IN BRIEF

- One hundred and eighty dental surgeries were tested for environmental mercury.
- Sixty eight per cent had environmental mercury readings over the occupational exposure standard.
- Greater emphasis is needed in the safe handling of mercury.
- Dentists were more likely to have suffered a kidney disorder than the control group.

Mercury vapour levels in dental practices and body mercury levels of dentists and controls

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Aim A study of 180 dentists in the West of Scotland was conducted to determine their exposure to mercury during the course of their work and the effects on their health and cognitive function.

Design Data were obtained from questionnaires distributed to dentists and by visiting their surgeries to take measurements of environmental mercury.

Methods Dentists were asked to complete a questionnaire including items on handling of amalgam, symptoms experienced, diet and possible influences on psychomotor function such as levels of stress and alcohol intake. They also completed the 12-item General Health Questionnaire. Dentists were asked to complete a dental chart of their own mouths and to give samples of urine, hair and nails for mercury analysis. The dentists were visited at their surgeries where environmental measurements were made in eight areas of the surgery and they undertook a computerised package of psychomotor tests. One hundred and eighty control subjects underwent a similar procedure, completing a questionnaire, having their amalgam surfaces counted, giving urine, hair and nail samples and undergoing the psychomotor test procedure.

Results Dentists were found to have, on average, urinary mercury levels over 4 times that of control subjects although all but one dentist had urinary mercury below the Health and Safety Executive health guidance value of 20 $\mu\text{mol mmol}^{-1}$ creatinine. Urine was found to be a better biological marker for mercury exposure than hair or nails.

Dentists were significantly more likely than control subjects to have suffered from disorders of the kidney but these symptoms were not

significantly associated with their level of mercury exposure as measured in urine. One hundred and twenty two (67.8%) of the 180 surgeries visited had environmental mercury measurements in one or more areas above the Occupational Exposure Standard (OES) set by the Health and Safety Executive. In the majority of these surgeries the high levels of mercury were found at the skirting and around the base of the dental chair. In 45 surgeries (25%) the personal dosimetry measurement (ie in the breathing zone of dental staff) was above the OES.

Conclusion On the basis of these findings, it is recommended that greater emphasis should be made relating to safe handling of amalgam in the training and continuing professional development of dentists, that further studies are carried out on levels of mercury exposure of dental team members during the course of their working day, and that periodic health surveillance, including urinary mercury monitoring, of dental personnel should be conducted to identify possible effects of practising dentistry.

In 2001, amalgam restorations were preferred by over 75% of GDPs in the UK¹ and by 54% of GDPs in the USA² for restoring cavities in loadbearing situations in posterior teeth. Using dental amalgam may lead to exposure of dental healthcare workers (DHCWs) to mercury by two routes, namely, from restorations of dental amalgam in the DHCWs' own mouths, and/or, from handling the material whilst treating patients. DHCWs may be exposed to mercury during the preparation of the dental amalgam, the insertion and removal of amalgam restorations, storage of mercury and waste amalgam, autoclaving of instruments contaminated with mercury, notwithstanding any spills that may occur within the surgery. In this respect, it has previously been considered that mercury may vaporise during removal, mixing and polishing of amalgam restorations.³

Mercury has been demonstrated to have effects on the kidney and central nervous system^{4,5} and has been implicated in adverse effects on other body systems.^{6,7} A number of authors have maintained that the use of amalgam results in significant adverse health effects⁸⁻¹⁰ although other reports assert that the health risk from amalgam restorations is negligible for the majority of dental personnel and patients.^{11,12}

Low concentrations of urinary mercury reported in recent studies of DHCWs^{3,13,14} contrast with those published a decade or so ago.¹⁵⁻¹⁷ These reductions may be considered to be due to greater awareness of the possible problems caused by excessive mercury intake, the use of automated methods of amalgam preparation and improvements in mercury hygiene in dental surgeries.¹⁸⁻²¹

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A pilot study using a computerised package of psychomotor tests involved only 39 dentists but significant reductions in memory functioning were measurable in the dentists when compared with a control group.²² This project justified a larger study of mercury exposure amongst dentists in general dental practice and its potential effects.

It was therefore the purpose of this study to measure mercury vapour levels at a variety of sites in dental surgeries and to establish whether any correlation existed between mercury vapour levels and the body mercury levels of a group of DHCWs. Another associated paper has described the effect on health and neuropsychological functioning of dentists exposed to chronic low levels of mercury.²³

METHODS

Selection of participants

From the list of almost 1,000 registered dentists practising in the Greater Glasgow, Ayrshire and Arran, Argyll and Clyde and Lanarkshire Health Boards a random sample of 180 dentists was selected by means of the random sample facility within SPSS. These dentists were sent a letter which provided details of the project and were subsequently contacted by telephone to ascertain whether they would be prepared to take part in the project. A number of dentists also responded to an article in the ‘Scottish Dentist’ magazine and volunteered to participate.

Ethical permission was obtained from the Area Dental Ethics Committee from Glasgow Dental Hospital and School/Greater Glasgow Health Board.

Participating dentists

The participating dentists were contacted by telephone and an appointment made to visit their surgery to conduct the tests described below. Prior to the visit the dentist was sent a questionnaire. This requested information about amalgam preparation, mercury storage practices and mercury spillages. Other potential influences on psychomotor response such as alcohol intake, stress and regularly taken medication were also included. The questionnaire also requested information on personal habits such as the use of chewing gum and bruxism. Dentists were asked to complete (by self-examination) a dental chart for their own teeth to record the number of amalgam surfaces. The questionnaire also included the *General Health Questionnaire version 12*, to try to assess the amount of psychological disorder of the respondents.²⁴

The participating dentists’ levels of exposure to mercury were assessed as follows:

- Subjects were asked to provide a sample of urine on the day of the visit to the surgery for analysis of mercury concentration. Analysis was conducted by cold vapour atomic absorption spectroscopy and results expressed in relation to creatinine content

in order to take into account the concentration of an individual’s urine.

- Subjects were asked for samples of head hair, pubic hair, finger nails and toe nails.

Control group

Control subjects, matched to dentists by academic ability (in the form of a university degree), were recruited from the University of Glasgow. Subjects for the control group were invited to participate via an article published in the *University of Glasgow Newsletter* and by emails sent to university employees and postgraduate students. Emails were targeted to those staff likely to meet the requirements of having a first degree and not to have been exposed to mercury on a regular basis. The control group members were asked to complete a questionnaire similar to that of the dentists but excluding questions specifically relating to the use, storage and spillage of amalgam. The number of amalgam surfaces in the mouths of the control subjects was counted by a dentist. These subjects were also asked to provide samples of urine, hair and nails for mercury analysis.

Environmental mercury concentration

The levels of mercury vapour in the dental surgeries were measured using a Jerome 431-X Gold Film Mercury Vapor Analyzer^{25,26} and Personal Mercury Dosimeter (worn as close as possible to the wearer’s breathing zone, connected by tubing to a pump). The Jerome 431 is designed for analysis of indoor air mercury vapour levels in the workplace environment and for the location of mercury spills (http://www.azic.com/products_431.aspx). During the visit to the dentist’s surgery, measurements were taken of airborne mercury levels present in the air and at the eight areas within the surgery:

- Around the base of the chair
- At the skirting board below the area where the mercury is stored
- Beside the mixing device (amalgamator or the area around the capsules and capsule mixer)
- Above the storage area for waste amalgam
- Above the autoclave
- Above the work surface where the preparation of amalgam usually takes place
- Using the personal mercury dosimeter (worn as close as possible to the wearer’s breathing zone, connected by tubing to a pump), and at roughly head height.

Statistical methods

All of the biological mercury levels (for urine, hair and nails) were highly positively skewed. However a logarithmic transformation (base 10) resulted in a normal distribution for each. Ninety-five per cent confidence intervals for the ratio of geometric mean mercury concentrations of dentists and controls were com-

Table 1 Numbers of dentists and controls indicating that they had suffered from symptoms

	Number of dentists (n = 170)	Number of controls (n = 179)	P value	Corrected P value
Memory disturbance	44 (25.9%)	17 (9.4%)	<0.0001	<0.0001
Loss of appetite	11 (6.5%)	24 (13.3%)	0.032	0.26
Tiredness	106 (62.4%)	101 (56.1%)	0.24	
Hand tremor	18 (10.6%)	13 (7.2%)	0.27	
Gastro-intestinal disturbance	44 (25.9%)	40 (22.2%)	0.42	
Problems with sleeping	60 (35.3%)	65 (36.1%)	0.87	
Poor concentration	55 (32.4%)	59 (32.8%)	0.93	
Nervousness	38 (22.4%)	40 (22.2%)	0.98	

puted. Chi-square tests were used to compare the percentages of dentists and controls suffering from various symptoms and disorders.

Multiple logistic regression was used to examine the effect of job category (dentist or control) and urinary mercury concentration on occurrence of various symptoms and disorders after adjusting for age and sex.

Spearman's Rank correlation coefficient was used to examine the relationship between environmental mercury and biological mercury levels, and between environmental mercury levels and the numbers of amalgam fillings placed and removed.

Because of the large number of significance tests reported, Bonferroni's method of multiple comparisons was applied separately to each table of results. Both corrected and uncorrected *P* values are reported where appropriate. Thus, for example, significant *P* values in Table 1 were multiplied by 8.²⁷

RESULTS

From the random sampling 129 dentists (71.7%) were recruited, with the remaining 51 dentists (28.3%) being self-selected volunteers, giving a total sample of 180 dentists. The volunteers and randomly sampled dentists were compared on all demographic variables and on all biological and environmental mercury measures, with the only variable on which they differed being found to be sex, where 55% of 129 randomly sampled dentists were male, compared with 73% of the 51 volunteers (*P* = 0.04). This significance disappears if multiple comparisons are allowed for.

A total of 180 controls were also recruited. Significantly more dentists were male (60%) than the controls (47.2%) (*P* = 0.015). The dentists were significantly older than the control subjects with the mean difference in age being 7.2 years (95% CI = 5.17 to 9.25) (*P* < 0.001). An adjustment for this age difference between controls and dentists was incorporated in all analyses where appropriate. Dentists and controls lived in the same general geographical area.

Questionnaire results

A total of 170 (of the 180 in the sample) completed and returned the questionnaire, although not all dentists answered all questions. Of the control subjects, 179 completed and returned the questionnaire.

The mean number of years of practice as a dentist was found to be 15.6 (range = 6 months to 39 years). The mean number of hours worked in the surgery was found to be 32.8 hours (range = 6 to 43 hours). Forty-seven per cent of premises have been used as a dental surgery for over 20 years, with only 6% used as a dental surgery for less than 5 years.

The respondents were asked 'if they had ever experienced a mercury spillage from a thermometer, sphygmomanometer or when filling an amalgamator'. In reply, 27.3% of the respondent dentists indicated that they had experienced such a spillage. Of the dentists who answered the question, 55.4% reported that they used an amalgamator in the surgery, 36.1% used single-use capsules and 8.4% used both. Of those respondents who used an amalgamator, 18.1% indicated that they themselves filled it. Forty-five per cent of the respondent dentists used encapsulated amalgam, with the results indicating the mean time that they had used capsules was 5.0 years, with a minimum of 1 month and a maximum of 32 years.

The mean number of amalgam fillings placed in an average week was found to be 35.5 (range = 2 to 170) and mean number removed was found to be 30.6 (range = 0 to 170).

In response to the question on whether respondents had ever suffered from, and required medical treatment for, disorders of the heart and/or lungs, liver, kidney, blood, nervous system or immune system or if they had suffered fertility problems, dentists were significantly more likely to have suffered from kidney disorders (6.5%) than control subjects (0.6%), but were not more likely to suffer from any of the other conditions mentioned. This difference remained significant after correcting for multiple comparisons and after adjusting for age and sex using logistic regression (adjusted odds ratio of kidney disorders for dentists: 15.2 (95% CI = 1.8 to 126.3, *P* = 0.01).

Both dentist and control groups were asked a number of questions about specific symptoms that may be associated with mercury exposure. These were loss of appetite, hand tremor, poor concentration, gastro-intestinal disturbance, nervousness, problems with sleeping, memory disturbance and tiredness. The responses are summarised in Table 1. The effect of the job on memory disturbance remains significant after adjusting for age and sex by logistic regression (adjusted odds ratio of memory disturbance for dentists: 3.15 (95% CI = 1.64 to 6.03, *P* < 0.001).

An age effect on reported memory disturbance was found for dentists, with older dentists reporting memory disturbance more often than younger dentists. This was not observed amongst the control group. The effect of urinary mercury concentrations on reporting memory disturbance was examined for dentists and controls separately by logistic regression and was not significant after adjusting for age and sex for dentists (*P* = 0.36) nor for controls (*P* = 0.09).

There were no significant differences in the level of reported alcohol consumption between dentists and controls or in those reporting kidney disorders or memory disturbance and those who did not report these symptoms. Dentists had, on average, more surfaces in their teeth filled with amalgam (mean = 13.7) than had controls (mean = 11.7) but these differences were not statistically

Table 2 Environmental measurements of mercury in surgeries. (In interpreting these results, it should be noted that the UK Health and Safety Executive has set the occupational exposure standard (OES) for mercury vapour at 25 µg per cubic metre for 8h a day, 40 hrs a week)

Measurement area	<i>n</i>	µg per cubic meter time weighted average			
		Mean	Median	Minimum	Maximum
Chair	180	28.9	16.3	0	236
Skirting	180	38.9	21.2	0	484
Mixing device	110	37.8	21.0	0	289
Capsule storage and preparation	43	15.2	10.3	0	122
Waste amalgam storage	163	10.7	8.3	0	47
Autoclave	66	11.7	8.7	0	56
Preparation area	179	10.4	8.0	0	89
Dosimeter	153	29.2	15.0	0	452
Air	112	6.5	5.7	1	24

Table 3 Percentage of surgeries where averaged environmental readings were above occupational exposure standard of 25 µg per cubic metre

Area	Number of surgeries measurements taken	Number of surgeries where OES exceeded (%)
Chair	180	68 (38)
Skirting	180	80 (44)
Mixing device	110	46 (42)
Capsules	43	38 (5)
Storage container	163	10 (6)
Autoclave	66	4 (6)
Preparation area	179	7 (4)
Dosimeter	153	45 (29)
Air	112	0 (0)

significant. Control subjects were significantly ($P < 0.05$) more likely to have had dental treatment in the previous month than the dentists.

Dentists reported that they ate significantly ($P < 0.001$) more meals which include fish or seafood in the average week than did control subjects, with dentists eating an average of 2.1 fish meals per week (range = 0 to 10 meals), and controls eating an average of 1.4 fish meals per week (range = 0 to 8 meals).

General health questionnaire version 12

There was no significant difference between the mean GHQ-12 scores for dentists and controls ($P = 0.24$). Dentists had a mean score of 11.0 (range = 2–33) and controls had a mean score of 11.6 (range = 1–31).

Environmental mercury measures

Measurements of environmental mercury were taken from eight surgery areas as described in the methods section. Measurements in the region of the skirting and chair were made for all surgeries. The number of other areas in which measurements were taken varied depending on the type of equipment which was used in the surgery. The number of surgeries for which measurements were made in particular areas is shown in Table 2. In most instances, two measurements were taken in each area, although never at the same point. However, on occasions, up to four measurements were taken because of variations in layout of individual surgeries. The exception was for the personal dosimetry measurements when only one measurement was taken. Multiple measurements were averaged for each of these surgery areas. The results of these environmental mercury measurements are presented in Table 2. It should also be noted that those surgeries using only amalgam-

Table 4 Rank correlation of urinary mercury concentrations and environmental measurements

	Correlation with urinary mercury concentration	P value	Corrected P value
Chair	0.13	0.11	
Skirting	0.17	0.04	0.36
Mixing device	0.12	0.24	
Capsule storage	0.38	0.015	0.14
Amalgam storage	0.40	<0.001	<0.01
Autoclave	0.40	0.002	0.02
Preparation area	0.49	<0.001	<0.01
Dosimeter	0.43	<0.001	<0.01
Surgery air	0.43	<0.001	<0.01

ators will not have a measurement for capsule storage, and dentists using only pre-loaded capsules will not have a measurement for a mixing device.

The Health and Safety Executive has set the occupational exposure standard (OES) for mercury vapour at 25 µg per cubic metre for 8h a day, 40 hrs a week. Results from 180 surgeries showed that in 68% ($n = 122$) of dental surgeries the direct reading instrument displayed levels of mercury which were higher than that of the occupational exposure standard in one or more separate areas. The number of surgeries where the average of readings in a particular area exceeded the OES is shown in Table 3.

From Table 4 it can be seen that there are significant correlations between levels of mercury in urine and the environmental measures taken around the mercury storage areas, autoclave, preparation areas and the dosimeter measurements.

Spearman's Rank Correlation was carried out between the environmental mercury measures and the numbers of fillings placed and removed. The results are shown in Table 5.

No significant correlation was found between the length of time the work premises had been used as a dental surgery and any of the environmental measures taken.

More than half the dentists were using an amalgamator or both an amalgamator and capsules ($n = 108$, 59%). Mean measurements of biological and environmental mercury were compared for those dentists who used amalgamators and those who used capsules only. Those dentists who used both amalgamators and capsules were included in the amalgamator group. After adjusting for multiple comparisons, no significant differences were found in the environmental mercury measurements or on the biological mercury measures between dentists who used capsules and those who used amalgamators.

Table 5 Rank correlation of number of fillings placed and removed and environmental measurements

	Correlation with number of fillings placed	P value	Corrected p value	Correlation with number of fillings removed	P value	Corrected P value
Chair	0.07	0.40		0.07	0.37	
Skirting	0.14	0.08		0.09	0.26	
Mixing device	-0.24	0.02	0.13	-0.18	0.07	
Capsule storage	0.41	0.01	0.09	0.36	0.03	0.27
Amalgam waste storage	0.04	0.61		0.01	0.94	
Autoclave	0.25	0.06		0.24	0.07	
Preparation area	0.15	0.06		0.13	0.11	
Dosimeter	0.12	0.18		0.12	0.16	
Surgery air	0.32	0.002	0.02	0.18	0.08	

Table 6 Mercury analysis for urine, hair and nails

	<i>n</i>	Mean	Standard deviation	Median	Minimum	Maximum
<i>Urinary mercury (nmol Hg mmol⁻¹ creatinine⁻¹)</i>						
Dentists	162	2.58	2.76	1.70	0.02	20.90
Controls	163	0.67	0.68	0.50	<0.01	4.2
<i>Head hair (mass Hg g⁻¹)</i>						
Dentists	161	1.00	0.77	0.80	0.10	5.67
Controls	161	0.57	0.48	0.47	0.04	3.86
<i>Public hair (mass Hg g⁻¹)</i>						
Dentists	167	0.88	1.00	0.69	0.09	11.71
Controls	168	0.46	0.36	0.37	0.03	2.54
<i>Finger nail (mass Hg g⁻¹)</i>						
Dentists	164	5.25	20.60	1.05	0.12	239.60
Controls	155	0.32	0.30	0.23	0.02	2.49
<i>Toe nail (mass Hg g⁻¹)</i>						
Dentists	163	0.71	1.38	0.38	0.20	14.74
controls	155	0.24	0.19	0.18	0.02	1.22

Biological measurements

Urinary mercury analysis

These results are presented in Table 6. A large and highly significant difference was found between urinary mercury levels of dentists and controls, with the geometric mean urinary mercury for dentists being 4.17 times that for the control group (95% CI = 3.36 to 5.19). This difference was slightly reduced, but still significant after using analysis of covariance to adjust for the number of fish meals consumed each week (adjusted ratio of geometric means: 3.90, 95% CI = 3.13 to 4.86). There was no significant correlation between urinary mercury and age for dentists ($r = -0.02$, $P = 0.84$) nor for controls ($r = 0.12$, $P = 0.14$).

There was, amongst dentists, a significant correlation between the number of hours worked in the surgery and urinary mercury ($r = 0.22$, $P = 0.006$) but no significant correlation with this and head hair, pubic hair, finger nail or toenail mercury levels.

There was, amongst dentists, a highly significant correlation, between the number of amalgam fillings they placed and removed in a week and urinary mercury concentration ($r = 0.38$, $P < 0.001$, and $r = 0.29$, $P < 0.001$).

Spearman's rank correlations were carried out to determine if there is a relationship between the number of amalgam restorations in subjects' own mouths and biological mercury measurements. The number of teeth with amalgam fillings, the number of occlusal amalgam surfaces and the total number of amalgam surfaces are all significantly correlated with urinary mercury. Correlations were highly significant for all these variables in both dentists ($r = 0.23$, $P = 0.005$; $r = 0.21$, $P = 0.01$; $r = 0.19$, $P = 0.02$) and control subjects ($r = 0.62$, $P < 0.001$; $r = 0.64$, $P < 0.001$; $r = 0.63$, $P < 0.001$).

Neither the use of chewing gum or bruxism had a significant effect on urinary mercury measurements for dentists or controls.

DISCUSSION

Methodology

This extensive study used contemporary methods of analysis of mercury levels combined with a questionnaire designed to provide a picture of the dentists' health and behaviour.

Of the 180 dentists in the study, 129 were sampled randomly from the population of registered dentists in the West of Scotland; the remaining 51 volunteered to participate following local advertising. Apart from a difference in gender (55% of randomly sampled and 73% of volunteer dentists were male),

there were no other differences in the demography nor exposure to mercury vapour as assessed by biological or environmental measurements of the two dentist subgroups. As an additional check that the inclusion of volunteer dentists was not having an undue influence on the results of the study, the key analyses were repeated with the volunteer dentists excluded, comparing only randomly sampled dentists with controls. The conclusions of the study were unaffected by this. For example, the adjusted odds ratio of memory disturbance for randomly sampled dentists compared with controls is 3.68 (95% CI = 1.84 to 7.34) compared with 3.15 reported earlier for all dentists. Also the adjusted ratio of geometric mean urinary mercury concentrations for randomly sampled dentists compared with controls is 3.75 (95% CI = 2.92 to 4.80) compared with 3.90 reported earlier for all dentists.

The control group which was selected could be considered to be a convenience sample, not wholly comparable to the dentist group in some respects. In the pilot study²² general medical practitioners were used as controls, which may be considered a more comparable group in terms of education, exposure to patient groups, levels of occupational stress and so on. However, the difficulties in gaining the co-operation of such a large group of doctors to act as controls was considered insurmountable and a group of graduates was selected as an alternative.

Brown and Sherriff²¹ have recently produced valuable information using disposable mercury monitors based on palladium chloride in over 3,000 dental surgeries throughout the UK. These monitors, which demonstrated an improvement in mercury hygiene practices during the period 1981 to 2001, have proved to be reliable first-level indicators of high concentrations of mercury vapour in contaminated dental surgeries. However, their function is different from the test apparatus used in the present study and direct comparison with the findings of Brown and Sherriff and those of the present work is therefore inappropriate.

Pohl and Bergman²⁸ observed that it is difficult to link intermittent mercury vapour recordings to the real exposure of dental staff. Metallic mercury is slowly volatilised at room temperature and about 80% of the vapour entering the lungs can be absorbed. It is likely that environmental readings will fluctuate throughout the day in a dental surgery, as found by Nixon and co-workers,²⁹ and that increased ventilation will reduce the amount of mercury vapour in the air. However the readings found in the areas of the

skirting board and the base of the chair are least likely to be affected by ventilation.

It was not possible in this study to control the time and conditions of the environmental mercury measurements, as we were working with a large group of self-employed dentists, for whom it was usually necessary to undertake environmental measurements during the dentist's lunch break. Also, the type of treatment procedure immediately preceding the measurement could not be controlled, neither could any determination be made of the usual levels of ventilation within individual surgeries. These factors would be expected to affect the levels of mercury measured in air, by the dosimeter and around the equipment which had been used during the period immediately preceding the monitoring procedure. It is less likely that there would have been much effect of these factors on the levels of mercury measured at floor level which is more likely to be a reflection of general hygiene practices.

Biological measurements

The urinary mercury levels found in the dentists included in this study were similar to those reported in other studies in recent years and very close to those reported by Langworth *et al.* in their study of dentists and dental nurses in 1997.³⁰ Biological uptake of mercury as measured by urinary mercury analysis amongst the dentists in our study was found to be related to the number of hours worked in the surgery, the number of amalgam fillings placed and removed and the number of amalgam surfaces they had in their own mouths. Amongst control subjects, urinary mercury levels were highly correlated with the number of amalgam fillings they possessed.

Only one dentist, and none of the controls in this study, had a urinary mercury level which exceeded the Health and Safety Executive's health guidance value of 20 $\mu\text{mol mmol}^{-1}$ creatinine. There was, however, a large and highly significant difference between the urinary mercury levels of our dentists and controls, with the dentists having a mean urinary mercury concentration of 4.17 times that of the controls. This contrasts to some extent with the findings of Nixon and colleagues in 1981, who found that 56% of the 358 DHCWs tested had urinary mercury levels within the normal range = 29. These workers found that urinary mercury levels were higher in those subjects who worked longer hours, but that this was not statistically significant, and that there was no correlation between urinary mercury level of the dentist and number of patients and amalgams placed. The contrast in these results and those of the present study may relate to the different testing methods employed.

As with previous research,¹⁹ our study found that urine was a better biological marker for mercury exposure in dental practice than analysis of mercury in hair and nails. Although head hair, pubic hair, finger nail and toe nail samples from dentists gave higher mean mercury concentrations than those from controls, correlations between these and measures of occupational exposure were weak compared with urinary mercury concentrations. Concentrations of mercury in hair and nails was significantly associated with the number of fish meals consumed. The dentist with the highest finger nail mercury levels reported that he did not wear gloves. He was counselled regarding this.

It is known that mercury accumulates in the kidneys of dental staff.³¹ In our study, dentists were significantly more likely than control subjects to report that they had suffered from and received treatment for a kidney disorder, but there was no observed relationship between levels of urinary mercury and reporting of kidney disorders. Vershoor *et al.*¹⁸ similarly reported a relatively high percentage of dental staff exhibiting renal dysfunction but found no significant relationship between urinary mercury levels and kidney disorders. These authors suggested that other potential nephrotoxic agents used in dental practice,

including antibiotics, local anaesthetics or composite resins, might be responsible for the observed increase in protein excretion. The mean concentration of urinary mercury in our study was considerably below the threshold level of 50 $\mu\text{g g}^{-1}$ creatinine, below which there is no effect on kidney function as suggested by Roels *et al.*³² It is therefore unclear what might be responsible for this observed incidence of renal symptoms reported by dentists.

In addition to reporting a high incidence of kidney disorders, the dentists in our study also reported a significantly higher incidence of memory disturbance than did the control subjects.²³ As with reported kidney problems, the reporting of memory disturbance was not related to urinary mercury concentration.

The general health questionnaire (GHQ) was used to compare the psychological health of the dentists and controls.²⁴ There were no significant differences in GHQ scores between the two groups, and there was no significant relationship between GHQ score and urinary mercury levels.

The increased levels of self-reported kidney disorder and memory disturbance in this group of dentists suggests that there are aspects of practising dentistry which may have a detrimental effect on some aspects of health, although these cannot necessarily be attributed to exposure to mercury vapour. These findings may warrant further studies of the influences on the health of dentists.

Environmental measurements

Sixty-eight per cent of the surgeries in this sample exceeded the occupational exposure standard (OES) in one or more areas of the surgery. Herber *et al.*¹⁹ showed that mercury exposure was directly related to the hygienic measures taken in the dental practices, and many other studies have indicated that good hygiene is essential in minimising exposure to mercury vapour.^{8,13,20} The areas showing greatest levels of mercury contamination were the base of the dental chair, the skirting board and the mixing device in surgeries where an amalgamator was used. In addition, 29% of personal dosimeter readings were above the OES. The skirting board is affected by any spills that may occur, any leaking from capsules during trituration and the lack of any sealant or curved surface at the edge of the floor and during general cleaning of the floor. The levels of mercury vapour around the base of the chair may be affected by amalgam placement, removing old amalgam restorations and polishing³⁰, and floor cleaning. In our study, it was observed that some dental chairs incorporated an inflexible plastic skirt concealing debris that gave high recordings of mercury vapour. It would appear essential that greater attention is paid to cleaning these areas, but also that manufacturers of dental units and designers of dental surgeries make the cleaning of the floor/wall interface and the base of the chair much easier.

There was no significant association between levels of mercury in urine samples and the levels of environmental mercury measured around the chair, skirting board or mixing device – the areas of greatest contamination. However, there were significant correlations between urinary mercury and environmental mercury measurements in the amalgam storage and preparation areas, surgery air and with personal dosimeter readings. The association between urinary mercury and environmental mercury levels in these areas may be a result of these being in the dentists' breathing zone, whereas contamination at floor level may have little biological impact.

There was a significant association between the number of fillings placed per week by the dentists and levels of mercury in surgery air. Although one report³³ has attributed low levels of urinary mercury to the use of amalgam capsules, Skare *et al.*¹³ reported that the use of capsules increased urinary mercury

exposure. The results of the present study did not indicate any difference in urinary mercury concentrations between dentists who used only amalgamators or amalgamators and capsules and those who used capsules only. This is in agreement with the results of Brown and Sherriff,²¹ who found that the incidence of high mercury vapour concentrations in dental surgeries did not appear to be related to whether amalgamation took place in a Dentomat (Degussa Ltd, Handforth, UK) or in disposable capsules. However, there may be a tendency amongst some dental staff to consider use of capsules as a lesser risk and be, as a result, less prudent in their handling of amalgam and in the cleaning of preparation equipment.

Nixon and co-workers screened 200 dental surgeries for mercury vapour in 1981,²⁹ finding that only 10% of surgeries tested had an ambient vapour concentration greater than 20 µg per cubic metre, finding that levels were higher in a surgery that had had a mercury spillage some years prior to the test, and that surgeries with larger volumes had lower ambient mercury levels. However, it is difficult to correlate these findings with the present occupational exposure standard of 25 µg per cubic metre as the mercury vapour levels that may be measured today are substantially less than those measured 20 years ago.

Overall findings

A number of authors have suggested that uptake of mercury varies considerably between individuals exposed to similar environmental or other exposure levels and that there are those who are particularly susceptible to mercury toxicity.³⁰ High intra-individual variation may require an average to be taken of several urinary mercury determinations.³⁴ It is for this reason that biological monitoring of mercury has been considered less reliable than direct environmental exposure measurements. The areas of the surgery where we measured highest environmental contamination of mercury were not within the dentists breathing zone. However, there were significant correlations between mercury measured by personal dosimetry and other breathing zone areas and urinary mercury measurements. As urinary mercury levels are well below the Health and Safety Executive biological guidance values, the Occupational Exposure Standard could be considered to be set at too high a level. However, an environmental exposure limit for those working with mercury (of 25 microgram per cubic metre) has been widely accepted by most European countries. Further studies of true environmental exposure in the dental surgery during a normal working day and the effect of ventilation and heating on the levels of mercury vapour are therefore indicated.

The results of this study have raised a number of important issues with regard to mercury hygiene in the dental surgery. As a result, the following recommendations would appear appropriate:

- Greater emphasis should be placed on the importance of appropriate occupational hygiene practice, both during training and continuing professional development in order to ensure that instances of mercury contamination within dental surgeries be reduced.
- Longitudinal studies are warranted to measure the variations in exposure of all members of the dental team to environmental mercury over the working day.
- Health surveillance of dental staff, to identify increased incidence of disorders and symptoms that can be linked to aspects of practising dentistry, should be conducted on a periodic basis.
- Dental surgeries and dental chairs should be designed to prevent mercury accumulation.

Finally, the high levels of bodily contamination with mercury found in the dentists tested, despite any correlation with frank ill-

ness, may be considered less than ideal. Taken alongside environmental concerns, it would therefore appear that the search for a dental restorative material with amalgam-like properties of low cost but good clinical performance, should be stepped up. Furthermore, given the highly significant correlation in dentists between the number of amalgam fillings placed and removed in a week and urinary mercury concentration, there would appear to be a strong indication for the use of rubber dam, especially when removing old amalgam restorations.

CONCLUSIONS

- The urinary mercury levels found in this group of dentists, although over four times that of the control group, is below the Health and Safety Executive guidance value.
- The environmental mercury measurements suggested that in more than two thirds of surgeries further efforts should be made to improve occupational hygiene practice and to ensure that all areas of the surgery have mercury levels below the occupational exposure standard.
- Dental staff reported a higher incidence of symptoms which seem unrelated to mercury exposure and suggest a need for further studies of occupational influences on the health of dentists.

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