The Relationship Between Amalgam Restorations and Mercury Levels in Male Dentists and Nondental Health Professionals

Anil Joshi, BDS, MPH; Chester W. Douglass, DMD, PhD; Hyun-Duck Kim, DDS, PhD; Kaumudi J. Joshipura, BDS, ScD; M. Chu Park, DMD; Eric B. Rimm, ScD; Michael J. Carino, DDS; Raul I. Garcia, DMD, MMS; J. S. Morris, PhD; Walter C Willett, MD, DrPH

Abstract

Objectives: *The objectives of this study were: (1) to compare the mercury levels in general dentists with the mercury levels in other health professionals using toenail clippings as a biomarker, (2) to identify risk factors associated with high mercury levels, and (3) to compare practice characteristics of dentists with high and low mercury levels.* ***Methods:*** *A sample of 579 men was randomly selected from the 33,737 men participating in the Health Professionals Follow-up Study who had provided toenail samples in 1987. A questionnaire was sent to these male subjects in 1991 to obtain information on fish consumption, toothbrushing frequency, number of teeth, number of amalgam restorations, general practice or specialty status, number of amalgam restorations placed and removed per week, mercury storage and handling procedures, and mercury spillage incidents. A measure of long-term mercury exposure was obtained from toenail samples using neutron activation analysis for the 410 respondents (71% response rate). The 90th percentile mercury level in toenails (0.88 ppm) was selected as the threshold for elevated toenail mercury level.* ***Results:*** *No relationship was found between the number of dental amalgams and toenail mercury levels among general dentists, dental specialists, and nondental health professionals. General dentists were found to have more than twice the level of mercury in toenails than nondental health professionals (mean level=0.94 vs 0.45) and 60 percent higher than dental specialists (mean=0.59). The combined use of disposable capsules and water storage of scrap amalgam appeared to reduce the risk of elevated mercury levels. Regardless of professional status, consumption of tuna and saltwater fish were the primary exposure factors that were positively associated with toenail mercury levels.* ***Conclusions:*** *As shown by the associations with dental profession and fish consumption, the mercury content of toenails is a stable biomarker of cumulative long-term mercury exposure. The lack of association between nail mercury levels and number of amalgam restorations suggests that avoidance of mercury amalgam restorative materials cannot be justified by the presence of mercury released from dental amalgams. [J Public Health Dent 2003;63(1):52-60].*

Key Words: amalgam, restorations, mercury, fish, dentists, risk factors, biomarker.

The potential for health hazards due to mercury continues to be a controversial issue for dentists, patients, and environmentalists. One can now find 52 different subject categories that "document" the wide array of health threats from dental amalgam mercury at http://www.amalgam.org. Subjects discussed range from impaired kidney function to cardiac dysfunction, fetal malformations, and infertility. In view of the continuing questions regarding the use of dental amalgam in restorative dentistry, the present study is particularly relevant and timely.

Although dental professionals are occupationally exposed to mercury (2-4), the current focus of controversy is concerned with the safety of patients, based on studies showing mercury vapor released from dental amalgam restorations. A recent publication based on a random survey of the public in Australia (5) reported that 37.5 percent of the sample were concerned about mercury in fillings, 16.2 percent asked to have fillings that don't contain mercury, and 4.7 percent had fillings replaced because they contained mercury. Several studies have shown release of small amounts of mercury in the form of metallic vapor and ions (6-10). Based on these studies, it seems logical to hypothesize that the higher the number of amalgam restorations (other factors being constant such as recency of restorations, brushing frequency, chewing, and bruxism), the greater will be the amount of mercury release. Nylander et al. (11) suggested that these mercury vapors are inhaled and the mercury is absorbed into the blood stream and transported to target tissues, especially in the kidney and central nervous system.

In addition to dentist and patient safety concerns, several European countries have recognized theoretical environmental consequences due to the use of mercury by the dental profession. Accordingly, recommendations have been made to reduce mercury discharge (12) and to conduct fur-

Send correspondence and reprint requests to Dr. Douglass, Harvard School of Dental Medicine, Department of Oral Health Policy and Epidemiology, 188 Longwood Avenue, Boston, MA 02115. E-mail: chester_douglass@hsdm.harvard.edu. Drs. Joshi, Kim, Joshipura, and Park are with the Harvard School of Dental Medicine. Drs. Rimm, Willett, and Joshipura are with the Harvard School of Public Health. Dr. Carino is in the Office of the Surgeon General, United States Army, Washington, DC. Dr. Garcia is with the Boston University Goldman School of Dental Medicine and Massachusetts Veterans Epidemiology Research and Information Center. Dr. Morris is with the Research Reactor Facility, University of Missouri, Columbia, MO. The study was supported by research grants from NHLBI #HL35464, NCI #CA55075, and by the NIDCR (K24 DE 00419). Manuscript received: 6/15/01; returned to authors for revision: 9/13/01; final version accepted for publication: 2/13/02.

ther research on the proper storage conditions (dry or in liquid) for amalgam scraps and used capsules. Some countries have developed policies to phase out use of dental amalgam restorations (13,14). However, there is no clear evidence about any environmental damage or clinically detectable pathology caused by mercury in dental amalgams. One recent study showed that levels of mercury exposure comparable to those found with amalgams were correlated with what they termed "subtle" mood disturbances, motor function, and cognition (15). Those investigators suggested that mercury exposure showed greater association with CNS effects than longer term body burden of mercury. The measures of mood, motor function, and cognition were, however, within an apparently normal clinical range, hence the differences between people with high and low mercury levels were slightly adverse but at a preclinical level.

The present study was designed to document mercury levels in a large study population related to dietary, occupational, and dental amalgam exposure. The specific aims of the study were: (1) to compare the mercury levels in general dentists with the mercury levels in other health professionals using toenail clippings as a biomarker, (2) to compare practice characteristics of dentists with high and low mercury levels, and (3) to examine the relationships of dental amalgams and other contributors to mercury levels.

Methods

The Health Professionals Follow-up Study (HPFS) is a large, prospective study initiated in 1986 to investigate the dietary etiology of cardiovascular disease and cancer. It includes 51,529 men 40–75 years of age from seven health occupations. Dentists comprise 57.6 percent (29,683) of the study population. Other health professionals include veterinarians (19.6%), osteopathic physicians (4.3%), podiatrists (3.1%), pharmacists (8.1%), and optometrists (7.3%). In 1986 all cohort members completed a mailed questionnaire about dietary intake, medical history, and various health-related behaviors. Every two years, follow-up questionnaires are sent to update information on newly diagnosed diseases during the previous two years. In 1987 sets of toenails were collected from 33,737 cohort members and stored for subsequent analysis (16). The details of the cohort population and methods of the Health Professionals Follow-up Study and the toenail collection have been reported by Rimm et al. (17) and Yoshizawa et al. (16).

The data for this study were obtained from a sample of 579 men from the HPFS who were selected as controls for a nested case-control study of toenail trace element levels and coronary heart disease risk. Randomly selected controls were matched to CHD cases on age, smoking status, and time (month) of return of their toenail clippings. Thus, the distribution of age and smoking status of these samples reflect those of the coronary heart disease cases rather than those of the overall cohort.

All 579 subjects were sent a short supplementary questionnaire in 1991 to obtain information on fish consumption (tuna, saltwater fish, and freshwater fish), toothbrushing frequency, and three dental variables: (1) number of teeth, (2) number of teeth with "silver" amalgam restorations, and (3) number of "silver" amalgam restorations on occlusal surfaces. In addition, dentist participants were asked about their dental practice characteristics regarding (1) general practice or specialty; (2) number of amalgam restorations placed per week; (3) number of amalgam restorations removed per week; and (4) mercury storage procedures, mercury spillage incidents, and method of handling of amalgam preparation (4,18). A response rate of 70.8 percent (410/579) was achieved.

Because urine and blood, the most commonly used biomarkers of mercury, are measures of short-term exposure (19-21), toenail mercury level was used as a longer term relatively stable biomarker of the body burden of mercury. Mercury levels from toenail samples of these subjects were measured using neutron activation analysis at the University of Missouri Research Reactor (MURR) in Columbia, MO. Prior to the analysis, the toenail clippings were washed with deionized water by use of a sonicator (22). Neutron activation analysis of toenail samples is a highly sensitive technique and allows for the estimation of mercury levels in amounts of 10^{-10} grams (23). It is particularly appropriate for studying subjects with relatively low level exposures, such as the nondental health professionals in this study.

Although specialists such as prosthodontists and endodontists occasionally may provide a few procedures involving the use of dental amalgam, dental specialists are not as regularly exposed to mercury vapors as are general dentists. Therefore, in our analyses we considered dental specialists as a separate category and hypothesized that their mercury exposure would be higher than nondentists but lower than general dentists. Of the 50 dental specialists in the study sample, five were pediatric dentists and were included in the general dentists group because their pattern of restorative services rendered is similar to the case mix of general practitioners.

Since there is no standard for elevated toenail mercury level, the 90th percentile mercury level in toenails among the 196 nondentists, 0.88 ppm, was selected as the threshold level for elevated toenail mercury level. Using this threshold, the 132 dentists in this study were divided into those with elevated body mercury level (n=49) and with normal body mercury level (n=83). The ranges of toenail mercury were .90–13.76 ppm (median 1.47 ppm) in the elevated body mercury level group and .06–.86 ppm (median=.44 ppm) in the normal body mercury level group.

We were interested in knowing whether the presumed risk factors or handling methods led to elevated mercury levels. Both mean and median levels of mercury were computed for each of the three study groups, viz. nondentists, general dentists, and dental specialists. Since the findings were consistent for mean and median levels of mercury, most tables include only one of these two measures. Further, because the mercury levels were not normally distributed, they were log transformed before statistical tests were carried out, or nonparametric statistics were used such as Kruskal-Wallis test and Spearman correlation. The dependent variable, mercury level, was log transformed and was evaluated using linear regression. Tuna and saltwater fish consumption were modeled as continuous variables with consumption frequencies weighted as follows: <1 serving/month=0; 1–3 servings/month= 0.5; 1

serving/week=1.0; 2–4 servings/week=3; and 5–6 servings/week=5.5). Associations between amalgam handling methods and elevated Hg level in toenails were evaluated using logistic regression controlling for age, number of teeth with amalgam, and saltwater fish consumption.

Results

The mean age of general dentists, specialists, and nondentists ranged from 60.9 to 61.5 years, and the mean number of occlusal amalgam restorations varied between 3.8 for specialists and 4.8 for general dentists and nondentists (see Table 1). The nondentists had significantly fewer teeth and lower frequency of toothbrushing than the two groups of dentists; general dentists and specialists had 27 teeth on average; the nondentists reported only 23.7 teeth on average, $P<.05$). As hypothesized, the general dentists had significantly higher levels of mercury than nondentists and specialists. The mean toenail mercury levels for dentists (0.94 ppm) was twice as high as the nondentists (0.45 ppm) and approximately 60 percent higher levels than for specialists (0.59 ppm). A similar trend was seen in the three study groups when median mercury levels were compared.

Consumption of tuna fish and other saltwater fish could contribute to the blood and toenail levels of mercury and may confound the occupational exposure effect. We therefore examined the mercury levels in three occupational groups stratified by frequency of tuna consumption. Mercury levels increased with increasing consumption of tuna fish for all three study groups, supporting the hypothesis that tuna consumption leads to higher mercury levels (Table 1). Nevertheless, within each level of tuna consumption, the differences between occupational groups remained similar to those in Table 2.

To understand the relationship between amalgam restorations and body mercury levels, we examined mercury

TABLE 1
Mercury Levels in Three Health Profession Groups, by Frequency of Tuna Consumption

	Tuna Consumption					
	Almost Never		Once/Week		≥Twice/Week	
	n	Mean (SD)	*n*	Mean (SD)	*n*	Mean (SD)
General dentist	46	0.81 (0.99)	106	0.85 (0.73)	17	1.78 (1.51)
Specialist	20	0.40 (0.31)	20	0.64 (0.44)	5	1.15 (1.36)
Nondentist	67	0.33 (0.23)	112	0.45 (0.35)	17	0.89 (0.68)

TABLE 2
Age, Number of Teeth, Amalgam Restorations on Occlusal Surfaces, Toothbrushing Frequency, and Mercury Levels by Study Groups

Study Subjects	No. of Subjects	Age Mean (SD)	No. of Teeth Mean (SD)	No. of Occlusal Restorations Mean (SD)	Toothbrush Frequency per Day Mean (SD)	Mercury Levels (ppm) Mean (SD)	Mercury Levels (ppm) Median (10th, 90th Percentile)
General dentists	169	60.9 (8.4)	27.0 (4.5)	4.8 (4.1)	2.5 (1.1)	0.94 (0.95)	0.62 (0.22, 1.93)
Dental specialists	45	60.1 (7.2)	27.1 (4.5)	3.8 (4.3)	2.1 (0.9)	0.59 (0.59)	0.37 (0.09, 1.32)
Nondentists	196	61.5 (7.8)	23.7* (7.6)	4.8 (4.1)	1.8* (0.8)	0.45 (0.38)	0.33† (0.13, 0.86)

*Nondentists have significantly lower numbers of teeth and toothbrush frequency than the other two groups (Kruskal-Wallis test; $P<.05$).
†Toenail mercury levels are significantly different in the three groups. Kruskal-Wallis test (chi-square approximation=50.4; DF=2; $P=.0001$).

TABLE 3
Mercury Levels by Number of Amalgam Restorations and Tuna Consumption (Nondentist Group)

	Number of Amalgam Restorations							
	0		1–4		5–10		>10	
Frequency of Tuna Consumption	*n*	Median Hg (ppm)	*n*	Median Hg (ppm)	*n*	Median Hg (ppm)	*n*	Median Hg (ppm)
Almost never	11	0.31	22	0.22	22	0.27	10	0.26
≤Once/week	22	0.31	38	0.46	42	0.31	7	0.43
≥Twice/week	2	1.05	6	0.78	7	0.48	2	0.77
All	35	0.31	66	0.36	71	0.32	19	0.35

TABLE 4
Mercury Levels (Hg) by Number of Amalgam Restorations and Tuna Consumption (Dentist Group)

	Number of Amalgam Restorations							
	0		1–4		5–10		>10	
Frequency of Tuna Consumption	*n*	Median Hg (ppm)	*n*	Median Hg (ppm)	*n*	Median Hg (ppm)	*n*	Median Hg (ppm)
Almost never	18	0.36	24	0.52	21	0.38	2	0.18
≤Once/week	25	0.64	41	0.59	41	0.58	10	0.74
≥Twice/week	4	0.44	12	1.17	5	1.50	1	1.45
All	47	0.54	77	0.62	67	0.53	18	0.67

TABLE 5
Spearman Correlation Coefficients Between Toenail Mercury Levels and Selected Exposure Variables

Exposure Variables	Dentist (GP) (*n*=169)	Dentist (SP) (*n*=45)	Nondentist (ND) (*n*=196)	All (*n*=410)
Number of teeth	0.07	0.10	0.06	0.13*
Occlusal restorations	0.00	0.06	–0.05	–0.02
Brushing frequency	0.12	0.20	–0.03	0.16*
Tuna fish consumption	0.26*	0.30*	0.34*	0.31*
Saltwater fish consumption	0.32*	0.41*	0.35*	0.35*
Freshwater fish consumption	0.01	–0.03	–0.06	–0.03

GP=general practitioner; SP=dental specialist; ND=nondental health professional.
*Significant at the .05 level.

TABLE 6
Results of Multivariate Regression Analysis to Identify Predictors of Toenail Mercury Levels

Independent Variables	Regression Coefficients	Standard Error of Coefficient	*P*-value
Age (years)	–0.005	0.004	.21
Tuna consumption frequency*	0.18	0.05	.0001
Saltwater fish consumption frequency*	0.24	0.05	.0001
Occupational status (two indicator variables)			
General dentist (1, 0)	0.56	0.08	<.0001
Dental specialist (1, 0) (Nondentist=referent)	0.04	0.13	.70
Number of occlusal restorations	–0.009	0.009	.29
Toothbrushing frequency	0.03	0.04	.41
Intercept	–0.97	0.33	.003

*Continuous variable: 0.0=almost never; 0.5=1–3/month; 1.0=1/week; 3.0=2–4/week; 5.5=5–6/week.
Dependent variable: log-transformed toenail mercury levels.
Model description: *n*=397; adjusted R^2=.26; F=21.23, degrees of freedom=7; *P*<.0001.

levels in individuals categorized by number of occlusal amalgams within strata of professional groups (general dentists, dental specialists, and nondentists) and tuna consumption. Because nondentists have no occupational exposure to mercury, the relationship between amalgam restorations and mercury levels should be seen most clearly in that group. For nondentists, the mean level of mercury remained virtually constant with increasing number of amalgam restorations (range=0.40–0.49 ppm; data not shown in the table). Table 3 shows similar trends using median mercury levels. Conversely, there was a clear pattern of increasing mercury levels with increased levels of tuna consumption (Table 1). Table 4 shows similar median mercury level trends for general dentists and specialists combined.

Spearman correlation coefficients between mercury levels and several "dental" and fish consumption variables are shown in Table 5. Consistent with the previous data, no correlation was found between occlusal amalgams and mercury levels; however, tuna or saltwater fish consumption were significantly associated with mercury levels in all three study groups. Table 6 shows the results of a multiple regression analysis carried out to identify the dental and fish consumption variables that were independently associated with mercury levels. Consistent with the stratified analysis, the number of occlusal amalgam restorations was not associated with toenail mercury levels after controlling for tuna consumption, saltwater fish consumption, and occupational status.

An analysis of practice charac-

TABLE 7
Practice Characteristics of General Dentists and Mercury Levels

Practice Characteristic	*n*	Mean (SD)	Median	10th Percentile	90th Percentile
Number of amalgams placed per week					
0–4	7	0.80 (0.41)	0.76	0.25	1.36
5–24	33	0.97 (0.87)	0.73	0.25	1.83
25–49	60	0.83 (0.93)	0.52	0.22	1.73
50–74	33	1.13 (1.27)	0.67	0.18	3.22
75–100	16	0.78 (0.58)	0.61	0.15	1.55
100+	7	1.74 (1.18)	1.64	0.44	3.54
Number of amalgams removed per week					
0	5	0.55 (0.40)	0.35	0.25	1.20
1–4	27	1.03 (1.14)	0.73	0.23	1.89
5–9	36	1.03 (1.14)	0.70	0.22	2.96
10–19	44	1.10 (0.96)	0.81	0.26	2.68
20–29	27	0.71 (0.71)	0.48	0.15	1.55
30 or more	16	0.81 (0.87)	0.44	0.18	2.21
Percent of amalgams removed by drycutting					
0	124	0.94 (0.92	0.66	0.21	1.77
1–49	25	1.11 (1.21)	0.69	0.22	2.54
50–100	9	0.83 (0.87)	0.58	0.15	3.01
Amalgam preparation method					
Premixed disposable capsules in amalgamators	63	0.94 (0.88)	0.67	0.23	1.93
Reusable capsules or cylinders in amalgamators	94	0.90 (0.90)	0.61	0.22	1.83
Hand-mixed with mortar and pestle	4	0.64 (0.20)	0.69	0.36	0.82
Other	5	2.07 (1.14)	1.32	0.11	5.36
Percentage of time dentist removed excess mercury from amalgams (as opposed to auxiliary)					
None	88	0.88 (0.87)	0.61	0.19	1.75
1–19	30	0.91 (0.91)	0.57	0.24	2.12
20–74	16	1.02 (0.95)	0.67	0.25	3.01
75–99	10	0.72 (0.53)	0.51	0.24	1.62
100	25	1.18 (1.30)	0.73	0.30	2.96
Number of times mercury spilled in office per year					
0	79	0.98 (0.95)	0.73	0.23	1.89
1–3	52	0.89 (0.99)	0.55	0.22	1.93
3–10	19	0.79 (0.85)	0.44	0.21	2.54
>10	7	1.34 (1.43)	0.79	0.29	4.32
Total chairside hours spent per week					
<30	26	0.84 (1.13)	0.58	0.24	1.75
30–40	111	1.01 (0.95)	0.64	0.24	2.21
>40	32	0.75 (0.71)	0.57	0.17	1.20

teristics of general dentists using mean and median levels of mercury did not show any linear trend with increasing number of amalgam restorations placed per week (Table 7). However, seven dentists who reported placing more than 100 amalgam restorations per week did have more than twice the mean level of mercury (mean=1.74; SD=1.18) than dentists who placed fewer than 100 amalgams. The analysis of toenail mercury levels and number of amalgam restorations removed per week showed an initial increase in median mercury levels with increasing number of amalgam restorations removed per week. However, the median mercury levels decline once a threshold of 20 amalgam restorations removed per week was reached. Moreover, the median mercury levels were significantly lower in dentists who removed more than 20 amalgam restorations per week than in dentists who removed fewer than 20 per week (Wilcoxon rank-sum test; $P<.05$). Twenty-one percent (34/168) of general dentists reported removing amalgam with high-speed handpiece without water spray. However, there was no significant difference in mercury levels between those who employed drycutting of amalgam restorations and those who did not.

The relationship between practice characteristics of general dentists and

TABLE 8
Association Between Presumed Risk Factors and Elevated Mercury Level

Risk Factor Category	Elevated Hg (≥90th Percentile) No. (%)	Normal Hg (<90th Percentile) No. (%)	Crude OR (95% CI)	Adjusted OR (95% CI)
Amalgam mixing methods				
Reusable capsule (RC)	18 (36.7)	31 (37.4)	Referent	Referent
Disposable capsule (DC)	31 (63.3)	52 (62.3)	0.97 (0.47, 2.02)	0.73 (0.37, 1.85)*
Scrap amalgam storage methods				
Nonwater (NS)	45 (91.8)	70 (84.3)	Referent	Referent
Water storage (WS)	4 (8.2)	13 (15.7)	0.48 (0.15, 1.56)	0.39 (0.11, 1.43)*
Combination of methods				
RC and NS	28 (96.6)	44 (89.8)	Referent	Referent
DC and WS	1 (3.4)	5 (10.2)	0.31 (0.03, 2.83)	0.18 (0.02, 1.81)†

*Adjusted for age, number of teeth with amalgam, and saltwater fish consumption as well as mutually (n=132).
†Adjusted for age, number of teeth with amalgam, saltwater fish consumption (n=78).

mercury level was further examined using multiple regression analysis (Table 8). No practice variables were significantly associated with mercury levels except number of restorations removed per week; removal of 20 amalgams or more per week was, unexpectedly, negatively associated with mercury levels.

With regard to practice characteristics, only 13 percent of dentists used the water storage method when their remaining scrap amalgam was discarded and 37 percent of them used disposable capsules when mixing amalgam. However, the distribution of the use of the water storage method did not differ between the elevated body mercury level group and the normal body mercury level group (P>.05). Only six dentists 4.5 percent used both the water storage and disposable capsules. The prevalence of amalgam mixing methods were similar between the elevated body mercury level group and normal body mercury level group (P>.05).

Compared to the use of reusable capsules, the use of disposable capsules did not appear to reduce the elevated body mercury (crude OR=0.97; 95% confidence interval [CI]=0.47, 2.02). In contrast, the use of water storage for scrap amalgam might reduce the risk of the elevated body mercury level (crude OR=0.48; 95% CI=0.15, 1.56 compared to the use of the nonwater storage) although the association was not significant. When associations were adjusted for covariates such as age, number of teeth with amalgam restorations, and saltwater fish consumption, the use of disposable capsules and the use of water storage both remained associated with a nonsignificant reduction in risk of elevated body mercury level.

Hence, the combined use of disposable capsules and a water storage method may, with larger sample sizes, show a dramatic reduction of the risk for elevated mercury level compared with the combined use of reusable capsules and a nonwater storage method.

Discussion

Amalgam Restorations and Mercury Levels. The present study provides further evidence that there is no important relationship between number of dental amalgams and body burden of mercury. These results are consistent with the findings of Chang et al. (4), who compared the blood mercury levels in dentists and nondentists and also analyzed the relationship between amalgams and mercury levels. On the other hand, several studies have reported contrary findings (7,24-27). Explanations for these discrepancies could be the choice of biomarker and confounding of the relationship between dental amalgams and mercury levels by fish consumption or other factors.

Blood and urine may be a good measure of recent exposure of mercury released from dental amalgams, but they do not necessarily represent the long-term cumulative body burden of mercury. For example, the amount of mercury detected in urine reflects an exposure over a period of two to four months and may be an index of renal concentration of mercury (19) rather than total body burden. Other investigators have also suggested that urine-mercury measurements may reflect kidney dysfunction rather than actual mercury exposure levels (20). Even when 24-hour samples are used, the day-to-day variation can be high, as urinary mercury concentrations on two consecutive days can differ by 25–50 percent (21).

Blood mercury reflects exposure for even a shorter time frame, perhaps only a few days and is generally considered as a measure of recent exposure (19). Thus, studies showing a positive relationship between dental amalgams and urine levels in nonoccupationally exposed subjects (patients) may be indicative of increased mercury release from amalgams and not necessarily the increased body burden of mercury. Unless the biotransformation and metabolism of these mercury vapors is such that a substantial portion of the mercury is entrapped in brain tissue and other body organs soon after their inhalation or absorption (either in the operatory or intraorally), biomarkers such as urine or blood would seem to be limited for understanding the relationship between dental amalgams and mercury levels in the body.

Secondly, data from studies that have used several biological samples such as urine, serum, and whole blood as biomarkers of mercury levels in the body (25-27) indicate that the correlation between dental amalgams and mercury levels is much stronger when urine is used as opposed to serum or whole blood.

Similar to our findings, Langworth et al. (25) noted that number of amalgam surfaces was poorly correlated with the blood mercury or serum mercury levels, while the number of amalgam surfaces was the best predictor of urine mercury, which explained 15 percent of the total variation. In separate multiple regression models, Akesson et al. (26) reported that the association between amalgam surfaces and urine mercury levels was three times higher than the association between amalgam surfaces and blood mercury levels. Kingman et al. (27) found a significant correlation between the number of surfaces exposed to amalgam and urinary mercury concentrations (r=.34), but a weak correlation with blood mercury concentrations (r=.09). Given that toenails reflect integrated blood mercury levels, our findings are consistent with these studies showing no or only a weak relationship between amalgam surfaces and mercury levels in the body. However, it can be argued that toenails are a more stable and therefore better biomarker for mercury because they reflect an integrated measure of mercury over time.

In a separate investigation, Garland et al. (22) reported that the reproducibility of toenail mercury levels over a six-year period as measured by Spearman correlation coefficients was found to be 0.56. Thus, the absence of any relationship between number of dental amalgams and toenail mercury levels in our data, despite strong associations between occupational exposure and mercury and fish consumption and nail mercury levels, strongly suggests that the cumulative contribution of mercury from dental amalgams is negligible.

Many of the earlier studies that are often cited to document a positive relationship between amalgam restorations and mercury levels (8,18,24) did not control for consumption of tuna or saltwater fish while analyzing the relationship between amalgams and mercury level. One previous study (28) found that mercury consumption from food frequency questionnaires were correlated with toenail mercury levels (r=.42; P=.001); the correlation between tuna consumption and mercury levels was 0.54 (P<.001). Despite the fact that urine reflects inorganic mercury, a recent study (25) showed "a tendency toward increasing U-Hg values with rising fish consumption (P=.12)." Also, as shown in our analysis, consumption of tuna had a substantial effect on mercury levels regardless of the professional status. Thus, the correlation between dental amalgams and urine mercury levels in these earlier studies could have been confounded by fish consumption. A high correlation between hair mercury levels and fish consumption has also been found (29).

Organic vs Inorganic Mercury. The growth of toenails has been shown to reflect dietary intake of selenium over the preceding 26–52 weeks (30) and dietary intake has been shown to correlate well with toenail mercury (28). We expect that the high correlation of toenail mercury levels with fish consumption suggests that toenails at least reflect organic mercury from fish consumption. However, in addition to diet, the exposure of general dentists to mercury is through inorganic mercury vapors in the operatory or from amalgam restorations in their own mouth. The neutron activation analyses of toenail specimens used in this study quantifies total mercury and does not differentiate the proportions of inorganic and organic forms of mercury in toenails. However, indirect evidence suggests that toenails do, in fact, also reflect inorganic mercury. First, the mercury level in toenails is a cumulative reflection of average concentration of mercury in blood integrated over a period of time. Chang et al. (4) showed that inorganic mercury levels were not only found in blood of dentists, but were more than twice the levels of inorganic mercury found in nondentists. Second, the organic mercury levels were not different in dentists and nondentists after controlling for fish consumption. Therefore, if toenails reflect only the integrated organic blood levels of mercury over the time of nail growth, then the mercury levels in toenails would be no different among the three groups in our study. However, since general dentists showed more than twice the level of mercury levels in their toenails than the other two groups in the "no tuna" consumption category, the mercury levels in toenail also must reflect exposure to inorganic mercury. Therefore, toenail mercury levels must reflect exposure to both organic and inorganic mercury.

Hence, the evidence that mercury release is related to the number of dental amalgams and is associated with urine mercury levels may be misleading. The most important issue is the extent to which mercury from amalgams and its biochemical transformation increases the body burden and may potentially create harmful effects. Here, an appropriate biomarker of cumulative burden of mercury in the body is critical.

Practice Characteristics and Mercury Levels. The practice characteristics examined in this study explained little variation in mercury levels among the general dentists. One would expect a higher mercury level with increasing number of amalgams removed because of the excess mercury vapors or aerosols that the process generates. In our data this expected but weak trend was visible only until the number of amalgams removed reached a limit of 20 restorations per week. The mercury levels declined as the number of amalgams removed increased beyond this level. No explanation is offered except for a speculation that dentists who remove considerably high number of amalgam restorations may be more aware of the potential harmful effects of mercury vapors and take extra precaution regarding mercury hygiene in their office. Despite the clear danger of drycutting the amalgam, 21 percent of the general dentists in our study reported that they removed amalgams using a high-speed handpiece without water spray. However, drycutting was not found significantly associated with mercury levels in our bivariate or multivariate analysis.

The hygienic handling of mercury amalgam in dental practice could be a critical factor in reducing occupational exposure of dentists to mercury vapor. This study found that only 12.9 percent of dentists used the water storage method when their remaining scrap amalgam was discarded and only 4.5 percent of dentists used both the water storage and disposable capsules. In a recent study in Thailand (31), about half of dentists reported storing excess amalgam under water, 78 percent reported using sealed amalgam capsules systems at least sometimes, and nearly half reported disposing of used capsules in the bin. More awareness and practice in hygienic handling of amalgam may be needed among dentists. Even though these data reflected the status of dentists aged 40–76 years in 1987, and practices could have improved since then, in 1995 more than 75 percent of US dentists saved scrap amalgam (32). The use of disposable capsules in mixing amalgam could reduce the risk of elevated body burden mercury levels much more than the use of reusable capsules. These results were consistent with the findings of Schneider (33), Martin et al. (32), and Kim et al. (34). The use of the water storage method for scrap amalgam appeared to be more important than the use of disposable capsules, similar to results of Kim et al. (34). The combined use of water storage method for scrap amalgam and disposable capsules in mixing amalgam may be the most effective for the hygienic handling of mercury amalgam in dental offices; however, a larger sample size will be needed to evaluate this.

Conclusions

- In a study of 410 health professionals, general dentists were found to have more than twice the level of mercury in toenails than nondental health professionals and 60 percent higher than dental specialists.
- No relationship was observed between number of dental amalgams and the level of toenail mercury levels in any of the three study groups: dentists, dental specialists, and nonoccupationally exposed health professionals ("patients").
- Toenails were found to be an appropriate biomarker of cumulative long-term exposure of mercury.
- No practice characteristics examined in the study were found to be significantly associated with high mercury levels. Although no statistically significant association between drycutting of amalgam and mercury levels was found, 21 percent of the general dentists in our study reported using high-speed handpiece without water spray.
- Irrespective of the professional status, consumption of tuna fish and saltwater fish was positively associated with toenail mercury levels.
- While many European countries have implemented the policy of phasing out the use of dental amalgam and its use has declined considerably in the United States, the findings of this study suggest that the avoidance of amalgam cannot be justified by the presence of mercury released from dental amalgams.
- The combined use of disposable capsules and water storage method could reduce the risk of elevated mercury levels.

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