

Estimated Quantity of Mercury in Amalgam Waste Water Residue Released by Dentists into the Sewerage System in Ontario, Canada

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A b s t r a c t

Aim: To estimate the quantity of dental amalgam that Ontario dentists release into waste water.

Methods: Information from a self-administered postal survey of Ontario dentists was combined with the results of other experiments on the weight of amalgam restorations and the quantity of amalgam waste that bypasses solids separators in dental offices. Algorithms were developed to compute the quantity of amalgam waste leaving dental offices when dentists used or did not use ISO 11143 amalgam particle separators.

Results: A total of 878 (44.0%) of 1,994 sampled dentists responded to the survey. It was estimated that Ontario dentists removed 1,880.32 kg of amalgam (940.16 kg of mercury) during 2002, of which 1,128.19 kg of amalgam (564.10 kg of mercury) would have been released into waste water in Ontario if no dentists had been using a separator. Approximately 22% of the dentists reported using amalgam particle separators. On the basis of current use of amalgam separators, it was estimated that 861.78 kg of amalgam (430.89 kg of mercury or 170.72 mg per dentist daily) was released in 2002. The use of amalgam separators by all dentists could reduce the quantity of amalgam (and mercury) entering waste water to an estimated 12.41 kg (6.21 kg of mercury, or 2.46 mg per dentist per day).

Conclusion: Amalgam particles separators can dramatically reduce amalgam and mercury loading in waste water released from dental offices.

MeSH Key Words: dental amalgam/analysis; dental waste/analysis; mercury/analysis; water pollution, chemical/analysis

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The waste residue generated by dentists during the placement and removal of amalgam restorations contains approximately 42% to 54% mercury by weight, although the actual percentage of mercury depends on the brand of amalgam used in the original restoration.¹⁻⁴ In offices equipped with only conventional solids separators (i.e., no ISO-certified separator⁵), up to 60% of this amalgam residue is released into the waste water.^{6,7} Dentistry reportedly contributes between 10% and 70% of the mercury loading of many U.S. municipal public sewage treatment plants.⁸ Various American studies^{7,9-16} have reported highly variable quantities of mercury released from dental offices into waste water. For example, Cailas and others⁸ reported a range of mercury concentration in dental waste water from 12 to 480 mg/L, whereas Larry Walker Associates¹² reported an average production of 250 mg of mercury per dentist per day.

In Canada, O'Connor Associates Environmental Inc.¹⁴ estimated that dentists release 686 kg (or 125 mg per dentist per day) of mercury into waste water annually, 85% of which enters municipal sewage treatment plants. In another Canadian study, CC Doiron & Associates¹⁷ estimated that 781 kg mercury (or 131 mg per dentist per day) enters the sewerage system annually. However, both studies^{14,17} used estimates for key variables, such as the numbers of amalgam restorations placed and removed by dentists annually and the proportion of waste amalgam that bypasses conventional particle separators. The authors of the reports recognized these limitations.^{14,17} Nonetheless, it is very difficult to determine best management practices when the problem is poorly defined and the subject of considerable speculation. Therefore, the Royal College of Dental Surgeons of Ontario (RCDSO) commissioned a

study to acquire reliable data on the release of mercury from dental offices in Ontario.

The aim of this study was to determine the quantity of amalgam particles and the associated quantity of bound mercury released from dental offices into the public sewerage system in Ontario.

Materials and Methods

Sample Size and Selection of Participants

The study population was drawn from the RCDSO membership list, which consisted of 7,150 dentists, including specialists, licensed to practise in Ontario in 2002. From that list, the names of 235 dentists with addresses outside Ontario were removed, which left 6,915 dentists practising in Ontario. The appropriate sample size for this study was determined to be 2,000 (Box 1). The random number generator in Epi-info version 6.04b (U.S. Centers for Disease Control and Prevention, Atlanta, Ga.) was used to generate 2,000 names from the list of 6,915 dentists.

Data Collection

A self-administered questionnaire and a self-addressed envelope were sent by mail to the selected dentists in March 2002. Dentists were asked to return the completed questionnaire no later than May 31, 2002. As a follow-up, the questionnaire was sent again to dentists who had not responded by the end of June 2002. A reminder urging dentists who had not returned their questionnaires to do so promptly was published in the RCDSO's July/August 2002 edition of *Dispatch*.

The questionnaire asked the dentist to report the number of 1-, 2-, 3-, and ≥ 4 -surfaced amalgam restorations and core amalgam buildups he or she removed during the current

week (i.e., the 7 days immediately after the day on which the questionnaire was received), as well as the number of weeks usually worked in a year and whether he or she was a specialist. Dentists were also asked if they had installed an amalgam particle separator meeting the ISO 11143 specification.⁵

Data Analysis

An algorithm was developed to calculate the weight of amalgam each dentist removed weekly (Box 2) on the basis of data obtained from the questionnaire. The 2 main variables in the algorithm — weight of amalgam restorations and number of restorations removed — vary around “true” but unknown values. Both factors were varied to generate a sensitivity analysis for the quantity of amalgam removed. The joint probability from combining the probabilities of the weights and numbers of restorations was 90%. However, where only one of the factors varied, the probability was 95%.

The quantity of amalgam produced by each dentist that bypassed solids separators at chairside was 60%^{6,7} of the weight of amalgam that each dentist removed. For dentists who reported using an ISO-certified separator, the quantity bypassing a solids separator at chairside was further reduced by 98.9% (range 97.51% to 99.95%); this is the average level of efficiency reported for currently available amalgam separators operating at full capacity.^{6,18,19} To estimate the quantity of amalgam removed annually and the quantity that bypassed chairside solids separator or ISO-equivalent separators,⁵ the quantity derived for each week was multiplied by the number of weeks that the dentist reported working annually. For those who did not provide information on the number of weeks worked annually, the mode of the number of weeks worked by dentists reporting this information was used.

The frequency, mean, standard deviation (SD), median, sum, and upper and lower 95% confidence limits (CL) were employed in conducting univariate analyses. Bivariate

Box 1 Equation and assumptions used to determine sample size

$$n = z_{1-\alpha/2}^2 \sigma^2 / \epsilon^2 \mu^2$$

Where

n = sample size (65% of required sample size, because of anticipated nonresponse rate of 35%)

$z_{1-\alpha/2}$ = 1.96 (95% confidence level)

σ = standard deviation (SD) of mean weight of mercury released weekly

μ = mean weight of mercury released daily

ϵ = precision of measurement of mean weight (within 5% of μ)

Assumptions

Working unknown SD was 8.76 g; roughly 98% of all observations lie within 4 SD when the distribution of a variable is normal.

Working mean for total amount of amalgam removed was 9.52 g (the 17 restorations removed were 2-surfaced and each weighed 0.56 g — the lower limit for the 95% confidence interval for the weight of 2-surfaced amalgams^{19,22})

Lowest limit = 0.00 (no amalgams removed during the week)

Highest limit = 35.02 g (17 amalgams removed, each weighing 35.02 g, the upper limit for the 95% confidence interval for the weight of 4-surfaced amalgams^{19,22})

Hypothesis: Amalgam placement does not significantly contribute to mercury loading of dental waste water.

Box 2 Algorithm for calculating weight of amalgam removed weekly by each dentist

$$Wt = \sum_{\text{surface}1}^{\text{surface}\geq 4} Wt_{1\text{surface}}$$

$$Wt_{1\text{surface}} = \sum_{\text{Tooth}1}^{\text{Tooth}j} N_{1\text{surface}} \times Hg_{1\text{surface}}$$

where

Wt = weight of all restorations removed from 1-surfaced to ≥ 4 -surfaced amalgams,

$Wt_{1\text{surface}}$ = weight of all 1-surfaced amalgam restorations removed from tooth_{*i*} through _{*j*},

$N_{1\text{surface}}$ = number of 1-surfaced amalgam restorations removed from tooth_{*i*} through _{*j*},

$Hg_{1\text{surface}}$ = weight of 1-surfaced amalgam restoration,

Tooth_{*i*} through _{*j*} = cuspid, premolar, mandibular molar, maxillary molar

Table 1 Characteristics of 878 Ontario dentists responding to a self-administered questionnaire on amalgam removal^a

Characteristic	Responded to first mailing (n = 550)	Responded to second mailing (n = 328)	Total (n = 878)	p value
% registered to an address in metro Toronto	28.4 (539)	31.4 (302)	29.5 (841)	
Eligibility for inclusion				0.83 ^c
% not completing questionnaire	4.4	5.2	4.7	
% not placing or removing amalgam during current week	16.6	17.1	16.7	
% placing or removing amalgam during current week	79.1	77.7	78.6	
% general practitioners	89.5 (525)	91.4 (312)	90.2 (837)	0.39 ^c
% with an ISO-certified separator	21.3	24.1	22.3	0.33 ^c
Mean ± SD no. of years in practice	21.2±10.7 (520)	18.4±11.6 (302)	20.1±11.0 (822)	< 0.001 ^d
Mean ± SD no. of weeks worked/yr				
All respondents	36.1±19.4	35.6±19.7	35.9±19.5	0.73 ^d
Dentists placing or removing amalgam	45.6±6.3 (435)	45.8±5.6 (255)	45.7±6.0 (690)	0.70 ^d

^aData are presented as percentage of respondents or as mean ± standard deviation (SD); where the number of respondents is different from the n value at the top of the column, the number of respondents is given in parentheses

^b χ^2 test based on addresses in list of dentists

^c χ^2 test

^dAnalysis of variance

analyses were carried out with Pearson's correlation, chi-square and analysis of variance (ANOVA) tests. All data were entered and analyzed with SAS version 8.02 software (SAS Institute Inc, Cary, N.C.).

Study Assumptions

The mercury content of a finished restoration should be comparable to the mercury–alloy ratio of the original mix of amalgam. Various authorities^{1–4} report that this proportion varies between 42% and 54%; however, modern lathe-cut and admixed alloys contain 50% mercury and spherical alloys a lesser amount — approximately 42%. Many investigators^{7,11,13,14,20} have used 50% as the weight of mercury bound in dental amalgam alloy; in only one study did the author use 42% as the percentage of mercury bound in the alloy.²¹ For this study, mercury was assumed to constitute 50% of the weight of dental amalgam restorations.²¹ The estimated weights of various types of dental amalgam restorations are reported elsewhere.²²

Results

Response Rate

Nearly half of the randomly selected Ontario dentists responded (878/1,994 or 44.0%); 6 of the questionnaires were undeliverable. Those who responded were similar to those who did not respond (χ^2 test). Similarly, the survey respondents were not significantly different from all Ontario dentists: 31% of dentists in the RCDSO register had an address in metropolitan Toronto and 89% were listed as general practitioners, whereas among survey respondents, 29.5% had a metro Toronto address ($p = 0.22$ by χ^2 test) and 90.2% were general practitioners ($p = 0.26$ by χ^2 test).

Characteristics of Respondents

Table 1 compares the characteristics of dentists who responded to the first mailing (in March 2002) and those who responded to the second mailing (in June 2002). These 2 groups of respondents were generally similar, the only difference being that dentists who responded to the second mailing had practised for fewer years (ANOVA, $p = < 0.001$). The 10 dentists who reported placing or removing amalgam restorations but who did not report on the number of weeks they worked per year were assigned the modal value of 48 weeks obtained for those who responded to this question and who were still placing or removing amalgam restorations. There was no significant statistical association between the number of weeks worked annually and the mailing to which dentists responded ($p \geq 0.70$). Overall, 82% of all the dentists placed or removed amalgam restorations during the current week; however, 78% of the specialists neither placed nor removed amalgam restorations during this period.

Quantity of Amalgam Removed from Existing Restorations

Table 2 shows the quantities of amalgam that the responding dentists removed from 1-, 2-, 3-, and ≥ 4 -surfaced restorations and core amalgam buildups during the current week. The average weight of each type of amalgam was used to estimate the quantity of amalgam removed. This amount was estimated as 5.86 g of amalgam per dentist per week, ranging from 5.47 to 6.26 g on the basis of lower and upper 95% CLs of the weight of each amalgam, respectively (Table 2). The weight of amalgam removed during the current week was not associated with the use of ISO-

Table 2 Weight of amalgam restorations removed during one week by 878 Ontario dentists

	Mean weight (and SD) of restorations removed weekly by each dentist and total weight of restorations removed weekly by all 878 Ontario dentists (g) ^a								
	Lower 95 % CL			Mean			Upper 95 % CL		
	Mean	SD	Total	Mean	SD	Total	Mean	SD	Total
1-surfaced	0.47	1.19	411.9	0.52	1.32	456.0	0.57	1.45	500.1
2-surfaced	1.62	3.54	1,427.4	1.77	3.86	1,554.3	1.91	4.18	1,681.2
3-surfaced	1.90	3.89	1,668.2	2.02	4.15	1,778.0	2.15	4.40	1,887.7
≥ 4-surfaced	1.39	3.37	1,218.3	1.46	3.56	1,283.4	1.54	3.74	1,348.5
Core buildup	0.08	0.69	74.7	0.09	0.73	78.7	0.09	0.76	82.6
Total	5.47	10.34	4,800.4	5.86	11.10	5,150.3	6.26	11.85	5,500.2

SD = standard deviation, CL = confidence limit

^aWeekly weight of amalgam removed is based on number of restorations removed (as reported by survey respondents) and mean and 95% confidence limits of weights of restorations²²: 1-surfaced = 0.31 (0.28, 0.34) g, 2-surfaced = 0.49 (0.45, 0.53) g, 3-surfaced = 0.81 (0.76, 0.86) g, ≥ 4-surfaced = 1.38 (1.31, 1.45) g, core buildups = 1.38 (1.31, 1.45) g

Table 3 Summary of weight of amalgam and mercury removed annually

Type of amalgam restoration	Weight (kg) of amalgam restorations removed annually ^a					
	For 878 dentists in survey			Estimate for all dentists in Ontario		
	Lower 95% CL	Mean	Upper 95% CL	Lower 95% CL	Mean	Upper 95% CL
1-surfaced	19.06	21.11	23.15	150.15	166.24	182.33
2-surfaced	66.06	71.93	77.80	520.26	566.52	612.77
3-surfaced	77.37	82.46	87.56	609.39	649.48	689.58
≥ 4-surfaced	56.58	59.61	62.63	445.64	469.45	493.26
Core	3.45	3.63	3.82	27.18	28.63	30.08
Totals						
Weight of amalgam removed	222.53	238.74	254.96	1,752.63	1,880.32	2,008.01
Weight of mercury removed	111.27	119.37	127.48	876.32	940.16	1,004.01

CL = confidence limit

^aSummary weights are based on mean and 95% confidence limits of weights of restorations (see Table 2)

Table 4 Number of amalgam restorations removed annually by the 878 responding dentists

Type of amalgam restoration removed	Mean no. of amalgam restorations removed annually per dentist		
	Lower 95% CL	Mean (SD)	Upper 95% CL
1-surfaced	64.65	77.55 (194.75)	90.44
2-surfaced	142.96	167.20 (365.84)	191.43
3-surfaced	100.00	115.96 (240.82)	131.91
≥ 4-surfaced	41.14	49.19 (121.58)	57.25
Core buildup	1.38	3.00 (24.00)	4.62
Overall	359.30	412.9 (809.14)	466.49

SD = standard deviation, CL = confidence limit

certified separators ($p = 0.53$) or the number of weeks worked in a year ($p = 0.78$). However, dentists who worked for more weeks in a year removed more amalgam (Pearson's correlation, $\rho = +0.09$, $p = 0.01$) and those who had been in practice for only a few years removed less amalgam annually ($\rho = -0.17$, $p < 0.001$). The quantity of amalgam removed by all Ontario dentists during 2002 was estimated at 1,880.32 kg (representing 940.16 kg of mercury) (Table 3). When estimates derived from the lower and upper 95% CLs of the weights of amalgam restorations were used, the quantity ranged from 1,752.63 kg (876.32 kg of mercury)

to 2,008.01 kg (1,004.01 kg of mercury). However, only 60% of these estimated quantities would bypass conventional solids separators in the dental office.^{6,7}

The mean number of amalgam restorations removed annually by each dentist ranged from 359.30 to 466.49 (mean 412.9) (Table 4). The sensitivity analysis presented in Table 5 shows 9 possible scenarios for the estimated quantity of amalgam (and estimated quantity of mercury) that Ontario dentists removed during 2002. There is a 90% chance that Ontario dentists removed between 1,498.96 kg (low estimates of both numbers and weights of amalgam)

Table 5 Sensitivity analysis of estimated weight of amalgam and mercury (kg) removed by all Ontario dentists in 2002

Estimates based on total no. of 1-, 2-, 3-, and ≥ 4-surfaced amalgams and core amalgam buildups removed annually	Estimates based on weight of 1-, 2-, 3-, and ≥ 4-surfaced amalgams and core amalgam buildups					
	Amalgam			Mercury		
	Lower 95% CL of weight	Mean	Upper 95% CL of weight	Lower 95% CL of weight	Mean	Upper 95% CL of weight
Lower 95% CL of total no. of teeth from which amalgam was removed	1,498.96	1,608.38	1,717.81	749.48	804.19	858.91
Estimated total no. of teeth from which amalgam was removed	1,752.62	1,880.32	2,008.01	876.31	940.16	1,004.01
Upper 95% CL of total no. of teeth from which amalgam was removed	2,006.29	2,152.25	2,298.21	1,003.15	1,076.13	1,149.11

CL = confidence limit

Table 6 Summary of estimated quantities of amalgam and mercury released into local sewerage systems annually by 878 dentists and estimates for all Ontario dentists in relation to level of compliance with use of amalgam particle separator

Compliance with use of separator	Estimated quantity released annually (kg) ^a					
	Amalgam			Mercury		
	Lower 95% CL	Quantity	Upper 95% CL	Lower 95% CL	Quantity	Upper 95% CL
For 878 dentists, weekly						
0% compliance	2.88	3.09	3.30	1.44	1.55	1.65
22% compliance (current level)	2.20	2.36	2.52	1.10	1.18	1.26
100% compliance	0.032	0.034	0.036	0.016	0.017	0.018
For 878 dentists, annual estimate						
0% compliance	133.52	143.25	152.97	66.76	71.63	76.49
22% compliance (current level)	101.98	109.42	116.86	50.99	54.71	58.43
100% compliance	1.47	1.58	1.68	0.74	0.78	0.84
For all Ontario dentists, annual estimate						
0% compliance	1,051.58	1,128.19	1,204.81	525.79	564.10	602.41
22% compliance (current level)	803.22	861.78	920.35	401.61	430.89	460.18
100% compliance	11.57	12.41	13.25	5.79	6.21	6.63

^aLimits based on the weight of an amalgam restoration.²²

and 2,298.21 kg (high estimates of both numbers and weights of amalgam) of amalgam during 2002 (749.48 to 1,149.11 kg of mercury). Consequently, there was a 90% chance that the quantity of mercury bound in the amalgam that eventually bypasses chairside solids separators installed in dental offices across the province during 2002 ranged from a low of 449.69 kg (60% of 749.48 kg) to a high of 689.47 kg (60% of 1,149.11 kg).

Dentists' Release of Amalgam to the Sewerage System

If it is assumed that no Ontario dentists used ISO-certified separators, the quantity of amalgam released during 2002 would be estimated at 1,128.19 kg (60% of 1,880.32 kg, i.e., the estimate derived from the mean weight of amalgams and mean number of restorations removed annually) (Table 5). Consequently, 564.10 kg of mercury would have been removed by all dentists during 2002 (223.50 mg mercury per dentist per day). The figures presented in Table 6 are derived from the estimated annual

removal of 1,880.32 kg of amalgam (Table 5). Therefore, given the current level of use of separators (22%) and the efficiency of amalgam particle separators (98.9%^{6,18,19} of amalgam wastes captured) the estimated quantity released during 2002 was 861.78 kg of amalgam (430.89 kg or 170.72 mg mercury per dentist per day) in 2002. If all dentists used this device, there is a 95% chance (varying either the weight of amalgams or the numbers of restorations removed) that the quantity of mercury contained in amalgam waste water exiting dental offices in Ontario would range from 5.79 kg (or 2.29 mg per dentist per day) to 6.63 kg (or 2.63 mg per dentist per day), an average of 6.21 kg or 2.46 mg per dentist per day (Table 6).

Discussion

This study was conducted to estimate the annual release of dental amalgam into waste water in Ontario. Twenty-two percent of the dentists reported using an ISO-certified amalgam-separating device. Given this level of separator use, the average weight of amalgam restorations and the

average number of restorations, it was estimated that Ontario dentists released 861.78 kg of amalgam (430.89 kg of mercury or 172.70 mg per dentist per day) into waste water in Ontario in 2002. The estimated quantity of mercury released by each Ontario dentist was higher than the estimates of O'Connor Associates Environmental Inc. (125 mg per dentist per day)¹⁴ and CC Doiron & Associates (131 mg per dentist per day).¹⁷ However, if all dentists who carry out amalgam treatments had used ISO-certified separators, then Ontario dentists would have released only 6.21 kg of mercury (or 2.46 mg per dentist per day) in 2002.

The proceedings of the 1995 Canadian Mercury Network meeting indicated that the total release of mercury from all sources in Ontario was 1,587 kg.²³ Assuming that this value represents current production, then dentistry may have contributed 27% (430.89/1,587 kg) of this loading. The use of ISO-certified amalgam particle separators by all dentists could dramatically reduce dentistry's share of mercury in Ontario's municipal sewage treatment plants to barely 0.54%.

The response rate in this study was 44.0%, much higher than the 12% to 28% response rates reported in previous studies.^{10,11} Study participants were selected at random, and each Ontario dentist had an equal probability of being included in the sample. Nonrespondents might have practised for fewer years, since those who responded late had been in practice for fewer years; nonetheless, time in practice did not significantly influence dentists' production of amalgam waste. The possibility of recall bias²⁴ was eliminated by requesting prospective information on the actual numbers of restorations removed during a 7-day period rather than recall of such activity.

For these estimates, results of other experiments conducted under the RCDSO grant were used: weights of amalgam restorations²² and quantity of mercury bypassing conventional solids separators.⁶ Others^{10,11,13,21} have employed different approaches to estimating mercury. In Seattle, the concentration of mercury released from amalgam was obtained by filtering the waste water samples collected from 8 volunteer dentists through a #40 mesh.¹¹ The waste water sample contained 150 mg of mercury per litre (90% CLs 12 and 480 mg/L). This concentration of mercury in dental waste water was combined with the results of a survey of dental clinics (28% response rate). The authors estimated that dentists released 51 lbs (90% CLs 23 and 73 lbs) of mercury annually to the public sewerage system, which represented 14% of total mercury loading in the system.

In the San Francisco Bay area, the estimated daily release of mercury in dental amalgam by each dentist was 40 mg.¹³ This estimate combined information derived from interviews of dentists¹³ with the quantity of mercury released by each dentist obtained from the Seattle study.¹¹ A study by the Northern Virginia Planning District¹⁰ combined information on the concentration of mercury in grab samples

from the waste tanks of volunteer dentists and dentists' responses (12% of 480) on the placement and removal of amalgam. The study reported that dentists released 0.06 lbs (27.24 g) daily. A Massachusetts study¹³ combined the flow-rate from dental offices with the average mercury mass loading of various pieces of equipment in dental offices to determine release of mercury; however, the study derived mercury mass loading from a convenience sample of dental offices. According to that study, each dentist released between 0.46 and 271 g of mercury per day.

Studies continue to put the concentration of mercury in dental waste water at between 12 and 480 mg/L or 10% to 70% of public sewerage system loading of mercury.⁸ A recent report prepared for the Association of Metropolitan Sewerage Agencies¹² shows that dentists contribute between 35% and 40% of the influent load of mercury in U.S. publicly owned sewage treatment plants. In Palo Alto, dentists' contribution of mercury to publicly owned sewage treatment plants was estimated at 47% in 2000.²¹ In the current study it was estimated that each dentist released 172.70 mg of mercury per day and that dentistry could have contributed 27% of the sewerage system loading of mercury in Ontario if no amalgam separators were used. Therefore, these findings are broadly within reported ranges in the absence of amalgam separators. However, if all dentists who use amalgam were also to use ISO-certified amalgam particle separators or equivalent equipment, then dentistry's contribution of mercury to Ontario's sewerage system would be reduced to 0.54%. ♦

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