury Pollution Prevention Task Force, 1997.

7. O'Connor Associates Environmental Inc. Mass balance of dental-related mercury wastes in Canada, with a discussion of environmental impacts and alternative dental restorative materials. Ottawa: Office of Transboundary Air Issues and National Office of Pollution Prevention Environment Canada, 2000.

8. Municipality of Metropolitan Seattle. Dental office waste stream characterization study. Seattle: Municipality of Metropolitan Seattle, 1991.

9. MacDonald DB, Fitzegerald JF, McManus K. Mercury in dental facilities. Massachusetts: Massachusetts Water Resources Authorities Sewerage Division Toxic Reduction and Control Department, 1997.

10. Letzel H, de Boer FA, van't Hof MA. An estimation of the size distribution of amalgam particles in dental treatment waste. *J Dent Res* 1997; 76(3):780-8.

11. Drummond JL, Cailas MD, Wu TY. An estimation of the size distribution of amalgam particles in dental treatment waste. *J Dent Res* 1997; 76(10):1620.

12. Drummond JL, Hathorn RM, Cailas MD, Karuhn R. Particle size analysis of amalgam powder and handpiece generated specimens. *Dent Mater* 2001;17(4):322-32.

13. National Wildlife Federation. Clean the rain clean the lakes II: mercury in rain is contaminating New England's waterways. Ann Arbor, Michigan: National Wildlife Federation, 2000.

14. Pilgrim W, Schroeder W, Porcella DB, Santos-Burgoa C, Montgomery S, Hamilton A, and others. Developing consensus: mercury science and policy in the NAFTA countries (Canada, the United States and Mexico). *Sci Total Environ* 2000; 261(1-3):185-93.

15. Pilgrim W, Poissant L, Trip L. The Northeast States and Eastern Canadian Provinces mercury study: a framework for action: summary of the Canadian chapter. *Sci Total Environ* 2000; 261(1-3):177-84.

16. Trip L. Canada-wide standards: a pollution prevention program for dental amalgam waste. *J Can Dent Assoc* 2001; 67(5):270-3.

17. Lugowski SJ, Smith DC, Bonek H, Lugowski J, Peters W, Semple J. Analysis of silicon in human tissues with special reference to silicone breast implants. *J Trace Elem Med Biol* 2000; 14(1):31-42.

18. Telliard WA. Method 1631, Revision B: Mercury in water by oxidation, purge and trap and cold vapor atomic fluorescence spectrometry. Washington: United States Environmental Protection Agency, 1999:33.

19. International Standard Organization. International Standard Organization 11143: Dental Equipment - Amalgam Separators: International Standard Organization, 1999.

20. Mackert JR Jr, Berglund A. Mercury exposure from dental amalgam fillings: absorbed dose and the potential for adverse health effects. *Crit Rev Oral Biol Med* 1997; 8(4):410-36.

21. Kremers L, Halbach S, Willruth H, Mehl A, Welzl G, Wack FX, and others. Effect of rubber dam on mercury exposure during amalgam removal. *Eur J Oral Sci* 1999; 107(3):202-7.

22. Berglund A, Molin M. Mercury levels in plasma and urine after removal of all amalgam restorations: the effect of using rubber dams. *Dent Mater* 1997; 13(5):297-304.

23. Sandborgh-Englund G, Elinder CG, Langworth S, Schutz A, Ekstrand J. Mercury in biological fluids after amalgam removal. *J Dent Res* 1998; 77(4):615-24.

24. Smith DC, Lewis DW. Study calls for dental office investigations. *Ont Dent* 1987; 64(6):21-6.

25. Ferracane JL, Engle JH, Okabe T, Mitchem JC. Reduction in operatory mercury levels after contamination or amalgam removal. *Am J Dent* 1994; 7(2):103-7.

26. Westman JF, Tuominen T. Amalgam waste management: issues and answers. *Northwest Dent* 2000; 79(2):29-36.

27. Surmont P, Enody E. [Evaluation of amalgam separators]. *Rev Belge Med Dent* 1993; 48(4):17-26.

28. Arenholt-Bindslev D, Larsen AH. Mercury levels and discharge in wastewater from dental clinics. *Water Air & Soil Pollution* 1996; 86:93-9.

29. Turchi CS, Albiston J, Stewart R. Removal of mercury from dental amalgam wastes. *J Dent Res* 2000; 79:Abstract #3213.

30. Pederson ED, Jones GK, Stone ME, Karaway RS, Auxer R, Davis SL. Evaluation of commercial mercury removal device. *J Dent Res* 2000; 79(IADR Abstract):Abstract #1386.

31. Stone ME, Pederson ED, Jones GK, Karaway RS, Auxer RA, Davis SL. Evaluation of an integrated system to remove mercury from dental unit wastewater. *J Dent Res* 2000; 79(IADR Abstract):Abstract #3216.

32. Fan PL, Batchu H, Chou HN, Gasparac W, Sandrik J, Meyer DM. Laboratory evaluation of amalgam separators. *J Am Dent Assoc* 2002; 133(5):577-84.

33. Pederson ED, Stone ME, Ovsey VG. The removal of mercury from dental-operatory wastewater by polymer treatment. *Environ Health Perspect* 1999; 107(1):3-8.

34. Holton WC. Quick fixes for quicksilver. *Environ Health Perspect* 1998; 106(2):A74-6.