

**A Study of the Fate of Mercury from  
the Placement and Removal  
Of  
Dental Amalgam Restorations**

Final Report

Part 1: Removal of Dental Amalgam Restorations

Presented to the Royal College of Dental Surgeons of Ontario

By

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## Executive Summary

Sixty percent of the weight of the dental amalgams removed during this experimental work, using a conventional vacuum pump system, would have entered the sewage stream as micron and sub-micron sized particles. These particles contain approximately 50% by weight mercury alloyed in the amalgam particles. In our study, when we separated particles from the effluent relatively little mercury- 0.149 mg/L was found to be dissolved in the waste water compared to 31.148 mg/L of mercury bound in particles. The percentage of particles entering waste water can be expected to vary depending on the particular brand and size of pump, the water flow rate that is used, and the rate at which particles enter the system. None of these pumps was designed to remove micron or sub-micron sized particles and all systems based on this technology will allow significant amounts of particulate amalgam into wastewater.

There is no doubt that installation of an amalgam separator that meets the ISO specification 11143:1999 is an important and effective method to minimize the amount of amalgam particles entering the sewer system. In this work the amalgam particle separator removed 99.4% of the amalgam particles from the waste water stream. While dental amalgam particles entering the wastewater have not been linked to a proven mercury pollution problem, it makes sense, as a precautionary measure, to remove as much of the particles as possible at the dental office site.

Installation of an amalgam separator that conforms to ISO specifications does not assure compliance with the Bylaw limiting mercury to 0.01mg/L of waste water unless a very large dilution factor is allowed. ISO specification 11143:1999 requires separators to remove 95% of amalgam particles of a specified particle size distribution under the conditions specified for the test. The specification does not mention testing for the concentration of mercury in waste water. Some advertisements claim compliance with the 0.01mg/L Bylaw. However, there is a surprising absence of independent scientific reports to support claims that are being presented.

Testing waste water from dental offices for compliance with this Bylaw is impractical because of the high number of variables experienced in field testing. For example, samples must be taken at the same time as an amalgam is being removed. At any other time there are only a small number of residual particles entering the system. In order to collect all the particles of amalgam the discharge pipe leading from the office vacuum system must be separated from the drain. All the effluent must be collected because almost all the mercury is bound in particles of amalgam. These particles are not dissolved in solution and evenly distributed in the waste stream. Rather, because of their relatively high specific gravity, they are concentrated in the bottom of the waste stream. Sequential sampling over a long time period will be affected by the same problems but a very large dilution factor will be superimposed because amalgam restorations are being removed for only a relatively short period of time each day with the exception of large group practices.

The view that testing water is impractical is consistent with our findings and those of Martin Shaw from the City of Toronto Water and Emergency Services. His conclusions are presented in “An Assessment of Advanced Dental Waste Amalgam Separator Systems” dated March, 2001. He states that: “**it is not practical to regulate by sampling and determination of concentrations, loadings or removal efficiencies**”. It is difficult to justify water testing because of the large number of variables and the fact that installation of ISO compliant separators does not assure compliance with the Bylaw. It would therefore appear reasonable for the City of Toronto to have exercised restraint and developed a law consistent with findings from their own in-house study and recommendation.

If regulators proceed to enforce this Bylaw with water testing in spite of the problems that are known, there is an urgent need for the City of Toronto to publish and circulate the detailed protocol that will be followed.

**THE OBJECTIVES OF PART 1 OF THE STUDY ARE TO:**

- A) Measure the percentage of amalgam waste entering the sewer system from the removal of dental amalgam restorations in dental offices equipped with conventional particle traps.
- B) Measure the percentage of amalgam waste entering the sewer system from the removal of dental amalgam restorations when dental offices are equipped with separators that meet the International Standards Organization specification number 11143:1999 for amalgam separators.
- C) Determine the weight of dental amalgam required to restore the different classes of cavity preparations
- D) Measure the concentration of mercury in wastewater under specific conditions and examine the feasibility of using ISO separators to meet the bylaw limiting the mercury to 0.01mg Hg/liter of water entering the sewer system.

**Objective A: To measure the percentage of amalgam waste entering the sewer system from dental offices equipped with conventional particle traps.**

*See page16 for the research report related to objective A*

About 95% of dental offices are equipped with high volume impeller pumps that require a continuous flow of water during pump operation in order to produce vacuum. These are often called wet pumps or water seal pumps. There are far more similarities than differences between various brands of wet pumps. Of course these pumps vary in size and the volume of water used. In these systems there are normally two solids separators, one separator for large particles located at the side of the dental chair and a second solids separator for relatively smaller particles located near the pump. Therefore, when debris enters the high volume suction tube, large bulk particles of amalgam or other debris, that can be up to several millimeters in size are separated by a very coarse screen in the solids separator at the chair, while smaller particles that pass through the chair-side trap travel into the secondary separator. The secondary separator is normally a translucent container that can hold approximately one liter of water. The size of this container can vary to some extent between brands of pumps. The secondary solids collector contains a screen of relatively large pore size. This screen was not intended to act as a separator for micron and sub-micron size particles such as those that result from removal of dental amalgam. Never the less it does act, to a minor degree, as a sedimentation trap because some particles with a high specific gravity, including some particles of dental amalgam settle out in the separator and are removed from the effluent waste.

In our experimental work, which is included in this report, we removed dental amalgam from teeth using the dental high-speed turbine handpiece and tungsten

carbide burs. We observed that 32% of the weight of the amalgam is removed as bulk pieces by the chair-side separator, 9% is removed as micron-sized particles by the secondary separator near the pump; the remaining 59% of the particles of micron and sub-micron dimensions pass through the screen in the secondary separator and enter the waste water. Dental amalgam particles contain 50% by weight mercury bound in alloy form; this percentage by weight represents a significant amount of mercury lost to the sewer system.

Virtually all the mercury is bound in the particles and not dissolved in the water. Some of the particles are extremely small and remain suspended in water for a long time period. The Environmental Protection Agency of the United States considers particles of amalgam smaller than 0.45 microns as dissolved; still this is not free mercury. However, since the surface area to volume ratio of these tiny particles is very high the potential for accelerated degradation by corrosion processes is enhanced. One cannot assume that mercury in dental amalgam alloy has the same environmental effect as mercury in other organic or inorganic forms. Studies are yet to characterize the release of mercury from dental amalgam particles in waste water or sewage sludge. The extent to which mercury is released from particles of amalgam in sewage sludge used to amend farmland is unknown. This will depend on corrosion dynamics in the soil at the site and the nature of corrosion products formed during the process. Mercury would have to be released first from dental amalgam particles to be comparable to other forms of mercury. The environmental toxicity of mercury depends on the chemical form in which it is found. However, incineration of sewage will release mercury from any particles of dental amalgam contained therein. Landfill is considered a safe disposal for mercury. Therefore, amalgam particles in sewage that is sent to landfill are considered to be safe.

The claim that landfills are a safe disposal site for mercury or other toxic elements is arbitrary and may provide a false sense of security. It may be safe in the short term but lead to unforeseen problems in the very long term. Still, this is unlikely since there is a lot of experience with landfill sites including results of monitoring operations. While dental amalgam particles entering the waste water have not been linked to a proven mercury pollution problem, it makes sense, as a precautionary measure, to remove as much of the particles as possible at the dental office site. Furthermore, there is a great deal of anxiety within certain members of society about the toxic effects of mercury based on the disasters caused by methyl mercury poisoning from eating fish in *Minamata*, Japan, and from accidentally eating grain that had been preserved with methyl mercury fungicide in Iraq. In general, people do not understand that the toxicity of mercury depends on its chemical form, its concentration, and whether or not it is bound in an alloy such as dental amalgam. Implementing practices that minimize the loss of particles at the dental office site provides reassurance that concerns are being addressed.

**Objective B: To measure the percentage of amalgam waste entering the sewer system from the removal of dental amalgam restorations when dental offices are equipped with separators that meet the International Standards Organization specification number 11143 for amalgam separators.**

*See page 16 for the research report related to objective B*

In our research, using a conventional high volume suction system equipped with conventional solids separators, we were able to collect approximately 40% of the mass of dental amalgam during the removal of dental amalgam restorations. The remaining 60 % of the amalgam mass bypassed the solids separators into the waste water. When we included an amalgam particle separator in the system 99.4% of the amalgam particles were removed. By specification, amalgam separators that meet ISO specification 11143:1999 and are properly maintained trap at least 95% of mass fraction of the amalgam particles generated during the removal of amalgam restorations in a dental office. Therefore, the installation of an amalgam separator that conforms to this specification is an important and effective method to minimize the amount of dental amalgam particles entering the sewer system.

**Objective C: To determine the weight of dental amalgam required in order to restore the different classes of cavity preparations**

*See page 36 for the research report related to objective C*

Experiments were carried out to measure the weight of amalgam being removed from various classes of dental amalgam restorations. These experiments are included in this report. Both artificial and extracted human teeth were used for this work. This work compliments information that we plan to obtain from a questionnaire that will be sent out to ask dentists about the number of dental amalgams that they remove. When the number of restorations that are removed is known we will use the weights determined in these measurements with the numbers of restorations removed to provide improved estimates of the total weight of dental amalgam removed in Ontario during the course of dental treatment.

**Objective D: To measure the concentration of mercury in wastewater under specific conditions and examine the feasibility of using ISO separators to meet the bylaw limiting the mercury to 0.01mg Hg/liter of water entering the sewer system.**

*See page 16 for the research report related to objective D*

A number of tests were carried out in order to measure the mercury content in water (total mercury including mercury bound in the particles) under different operating conditions. We set up a representative high volume vacuum pump and an ISO

approved amalgam separator according to the manufacturer's directions. The set up included a high volume vacuum line that allowed the amalgam particles to be evacuated through the separator. Amalgams were removed with a high-speed, water-cooled hand-piece fitted with a tungsten carbide bur. Water for sampling was collected directly from the exit orifice of the separator. There was no piping connected to the exit port of the separator that could allow particles to settle and reduce the content of particles in the samples. We have attached the experimental work that has been accomplished. The following statements are overall conclusions drawn from this work and associated literature that we reviewed.

As background, the International Standard for Amalgam Separators (ISO 11143) was prepared by Technical Committee ISO/TC 106, Dentistry, Subcommittee SC 6, Dental equipment. The International Organization for Standardization (ISO) is a worldwide federation of national standards bodies. These national bodies are referred to as ISO Member Bodies. Canada is a Member Body of the ISO. The work of preparing International Standards is performed through ISO technical committees made up of scientists from member bodies, international organizations and government and non-government agencies that work in liaison with ISO. The ISO standard for amalgam came into effect in 1999. It is a modern and highly effective test that is accepted around the world.

Amalgam separators are a class of dental equipment designed to retain amalgam particles carried in the wastewater from the dental office facility in order to reduce the number of particles and therefore the total mass of amalgam entering the sewage system. Amalgam separators are classified according to the method of separation into the following types:

- Type 1: Centrifugal system
- Type 2: Sedimentation system
- Type 3: Filter system
- Type 4: Any combination of types 1,2 and 3.

In order to be valid the test sample of amalgam used in the ISO specification for amalgam separators has a particle size distribution that reflects clinical conditions in dental offices. These particle size distributions are based on scientific investigations carried out to determine the particle size distribution of amalgam particles in wastewater by American, Dutch and German Dental Associations. The sample of amalgam particles used for testing is comprised of three fractions.

Fraction 1 (60% mass fraction): Sixty percent of the mass of the sample is made up of particles equal to or less than 3.15 mm and greater than 0.5mm largest dimension.

Fraction 2 (10% mass fraction): Ten percent of the mass of the sample is made up of particles equal to or less than 0.5mm and greater than 0.1mm.

Fraction 3 (30% mass fraction): Thirty percent of the mass of the sample is made up of particles equal to or less than 0.1 mm.

The test can be summarized briefly as follows. Ten grams of amalgam particles made up of the particle size distributions just described are treated with a solution of sodium pyrophosphate to prevent air bubbles from sticking to the amalgam particles and act as a dispersing agent. This test slurry, making up about 1 liter of suspended particles, is fed evenly into the amalgam separator over a period of 2 minutes. During this time period the water flowing through the separator, including the volume of the test slurry, is adjusted to the maximum flow rate as specified by the manufacturer. This test is repeated three times on an empty separator and three more times on a separator operating at its maximum filling level. The lower value of the efficiency calculated from the two test series is the efficiency of the amalgam separator.

In order to pass ISO standard number 11143 for amalgam separators the efficiency of the separator shall be at least 95% (mass fraction) of the 10 gm of particles delivered into the separator. Therefore, the separator must remove at least 9.5 grams of the 10 grams of particles delivered into the water stream during the test. The remaining 0.5 grams would be discharged into the sewer system. *The ISO standard for amalgam separators does not set out any specification for measuring the mercury content of effluent water nor is the mercury content of influent or effluent water mentioned at any point in the specification.* Furthermore, there is no requirement for any chemicals to be included in the separator to absorb mercury from the water. Therefore, there is no basis (related to this specification) for assuming that installing an amalgam separator that conforms to ISO Specification 11143 will automatically meet the City of Toronto's Bylaw if water sampling includes all the mercury, i.e., both dissolved mercury and mercury bound in particles. This Bylaw, states that effluent water must contain no more than 0.01mg of mercury per liter and that this effluent bypassing the separator into the sewer is not diluted.

Furthermore, the following calculations clearly demonstrate that it is very unlikely that a dentist who installs an ISO compliant separator will meet the City's standard of a concentration of 0.01 Hg/liter in effluent water unless a very large dilution factor is allowed. In the test specification an ISO approved separator may discharge up to 0.5 grams out of the 10 grams of the amalgam alloy particles delivered into the separator during the test, if it operates at 95% efficiency. For the purpose of this calculation it is reasonable to assume that amalgam particles contain approximately 50% mass fraction mercury because this has been the composition of amalgams since the introduction of amalgam capsules. Therefore 0.25 grams ( $0.5/2$ ) of mercury bound within the particles pass through a separator into effluent water when it is operating at the minimum efficiency allowed by this specification during the 2-minute duration of this test. In order to meet a limit of 0.01 mg Hg/liter the water flow rate through the separator would have to be 250 mg divided by 0.01mg/L or 25000 liters during the two minute test period. This would be 12500 liters/minute. Alternatively, a separator operating with an efficiency of 99% would allow 0.1 gm (100mg) of particles to enter the wastewater during the 2-minute period of the test. In this scenario the water flow

rate would have to be 50 mg Hg (weight of particles/2) divided by 0.01 liters during the two minutes of this test. Therefore, a separator operating at 99% efficiency under this test would require a water flow rate of  $(5000/2)$  2500 liters/ minute to meet the Bylaw requirement of no more than 0.01 mg Hg (total)/liter. These flow-rates would be artificial and would constitute a dilution of the effluent – an infraction under the present law.

It can be argued that it would be unusual, even impossible, for 10 grams of amalgam alloy particles to enter an amalgam separator, even in multiple operator practices, over a 2 minute time period. Of course, removal of dental amalgam restorations under normal operating conditions would never liberate this much particulate material in a 2-minute period. On the other hand there are other circumstances where this high rate of particle flow could be discharged into a separator for a brief period of time. For example, particles of amalgam can accumulate within the tubing and piping leading from the dental operator/s in regions where there are joins in the pipes, rough walls, sewer gas traps or low regions in the piping. Under low water flow rates particles can accumulate even in perfectly smooth and straight piping because of the relatively high specific gravity of amalgam. Therefore, use of a dispersant, or a sudden temporary surge in fluid flow or turbulence caused by cleaning the high volume suction hose, can flush the collected particles into the separator at such a high rate that an instantaneous ingress of particles could be equal to, or exceed the rate of delivery in the ISO test.

Martin Shaw of the City of Toronto Works and Emergency Services Branch has previously identified the extreme difficulty in sampling waste water from dental offices. His work is reported in “*An Assessment of Advanced Dental Waste Amalgam Separator Systems*” March, 2001. Even during the course of his study separators were being updated. At least one machine failed and was replaced with a newer model. He reported that: “when emptying sampling vessels it was observed that fine amalgam particles had settled to the bottom and clung to the bottom of vessels even when the vessel was agitated and inverted”. One of the systems failed to meet the Bylaw. The concentration of Hg in effluent using this system was 0.44 mg/liter in one location and 1.59 mg/liter in the second location. He concluded that two of the three systems he tested “appeared” to be capable of meeting the Bylaw limits. He points out that: “most dental practices do not have dedicated sampling manholes that would allow sampling at the street/municipal sewer”. He then goes on to recommend that: “The dental practice should be regulated by the presence/absence of AWAS” (Advanced Waste Amalgam Separators) “of a stated technical proficiency and proper operations thereof”. He states that: “*it is not practical to regulate by sampling and determination of concentrations, loadings or removal efficiencies*”. Examination of his data suggests that only one of the separators can be deemed to be consistently in conformity with the 0.01 mg/L concentration of mercury in the effluent wastewater. It would therefore appear reasonable for the City to have exercised restraint and developed a law consistent with findings from their own in-house study and recommendation. It is therefore inconceivable and extremely unfair to dentists that the city would proceed to enforce this Bylaw, and report that it will

apply to dental offices, in direct contradiction to Martin Shaw, and to our knowledge, without conducting any further clinical research or measurements what so ever on which to base this decision. Water testing by the City will be costly, not only for taxpayers to pay inspectors, but also for dentists who will feel compelled to test water in an effort to know their mercury concentration in advance of visits from City inspectors

Amalgam separators have been used in dentistry in many regions around the world for about 13 years. During this time manufacturers and scientists have gained a great deal of experience with tests that make sense and those that don't. When dental offices are sampled there is a high level of uncertainty because of the large number of variables that cannot be controlled. This is why it makes sense that the ISO test is based on ability to retain particles of amalgam rather than on the content of mercury in the effluent. Even when the sampling technician secures the test sample in what he thinks is exactly the same manner there will be a very high standard deviation from one time to another in the same office.

The following conditions are examples of variables in the dental office that cause a high level of uncertainty and make it impossible to interpret if the results are valid.

- the water flow rate and water pressure affect whether particles can settle before reaching the sampling valve.
- Unlike a solution with an even concentration of solute in solvent, the particles in amalgam form a partially suspended slurry of continuously varying concentration. Furthermore, due to the relatively high specific gravity of amalgam, the particles are more concentrated in the lower level of the waste stream.
- if a sampling valve is placed on the exit pipe in order to secure a sample, the location of the valve is a variable as it may or may not be in a region where amalgam particles accumulate.
- the presence of sewer gas traps and rough or pitted piping impede the movement of particles that get lodged against the pipe. Polyvinyl chloride piping will have relatively smooth internal walls, but crevices at joints still exist and building codes frequently outlaw PVC due to fire regulations.
- the amount of amalgam sediment already in the water-line in front of the sample site is another variable.
- if metal piping has been used in the office plumbing ahead of the sample site some degree of galvanic corrosion will occur and may increase or decrease the test measurement depending on whether the corrosion dynamics result in amalgam being the cathode or anode in the galvanic cell.

- the presence of particles of other metals such as gold or chromium alloys in contact with amalgam particles can form galvanic couples in the presence of an electrolyte and therefore affect the rate of corrosion and therefore, influence the amount of mercury in the sample.
- the point of time at which the water sample is taken relative to various office operations is another important variable. For example, variables include how recently amalgams were removed, how recently the suction line has been flushed or cleaned and the chemical and physical nature of the cleaning solution and whether it acts as a dispersant.
- whether the same sewer pipe that is tapped for the test services more than one office or business.
- whether the sample will be taken when cutting and the type of bur – large/small flute bur – will cause variations in the particle size.
- the length of piping from operatory site to the suction pump and sampling valve will give the opportunity for effluent wastes to pick up Hg and thus increase the Hg load of the effluent.

Many of these variables are impossible to control under field conditions and result in data with a very high standard deviation in the same office from the same test valve even when the technician thinks the test is being conducted under the same conditions.

It is worthy to note that the only separator that consistently conformed to the City's Bylaw operates in a batch mode allowing all waste to settle in a tank before being discharged automatically at 3.00 am. Therefore, the practicality of obtaining samples under these circumstances is not known.

There is an urgent need for the City of Toronto to publish the protocol that will be followed if water testing is to be used as a method of enforcing compliance with the Bylaw.

The city does not have a current published and circulated protocol that dentists can use in order to carry out tests to determine if they are in compliance with the requirement to have a Hg content not exceeding 0.01mg Hg/liter. Without the City's protocol, the dentist has no idea how the City intends to perform the tests. The City has ignored the research and recommendations of their own expert on this issue. The production of amalgam particles normally peaks and lasts for only 2 to 4 minutes while an amalgam restoration is being removed so the time that the sample is taken is important. Without any protocol, the dentist may carry out tests and get values in compliance with the bylaw whereas the City may carry out tests that are over the limit. In fact tests taken in exactly the same manner by the City and the dentist may be over and under the limit in sequential tests taken hours, days or months apart due to confounding variables. The extent of variation was demonstrated by results of tests made by the City of Toronto at the University of

Toronto, Faculty of Dentistry on Nov 20, 23 and 24, 2000 at 2 pm. The mercury measured in the waste water collected was below the level of detection (below 0.00005 mg/l) on two different days and was 0.00011 mg/l on the third day, a difference of 220% at the minimum. Since the City of Toronto did not report whether or not the concentration of Hg in the incoming water was tested, the impact of Hg in incoming water on the tests is unknown. In the light of these issues and all the confounding variables associated with measuring mercury in the waste water from dental offices it is inconceivable that testing waste water for compliance enforcement would be practical or justifiable.

## **<sup>1</sup>The Weights of Solid and Effluent Wastes from the Removal of Dental Amalgam Restorations**

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## ABSTRACT

**Aim:** The aim of this study was to determine the amount of amalgam that is found in the different wastes streams during the removal of dental amalgam restorations.

**Methods:** Dental amalgam restorations were removed from dentoform (anatomic replicas) and natural teeth using a dental high-speed hand-piece and tungsten carbide bur. A conventional suction system was used to collect debris from the operating site. The weights of bulk pieces of amalgam trapped in the primary and secondary solids collectors were determined. The small particles that passed through the system in the effluent were filtered (using 15  $\mu\text{m}$  filter paper) from the effluent and weighted. The concentrations of total mercury in the effluent collected during the removal of amalgams (instantaneous flow-through) - with and without an ISO 11143:1999 certified separator - were measured using Cold Vapor Atomic Absorption Spectrometry. **Results:** Sixty percent by weight of the amalgam removed was found to be in the effluent. About a third of the wastes were retained in the primary solids collector (primary trap) normally located at the side of the chair. Less than 10% of the wastes were retained in the secondary solids collector (secondary trap) associated with the vacuum pump. The ISO 11143:1999 compliant separator reduced the concentration of instantaneous flow-through discharge by 99.4%, from 31.297 mg/L to 0.18 mg/L. **Conclusion:** The effluent discharged into the wastewater stream from a conventional high volume vacuum system may contain approximately 60% by weight of the amalgam debris generated from the removal of dental amalgam restorations. Installation of an amalgam particle separator that conformed to the ISO 11143 standard was an effective method of removing this debris.

## INTRODUCTION

During the process of removing dental amalgam restorations waste is generated in the form of small particles as well as bulk pieces of amalgam. There is enormous variation in the size and shape of waste amalgam debris. The bulk portions are irregularly shaped pieces of amalgam that break away during the process of removing the amalgam restoration from the tooth. The bulk portions may be up to several millimeters at the widest dimension. The small particles produced from contact with burs operated by an air turbine hand-piece take the form of chips and filings varying in size from a few microns to sub-micron dimensions. Normally, water, saliva, and waste amalgam are removed from the operating site and oral cavity by means of high volume suction. The bulk portions of amalgam are relatively easy to capture in the chair-side solids separator (primary trap) because of their substantial size. Virtually all the particles of micron and sub-micron dimensions produced by contact with the bur pass through the primary trap and enter the secondary solids separator (secondary trap) associated with the vacuum pump. Here some of the micron-size particles settle to the bottom of the trap, but turbulence of water passing through the trap carries the remainder into the waste stream.

Searches through the MEDLINE and the Environmental Health Information Services (EHIS) using amalgam AND wastewater or mercury AND wastewater as keywords revealed no study that had evaluated the distribution of amalgam wastes generated during the removal of dental amalgam restorations between solids that are recoverable at the chair-side and the wastewater. Mercury use and waste generation in dentistry has been dominated by estimates and assumptions (Arenholt-Bindslev, 1992). However, there are reports that have been written for governments that contain

statements about the distribution of dental amalgam waste (Obenauf & Skavroneck, 1997; Environmental Canada ARET Secretariat, 1998). In one such report it was estimated that Canadian dentists in 1998 lost 781 kg of mercury to the sewer and another 474 kg to garbage. It was further estimated that 9% of dentistry's estimated 5.6 tonne/year annual flux of mercury in Canada was uncontrolled during its life cycle (Environmental Canada ARET Secretariat, 1998).

Obenauf and Skavroneck (1997) divided the release of mercury arising from purposeful use in dental facilities in the Greater Milwaukee Metropolitan Sewage District in 1997 into three streams – air, solid waste, and wastewater. They estimated that 60% by weight of the mercury from dental offices ended up in wastewaters; the remaining 40% was reportedly released as solid wastes. In this report they did not consider that, at the overall environmental level, Dentistry contributed to mercury released directly into the air. However, Rubin and Yu (1996) have estimated that the mercury burden of discharged air from dental clinics was on average  $0.092 \text{ mg Hg/m}^3$  with a range of  $0.010 \text{ mg/m}^3$  to  $0.237 \text{ mg/m}^3$ . Some studies have reportedly captured 75% of amalgam wastes at the chair side as solids (Westman & Tuominen, 2001).

Arenholt-Bindslev (1992) and Arenholt-Bindslev and Larsen (1996) have reported that wastewater from dental clinics had a high burden of mercury; this burden varied highly between clinics, and was reduced when amalgam separators that conformed to Swedish standards were used, but was not influenced by the number of amalgam surfaces produced or removed. Estimates of dentistry's contribution to the total mercury load at treatment facilities have varied from 9-14% in San Francisco, Seattle and Palo Alto to as high as 76-80% in Minneapolis and St. Paul (Westman & Tuominen, 2001).

The actual and potential effect of mercury in amalgam particles wastes is of environmental concern (Arenholt-Bindslev, 1992; 1998; Arenholt-Bindslev & Larsen, 1994; Fan, *et al.*, 2000; Trip, 2001; Westman & Tuominen, 2001). Considerable attention has, therefore, been focused on mercury bound in dental amalgam particles that are released as wastes into the environment from dental facilities.

It is important to quantify the waste generated from the removal of dental amalgam into that portion collected in solids separators and the portion which is lost as effluent to the sewerage system. The solids portion can be easily collected in the office and disposed of safely, while the ultimate fate of that portion that enters the sewer system is more obscure. Although Arenholt-Bindslev (1992) has stated that the environmental burden of mercury due to dentistry only becomes important when other general sources have been controlled, the prevailing philosophy for management of environmental mercury is a zero tolerance from anthropogenic sources. Therefore, an understanding of the mercury burden in wastes associated with the removal of dental amalgam restorations will enable policies to be fine-tuned to address major sources of mercury wastes in dentistry.

The aims of this study were therefore to conduct an audit to quantify the amount of amalgam retained in solids separators and the amount lost to the sewerage system during the removal of dental amalgams, as well as to determine the concentration of mercury in the wastewater that enters the sewer system.

## MATERIALS AND METHODS

Sets of previously restored natural and dentoforn teeth were pooled and weighed with amalgam restorations *in situ*. The restorations were then removed with a dental high-speed hand-piece and tungsten carbide bur in a procedure that mimicked normal operatory conditions. The total weight of amalgam restorations removed from each set of teeth was obtained from the weight difference of the set of teeth with and without the restorations. The weight of bulk pieces of amalgam wastes was obtained by weighing the amalgam scraps that were retained in the primary solids separator (chair-side trap) in the conventional suction line. The smaller particles of waste that passed through the primary solids separator and collected in the secondary solids separator (trap at vacuum pump level) were filtered from the water using 15 $\mu$ m pore-size filter. The weight of the fine particles was obtained from the weight difference of the dried filter paper and amalgam particles and the filter paper before use.

In addition, the total mercury concentration in the wastewaters that would have been discharged directly into the sewer was measured with and without an amalgam-separating device that conformed to ISO 11143 specification (ISO, 1999) connected to the conventional suction system. The total mercury contained in these effluents was measured. During the sampling process, the discharge pipe from the vacuum pump was disconnected from the sewer system so that samples of wastewater that were collected contained all the amalgam particles being discharged during the time that the sample was being collected. In one instance, when an ISO 11143:1999 certified separating device was not connected to the conventional vacuum pump, all the effluent that would have been discharged into the sewer was collected. Samples were collected in Teflon bottles

that had been pre-cleaned in 30% nitric acid (trace element grade) and then cleaned using procedures described by Lugowski, *et al.* (2000) This process for preparing our sample bottles is similar to the EPA protocol (Telliard, 1999) but includes additional nitric acid pre-cleaning. Sample preparation was performed in a Clean Room Facility - Class 100. The samples of wastewater contained mercury dissolved in water as well as mercury bound in the particles of amalgam. The particles of amalgam were separated from the water using sedimentation for samples of large volume (1 L) or centrifuging for samples of small volume (100 ml). The supernatant was preserved according to EPA protocol (Telliard, 1999) using high purity HCl. (Ultrex grade 5ml of acid per liter of sample). Mercury in solution was measured using a Varian VGA 77 Cold Vapor System and an Atomic Absorption Spectrophotometer (AAS) Model Spectra 880. The detection limit for these measurements was 0.1ng/g. A Standard Reference Material SRM 1641d from the National Institute of Standards and Technology, Gaithersburg, U.S.A. containing a certified mercury level of  $1590 \pm 18$  ng/g was used to validate the accuracy of our analysis. Our values for the reference sample at different times during the analyses were 1593.2, 1600.9, and 1596.8 ng/g.

Measuring the high concentration of mercury in samples containing particles with AAS is difficult. Therefore, for these samples we decided to measure copper in such samples because the composition of the amalgam was known. In order to establish the amount of amalgam particles separated from the water, the amalgam particles were digested in nitric acid and the concentration of copper was measured using flame atomic absorption spectrophotometry. The ratio of copper to mercury in the deposit was used to calculate the concentration of Hg since we were using an alloy for dental amalgam

containing 11.8% copper by weight that had been combined with 49.5% by weight mercury. When mercury was combined with this alloy the resulting dental amalgam contained 5.94% copper by weight.

## RESULTS

A total of 96.60 grams of dental amalgam was removed from 152 restorations in Experiments 1-4 (Table 1). The average weights of restorations removed from experiments conducted with dentofom teeth – 0.59 and 0.55 grams – were lower than those from natural teeth – 0.62 and 0.87 gram

As seen in Table 2 we were only able to account for between 39% and 41% of the weight of restorations removed in the Experiments 1-4. The efficiency of the secondary solids separator to remove fine amalgam particles was very low – being about 8.5% (range 7-10%). The primary separator at the chair-side retained about one third of the wastes.

It was assumed that the remaining weight of amalgam particles in Experiments 1 to 4 was in aerosol, effluent wastes, and possibly errors associated with particle recovery and weighing. Therefore, in Experiment 5, we enclosed the cutting area to prevent amalgam particles from escaping; and further, all the wastewater discharge from the conventional vacuum pump was collected. In this experiment 70 liters of wastewater effluent was collected. Table 2 shows that this process only marginally increased amalgam particle recovery to 43%; the gain resulting from fine particles trapped in the secondary solids separator. Filtration of the 70 liters of effluent through a 15  $\mu$ m pore

size filter paper yielded another 40% of the total weight of amalgam restorations removed. We could not directly account for 17% of amalgam wastes generated; the filtrate from the effluent is expected to contain particles  $< 15 \mu\text{m}$  in diameter.

Experiment 5, in which 21.28 grams of dental amalgam was removed from 42 tooth surfaces, was conducted in 62 minutes discharging 70 liters of wastewater effluent. Of the 21.28 grams of amalgam, 57% passed through the suction system and entered the effluent that was collected. The weight of amalgam particles in the 70 liters of effluent was 173.28 mg/L; the amalgam particles were discharged into the effluent at an average rate of 2.79 mg/L/min.

The mercury in wastewater samples collected when an ISO 11143:1999 separator was not connected was considered as being in amalgam particles and in solution. Table 3 shows that without the separator used in this study, there was a high concentration of mercury in the effluent, the average concentration being 31.297 mg/L. Only a relatively minute quantity of the mercury was dissolved in solution, being 0.1493 mg/L on average. When the ISO certified separator used in this study was connected to the conventional vacuum suction system the total mercury concentration of the discharged wastewater dropped drastically to between 0.0486 mg/L and 0.2917 mg/L with an average of 0.1800 mg/L – a 99.4% reduction in total mercury concentration.

## DISCUSSION

We conducted an audit of dental amalgam wastes generated during the removal of dental amalgam restorations. The bulk, 57-61%, of the waste generated was contained in

dental effluent wastes. About one third (31-33%) of the wastes were retained in the primary solids separator (coarse particle filter), whilst, about a tenth – 7 to 12% – is retained in the secondary solids separator. In Experiment 5, where we enclosed the operating area, the effluent waste particles that passed through the secondary solids separator, and that were removed from solution by a filter with a 15 µm pore size constituted 40% of the weight of restorations removed. About 40% of the wastes were retained in the primary and the secondary solids collectors. The average total mercury concentration was 0.1800 mg/L in the effluent when the ISO certified separator used in this study was connected in the system while the average mercury in effluent was 31.297 mg/L when it was not connected.

Our findings that only about 40% of amalgam wastes are recoverable as solid wastes at the chair-side is consistent with the results of Obenauf & Skavroneck (1997) but far less than the estimate of 75-80% claimed by Westman and Tuominen (2001). In our work we disconnected the discharge pipe from the suction system/amalgam separator from the sewer system. Samples of wastewater were collected from the discharge pipe, which had been completely disconnected from the drain, during the removal of dental amalgam restorations. This method of sample collection minimizes opportunities for particles to settle out of suspension in the wastewater stream as will occur if a sampling valve is inserted into a wastewater line downstream from the pump. Also, if only a part of the wastewater is collected through a sampling valve the amount of particles in the discharged wastewater will not be accurate because particles of amalgam are not distributed uniformly in the wastewater stream. Furthermore, if the vacuum system is shut down while a sample is taken many particles of amalgam will settle out of

suspension. Therefore, our sampling technique ensured that we obtained not only dissolved mercury, but also all the particles of amalgam in the wastewater. We used a high volume vacuum pump system that requires a continuous flow of water to maintain a seal with the impeller and maintain vacuum. We believe that this water seal system is used in 90-95% of offices in Ontario. In order to conserve water some pumps re-circulate a percentage of the water used to maintain the seal. However, the basic principles of operation and solids collection is similar between different brands of these pumps. Still, our ability to recover 40% as solid waste in solids separators may be biased because only one high volume vacuum pump system was used in this study. A lower or higher rate of water consumption by different brands of pumps, or by different water flow adjustments, may influence the concentration of amalgam particles and dissolved mercury as a consequence of the dilution factor.

We observed that most (99.5%) of the mercury, especially in the wastewater without a certified separator, was in particles. This is consistent with previous research that reported that less than 0.3% of amalgam waste is soluble (Westman & Tuominen, 2001). Chin, *et al.* (2000) have also reported that previous research document that dental amalgam scrap is not very soluble.

The lowest retention of 39% was obtained from Experiment 2 where more than 50% of the restorations removed were one surface restorations; probably because a higher percentage of the amalgam debris from the smaller restorations was in the form of particles too small to be trapped in the solids separators.

We observed that the total mercury concentrations of mercury in the effluents when the certified separator was not connected ranged from 13.34 mg/L to 43.00 mg/L;

average of 31.297 mg/L. These concentrations of total mercury in the effluents are comparable to those reported by Arenholt-Bindslev and Larsen (1996). Arenholt-Bindslev and Larsen (1996) reported concentrations of mercury that varied between  $9.7 \pm 1$  mg/L to  $306 \pm 30$  mg/L for samples obtained from dental clinics without separators. Since these were field tests the high range is expected because of the large number of variables associated with field-testing. Also, consistent with the findings of Arenholt-Bindslev and Larsen (1996) who were reporting on the effect of Swedish approved amalgam particle separators we observed that the use of an amalgam separating device that met ISO 11143:1999 reduced the mercury load in dental effluent waste; in this study the reduction in the mercury load of water sampled while amalgam was being removed was 99.4%. The mercury load of the effluent from the separator when restorations were being removed was 0.1800 mg/L on average.

The lowest level achieved by the Swedish approved separators was  $4.6 \pm 0.6$  mg/L (Arenholt-Bindslev & Larsen, 1996). Assessment of the mercury concentration of effluent discharge from a number of separators has shown that none was capable of reducing mercury concentration below 0.05 mg/L (Surmont & Enody, 1993). In our study, the lowest mercury concentration in discharge from the ISO certified separator used in this study was 0.0486 mg/L, a finding highly comparable to that of Surmont and Enody (1993). More recent studies still demonstrate the difficulty of separators to achieve concentrations in the order of 0.01 mg/L (Turchi *et al.*, 2000; Pederson *et al.*, 2000). Systems that combine sedimentation of particles with treatment of the remaining effluent with mercury absorbing materials have achieved discharge levels less than 2  $\mu$ g/L (Stones *et al.*, 2000). It is worthy of note that most advertisements of amalgam

separators, that comply with the ISO 1143:1999 standard, guarantee an efficiency of at least 95% for the removal of dental amalgam particles in dental wastewater but do not specify the total mercury in the effluent discharged after separation.

In our study, all five experiments yielded a quantity of waste in the same order of magnitude in the primary and secondary solids collectors, and in the effluent; i.e., approximately 30%, 10%, and 60%, respectively. Also, in Experiment 5, 17% of the particles generated during the removal of restoration had diameters  $< 15 \mu\text{m}$ . This is consistent with the cumulative mass distribution of amalgam particles as specified in the ISO 1143:1999 where it was reported that the diameter of about 17% of the mass of amalgam particles was less than  $15 \mu\text{m}$ .

In Experiment 5, there was an average increase in total weight of amalgam particles recovered by 3%. This proportion 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. Various experiments have demonstrated that removal of dental amalgam increases the body's burden of mercury (Mackert & Berglund, 1997; Kremer, *et al.*, 1999; Berglund & Molin, 1997; Sandborg-Englund, *et al.*, 1998) as well as the airborne mercury in the dental operatory (Smith & Lewis, 1987; Dunn, 1988; Ferracane, *et al.*, 1994).

In our experiments the wastewater contained about 60% by weight of the waste generated during the removal of amalgam restorations. This study as well as those of Arenholt-Bindslev and Larsen (1996) and Surmont and Enody (1993) suggest that amalgam separators conforming to approved certification standards may still not ensure that total mercury level can be brought to levels below 0.01 mg/L. Studies have

reportedly shown a low solubility for dental amalgam scrap particles (Chin, *et al.*, 2000; Westman & Tuominen, 2001). Our study showed that whereas the average concentration of mercury that was bound in the particles was 31.148 mg/L, the average concentration of mercury in solution was 0.1493 mg/L. The environmental effect of mercury in sewage sludge would depend on when and in which form mercury is released from these particles. McGroddy (1997) has commented that some agricultural soils showed an uptake of mercury from sludge-amended soil whilst other soils did not. It was suggested that this difference might be due to different forms of mercury in the sludge. She then noted the surprising lack on the relevant scientific information on the impact of amalgam particles on the environment. The release of mercury and speciation that occurs from mercury bound in dental amalgam particles still needs to be measured as the toxicity of mercury depends highly on its chemical form (McCormac, 1991). Kunzel (1996) has recently reported that amalgam waste is not further solubilized during any of the stages of standard waste treatment. There is no doubt that a significant amount of dental amalgam enters the wastewater stream unless particle separators are installed. However, the overall environmental benefit from the use of amalgam particle separators depends on more scientific information about the ultimate fate of mercury bound in amalgam particles as well as the relative contribution that dentistry makes to the overall mercury burden.

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Table 1. The weight of amalgam restorations and the types of surfaces from which the restorations were removed

Experiment	Description of restorations		Distribution (%) of the types (number of surfaces) of restorations removed				Weight (gram) removed per surface
	<i>Weight (gram)</i>	<i>No of surfaces</i>	<i>One</i>	<i>Two</i>	<i>Three</i>	<i>Four or more</i>	
1	23.60	27	33	30	22	15	0.87
2	35.74	58	52	28	9	10	0.62
3	17.62	31	35	32	23	10	0.59
4	19.64	36	36	39	14	11	0.55
*5	21.28	42	45	31	10	14	0.51

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

Experiment	Weight (grams) of restorations	Distribution (%) of the wastes generated during removal of restorations			Total (%) Recovery in Conventional High Vacuum Suction
		<i>Coarse Filter</i>	<i>Sedimentation Bowl</i>	<i>Effluent Waste</i>	
1	23.60	31	10	59	41
2	35.74	32	7	61	39
3	17.62	31	10	59	41
4	19.64	33	7	60	40
*5	21.28	31	12	57	43

**Table 3. Total mercury concentration in dental effluent discharge with and without an amalgam separator that meets ISO 11143 specification (ISO, 1999)**

Total mercury concentration without separator...		Total mercury concentration with separator that meets ISO specification
<i>in amalgam deposits</i>	<i>in solution</i>	
43.00 mg/L	0.0059 mg/L	0.2054 mg/L
13.34 mg/L	0.1677 mg/L	0.2316 mg/L
37.00 mg/L	0.0878 mg/L	0.2230 mg/L
34.40 mg/L	0.2505 mg/L	0.3391 mg/L
28.00 mg/L	0.2347 mg/L	0.2917 mg/L
<b>*31.1480 mg/L</b>	<b>*0.1493 mg/L</b>	0.2032 mg/L
		0.1805 mg/L
		0.2014 mg/L
		0.1306 mg/L
		0.0969 mg/L
		0.0834 mg/L
		0.1049 mg/L
		0.0486 mg/L
<b>Range (43.00mg/L – 28.00 mg/L)</b>		<b>(0.0486 mg/L – 0.3391 mg/L)</b>
<b>Total (Average) = 31.2973 mg/L</b>		<b>*0.1800 mg/L</b>

*\*Average*

# <sup>1</sup>Estimating the Weight of Dental Amalgam Alloy Restorations

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Adegbembo A.O. and Watson P.A. Estimating the weight of dental amalgam alloy restorations.

## ABSTRACT

**Objective:** Our aim was to estimate the weights of dental amalgam restorations.

**Method:** We obtained weights of restorations in dentoform teeth (n=368) and natural teeth (n=108) from the weights of teeth with and without restorations. Ordinary least squares regressions (OLS) using three covariates: 1) number of restored surfaces; 2) type of tooth – premolar, upper molar, or lower molar; and 3) whether the restoration was in a natural or dentoform tooth were developed to explain the weight of restorations. **Results:** The partial  $R^2$  for the covariates were 0.63, 0.05, and 0.02, respectively. Compared to dentoform teeth, restorations in natural teeth were significantly heavier. Model  $R^2$  for natural and dentoform teeth using the first two covariates were 0.65 and 0.73, respectively. For natural teeth, the partial  $R^2$  for the number of restored surfaces was 0.61. Estimated adjusted weights (95% Confidence Limits) of one, two, three, and four or more surfaces restorations in natural teeth were 0.30 gram (0.19, 0.42); 0.61 gram (0.47, 0.75); 1.19 gram (1.00, 1.39); and 1.85 (1.61, 2.10), respectively. **Conclusion:** The surface area of restorations provides the best estimate for the weight of dental amalgam restorations.

KEYWORDS: DENTISTRY RESTORATIVE MATERIALS DENTAL AMALGAM WEIGHT

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## INTRODUCTION

Silver amalgam restorations have been used in North America for approximately 175 years. Some of the early formulations were mixtures of silver powder and mercury with the silver powder produced by filing silver coins of the day. The restorations were of such poor quality that by the 1850's the use of amalgam was considered unethical by many dentists and this split the profession in a controversy known as the "amalgam wars" (1-3). These early problems were solved as a result of careful research so that modern amalgam is relatively easy to manipulate, exceptionally effective, long lasting and comparatively inexpensive (4-7).

Scientific studies have shown that there is no evidence to confirm that mercury released from dental amalgam restorations results in adverse effects on the health of the general population, other than the rare contact hypersensitivity reaction (1, 8-13). In fact, recent scientific studies now report adverse health effects that are claimed to be associated with mercury from amalgam restorations in some individuals may be psychosomatic in origin (14-16). Nevertheless, its use still remains controversial because of safety concerns (1, 3, 17). This is understandable considering the amount of adverse publicity that has surrounded dental amalgam.

One of the other major concerns is dentistry's contribution to the overall burden of environmental mercury (18-22). It is known that anthropogenic mercury contaminates the biosphere and the aquatic food chain (23-26); dentistry is estimated to be an important source of anthropogenic mercury (27-28).

Arenholt-Bindslev (18,19) has described the cycle of mercury in dentistry that showed the fate of mercury during the manipulation of dental amalgam in clinical

practice. Arenhölt-Bindslev and Larsen (29) reported a high burden of mercury in wastewater from dental clinics, especially those without Swedish-approved amalgam-separating devices. Studies in the US (27) and Canada (28) that have attempted to quantify the annual environmental flux of mercury from several anthropogenic sources, including dentistry, noted the difficulty in carrying out the exercise due to the lack of reliable data.

We are currently conducting studies to estimate the contribution of dentists to anthropogenic mercury in Ontario, Canada. Requisite information is the weight of dental amalgam restorations. We have found no study in the scientific literature that reported on the weight of dental amalgam restorations. The aim of the present study was therefore to develop a model to estimate the weights of dental amalgam restorations.

## **MATERIALS AND METHODS**

Dentoform teeth restored with dental amalgam by Dental students at the Faculty of Dentistry, University of Toronto, formed the pool from which restored teeth were selected for study. All restorations were placed previously by students as part of course requirements for operative treatment. Extracted natural teeth that had previously been restored with dental amalgam formed the second pool of restored teeth. Selected teeth were weighed with the restorations *in situ*. The dental amalgam restorations were then removed using an air turbine hand-piece and conventional high volume suction. The teeth were re-weighed. The weight of dental amalgam restorations placed in each tooth was obtained by calculating the weight difference of the tooth with and without the restoration.

Data were entered into and analyzed in SAS. The ordinary least squares (OLS) regression technique was used to develop explanatory models for the weight of restorations using the PROC GLM in SAS (30). The number of tooth surfaces filled, the type of tooth – premolar, lower molar, or upper molar – and whether the restoration had been removed from a natural or dentof orm tooth were the covariates in the model. We then developed separate models for weights of restorations placed in dentof orm and natural teeth.

## **RESULTS**

To estimate the weight of dental amalgam restorations, we removed restorations from dentof orm and natural teeth that had previously been restored with dental amalgam by dental students and practicing dentists. Table 1 shows that on average restorations in dentof orm teeth weighed less than those in natural teeth; the average weight of restorations in dentof orm teeth was 0.48 gm (SD=0.58) compared to 0.68 gm (SD=0.61) for the average restoration in natural teeth. For both dentof orm and natural teeth, the weight of restorations increased as the number of restored surfaces increased. Also, the weights of restorations generally decreased from lower molars to upper molars and then to premolars.

Table 2 shows the result of the model to predict the weights of dental amalgam restorations in natural and dentof orm teeth. The models explained between 65% and 73% of the weight of dental amalgam restorations. For all models, the type of tooth (lower molar, upper molar, or premolar), the number of surfaces restored, and whether the restoration had been placed in natural or dentof orm teeth significantly influenced the weight of a dental amalgam restoration. The most important explanatory covariate was

the number of surfaces restored; it accounted for at least 90% of the proportion of variance in the weights of restorations explained by all covariates in the model. Compared to estimates derived from using the type of teeth that tended to result in some degree of overlap in the 95% confidence intervals of the adjusted mean, estimates derived from using number of surfaces did not overlap.

The OLS model explained 70% (model  $R^2 = 0.70$ ) of the weights of restorations in all – dentiform and natural – teeth. The adjusted mean weight of restorations increased from 0.32 gm (95% Confidence Limits = 0.28; 0.37) for one surface restoration to 1.74 gm (95% Confidence Limits = 1.65, 1.84) for restorations with four or more surfaces. The adjusted mean weight of restorations in dentiform teeth was 0.72 gm (95% Confidence Limits = 0.69, 0.76) which was 0.22 gm less than the restorations in natural teeth. Also, for all teeth (dentiform/natural), the mean weight of restorations in premolars adjusted for the number of surfaces restored was 0.75 gm (95% Confidence Limits = 0.69, 0.82) which was 0.01 gm heavier than restorations in maxillary molars. Lower molars were 0.26 gm heavier than premolar restorations (adjusted mean weight = 1.01; 95% Confidence Limits = 0.96, 1.07).

Our model accounted for 65% (model  $R^2 = 0.65$ ) of the variation in the weights of dental amalgam restorations placed in natural teeth. For natural teeth, the adjusted mean weights of restorations consistently increased from premolars to upper molars and then to lower molars; and from one surface to four or more surfaced restorations. The adjusted mean weights were 0.82 gm (95% Confidence Limits = 0.64, 1.01) for premolar restorations, 0.98 gm (95% Confidence Limits = 0.86, 1.09) for upper molar restorations, and 1.17 gm (95% Confidence Limits = 1.04, 1.30) for lower molar restorations. For

one, two, three, four or more surface restorations the mean (95% Confidence Limits) was: 0.30 gm (0.19, 0.42); 0.61 gm (0.47, 0.75); 1.19 gm (1.00, 1.39); and 1.85 gm (1.61, 2.10), respectively.

For restorations in dentoform teeth that had been placed in a controlled environment, our model had an error variance of only 27% (model  $R^2 = 0.73$ ). Upper molars weighed 0.04 gm less, whilst lower molars weighed 0.28 gm more, than restorations in premolars. The weights of dental amalgam restorations again increased from 0.24 gm in one surface restoration to 1.62 gm in four or more surface restorations.

## **DISCUSSION**

We carried out OLS regressions to estimate the weight of dental amalgam restorations. The type of tooth (lower molar, upper molar, or premolar), the number of surfaces restored, and whether the restoration had been placed in a natural or dentoform tooth significantly influenced the weight of restorations. Irrespective of the type of tooth or whether the restoration had been placed in a natural or dentoform tooth, the weights of restorations increased as the number of surfaces restored increased; the number of surfaces restored singly accounted for at least 90% of the total variance explained by the models. In natural teeth, the weights of restorations increased from premolars to upper molars and then lower molars. However, with dentoform teeth, or with dentoform and natural teeth combined, premolar restorations were slightly heavier than those in upper molars.

A major limitation of this study is that our models were based on a nonrandom selection of teeth – natural and dentoform. In both cases the universe of teeth is difficult to obtain. Even where the universe of restored teeth can be identified, e.g. all restored teeth in Ontario; a random sample cannot be obtained ethically to remove restorations for the purposes of determining their weights. Assuming that this was possible, such a sample may still not represent the universe of restored teeth from which dental amalgam restorations will ultimately be removed. The model used in this study accounted for 65% of the weight of restorations placed in natural teeth. Despite the lack of a definite link between our sample of restorations and a defined universe of restorations, we believe that our estimates can be used with circumspection; we have provided confidence limits for our estimates.

Given the somewhat ordered variation in the surface area of teeth and number of tooth surfaces, these variables – type of tooth and number of surfaces – might have been treated as ordinal level variables. However, we have deliberately treated them as class variables so as to prevent the development of a model that is capable of predicting values outside the range of clinically feasible limits.

The trends in our study are consistent with clinical expectations. In clinical practice the size of restorations depends on, among other factors, the size of the cavities being restored and the amount of sound tooth tissue left (31). Restorations placed in a dentoform tooth by dental students under supervision is expected to be typical of that placed in a natural tooth, especially with respect to outline form and anatomy. Given the current epidemiology of dental caries, current teaching in restorative treatment emphasizes the need for dental students to simulate small cavities (31, 32). It is therefore

not surprising that restorations in dentiform teeth weighed less than those in natural teeth, some of which had been extracted many years previously. It is also possible that the natural teeth used in this study have undergone more than one restoration cycle.

Other expected trends in this study were as follows: The weight of restorations in all tooth types increased with the number of surfaces restored; more extensive restorations should have higher weights. Other studies have also shown that intra-oral, urinary, and blood mercury levels depended on, among other factors, the number of surfaces and the surface area of restorations with dental amalgam (33-35). Also, the burden of mercury measured in the brain and kidneys at autopsy has been positively correlated with the number of restored surfaces (36, 37). In natural teeth, restorations in lower molars weighed generally more than those on upper molars and premolars. The occlusal surface area of a premolar is less than that of a molar, the occlusal surface area of lower molars being largest. (38). The anatomy of upper molars gives possibilities for small restorations especially where the transverse ridge is preserved. It was therefore not surprising that those restorations in upper dentiform molars weighed less than their premolar counterparts.

Obenauf and Skavroneck (27) had assumed that the weight of an average restoration was 0.40 gm. This is 0.08 gm less than the weight of an average dentiform restoration and 0.28 gm less than restorations in natural teeth. However, the weight of an average restoration is liable to greater error. Therefore, studies that estimate the flux of mercury in dentistry should take account of the number of surfaces and to a lesser extent the type of tooth from which dental amalgam restorations had been removed. Such estimates should provide lower and upper limits of the estimate.

Mercury constitutes about 50% of the weight of amalgam (6). Based on our findings, removal of amalgam restorations from lower molar, upper molar and premolar teeth would be expected to release 0.59 gm (95% Confidence Limits = 0.52, 0.65), 0.49 gm (0.43, 0.55), 0.41 gm (95% Confidence Limits = 0.32, 0.50) of mercury that is bound in the waste, respectively. However, the number of surfaces from which dental amalgam restorations had been removed is a better explanatory covariate in our models since its partial  $R^2$  accounted for at least 90% of overall model  $R^2$  in all three models. Therefore, one, two, three, and four or more surface restorations from natural teeth would be expected to release 0.15 gm (95% Confidence Limits = 0.10, 0.21), 0.31 gm (95% Confidence Limits = 0.24, 0.37), 0.60 gm (95% Confidence Limits = 0.50, 0.69), 0.93 gm (95% Confidence Limits = 0.81, 1.05) of mercury in total, respectively. This quantity of mercury would be contained in the following waste streams: amalgam particles in solids separators, wastewater; minor loss at the chair, and as traces of mercury vapor (18).

The relative distribution of mercury between these waste streams depends on the reason for failure and subsequent removal of amalgam restorations (39-41). For example, restorations removed because of secondary caries can be expected to yield more fine particles when compared to complex restorations that are lost because of bulk tooth fracture. It is expected that extensive restorations covering many surfaces would be more amenable to sectioning and removal in large sized pieces.

Obenauf and Skavroneck (28) recommended that studies be conducted that document the amount and fate of mercury generated in dentistry. Our study provides the basis for developing more precise estimates of the amount of mercury generated from

dentistry. This can be done by combining our results with studies that assess the number of surfaces of dental amalgam restorations being removed.

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Table 1. Summary of the weight of dental amalgam restorations placed in dentoform and natural teeth

Tooth	No of restored surfaces	Weight of restorations (gram)					
		Natural teeth			Dentoform teeth		
		N	Mean	SD	N	Mean	SD
Premolar	1	4	0.18	0.09	60	0.17	0.12
	2	11	0.44	0.22	20	0.31	0.07
	3	4	0.99	0.52	20	0.49	0.13
Lower molar	1	26	0.50	0.38	40	0.34	0.17
	2	6	0.79	0.29	20	0.56	0.17
	3	5	1.36	0.23	20	0.74	0.17
	4 or more	3	1.90	0.20	28	2.01	0.89
Upper molar	1	25	0.27	0.21	93	0.17	0.12
	2	12	0.60	0.28	30	0.22	0.08
	3	5	1.22	0.35	19	0.65	0.12
	4 or more	7	1.90	0.97	18	1.19	0.38
All	All surfaces	108	0.68	0.61	368	0.48	0.58

Table 2. Summary of the results of ordinary least square regressions and the predicted weight of restorations in teeth

Model characteristics and predicted weights	Regression models for...		
	all teeth (n=476)	*dentoform teeth (n=368)	*natural teeth (n=108)
<b>Overall</b>			
• F-value	184.49	198.07	38.02
• Pr > F	<.0001	<.0001	<.0001
• R <sup>2</sup>	0.7024	0.7323	0.6508
<b>Partial R<sup>2</sup> (P) for Covariates</b>			
• Number of surfaces restored	0.6315 (<.0001)	0.6810 (<.0001)	0.6119 (<.0001)
• Type of tooth	0.0465 (<.0001)	0.0513 (<.0001)	0.0389 (0.0046)
• Dentoform/Natural teeth	0.0244 (<.0001)		
<b>Adjusted mean grams (95% Confidence Limits)</b>			
<b>Number of surfaces restored</b>			
• One surface	0.32 (0.28, 0.37)	0.24 (0.20, 0.29)	0.31 (0.19, 0.42)
• Two surfaces	0.48 (0.41, 0.54)	0.36 (0.29, 0.43)	0.61 (0.47, 0.75)
• Three surfaces	0.80 (0.73, 0.88)	0.62 (0.55, 0.71)	1.19 (1.00, 1.39)
• Four or more surfaces	1.74 (1.65, 1.84)	1.61 (1.52, 1.71)	1.85 (1.61, 2.10)
<b>Type of tooth</b>			
• Lower molar	1.01 (0.96, 1.07)	0.63 (0.57, 0.70)	1.17 (1.04, 1.30)
• Upper molar	0.74 (0.69, 0.80)	0.59 (0.54, 0.65)	0.98 (0.86, 1.09)
• Premolar	0.75 (0.69, 0.82)	0.91 (0.85, 0.96)	0.82 (0.64, 1.01)
<b>Dentoform/Natural teeth</b>			
• Natural teeth	0.95 (0.88, 1.01)		
• Dentoform teeth	0.72 (0.69, 0.76)		

\* Dentoform/Natural tooth not added in the model as covariate