The Contribution of Dental Amalgam to Mercury in Blood

K.R. SNAPP, D.B. BOYER[1,3], L.C. PETERSON[2], and C.W. SVARE

Department of Prosthodontics, [1]Department of Operative Dentistry, [2]Department of Family Dentistry, College of Dentistry, University of Iowa, Iowa City, Iowa 52242

We determined the exposure to mercury from dental amalgam by comparison of blood levels of mercury before and after removal of all amalgams from ten subjects. Baseline concentrations of mercury in whole blood were measured weekly for four to 18 weeks (median = 6.6 weeks) prior to removal. All amalgams were removed in a single appointment. The subjects had an average of 14 surfaces of amalgam, seven of which were occlusal surfaces. Weekly blood sampling was continued for five to 18 weeks (median = 7.6 weeks) after the amalgams were removed. The mean baseline concentration of total mercury in whole blood of the ten subjects was 2.18 (SD = 0.90) ng Hg/mL before the amalgams were removed. The baseline mercury levels were related to the number of amalgam surfaces. The linear correlation coefficient was 0.724 with number of occlusal surfaces, and 0.433 with total number of surfaces. After removal of the amalgams, nine of the ten subjects exhibited a statistically significant decrease in blood mercury at the 95% level of confidence. The mean decrease in mercury was 1.13 (SD = 0.60) ng Hg/mL. The half-time for elimination of mercury from blood after amalgam removal was 30.2 (SD = 5.8) days. Removal of the amalgams provided an additional exposure of 1.46 (SD = 1.17) ng Hg/mL that was rapidly cleared from the blood with a half-time of 2.9 days. The daily intake of mercury from amalgam in the subjects was estimated to be at least 1.3 μg.

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Introduction.

It has generally been assumed that the exposure of dental patients to mercury in dental amalgam is brief, and that it effectively terminates after the amalgam is set. Frykholm (1957) found that mercury levels in urine increased after amalgam restorations were placed in dental patients, but fell to zero after seven days.

Several recent studies have demonstrated increased levels of mercury vapor in the oral cavity or breath of subjects with amalgam restorations (Gay *et al.*, 1979; Svare *et al.*, 1981; Patterson *et al.*, 1985; Vimy and Lorscheider, 1985a,b). These investigators have suggested that because mercury vapor can be measured in the oral cavity, amalgams may expose the body to significant amounts of mercury. By use of vaporization rates of mercury from amalgam in the oral cavity, Vimy and Lorscheider (1985b) and Mackert (1987) estimated the daily intake of mercury, and Vimy *et al.* (1986) estimated the body burden. These estimates remain speculative, since they have not been substantiated by corresponding measurements in body tissues or fluids.

Others have attempted to establish whether amalgams expose the body to mercury by measuring the mercury content of blood of subjects with and without amalgams. Kröncke *et al.* (1980) and Ott *et al.* (1984) detected no difference in mercury concentrations in blood of subjects with and without amalgams. Abraham *et al.* (1984) found that subjects with amalgams had higher blood mercury than those without amalgams. They found a positive correlation between numbers of amalgams and the blood level of mercury.

Present information on mercury exposure from amalgam is inconclusive. Further work is needed to establish whether there is exposure and, if so, the amount of exposure. The purpose of this study was to address these questions by comparison of the concentrations of mercury in blood of subjects before and after removal of amalgam restorations.

Materials and methods.

The ten volunteer subjects consisted of five males and five females with an average age of 34 years (range, 25-51). They were university faculty, staff, and graduate students with no current occupational exposure to mercury. Individuals were selected who reported eating little or no fish and seafood, since these are known dietary sources of mercury. The subjects were asked to abstain from eating fish and seafood for the duration of the study.

In order to establish baseline blood levels of mercury, we took weekly blood samples for a minimum of four weeks, prior to removal of the amalgams. Subject D was an exception in that baseline measurements were taken one year earlier (mean = 2.98 ng/mL) and four months earlier (mean = 5.5 ng/mL). These measurements are not shown in Fig. 1. Preliminary measurements of mercury blood levels on two subjects indicated that the coefficient of variation, CV, of daily measurements was about 0.10. The number of samples needed for determination of the baseline mercury concentration with a 95% level of confidence was calculated by setting the 95% confidence level equal to 10% of the mean, $\bar{x}$; *i.e.*, $0.10\,\bar{x} = 1.96\,(CV \cdot \bar{x})/(N)^{1/2}$ (Blalock, 1979). Solving for N, the minimum sample size of four was found.

After the baseline blood mercury level was established, the subjects were scheduled for the clinical procedures. All amalgams were removed in one appointment, and temporary restorations were placed. Rubber dam isolation during removal of the amalgams was at the clinicians' discretion and was used in some cases and not others. The teeth were subsequently restored with cast gold inlays and crowns. In some instances, small single-surface cavities were restored with composite resin.

After the amalgam was removed, weekly blood sampling was continued. The duration of sampling was determined by use of the sequential analysis method, described by Dixon and Massey (1957). When this procedure is used, the number of observations to be made is not determined in advance; rather, the procedure is used after each successive observation to indicate when sufficient observations have been gathered to make a statistical decision. The sum of the post-removal mercury concentrations, Σx_i, was plotted *vs.* the number of observations, m, after each sample was taken. Critical lines were calculated,

$$\frac{\mu_1 - \mu_0}{\sigma^2} \Sigma x_i + \frac{\mu_0^2 - \mu_1^2}{2(\sigma^2)} m = \pm \ln \frac{\beta}{1-\alpha} \qquad \text{(Eq. 1)}$$

where μ_0 and σ are the mean and standard deviation of the

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[3]To whom correspondence and reprint requests should be addressed
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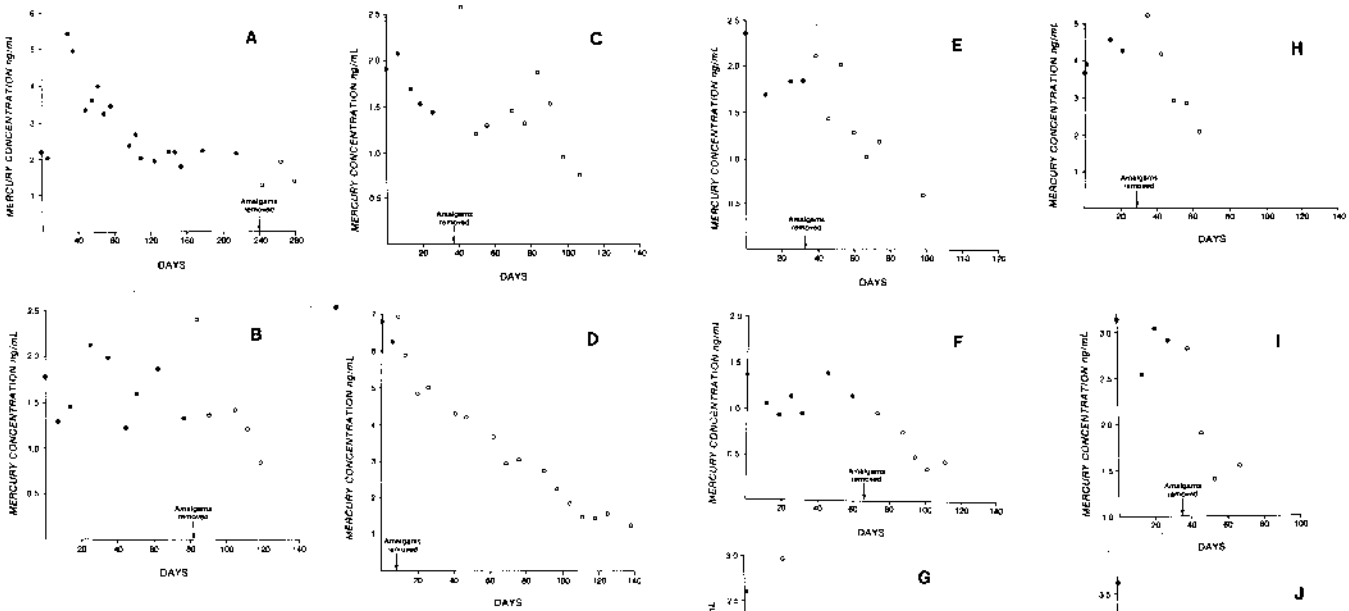

Fig. 1 — Blood mercury concentrations for each subject for the duration of the experiment. (●) Pre-removal readings, (○) post-removal readings. The letter on each graph identifies the subjects listed in Tables 2, 3, and 4. The decline in mercury for subject D is largely due to abstinence from the eating of fish (see the text).

baseline (pre-removal) mercury concentration, and μ_1 is the lower 95% confidence limit of the baseline mercury concentration. The risks α and β were set at 5%. Alpha is the risk of rejecting the null hypothesis when it is true, and β is the risk of accepting it when it is not true. When the plotted data points touched one of the critical lines, we had made sufficient observations to accept or reject the null hypothesis—*i.e.*, no change in mercury concentration.

Blood sampling and analysis.—Blood samples were drawn from an antecubital vein into 10-mL heparinized Vacutainers. The specimens were stored in ice, and analysis usually began within a few minutes of collection. The total mercury concentration of whole blood was measured by means of a modification of the cold-vapor technique of Sharma and Davis (1979). Triplet determinations were made on 2-mL aliquots from each blood specimen. Mercury vapor was released from blood by use of a sodium borohydride reducing agent and drawn through an ultraviolet spectrophotometer for quantification.

The apparatus consisted of a 17-mL partitioned glass reaction chamber connected by tubing to a solenoid shunting valve which was operated with a laboratory timer. The timer was set so that an air sample was automatically withdrawn from the reaction flask for four s every minute. The air sample was drawn through a drying tube and through a dual-beam ultraviolet spectrophotometer with a wavelength of 254 nm (Mercury Monitor, model 1255, Laboratory Data Control, Riviera Beach, FL). Air flow through the apparatus at 1.2 L/min was vacuum-driven, and controlled with a flow meter.

The spectrophotometer was calibrated before each blood sample was analyzed by injection of 0.5 mL of air saturated with mercury vapor at 0°C (1.09 ng Hg) into the headspace over 5 mL of water in a reaction flask. The procedure for measuring mercury in blood was as follows. The blood was stirred for prevention of separation of plasma and cells, and 2.0 mL was added to the reaction flask followed by 3.0 mL of double-distilled water, and one drop of antifoaming agent. Then 1.0 mL of sodium borohydride agent (50 g/L sodium borohydride in 1 mol/L NaOH) was placed in one partition of the reaction flask. The flask was stoppered, tipped to bring the reducing agent into contact with the blood, and magnetic stirring was begun. The timer was started, and air samples of the head space were taken every minute until the readings fell below the background (blank) values. Blank readings were taken by addition of the reducing agent and antifoaming agent to 5.0 mL double-distilled water with no blood, and by means of the same procedure.

TABLE 1
ANALYTICAL RECOVERY OF MERCURY FROM MERCURIC CHLORIDE STANDARD SOLUTION ADDED TO BLOOD

	Amount of $HgCl_2$ added (ng)			
Blood specimen	2	5	10	20
1	2.28	5.05	7.73	20.9
2	2.01	5.10	8.89	18.7
3	2.18	5.37	10.2	19.7
4	2.06	4.40	9.80	22.9
Mean	2.13	4.98	9.16	20.6
SD	0.121	0.411	1.10	1.81
CV	0.057	0.0826	0.120	0.0877
recovery %	106	99.6	91.6	103

Internal standards were run for determination of the analytical recovery of the technique by addition of known amounts of mercuric chloride to blood, after it had been tested as above. The analytical recovery averaged 100 (SD = 5.2)% over a range of 2-20 ng Hg (Table 1). The precision of repeated measurements on aliquots of the same blood specimen was CV = 6.6%. The detection limit, which is defined as twice the

standard deviation of 10 determinations of a near-blank concentration, was 0.26 ng.

Results.

The blood concentrations of mercury for each of the ten subjects, for the duration of the experiment, are given in Fig. 1. Mean baseline mercury levels before removal of the amalgams were determined over periods ranging from four to 18 weeks (median = 6.6 weeks). The mean baseline concentration for all subjects was 2.18 ng Hg/mL, and the range was 1.55 to 4.09 ng/mL (Table 2).

There was dietary interference with baseline mercury values for three of the subjects, as indicated by steadily declining mercury levels during the pre-removal period, and increasing values for a fourth subject. Subject A ate a meal of fish shortly after baseline measurements were begun, and blood mercury rose sharply. The subject consented to stay in the study for a protracted time, and the additional mercury was eliminated with a half-time of 42 days over the following three months. Blood mercury remained constant for four months before the amalgams were removed.

The mercury levels of subjects C and J also fell during the pre-removal period. Constant baselines were not achieved before removal of amalgam, so the rates of elimination could not be accurately determined. However, the rates were sufficiently slow, 70 days assuming a baseline of zero, to indicate clearance of organic mercury. Using the amount of mercury cleared after removal of amalgam as the baseline for subject C resulted in a half-time of 43 days for the pre-removal clearance rate. The last reading just before the amalgams were removed was taken as the baseline for subjects C and J. Presumably, blood mercury would continue to fall at a low rate during the post-removal period, if amalgam was not a source of mercury.

The fourth subject with dietary interference of mercury, Subject D, had a baseline value of 2.98 ng Hg/mL established several months before the study began. For the period of one week before the amalgams were removed, the blood values averaged 6.50 (SD = 0.39) ng Hg/mL. The earlier, lower value was taken as the baseline.

The baseline blood mercury concentrations are plotted *vs.* the number of occlusal surfaces of amalgam for each of the subjects in Fig. 2. The least-squares linear regression line is shown for which r = 0.724. The mercury concentration was more highly correlated with the number of occlusal surfaces than with the total number of amalgam surfaces, for which r = 0.433. Eleven subjects were included in this analysis because baseline data were available for one additional subject, who dropped out of the study before amalgams were removed. The mean number of occlusal surfaces was seven and of total surfaces, 14.

After removal of the amalgams, weekly blood analyses were continued, and sequential analysis plots were begun by means of critical lines calculated from the baseline data in Table 2. The plot for subject E is shown in Fig. 3. As long as the sum of the post-removal mercury concentrations remained between the critical lines, no decision could be made and sampling was continued. If the sum exceeded the upper line, the decision was that there was no difference between the post-removal and baseline mercury values. If the sum fell below the lower line, as is the case in Fig. 3, there had been a significant decrease in mercury at the 95% level of confidence.

A significant decrease in blood mercury was found for nine of the ten subjects. The number of observations required for each decision is shown in Table 2; the average was four. The decrease in mercury was calculated by subtraction of the last reading taken from the baseline value; this is also shown in Table 2. The mean decrease in blood mercury was 1.13 (SD = 0.60) ng/mL. Only subject J, for whom dietary interference was noted earlier, showed no change. This result was attributed to additional dietary interference in the post-removal period. A "no change" decision was reached for subject C at the 80-day reading (Fig. 1); however, sampling was continued, and a "lower mercury" decision was reached later. It was apparent that some additional mercury exposure had taken place with subject C during the post-removal period.

The first mercury concentration measured after removal of the amalgams was higher than the baseline for seven of the subjects. Values returned to baseline or below by the next measurement. The increase was attributed to exposure of the subjects to additional mercury during grinding of the amalgam. The first reading after removal was omitted from the sequential analysis for these seven subjects because of the additional exposure.

The clearance of mercury from blood following a single, brief exposure to mercury vapor is characterized by biphasic elimination; that is, a portion of the mercury is eliminated rapidly (half-time = 3 days) and a portion is eliminated at a slower rate (half-time = 30 days) (USEPA, 1984). Clearance of an accumulated amount of mercury from multiple small exposures, as might occur from amalgam present in the oral cavity over a period of time, would be expected to follow a single exponential decay, since the fast component is negli-

TABLE 2
TOTAL MERCURY CONCENTRATION OF WHOLE BLOOD SAMPLES OF SUBJECTS BEFORE AND AFTER REMOVAL OF AMALGAM RESTORATIONS

	Pre-removal blood Hg (ng/mL)			Post-removal blood Hg (ng/mL)	Decrease in blood Hg (ng/mL)	# of obs. to sig. decline
Subject	N	mean	SD	last reading	baseline-last value	m
A	9	2.09	0.150	1.39	0.70	2
B	9	1.63	0.324	0.83	0.80	4
C	1*	1.44	0.127	0.75	0.69	8
D	9	2.98	0.318	1.24	1.74	4
E	4	1.93	0.290	0.60	1.33	6
F	7	1.14	0.184	0.40	0.74	3
G	11	2.02	0.254	0.17	1.85	5
H	4	4.09	0.394	2.12	1.97	3
I	4	2.92	0.288	1.55	1.37	3
J	1*	1.55	0.181	1.40	0.15	—
Mean (SD)		2.18	(0.898)	1.04 (0.60)	1.13 (0.605)	

*Last value, not mean. SD from last three measurements.

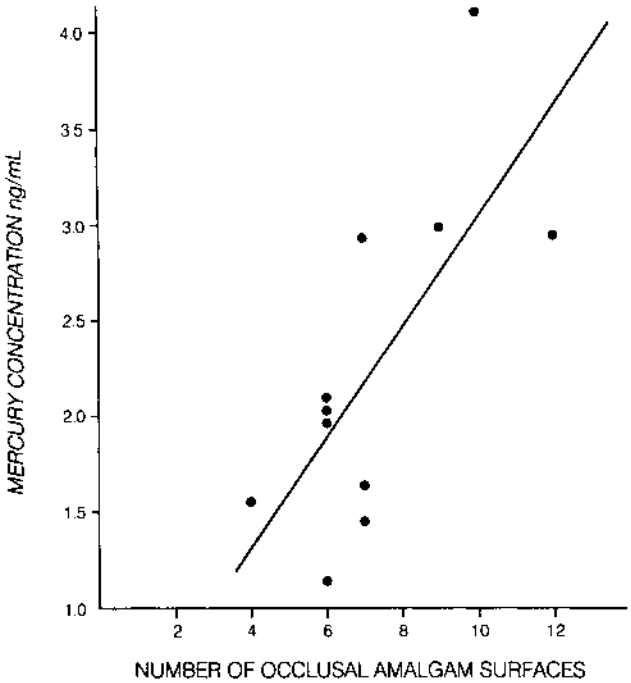

Fig. 2 — Mean baseline blood concentration of mercury for each subject plotted against number of occlusal amalgam surfaces. The linear regression line is shown, r = 0.72.

gible compared with the slow component (Rothstein and Hayes, 1964). We plotted our data on semi-log paper to determine whether mercury was eliminated at a single exponential rate (a straight line), or at a biphasic rate (a curve). A biphasic rate was found for most subjects because of the increase in mercury

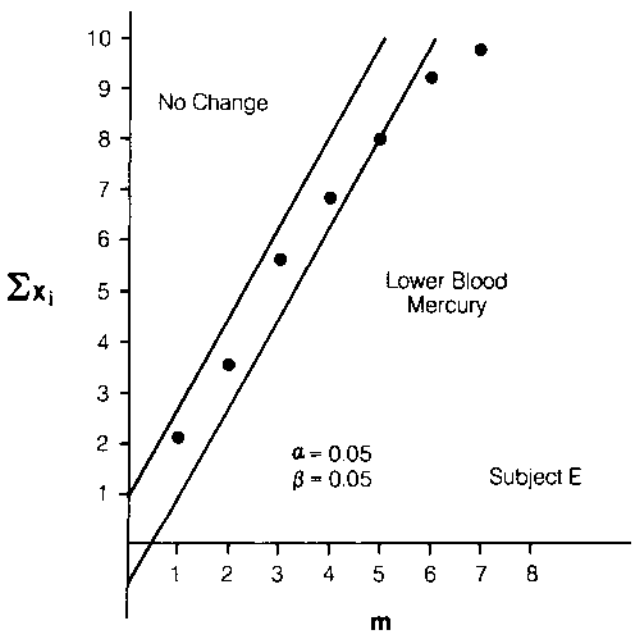

Fig. 3 — The sequential analysis plot for subject E. The sum of the post-removal blood mercury values is plotted *vs.* the number of observations, m. When the curve falls between the critical lines, sampling is continued. The region below the lower line designates a significant decrease. The region above the upper line designates no significant difference.

TABLE 3
ANALYSIS OF RATE OF ELIMINATION (HALF-TIME) OF MERCURY FROM WHOLE BLOOD AFTER REMOVAL OF AMALGAM RESTORATIONS

	Slow Component				Fast Component	
Subject	Half-time days	Intercept ng Hg/mL	Regression** r	p	Half-time days	Intercept ng Hg/mL
A	—	—	—	—	—	—
B	36.5	1.93	−0.848	0.0328	2.5	0.89
C	—	—	—	—	3.6	2.40
D	57.8	6.51	−0.978	0.0001	2.2	0.59
E	38.5	2.18	−0.922	0.0011	3.3	0.75
F	25.7	1.16	−0.957	0.0027	—	—
G	30.1	2.29	−0.889	0.0006	2.7	3.41
H	22.4	6.34	−0.979	0.0036	—	—
I	31.5	2.72	−0.852	0.0664	3.2	0.73
J	26.6	2.72	−0.863	0.1370	—	—
Mean*(SD)	30.2 (5.8)	3.23 (2.03)			2.9 (0.5)	1.46 (1.17)

*Subject D omitted from slow component means.
**Regression coefficient, r, and F test probability, p.

over background immediately after the amalgams were removed. Consequently, compartmental analysis or "curve stripping" (Solomon, 1960) was used to separate exposure due to removal of the amalgams from the long-term, accumulated exposure from the amalgams *in situ*.

The procedure is illustrated for subject G in Fig. 4. The newly established baseline concentration, after the amalgams were removed (0.17 ng Hg/mL for subject G), was subtracted from the post-removal readings, and the differences were plotted on semi-log paper. The equation of the slow component was determined by linear regression of these points. The slope is the rate of elimination, k, and the half-time, $t_{1/2}$, is ln2/k. The intercept is the amount of mercury cleared at the slow rate. The peak concentration of mercury in blood (Table 4) was obtained by extrapolation of the curve on the semi-log plot to the time of removal. The fast component was obtained by subtraction of the slow component from the extrapolated line. The slope of the "second subtraction" gave the half-time of the fast component. It should be cautioned that the fast com-

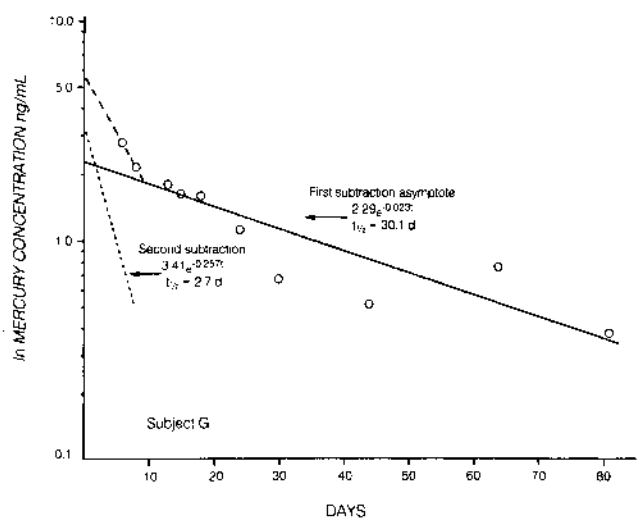

Fig. 4 — Semi-log plot of post-removal (blood mercury *vs.* time) for subject G. The solid line is the asymptote of the mercury concentrations minus the baseline concentration at the end of the experiment (0.17 ng Hg/mL). The slope is the rate of mercury clearance of the slow component. The bottom curve results from subtraction of the asymptote from the initial slope of the curve. The slope of the bottom curve is the rate of elimination of the fast component.

TABLE 4
PEAK CONCENTRATION OF MERCURY IN BLOOD AFTER REMOVAL OF AMALGAMS AND AMOUNT DUE TO REMOVAL

Subject	Peak Concentration ng Hg/mL	Hg due to Removal ng Hg/mL
A	2.09	—
B	2.82	1.19
C	4.10	2.66
D	7.10	1.08
E	2.93	1.00
F	1.16	—
G	5.70	3.68
H	6.34	2.25
I	3.45	0.53
J	2.72	1.17
Mean (SD)	3.48 (1.66)	1.70 (1.06)

ponent values are rough estimates, since they are based on extrapolations of only the first two data points after removal of the amalgam. For subject G, the half-times of the fast and slow components were 2.7 days and 30.1 days, respectively.

The results of the kinetic analysis are given for all of the subjects in Table 3. Subject G was the only case monitored sufficiently long after removal of the amalgams (190 days) to establish a new baseline. The other subjects were assumed to have a new baseline of zero. The effect of this assumption is that the half-times of the slow component are longer than if the baselines were not zero. The total mercury in the blood due to the grinding out of the amalgams is given in Table 4. This was calculated by means of subtracting the mean pre-removal concentration of Table 2 from the peak concentration after removal.

Kinetic analysis was not possible for subject A because too few post-removal readings were taken. The slow component could not be calculated for subject C because of dietary exposure during the post-removal period. We estimated the fast component assuming the rate of the slow phase to be 26 days. The half-time of the fast component could not be estimated for four of the subjects because of an insufficient number of readings immediately after removal.

Discussion.

Since total mercury in blood was measured in this study, it was important to control extraneous exposures to mercury so that any change in mercury after removal of the amalgams would not be masked by new exposures from other sources. It was also important to determine whether any decrease in blood mercury was due to removal of amalgam or to withdrawal of another source. Total mercury in blood consists of inorganic and organic mercury. The organic portion is almost entirely methyl mercury from fish and seafood. The inorganic portion may be from food, medicaments, and industrial and occupational exposure, such as dentistry.

In order to isolate the exposure due to amalgam, we employed three precautions: (1) Subjects with low exposure to mercury, either dietary or occupational, were selected and were asked to avoid consumption of fish during the study; (2) baseline blood levels of mercury were established over a period of at least one month. This period of monitoring also permitted detection of loss of mercury due to abstinence from fish; and (3) the kinetics of elimination of mercury after removal of the amalgams was determined in order to distinguish loss of inorganic from loss of organic mercury.

Despite the attempt to select subjects who ate little or no fish, three subjects exhibited slow clearance of blood mercury during the pre-removal period, and one subject during the post-removal period, that could be attributed to the cessation of eating fish. A constant baseline was established for subject A, prior to removal of the amalgams, by means of prolonged monitoring for 240 days. Constant baselines were not established with subjects C and D; however, the rate of elimination had dropped to a sufficiently low value, that clearance of inorganic mercury after removal of the amalgams would be detectable by its higher rate. This was the case with subject C; however, with subject J it was not possible to attribute loss of mercury to removal of the amalgams. Subject J had only four occlusal surfaces of amalgam, the fewest in the study. Post-removal dietary interference also prevented detection of a significant decline.

Analysis of the rate of elimination of mercury after removal of the amalgams was possible with eight of the subjects (Table 3). The mean half-time was 30.2 (SD = 5.8) days for seven of the subjects (subject D with $t_{1/2}$ = 57.8 days was omitted). This half-time confirms that inorganic mercury was being cleared. Rahola *et al.* (1973) measured a half-time of 26 days for clearance of inorganic mercury from whole blood. The half-time for clearance from blood of methyl mercury from fish is 52 days (Kershaw *et al.*, 1980). The half-time of the fast component was estimated for six of the subjects to be 2.9 (SD = 0.5) days. This is in good agreement with the value of 3.3 days reported by Cherian *et al.* (1978).

Total exposure due to the grinding out of the amalgams was estimated to be 1.7 ng Hg/mL for eight subjects (Table 4). For the six subjects for whom the fast component could be estimated, 86% (1.46 ng/mL) of the grinding dose was cleared at the fast rate. All of the mercury cleared at the fast rate was considered to be a result of the grinding exposure. Fourteen percent (0.23 ng/mL) of the grinding dose was cleared at the slow rate. Consequently, 7% of the slow component (0.23 ng/mL) was attributed to the removal of the amalgams, and 93% (2.90 ng/mL) was attributed to the long-term accumulation of mercury from the amalgams *in situ* in these six subjects.

The daily intake of mercury from amalgam, that results in blood concentrations of the level measured in this study, can be estimated from the equation

$$B = d \cdot (f/k) \cdot [1 - \exp(-kt)] \qquad \text{(Eq. 2)}$$

where B is the accumulation in blood in μg Hg/L, d is the daily dose in μg, f is the fraction of daily intake deposited in blood, and k is the elimination constant ($\ln 2/t_{1/2}$) (Task Group on Metal Accumulation, 1973). At steady state after a long-term exposure, the equation simplifies to $B = d \cdot f/k$. According to Cherian *et al.* (1978), the fraction of a dose of mercury vapor deposited in blood, f, is 2% *per* liter of blood. By use of the elimination half-time of 30 days found in the present study, $k = 0.0231\ d^{-1}$. The coefficient, a, relating daily intake to blood concentration is $f/k = 0.866$ day/L. The daily intake can be calculated by division of the steady-state blood concentration by the coefficient, a—*i.e.*, $d = B/a$.

The mean concentration of mercury in blood due to amalgam for the subjects of this study was 1.13 ng/mL (Table 2). Calculation of the corresponding daily intake resulted in a value of 1.13/0.866 = 1.30 μg/day. Since the subjects were not monitored until new baselines were established, this number represents an estimate of the minimum.

Mackert (1987) estimated a daily dose from amalgam restorations of 1.24 μg, that is very close to our findings. Mackert's value was calculated from the data of Vimy and Lorscheider (1985b), who measured intra-oral mercury vapor in 35 subjects

with an average of eight occlusal surfaces of amalgam. The subjects of our study had an average of seven occlusal surfaces.

The average daily intake of mercury from food, water, and air of the U.S. population not occupationally exposed to mercury has been estimated to be 24.9 μg/day (USEPA, 1984). Most of this amount, 21 μg, is inorganic mercury in food, of which only 10% is retained. Little of this mercury appears in blood. Rahola *et al.* (1973) found that only 0.27% of an oral dose of inorganic mercury appeared in whole blood after 24 hr. Inspired mercury vapor, on the other hand, is highly absorbed, with 80% retained (Nielsen-Kudsk, 1965), and 10% appears in the total blood volume (Cherian *et al.*, 1978). The difference in retention of inorganic compounds and elemental mercury vapor explains how a small dose of mercury vapor from amalgam can result in a significant portion of the mercury in blood, even though the estimated daily intake from food may be substantially higher. Elemental mercury vapor is rapidly oxidized to ionic mercury in blood, and is thereafter indistinguishable from mercury from inorganic compounds.

The average daily intake of organic mercury consists almost entirely of methyl mercury from fish and seafood, and is estimated to be 3.8 μg/day in the U.S. population (USEPA, 1984). Methyl mercury is highly retained and has an absorption rate of 95%, so that blood mercury levels are strongly influenced by fish consumption. The coefficient, a, relating average daily intake to steady-state blood concentration of methyl mercury was found to be 0.9 (Kershaw *et al.*, 1980). Consequently, an average daily intake of 3.8 μg would result in a blood level of 3.4 ng Hg/mL. Four of the subjects of our study lost an average of 2.5 ng Hg/mL after beginning a fish-free diet. This amount is consistent with blood levels expected from the typical U.S. diet, which contains only a small amount of fish.

Total mercury in whole blood in large groups of nonexposed individuals has been found to be ≤ 3 ng/mL (Goldwater, 1972) and ≤ 5 ng/mL (Snyder *et al.*, 1975). The amount of mercury in blood attributable to amalgam in our study, 1.13 ng/mL, is well within the normal concentration of the population in general. No adverse health effects have been attributed to those low exposures. Clinical evidence of toxicity begins to appear in the most sensitive adults at blood concentrations of 30 ng Hg/mL and over (Lauwerys, 1983). Consequently, the amount of mercury exposure due to amalgam does not appear to be hazardous.

REFERENCES

ABRAHAM, J.E.; SVARE, C.W.; and FRANK, C.W. (1984): The Effect of Amalgam Dental Restorations on Blood Mercury Levels, *J Dent Res* 63:71–73.

BLALOCK, H.M., Jr. (1979): **Social Statistics**, 2nd ed., New York: McGraw-Hill, pp. 215–217.

CHERIAN, M.G.; HURSH, J.B.; CLARKSON, T.W.; and ALLEN, J. (1978): Radioactive Mercury Distribution in Biological Fluids and Excretion in Human Subjects after Inhalation of Mercury Vapor, *Arch Environ Health* 33:109–114.

DIXON, W.J. and MASSEY, F.J., Jr. (1957): **Introduction to Statistical Analysis**, 2nd ed., New York: McGraw-Hill, pp. 310–313.

FRYKHOLM, K. (1957): On Mercury from Dental Amalgam. Its Toxic and Allergic Effects and Some Comments on Occupational Hygiene, *Acta Odontol Scand* 15:7 (Suppl. 22).

GAY, D.D.; COX, R.D.; and REINHARDT, J.W. (1979): Chewing Releases Mercury from Fillings, *Lancet* 1:985–986.

GOLDWATER, L.J. (1972): Normal Mercury in Man. In: **Mercury, a History of Quicksilver,** L.J. Goldwater, Ed., Baltimore, MD: York Press, pp. 135–149.

KERSHAW, T.G.; DHAHIR, P.H.; and CLARKSON, T.W. (1980): The Relationship between Blood Levels and Dose of Methylmercury in Man, *Arch Environ Health* 35:28–36.

KRÖNCKE, A.; OTT, K.; PETSCHELT, A.; SCHALLER, K.-H.; SZECSI, M.; and VALENTIN, H., (1980): Über die Quecksilberkonzentrationen in Blut und Urin von Personen mit und ohne Amalgamfüllungen, *Dtsch Zahnärztl Z* 35:803–808.

LAUWERYS, R.R. (1983): Biological Monitoring of Exposure to Inorganic and Organometallic Substances. In: **Industrial Chemical Exposure: Guidelines for Biological Monitoring,** Davis, CA: Biomedical Publications, pp. 9–50.

MACKERT, J.R., Jr. (1987): Factors Affecting Estimation of Dental Amalgam Mercury Exposure from Measurements of Mercury Vapor Levels in Intra-Oral and Expired Air, *J Dent Res* 66:1775–1780.

NIELSEN-KUDSK, F. (1965): Absorption of Mercury Vapor from the Respiratory Tract in Man, *Acta Pharmacol Toxicol* 23:250–262.

OTT, K.H.R.; LOH, F.; KRÖNCKE, A.; SCHALLER, K.-H.; VALENTIN, H.; and WELTLE, D. (1984): Zur Quecksilberbelastung durch Amalgamfüllungen, *Dtsch Zahnärztl Z* 39:199–205.

PATTERSON, J.E.; WEISSBERG, B.G.; and DENNISON, P.J. (1985): Mercury in Human Breath from Dental Amalgams, *Bull Environ Contam Toxicol* 34:459–468.

RAHOLA, T.; HATTULA, T.; KOROLAINEN, A.; and MIETTINEN, J.K. (1973): Elimination of Free and Protein-bound Ionic Mercury ($^{203}Hg^{2+}$) in Man, *Ann Clin Res* 5:214–219.

ROTHSTEIN, A. and HAYES, A. (1964): The Turnover of Mercury in Rats Exposed Repeatedly to Inhalation of Vapor, *Health Physics* 10:1099–1113.

SHARMA, D.C. and DAVIS, P.S. (1979): Direct Determination of Mercury in Blood by Use of Sodium Borohydride Reduction and Atomic Absorption Spectrophotometry, *Clin Chem* 25:769–772.

SNYDER, W.S.; COOK, M.J.; NASSET, E.S.; KARHAUSEN, L.R.; HOWELLS, G.P.; and TIPTON, J.H. (1975): International Commission on Radiological Protection. *Report of the Task Group on Reference Man*, New York: ICRP Publication 23.

SOLOMON, A.K. (1960): Compartmental Methods of Kinetic Analysis. In: **Mineral Metabolism**, Vol 1., C.L. Comar and F. Bronner, Eds., New York: Academic Press, pp. 119–167.

SVARE, C.W.; PETERSON, L.C.; REINHARDT, J.W.; BOYER, D.B.; FRANK, C.W.; GAY, D.D.; and COX, R.D. (1981): The Effect of Dental Amalgams on Mercury Levels in Expired Air, *J Dent Res* 60:1668–1671.

TASK GROUP ON METAL ACCUMULATION (1973): Accumulation of Toxic Metals with Special Reference to Their Absorption, Excretion, and Biological Half-times, *Environ Physiol Biochem* 3:65–107.

USEPA (1984): U.S. Environmental Protection Agency. Mercury Health Effects Update, EPA-600/8-84-019F, pp. 6-1 to 6-4, 4-32.

VIMY, M.J. and LORSCHEIDER, F.L. (1985a): Intra-oral Air Mercury Released from Dental Amalgam, *J Dent Res* 64:1069–1071.

VIMY, M.J. and LORSCHEIDER, F.L. (1985b): Serial Measurements of Intra-oral Air Mercury: Estimation of Daily Dose from Dental Amalgam, *J Dent Res* 64:1072–1075.

VIMY, M.J.; LUFT, A.J.; and LORSCHEIDER, F.L. (1986): Estimation of Mercury Body Burden from Dental Amalgam: Computer Simulation of a Metabolic Compartmental Model, *J Dent Res* 65:1415–1419.