Quantifying Mercury Emissions
Resulting from the Cremation of Dental Amalgam in Minnesota

Final Results

presented to

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by

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Overview – The Problem of Mercury

Minnesota contains vast numbers of lakes and 92,000 miles of rivers and streams (Minnesota Geospatial Information Office [MGDC], 2013). Mercury contamination resulting from air pollution has been detected in Minnesota's fish, and is of concern to human health. Methyl mercury, the type of mercury found in fish and wildlife, is highly toxic and when eaten can build up in the body of animals and humans over time. It is especially harmful to fetuses, babies, and young children (Bose-O'Reilly, McCarty, Steckling, & Lettmeier, 2010). Sources of atmospheric mercury deposition in Minnesota as a consequence of human activity include burning coal, taconite processing, and use of mercury in such products as fluorescent lights, dental fillings, thermostats, and switches. Naturally occurring sources, such as minerals in rocks and volcanoes, account for approximately a third of mercury in the environment (Minnesota Pollution Control Agency [MPCA], 2013).

Mercury and Cremation

Mercury is used in dentistry in the filling material known as dental amalgam. Dental amalgam is approximately 40-50% elemental mercury, 25% silver and a 25-35% mixture of copper, zinc and tin. Mercury incorporated into intact solid fillings has been considered to be inert. In contrast, mercury in dental amalgams is known to vaporize upon exposure to the high temperature of cremation (1400 to 2000 °F). It becomes airborne in the emissions at 674 °F and contributes to environmental mercury pollution (Mari & Domingo, 2009). The potential health effects of exposure to mercury released from dental amalgam restorations during cremation have generated public concern and debate.

Cremation in the United States is an increasingly popular form of disposition. In its recent Annual Statistics Report, the Cremation Association of North America (CANA) reports the 2014 national rate is 46.8% and this number is projected to increase to 52.9% by 2019. Further research indicates that while the growth rate is likely to slow as the cremation rate increases, no specific upper limit has been identified. The trend is also observed in Minnesota, where the cremation rate in 2014 was 57% and projected to rise to 64.3% by 2019. CANA attributes the rising cremation rate to a number of factors including cost (cremation and interment of cremated remains can be less expensive than traditional burial), increased range of

options available with cremation, environmental impact, geography, and religious acceptance (Cremation Association of North America [CANA], 2015, August)

In 2009, The Minnesota Pollution Control Agency (MPCA) projected mercury emissions associated with cremation would rise until 2025, before they begin to decline. This was thought to be a result of decreased dental caries (tooth decay), and the increased use of alternative non-mercury dental filling materials. The quantity of mercury released into the environment, from cremation of human remains, has been estimated many times, but is imprecise and disputable. Large-scale calculations for future projections have been generally based on trends in the caries rate, and the decreasing quantity of mercury sold to and used by dental offices (Northeast Waste Management Officials Association [NEWMOA], 2015). There is a paucity of studies that have actually measured mercury emissions from human remains during cremation. In most of these, the cremations involved human remains that were believed, but not confirmed, to have contained dental amalgam fillings.

Crematoria in Minnesota currently emit an uncertain quantity of mercury into the environment each year. The aging "baby boomer" population, composed of people born between the years 1946 and 1964, tends to have an increased number of dental amalgam fillings. This is due to the use of this material as the standard dental filling material for generations, before the advent and increased popularity of alternatives such as tooth-colored composites (Bharti, Wadhwani, Tikku, & Chandra, 2010). Determining the presence of mercury-containing dental amalgam fillings, prior to cremation, can be difficult depending on the state of the body being cremated. Rigor mortis and embalming can make viewing of the oral cavity difficult to impossible, and care must be employed to avoid damage to the fragile facial tissues. In contrast, the prevalence and distribution of dental amalgam *in vivo* can be much more easily assessed. The measurement and estimation of dental amalgam/mercury load within the mouth, prior to death and cremation, provides an important opportunity to accurately predict and manage mercury emissions.

The goal of this project was to assist the Minnesota Pollution Agency in determining the amount of dental mercury emitted into the environment as a result of cremation. Better emission estimates will help to address the needs and concerns of Minnesota communities in regards to the environmental impact of crematoria emissions. Improved estimates will also assist the funeral profession with proposed 2025 mercury reduction targets set by the MPCA.

Methodology

Purpose of the Research

The purpose of the project was to quantify the number of mercury-containing dental restorations in a population of Minnesotans aged 63 to 79 years. Data were generated from: Task A, patients seen at the University of Minnesota School of Dentistry and Task B, human whole-body donors to the University of Minnesota Anatomy Bequest Program. Investigations for Task A are described below. Due to low subject numbers, investigations for Task B are presented separately in an Appendix to this report.

Population of Interest

The US Census Bureau estimated the population of Minnesota in 2014 at 5,457,173 with 13.9% of the Minnesotans (758,547 individuals) over the age of 65 (United States Census Bureau [US Census], 2015). According to the Minnesota Department of Health, Office of Vital Records, the total number of deaths in Minnesota during calendar year 2014 was 41,510. Within this population of 41,510 deaths, a subpopulation of 11,871 individuals between the ages of 63-79 died during this time period. The total number of cremations performed during 2014 was 23,644, including 7,847 cremations of decedents between the ages of 63 and 79. The average age of death in Minnesota for 2011 was 75.9 years, the average age of cremation was 71.2 years. According to the Office of Vital Records, the standard deviation of the distribution of the ages of death for all Minnesotans was 8.0. Given the limited financial resources available to conduct this research, the decision was made to gather data from a sample of dental records from patients whose age at the time of their death was captured by one standard deviation above and one standard deviation below the mean age of cremation, which as previously noted was 71.2 years. In 2014, the population of interest selected for this research represents 29% of all deaths and 33% of all cremations in Minnesota.

The University of Minnesota School of Dentistry has a large and diverse patient pool with close to 400,000 dental records. In this research, the axiUm™ electronic dental records system utilized in the School was instrumental in anonymously selecting consenting subjects for the study. Sample size of 1,000 current patients from the School of Dentistry was chosen to ensure a confidence level of 95% and a margin of error of approximately 3% for average mercury per person, estimated from a previous pilot study.

Inclusion criteria for the study group, in addition to age, included status as a resident of Minnesota and recent completion of a full mouth dental charting. Subject selection did not discriminate between dentate (with teeth) and edentulous (having no teeth) subjects, because patients do present to the School of Dentistry to obtain dentures. According to the Minnesota Department of Health, the number of adults over 65 years who are missing all natural teeth has declined significantly both nationally and in Minnesota. In 2010, the rate of edentulism was estimated at 17 percent nationally and 11 percent in Minnesotans (Minnesota Department of Health [MDH], 2013).

Mercury Present in Dental Fillings of Patients at the U of M School of Dentistry

After obtaining Institutional Review Board (IRB) consent for this project (U of M IRB Study Number: 1309M42241), the Information Technology (IT) team at the University of Minnesota School of Dentistry performed a query of the axiUm™ electronic dental records system utilized in its clinics. IT screened, and then randomly selected, dental records for patients who: a) consented to release of information for research, b) currently reside in Minnesota, c) were born between the years 1934 and 1950, and d) had a recently completed, full-mouth dental-charting. When a non-eligible patient record was encountered, the record was excluded and the next patient record on the random list was selected. The first 1,000 patients to meet all the inclusion criteria were utilized as subjects for this study.

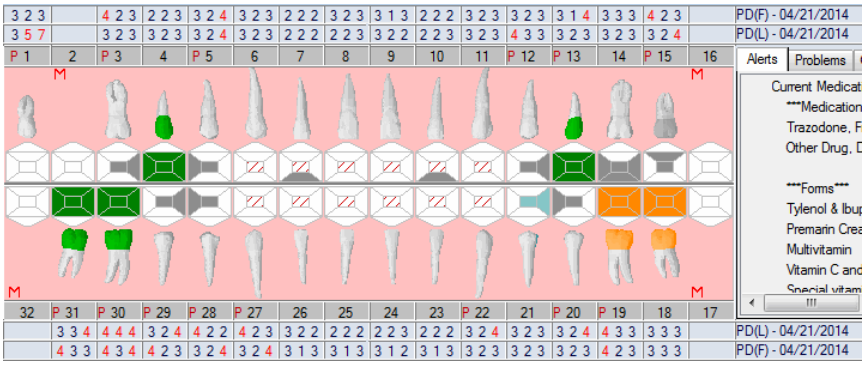
Out of 1,000 patient records reviewed for this research, 988 contained a zip code appearing within the State of Minnesota. The records indicated that patients residing in Minnesota represented 44 of the 87 Counties that make up the State. Additionally, 797 patient records indicated zip codes from the seven counties considered part of the Twin Cities Metropolitan area of Minneapolis and Saint Paul. Additionally, 191 records indicated that the patient resided outside the Metropolitan area. Finally, 12 records noted a zip code in the adjacent State of Wisconsin.

A total of 23,088 teeth were evaluated for dental amalgam. Dentate subjects (983) averaged 24 teeth each. This is in contrast to the mean number of teeth among seniors aged 65 to 74 between 1999-2004, in the US National Health and Nutrition Survey (NHANES), which was calculated to be 19.34. Seventeen subjects in the study were edentulous, and 59 were missing one complete arch of teeth, either maxillary (upper) or mandibular (lower). According to the National Institute of Dental and Craniofacial Research, older seniors, women, current smokers,

and those with lower incomes and less education are more likely to be edentulous. In this study, ethnic and socio-economic data, which may have impacted type or access to dental care, were not collected.

Demographic data recorded for each eligible subject included: zip code, gender, month and year of birth, and total number of teeth. A computer snapshot (screen-cap) of the axiUm™ dental-charting for each eligible subject was obtained (Fig. 1). Subjects were then de-identified and assigned an anonymous research identification number. A spreadsheet was utilized to record data from each screen-cap. Screen-cap data included the number of surfaces of dental amalgam and full crowns in: 1) maxillary (upper) anterior, premolar, and molar teeth and 2) mandibular (lower) anterior, premolar, and molar teeth (Fig. 2).

Fig. 1 AxiUm™ Dental Chart Screen-Cap



Key: gray = dental amalgam; green = porcelain fused to metal crown; gold = gold crown; blue = composite filling; M = missing tooth

Fig. 2 Data Collected

Research ID #	Zip Code	Gender	Month/Year Birth
1683	55407	F	03/1949
Surfaces of Amalgam	**Molars**	**Premolars**	**Anterior Teeth**
Maxillary Teeth	8	4	2
Mandibular Teeth	0	6	0
Crowns	**Molars**	**Premolars**	**Anterior Teeth**
Maxillary Teeth	0	2	0
Mandibular Teeth	4	0	0

Quantifying the weight of dental amalgam per tooth surface

Teeth with dental amalgam restorations were grouped into the following three categories: a) non-molars (premolars and anterior teeth), b) mandibular molars, and c) maxillary molars. The weight per tooth surface of dental amalgam was calculated using the findings of Adegbembo et al. for restorations in natural teeth (Adegbembo, Watson, & Rokni, 2004). Table 1 summarizes the values used.

Table 1 Weight of Dental Amalgam Per Surface

Teeth	Average Weight Dental Amalgam/Surface (g)
Non-molars	0.2543
Mandibular Molars	0.4426
Maxillary Molars	0.3380

Quantifying the weight of dental amalgam under crowns

The following two investigations were undertaken to aid in quantifying dental amalgam under crowns.

Investigation 1

Determine the size difference between premolar and molar crown interior volumes (crown preparations).

A set of stainless steel prefabricated crowns was utilized to determine the relative size difference between premolar and molar crown preparations. Crowns used were maxillary and mandibular 1st and 2nd premolars, and 1st and 2nd molars. The crowns were weighed twice: 1) empty, and then 2) filled with Imprint™ II Garant™ (3M™) vinyl polysiloxane impression material, to determine a ratio for the interior volumes. (Table 2)

Table 2 Interior Volume of Premolar and Molar Stainless Steel Crowns

Teeth	Average Weight Impression Material
Premolars	0.390 g
Molars	0.853 g

Interior volume of premolar stainless steel crowns is ~46% of molar crowns.

Investigation 2

Determine the volume of dental amalgam under crowns.

Twenty-five randomly extracted molar teeth with intact full crowns were acquired. Tooth structure, interior cement, and filling materials were removed utilizing a combination of decalcification, hand, and rotary instrumentation. The crowns were weighed twice: 1) empty, and then 2) filled with Imprint™ II Garant™ (3M™) vinyl polysiloxane impression material. Average weight of the impression material in the 25 empty crowns was computed to be 0.28 g.

Next, two empty stainless steel premolar crowns were filled and weighed with 1) impression material (average = 0.26 g), and then 2) dental amalgam (average = 2.04 g). This ratio was used to compute the average maximum weight of 2.20 g dental amalgam, for the 25 empty molar crowns. Non-molars (including premolars) at 46% contain a maximum of 1.01 g dental amalgam.

Subject demographics are shown below in Table 3.

Table 3 School of Dentistry Study Population

Characteristics	All Subjects N=1000
Age (years) – mean (SD)	70.9 (4.3)
Range – (min, max)	(63.1, 79.0)
Male – n (%)	525 (52.5)
Female – n (%)	475 (47.5)

Results

Tooth surfaces of dental amalgam counted are summarized in Table 4, along with the weight of dental amalgam calculated, per Adegbembo et al.

Table 4 Number of Surfaces and Weight of Dental Amalgam (N = 1000 subjects)

Tooth Type	Surfaces Amalgam	Weight/ Surface (g)*	Weight Amalgam (g)
Non-molars	3523	0.2543	895.9
Mandibular molars	1727	0.4426	764.4
Maxillary molars	2151	0.3380	727.0
Total:	7401		2387.3

*per Adegbembo et al.

Number of crowns observed is presented in Table 5. Crowns are grouped into non-molars and molars. Dental crowns can cover residual dental amalgam filling material, or amalgam used to build-up a tooth prior to crown placement. However, dental amalgam is not present under all crowns and when present varies in amount.

Table 5 gives an estimation of the dental amalgam under crowns. This scenario assumes that 1) half of the crowns cover dental amalgam, and 2) the amount present under these crowns is 50% of the maximum possible (calculated previously at 1.01 and 2.20 grams for non-molar and molar crowns respectively).

Table 5 Estimation of Dental Amalgam Under Crowns

Tooth Type	# Crowns	½ Crowns with amalgam	50% Maximum Weight Amalgam per Crown (g)	Dental Amalgam (g)
Non-Molar Crowns	3694	1847	0.51	941.97
Molar Crowns	3088	1544	1.10	1698.40
Total:	6782	3391		2640.37

Table 6 provides an estimation of the total dental amalgam and mercury in grams for the total subject group of 1,000.

Table 6 Total Dental Mercury

Restoration Type	Number	Weight Amalgam (g)	Mercury Content (@45%) (g)
Surfaces of Dental Amalgam	7401	2387.30	1074.28
Crowns	3391	2640.37	1188.16
Total Mercury present:		5027.67	2262.44

The mercury content of 45% was based on the average amount of mercury found in nine types of dental amalgam we surveyed. Results of this research study indicate a weight value of approximately 2.3 grams of mercury per subject.

Discussion

Dental Amalgam Under Crowns

An important early finding in this research was the observation of a significant number of full dental crowns in the population sampled. This discovery prompted further investigation into the amount of dental amalgam present under crowns. Residual amalgam may be left in place during tooth preparation for a crown, or it may be present due to its use as a sturdy material for building up the tooth. In general, crown preparation reduces tooth size, including existing restorative materials, such as composite or dental amalgam. The amount of dental amalgam under a crown can range from zero (none present) to the maximum value we previously computed for molars (2.20 g) and premolars (1.01 g).

Factors considered in estimating the amount of dental amalgam under crowns include: 1) Amalgam is not always present, and 2) If amalgam is present, the amount will vary. Quantifying the total amount of mercury in dental restorations within the oral cavity must take into consideration surfaces of dental amalgam plus dental amalgam in other locations, such as under crowns. Additional research to more precisely quantify the amount of dental amalgam under crowns is needed.

Edentulism

The rate of edentulism in the study population was much lower than the 11% rate estimated by the Minnesota Department of Health for the State of Minnesota. Subjects in the study were noted as dentulous if they had one or more remaining natural teeth. This resulted in seventeen (1.7%) of subjects in the study designated as edentulous, because they had no remaining natural teeth; three subjects (0.3%) had only two teeth each; and fifty-nine subjects (6%) were missing one complete arch of teeth, either maxillary (upper) or mandibular (lower). Data on socioeconomic status were not collected in this research. The higher number of subjects with teeth and extensive dental restorations (crowns and fillings) may be linked to socioeconomic factors, and/or access to care issues in the dental school. Further characterization of the patient population that visits the School of Dentistry can help in understanding factors that may have influenced the results.

Significance of Data

The Minnesota Pollution Control Agency (MPCA) maintains an inventory for sources of mercury air emissions in the state. A large number of lakes and rivers in Minnesota are mercury impaired, do not meet Federal Clean Water Standards, and contain fish with high mercury concentrations. For this reason, an active mercury air emissions reduction plan, with final reduction goals in 2025, has been implemented. The Minnesota Department of Health issues fish consumption advisories to minimize the human health impact of mercury-contaminated fish. Women of childbearing age and children are restricted to one meal of fish per month, from Minnesota bodies of water contaminated with mercury.

The MPCA used the data from this research to compute a more accurate estimate of annual mercury emissions for crematories in Minnesota. The Bay Area Air Quality Management District (BAAQMD) in California issued a memorandum calculating the average amount of dental mercury in each human in 10 different age groups based on data from the Center of Disease Control (CDC) National Health and Nutrition Examination Survey (NHANES) (Lundquist, 2012). The MPCA used the 10 age groups from the CDC Wonder Database separating out the infants under 1 year for an additional group (CDC, 2012). MPCA then used the 2.3 grams of mercury per person from the research project quantifying mercury emissions from cremation of dental amalgam in Minnesota by applying it to the ages 63 to 79. The age groups on either side of our sample groups were adjusted to 54 to 62 years and 80 years +. It was determined that the 2.3 grams/person from our study was a multiple of 1.77 higher than the BAAQMD grams per person estimate. To account for this a coefficient of 1.77 was used across the table to calculate new emission estimates for the age groups. The numbers were then multiplied by number of cremations in 2014 for that age group from Minnesota Department of Health's office of vital records. An edentulous population of 11% was removed from the top two age groups 63-79 and 80+, resulting in a total mercury emissions estimate for cremations in Minnesota in year 2014 at 95 lbs. This result is one-third lower than the previous MPCA estimate for 2014.

The results of this study are specific to residents of the State of Minnesota. Findings of a low edentulism rate and high number of dental restorations (fillings and crowns) are most likely linked to demographic and socioeconomic factors not assessed in this research. Mercury

emissions likely vary in other states based on factors such as access to dental care, employment status, educational attainment, dental insurance, and attitudes toward dental care such as anxiety and fear. Caution must be exercised in utilizing the results of this study to estimate mercury emissions from crematoria in other states or locations.

APPENDIX

Task B of the project utilized the Anatomy Bequest Program at the University of Minnesota. This is a whole-body donation program, the purpose of which is to support both education of health professionals and medical research. The program received 539 donors in 2013 and 567 donors in year 2014. The number of subjects aged 63 to 79 for both years totaled 464. All donors were from Minnesota, with the exception of 15 who were from Wisconsin. Cremation was used for final disposition, with the exception of five donors whose remains were buried instead of being cremated.

Donor cadavers utilized for this portion of the study were those used in the regular medical and dental anatomy courses. The average length of time cadavers remain in the regular anatomy lab is 12 months. Complete project set-up and funding occurred in the fall months of 2013, with evaluation of cadavers predominantly taking place throughout calendar year 2014. Qualifying criteria for the study group included age, and the ability to access the oral cavity to perform a full mouth dental charting. A total of 28 cadavers met these criteria. Subject selection did not discriminate between dentate (with teeth) and edentulous (having no teeth) subjects. The methodology to evaluate dental amalgam in fillings and crowns was the same as that utilized in Task A.

Results

Donor demographics are shown below in Table A.

Table A Anatomy Bequest Study Population

Characteristics	All Subjects N=28
Age (years) – mean (SD)	70.8 (4.6)
Range – (min, max)	(63.0, 78.0)
Male – n (%)	16 (57.1)
Female – n (%)	12 (42.9)

A total of 489 teeth in 28 cadavers were evaluated for dental amalgam. Dentate subjects (25) averaged 19.56 teeth each. This is close to the mean number of teeth among seniors aged 65

to 74 between 1999-2004, as noted in the US National Health and Nutrition Survey (NHANES), which was calculated to be 19.34. Three cadavers (~11%) were edentulous, close to the 11% value projected by the Minnesota Department of Health. Ethnic and socio-economic data, which may have impacted type or access to dental care, were not available for the donor group.

Tooth surfaces of dental amalgam counted are summarized in Table B, along with the weight of dental amalgam calculated per Adegbembo et al.

Table B Number of Surfaces and Weight of Dental Amalgam (N = 28 subjects)

Tooth Type	Surfaces Amalgam	Weight/ Surface (g)	Weight Amalgam (g)
Non-molars	51	0.2543	12.99
Mandibular molars	29	0.4426	12.84
Maxillary molars	26	0.3380	8.79
Total:	106		34.59

The number of crowns observed is seen in Table C along with an estimation of the dental amalgam under crowns. This scenario again assumes that 1) half of the crowns cover dental amalgam, and 2) the amount of amalgam present under these crowns is 50% of the maximum possible (calculated previously at 1.01 and 2.20 grams for non-molar and molar crowns respectively).

Table C Estimation of Dental Amalgam Under Crowns

Tooth Type	# Crowns	½ Crowns with amalgam	50% Maximum Weight Amalgam per Crown (g)	Dental Amalgam (g)
Non-Molar Crowns	82	41	0.51	20.91
Molar Crowns	65	32.5	1.10	35.75
Total:	147	73.5		56.66

Table D provides an estimation of the total dental amalgam and mercury in grams for the subject group of 28.

Table D Total Dental Mercury

Restoration Type	Number	Weight Amalgam (g)	Mercury Content

			(@45%) (g)
Surfaces of Dental Amalgam	106	34.59	15.56
Crowns	73.5	56.66	25.49
Total Mercury present:		91.25	41.05

Mercury content computed to approximately 1.5 grams of mercury per donor subject.

Discussion

Dental charting was completed for 28 cadavers, over a time period of approximately 14 months. This lower-than-expected number of eligible cadavers was due to the number of cadavers that could be accommodated in the anatomy laboratory each semester, plus the lengthy stay of the cadavers in the lab (average 12 months). The required specific age range for this study eliminated many subjects, who were observed to be either younger than 63, or older than 79 years of age. Access to the oral cavity in some cadavers was impaired or compromised for various reasons, and not possible at all in embalmed, un-dissected cadavers. As a consequence, the target goal of evaluating 100 cadavers was not achieved.

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