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# Mercury generation potential from dental waste amalgam

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## KEYWORDS

Contact and non-contact amalgam; Mercury generation; Dental wastewater

**Summary Objective.** The main objective of this study was to quantify the total amount of amalgam used in dental offices in the state of Illinois and to estimate the fractions of amalgam waste material generated during dental procedures. A second objective was to estimate the fractions of non-contact, contact, and tooth retained amalgam through an in vitro study.

**Methods.** The collection system consisted of containers placed in six dental offices and clinics to collect the material from the in-line trap (contact amalgam) and the excess dental amalgam not placed into the oral cavity (non-contact amalgam). In order to have comparable results, the data was adjusted by the number of dental chairs being used and the number of working days.

**Results.** The range for the non-contact amalgam was from 0 to 102 g, and for the contact amalgam, from 2 to 16 g. The median estimate of non-contact amalgam generated from the 6 dental offices was 421 mg/day/chair, whereas the median estimate of contact amalgam was 64 mg/day/chair. For the in vitro study, 40 one and two surface amalgams (bicuspid and molars), was distributed as follows,  $46 \pm 20\%$  in the tooth,  $43 \pm 19\%$  as non-contact amalgam, and  $11 \pm 4\%$  as contact amalgam.

**Conclusions.** Based on survey data from the ADA concerning the number of working days per year, the number of practicing dentists, a 50%, by weight, mercury content in amalgam, and the generation estimates from this project, it was estimated that the practicing dentists in the State of Illinois (6455) have the potential to generate 947 kg of non-contact mercury per year, which is recyclable, and 144 kg of contact mercury which has the potential to be discarded in the environment, or be partially recycled. If this approach is applied to the total population of practicing dentist in the United States (123,641), then 18,159 kg of recyclable, non-contact mercury may be generated per year, whereas 2763 kg of contact mercury may be discarded in the environment, or be partially recycled.

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## Introduction

The basic ingredients of amalgam, by weight, are silver (20-34%), tin (8-15%), copper (1-15%), other metals (0-5%), and mercury, which comprises

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42-52% of the total mass.<sup>1</sup> Mercury is a heavy metal, which is toxic at certain levels and in different forms. Its release into traditional waste streams, such as the municipal solid waste stream or the sewer system, and its potential point source discharge into the environment is becoming a major concern. Studies have found that the dental wastewater (DWW) stream can contribute from 10 to 70% of the total daily mercury load on wastewater treatment facilities.<sup>2-5</sup> Dental procedures generate a heterogeneous waste mixture of liquids and particles. A major component of this waste mixture is amalgam particles, known also as contact amalgam, with sizes ranging from large visible particles to sub-micron colloidal size suspensions.<sup>6</sup> A DWW stream study conducted by the University of Illinois at Chicago (UIC) and the Naval Dental Research Institute (NDRI), revealed that a dental clinic can generate up to 4.5 g Hg/day/chair.<sup>6-10</sup>

Clinical dental operations include placement, removal, and polishing of dental amalgam. These operations generate a particle size distribution, which contains amalgam, dentine, enamel, and other particulate matter. Although, much work has been done on the properties of dental amalgam as a restorative material, very few studies have focused on the assessment of the basic characteristics of the DWW stream and its components. Amalgam has a density of approximately 9.50 g/cm<sup>3</sup>.<sup>1</sup> A commissioned study by DÜRR (Dental GmbH and Co. KG) showed that the density of an amalgam and tooth matter mixture ranged from 2.81 to 6.43 g/cm<sup>3</sup>, with most values around 4 g/cm<sup>3</sup>.<sup>11</sup> This wide range of values indicates that amalgam and tooth matter inter-combine into a heterogeneous mixture during removal operations increasing, consequently, the variability of the samples. Furthermore, these relative high-density values suggest that gravitational settling of the particles in the DWW will be effective in removing a significant fraction of amalgam particulate.

Another distinct fraction of dental amalgam waste stream is the non-contact, residual, amalgam. This is the amalgam generated during the dental procedures that is mixed, but not used in the oral cavity. This waste is considered easily recyclable since separation is not required and the particles are not contaminated by human fluid contact. The environmental and economic aspects associated with the recycling of residual amalgam are adequately discussed in the available literature.<sup>12-14</sup> Nevertheless, no exact data exists on what proportion of this amalgam is recycled in the United States.

In the United States, the Great Lakes Water Quality Mercury Guidance for wildlife protection is 1300 pg/l mercury.<sup>15</sup> The implementation of this limit will likely expedite the requirements for treatment of this waste stream. In addition, the proposed virtual elimination strategy of high priority toxic substances, such as mercury, in the Great Lakes Region will likely make compliance of small quantity generators a necessity.

In recent years, many publicly owned treatment works (POTW) have had difficulties complying with the existing, or anticipated, requirements of their National Pollutant Discharge Elimination System (NPDES) wastewater treatment plant permits concerning priority pollutants.<sup>16</sup> Unregulated small quantity generators, such as dental clinics, are likely to be one of the main sources causing these compliance problems. The municipality of metropolitan Seattle investigated the mercury content of the waste generated from dental clinics.<sup>17</sup> The mercury concentrations in this wastewater stream were found to range from 12 to 480 mg Hg/l exceeding the local discharge limits of 0.2 mg Hg/l. In addition, the POTW in the Seattle Metropolitan area estimated that the 1650 dental offices in its service region contributed up to 14% of the total mercury load to the local wastewater treatment plant.<sup>17</sup> Regardless of the database limitations and the lack of experimental design, these findings signify the important contribution of small quantity generators to the heavy metal load of wastewater treatment facilities, which, as point sources of environmental pollutants, are very well regulated. Similar studies have found that the DWW stream has the potential to contribute:

- on average 11% or 0.1 kg Hg per day,<sup>3,18</sup>
- a minimum of 10% or 0.046 kg Hg per day,<sup>19</sup>
- as much as 76% or 0.34 kg Hg per day,<sup>5</sup> and
- on average 56 mg Hg/dentist/day with a maximum of 98 mg Hg/dentist/day.<sup>20</sup>

In addition, a Danish study reported an estimate for dental discharges of 100-200 g of mercury per year per office.<sup>21</sup>

In the United States, treatment, at the source, of the DWW stream is not yet clearly mandated. The Palo Alto Regional Water Quality Control Plant, Palo Alto, California, the Metropolitan Council Environmental Services, St Paul, Minnesota, and the Western Lake Superior Sanitary District (WLSSD), Duluth, Minnesota, implemented voluntary mercury pollution prevention and source control programs that did not require amalgam separators at dental offices. However, the sanitary districts implementing these programs found that the mercury effluent

levels were not reduced below the Great Lakes Initiative Criterion of 1.3 ng Hg/l. In the case of the WLSSD, the average effluent concentration was 4.7 ng Hg/l, with a maximum of 18.3 ng Hg/l.<sup>20</sup> The voluntary nature of these programs, as well as dental and residential discharges, were identified to be the likely cause of these high mercury levels.<sup>20</sup>

To facilitate the voluntary implementation of DWW treatment devices for the removal of amalgam particles, the Seattle sanitary district conducted a pilot evaluation of three DWW mercury separation devices.<sup>17</sup> Among these methods, filtration and gravity settling removed more than 90% of the mercury content (i.e. filtration 93.4–98.8%, gravity sedimentation 99.3%, and ion exchange 79.0%). At present, in Europe or the United States, none of the above techniques has been established as the prevailing treatment technique for dental offices and clinics.

The latest survey report by the American Dental Association (ADA) on the distribution of dentists and their practices for the state of Illinois,<sup>22,23</sup> indicates that there are 8173 professional state licenses, of which 7703 are engaged in dental practice. Of these practicing dentists, 6445 are general dentists who do the majority, if not all, of the amalgam restorations. The corresponding numbers for the United States are 164,664 professional licenses, of which 152,151 are engaged in dental practice and 123,641 in general dentistry. Also listed in the ADA survey report, is that the average dentist spends 32.9 h per week, or 1577 h per year, treating patients. By assuming a 7-hour working day, this results in 225 days per year that the dental office has the potential to do amalgam restorative work. In addition, the average dental office has 4.1 dental treatment chairs. From these chairs, one is assumed to be dedicated for dental hygiene and not restorative procedures; in which case, on average, 3.1 chairs have the potential to be used for placing and removing dental amalgams.

A recent study by de Cerreño, Panero and Boehme<sup>24</sup> focused on mercury discharge into the New York/New Jersey harbor. This study estimated that 4000 kg/yr of mercury was generated from dental offices, and 1000 kg/yr of mercury flowed into the wastewater of this region. Our previous research has indicated that over 50% of the mercury, and silver, can be collected from particles retained on the in-line trap.<sup>7</sup> By reducing these point sources of amalgam pollution through a voluntary program, which will require relatively simple changes in dental amalgam disposal practices, a significant amount of toxic metals has the potential to be recycled, instead of entering

the sewer or the solid waste disposal streams. This study was designed to assess the potentials of such a reduction program, by quantifying its components. A second objective was to estimate the fractions of non-contact, contact, and tooth retained amalgam through an in vitro study.

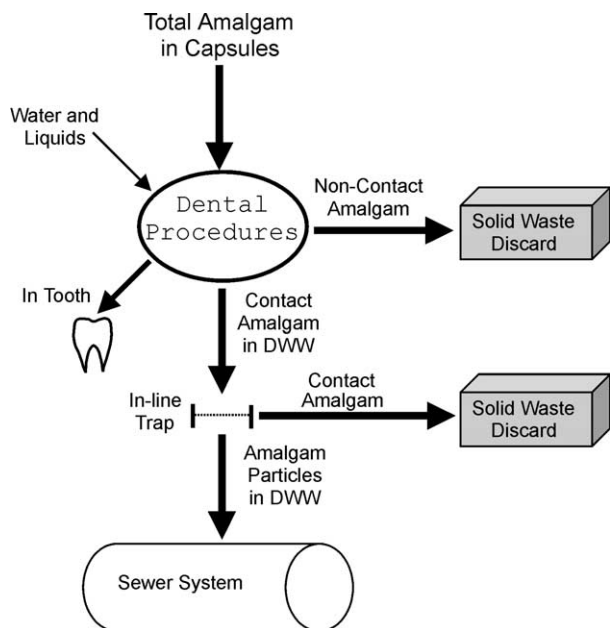
## Materials and methods

The collection system consisted of three containers placed in the participating dental offices in order to collect:

- (1) the material from the in-line trap, contact amalgam,
- (2) the excess dental amalgam that is not placed into the oral cavity, the non-contact amalgam, and
- (3) the amalgam capsules. (The number of capsules was used to approximate the total amalgam use.)

This data, along with findings from our previous research, allowed us to estimate the amount of amalgam being used, and the solid waste amount which can be discarded and eventually reach the environment. The data collected was the office location, the tooth that was treated, the number of amalgam surfaces removed, the number of surfaces of amalgam placed, and the number of capsules used to restore the tooth, either one, two, or three spill capsules. Six different dental offices volunteered to participate: 4 private offices with 1–3 dental chairs, and 2 clinics with up to 8 dental chairs. Once the containers were received, the number of amalgam capsules was counted, the non-contact amalgam was weighed, and the trap retained material was removed and weighed (i.e. contact amalgam). A schematic of the collection and amalgam flow process is presented in Fig. 1.

A second objective of this project was to determine the fractions of amalgam that are placed in the tooth, the non-contact amalgam fraction, and the amount that can be removed by the high-speed in-line evacuation system, the contact amalgam fraction (Fig. 2). Limited data is available on these components; for this reason an in vitro study was performed. Twenty bicuspid and twenty molar teeth were prepared with either one surface or two surface amalgams (i.e. 10 in each respective preparation for a total of 40 teeth). The teeth were restored with amalgam (2 spill capsules were only used), the non-contact amalgam separated and weighed, the tooth contoured, and the excess, or contact amalgam, collected and weighed. Ten

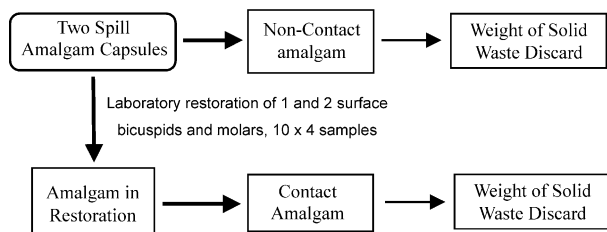


**Figure 1** Schematic of amalgam flow for amalgam placement procedures.

capsules of amalgam were mixed and then weighed to obtain an estimate of the average weight of amalgam in the capsules. From the initial average weight of the amalgam in the capsules, the corresponding non-contact amalgam and contact amalgam weights were subtracted, in order to obtain an estimate of the average weight per restoration. The percentage allocation of amalgam in these three basic components was then determined.

The aggregate amounts of contact and non-contact amalgam were estimated by using the following relationship:

- chairs per office  $\times$  (hours of patient care per year/7 h per day working)  $\times$  number of practicing dentists  $\times$  mg of non-contact, or contact amalgam, per year  $\times$  50% mercury in amalgam.



**Figure 2** Overall schematic of in vitro procedure for estimating the major fractions of the dental waste stream originating from amalgam capsules.

## Results

The 6 participating sites were sampled during a 12-18 month period, with a collection visit to the offices or clinics occurring about every three months. This yielded the 24 actual collection data points shown in Table 1. From the recorded information, it was found that the number of working days ranged from 16 to 134, the amalgam surfaces removed from 21 to 390, and the surfaces of amalgam placed from 0 to 240 for the participating offices. The reason for 0 surfaces placed in one of the offices, is that this was a mercury free office. The mercury free office was included to serve as a minimum collection site since amalgam would be removed, but not placed. The fractions of the collected amalgam waste were:

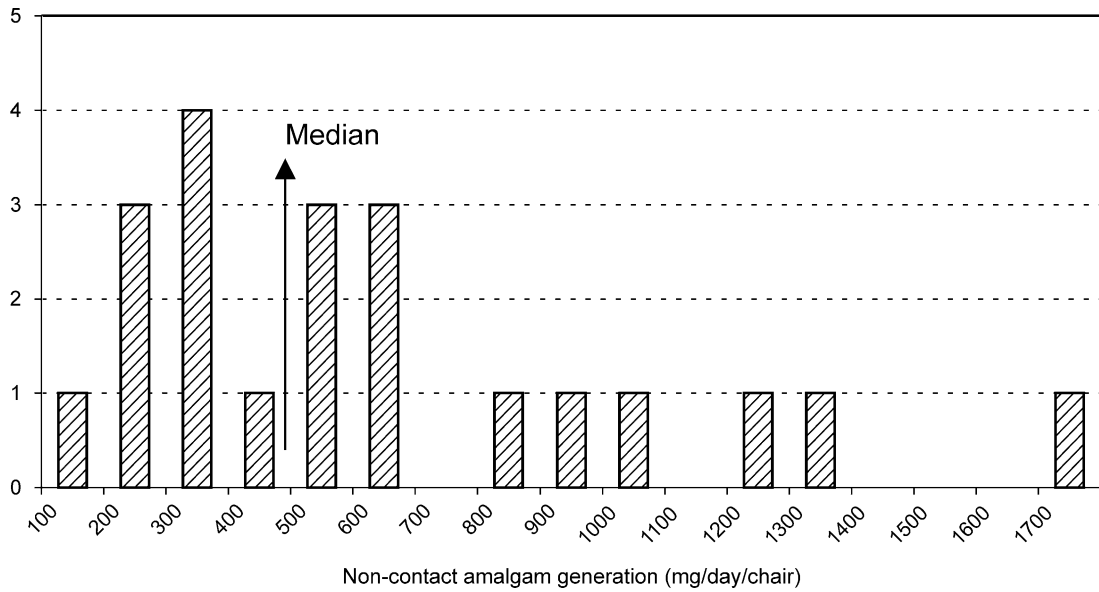
- non-contact amalgam (amalgam mixed, but not used in the tooth restoration), and
- contact amalgam (amalgam mixed and placed in the tooth, but removed when the restoration was contoured to allow function). The majority, by weight, of this amalgam is retained on the 700  $\mu\text{m}$ , in-line trap. The liquid suspension of this waste passes through the trap and is discharged into the sewer system, see Fig. 1.

The non-contact amalgam ranged from 0 to 102 g, and the contact, or trap retained amalgam from 2 to 16 g. The number of collected capsules ranged from 0 to 234, with the majority being 2 spill capsules. In order to allow comparisons between the collection sites, this data was normalized. The amalgam weight and the dental operational parameters were divided by the number of dental chairs and working days for each respective collection site, thus yielding a generation rate (i.e. mg/day/chair). The surfaces removed data, per day per chair, had a range from 0.2 to 3.0; whereas, the surfaces placed from 0.0 to 3.9, see Table 1. The results for the generated amount of non-contact amalgam ranged from 0 to 1672 mg/day/chair, with a median value of 421 mg/day/chair, see Fig. 3, and the amount of amalgam retained in the trap, contact amalgam, from 9 to 466 mg/day/chair, with a median value of 64 mg/day/chair, see Fig. 4.

Based on a sample of 10 two-spill amalgam capsules, the estimated average weight of the amalgam material was  $1.1 \pm 0.1$  g per capsule. The estimated overall percent allocation of amalgam, based on the 40 in vitro restorations,

**Table 1** Amalgam collection data.

Collection site	Number of chairs	Number of working days	Surfaces of amalgam removed	Surfaces of amalgam replaced	Non-contact amalgam (g)	Contact amalgam in trap (g)	Capsules collected	Surfaces of amalgam removed (day/chair)	Surfaces of amalgam replaced (day/chair)	Non-contact amalgam (mg/day/chair)	Contact amalgam in trap (mg/day /chair)
1	2	38	62	104	15.3	5.4	72	0.8	1.4	201	71
2	2	78	122	240	45.2	16.1	176	0.8	1.5	290	103
3	2	32	87	94	19.5	15.2	87	1.4	1.5	305	237
4	2	30	103	126	29.4	14.6	130	1.7	2.1	490	243
5	3	72	221	117	36.5	8.2	114	1.0	0.5	169	38
6	3	73	185	131	13.8	4.0	110	0.8	0.6	63	18
7	1	29	62	81	23.9	13.5	79	2.1	2.8	824	466
8	2	41	88	147	43.7	8.3	129	1.1	1.8	533	101
9	8	29	37	52	31.4	2.0	69	0.2	0.2	135	9
10	2	70	261	0	0.0	6.0	0	1.9	0.0	0	43
11	2	39	233	0	0.0	9.5	0	3.0	0.0	0	122
12	4	62	189	173	55.0	4.9	150	0.8	0.7	222	20
13	1	43	41	110	51.2	3.0	147	1.0	2.6	1191	70
14	1	61	133	224	102.0		188	2.2	3.7	1672	
15	2	85	208	105	71.5	3.2	111	1.2	0.6	421	19
16	2	54	109	212	55.3	6.3	156	1.0	2.0	512	58
17	1	45	88	174	54.8		152	2.0	3.9	1218	
18	3	40	83	166	24.7	3.9	120	0.7	1.4	206	33
19	3	134	390	237	41.7	5.8	136	1.0	0.6	104	14
20	7	19	21	46	99.2		159	0.2	0.3	746	
21	4	16	54	54	36.6		89	0.8	0.8	572	
22	1	44	25	132	43.5	6.2	129	0.6	3.0	989	141
23	4	48	133	133	85.4		234	0.7	0.7	445	
24	2	38	62	104	15.3	5.4	72	0.8	1.4	201	71
<i>Summary: statistics for all groups</i>											
Mean	2.7 ± 1.8	51 ± 26	128 ± 90	124 ± 68	43 ± 28	7.6 ± 4.5	119 ± 54	1.2 ± 0.7	1.4 ± 1.1	492 ± 437	100 ± 115
Median	2	44	103	126	42	6.1	129	1.0	1.4	421	64
25% Level	2	35	62	88	24	4.2	88	0.8	0.6	185	23
75% Level	3	66	187	170	55	9.2	151	1.5	2.0	659	117
Min	1	16	21	0	0	2	0	0.2	0	0	9
Max	8	134	390	240	102	16	234	3.0	3.9	1672	466

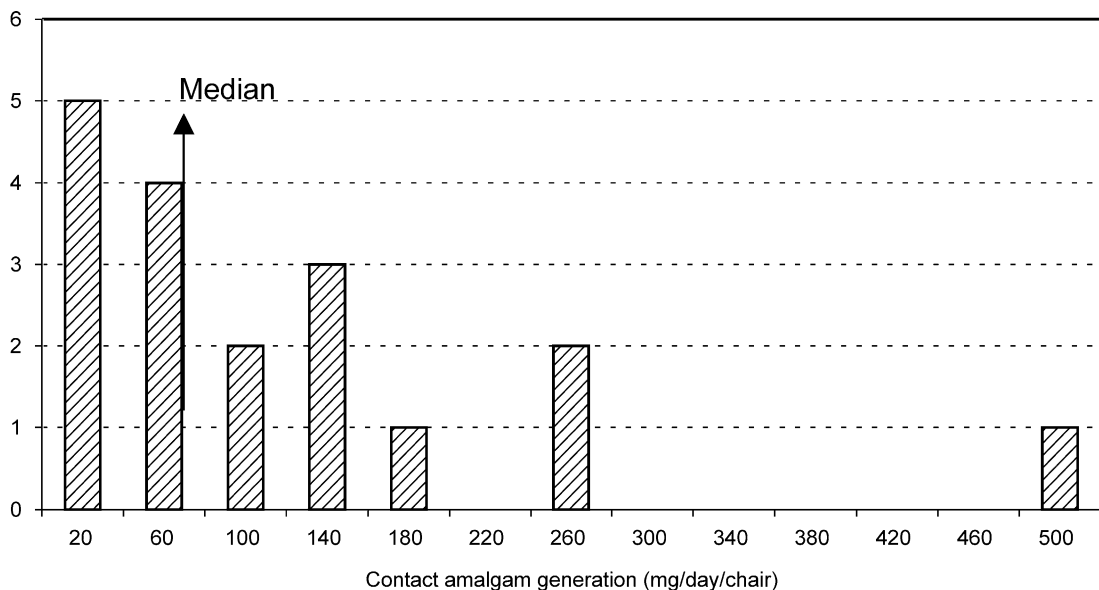


**Figure 3** Histogram of non-contact amalgam generation (Values under 100 are not depicted, however, the statistics are based on the entire sample).

was  $43.1 \pm 19.0\%$  in non-contact amalgam,  $10.7 \pm 3.6\%$  in contact amalgam, and  $46.2 \pm 19.5\%$  in the restoration. As seen in Table 2, the smaller, or the fewer, the surfaces of amalgam placed, the less the amount of amalgam in the restoration. Since the size of a double spill capsule of amalgam is fixed, it is understandable that as the size of the restoration increases, the amount of non-contact amalgam decreases, the amount of amalgam in the restoration increases, and the amount of contact

amalgam stays relatively constant. The ratio of the non-contact to the contact amalgam ranged from 7.2 to 2.1 for the one surface bicuspid to the two surface molar, respectively.

Using the data from the ADA surveys,<sup>22,23</sup> a 50%, by weight, mercury content in amalgam, and the median values of amalgam generation from Table 1, extrapolations pertinent to the overall dentist population were performed. These estimates indicate that the dentists in the State of Illinois have the potential to generate 947 kg of non-contact



**Figure 4** Histogram of contact amalgam generation (Values under 20 are not depicted, however, the statistics are based on the entire sample).

**Table 2** Percentage distribution for restorations, contact, and non-contact amalgam.

Surfaces	Restoration	Non-contact	Contact	Ratio NC/C
1-Surface bicuspid	24.8 ± 6.1	65.4 ± 5.6	9.9 ± 3.3	7.2
1-Surface molar	39.1 ± 11.8	49.3 ± 12.5	11.6 ± 2.2	4.5
2-Surface bicuspid	50.4 ± 5.8	37.6 ± 6.5	12.0 ± 4.8	4.3
2-Surface molar	70.6 ± 13.9	20.2 ± 11.6	9.2 ± 3.2	2.1
Mean for all surfaces	46.2 ± 19.5	43.1 ± 19.0	10.7 ± 3.6	4.5

mercury per year, which can be recycled, and 144 kg of mercury that has the potential to enter the environment as a solid waste discard (Calculations are in Appendix A). If this is extrapolated to the total population of practicing dentists in the United States (123,641), then dental practices have the potential to generate 18,159 kg of non-contact mercury per year, which can be recycled, and 2763 kg of mercury that has the potential to enter the environment.

## Discussion

The amalgam generation data per day per chair follows a highly skewed distribution, which has been previously identified as well.<sup>7</sup> This pattern can be seen in Figs. 3 and 4. For this reason the percentiles of the distributions are reported (Table 1), and the median is used for extrapolation.

A major finding of this project is the quantification of the amalgam generation rate for non-contact amalgam. The non-contact amalgam waste stream is easily recyclable. It contains a significant amount of uncontaminated amalgam, which has the potential to generate 211 mg of mercury/day/chair, and 126 mg of silver/day/chair. These calculations are based a 50% mercury and 30% silver, by weight, amalgam composition.<sup>1</sup> The other fraction of the dental waste stream (Fig. 1), contact amalgam, contains all the waste particles that are larger than 700 µm, since the average size opening in most chair-side traps is 700 µm. This waste stream generates 32 mg of mercury/day/chair, and 19 mg of silver/day/chair. A comparison can be made between this study and our previous work, by accounting for the, 7 to 1.5, difference in the median estimates of capsules used per day per chair (see Ref. 7 and Table 1, respectively). This comparison reveals that the present estimate of the generation rate of contact amalgam falls within the first quartile of the estimate from the UIC study,<sup>7</sup> which was conducted seven years ago. This reduction in the use of amalgam as a restorative

material can be attributed to the overall decreasing trend of usage of mercury containing materials, which has been observed during the last ten years. The ratios of non-contact to contact amalgam found in the amalgam bench scale study, see Table 2, establishes an important comparison limit range for actual amalgam generation estimates. This ratio, based on the results from dental samples, see Table 1, is close to 7.2, which falls near the upper range of ratio values found from the in vitro study (7.2, see Table 2).

By using the estimate that 50 tons of amalgam were used in the United States in 2001,<sup>25</sup> the gross amount of mercury from dental operations, which is available and has the potential to enter the environment, can be calculated as follows:

- 50 ton × 2000 lb/ton × 0.454 lb/kg × 50% mercury in amalgam = 22,700 kg of mercury available with the potential to enter the environment.

If one uses the mean estimates found in this study for the percentage of non-contact and contact amalgam from bicuspid and molars, see Table 2, then 9625 kg of non-contact mercury and 2361 kg of contact mercury are potentially available from newly placed amalgam operations. This approach does not consider the amalgam already in the discharge lines, assumes that all the amalgam is placed in restorations within one year, and neglects the amalgam purchased from previous years.

To obtain a generation range and to account for variability, the 25 and 75% percentile estimates can be used, see Table 1. These calculations give a range of 7980–28,425 kg of mercury for non-contact amalgam per year, and 993–5051 kg of mercury for contact amalgam per year. Regardless of the wide variability of the generation numbers, these estimates compare favorably with the gross amount of mercury from dental operations that is available and has the potential to enter the environment (i.e. 22,700 kg). In summary, a reduction and recycling program for the non-contact and contact amalgam

fractions of the dental wastewater stream, can make a significant contribution towards the minimization of mercury laden discards, which have the potential to be released into the environment.

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## Appendix A

### Estimated Illinois Mercury Discharge per year

*Non-Contact Mercury.* 3.1 chairs per office  $\times$  1577 h of patient care per year/7 h per day working  $\times$  6445 practicing dentists  $\times$  421 mg of non-contact amalgam per year  $\times$  50% mercury in amalgam = 947 kg of mercury per year

*Contact (Wastewater Discharge) Mercury.* 3.1 chairs per office  $\times$  1577 h of patient care per year/7 h per day working  $\times$  6445 practicing dentists  $\times$  64 mg of non-contact amalgam per year  $\times$  50% mercury in amalgam = 144 kg of mercury per year

### Estimated United States Mercury Discharge per year

*Non-Contact Mercury.* 3.1 chairs per office  $\times$  1577 h of patient care per year/7 h per day working  $\times$  123,641 practicing dentists  $\times$  421 mg of non-contact amalgam per year  $\times$  50% mercury in amalgam = 18,159 kg of mercury per year

*Contact (Wastewater Discharge) Mercury*

3.1 chairs per office  $\times$  1577 h of patient care per year/7 h per day working  $\times$  123,641 practicing dentists  $\times$  64 mg of contact amalgam per year  $\times$  50% mercury in amalgam = 2763 kg of mercury per year

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