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Historical exposure to mercury among Norwegian dental personnel

by Kristin Svendsen, PhD,¹ Tore Syversen, Dr Philos,² Inger Melø, McO,³ Bjørn Hilt, MD^{4,5}

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Objectives Due to public concern in Scandinavian countries about the health situation of dental nurses, the Norwegian Ministry of Labor and Social Inclusion initiated a project to look at previous exposure to metallic mercury and its possible effects on dental personnel. The aims of this part of the study were to: (i) describe Norwegian dental personnel's exposure to mercury during the last 50 years, (ii) develop a model for scoring that reflects the cumulative exposure on an individual basis, and (iii) relate the calculated score to earlier measured levels of mercury in urine.

Methods We obtained lists of previous and current dental employees in both the private and public sector and mailed them a questionnaire concerning their working conditions. We received a response from 655 dental nurses and 452 dentists. We also obtained urine mercury levels measured between 1970–1990 for 143 (22%) of the dental nurses and 130 (29%) of the dentists.

Results The results revealed a widespread exposure to mercury in both the individual exposure score and the measured mercury values in urine. For most respondents, however, the level of exposure to mercury seemed to be low. The use of copper amalgam, which is heated before it is applied, is of particular concern as a significant source of mercury exposure in dental personnel.

Conclusion It seems evident that the exposure to mercury among dental personnel varies substantially; this is important to take into account when making exposure assessments for this group of workers.

Key terms amalgam; copper amalgam; dental nurse; dentist; exposure assessment; Norway; nurse.

During the last two decades, there has been some concern in Scandinavian countries as to whether dental personnel have suffered long-term deleterious health effects from their previously assumed, low level, occupational exposure to metallic mercury from dental amalgam (1–7). One of the main challenges has been to assess the amount of mercury to which dental personnel have been exposed, preferably on an individual level. Studies of exposure levels in dental clinics have shown mostly low levels of mercury exposure, as indicated both by measured levels in the air at dental clinics and the urine of employees (8–11). Such results have, however, been linked neither to short- nor long-term health effects.

The acute toxic effects of metallic mercury on central nervous system functions are well known. Symptoms of

mercury poisoning include tremors, reduced psychomotor speed, paresthesias, and a fairly distinct constellation of psychological symptoms, such as nervousness, shyness, blushing, irritability, and lability of mood. Mild forms of this syndrome are termed micromercurialism, whereas more grave conditions, entailing psychotic symptoms, are called erethism (12).

Some previous studies on the health effects of mercury exposure have included exposure scores for the analyses of possible relationships between exposure to mercury and different outcomes (13), but most have applied biological indicators of exposure – mainly measurements of the current mercury levels in urine (4–6, 14).

Owing to the growing public concern over the health situation of dental nurses, the Norwegian Ministry of

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Labor and Social Inclusion initiated a project in order to investigate previous exposure to mercury and its possible late health effects among both dental nurses and dentists. A slightly increased occurrence of cognitive symptoms among Norwegian dental personnel has recently been published (15) based on a questionnaire which comprised the first part of the project. The aims of this part of the study were to: (i) elucidate and describe Norwegian dental nurses' and dentists' exposures to mercury during the last 40–50 years, (ii) develop a model for a relative score that reflects the cumulative exposure to mercury on an individual basis, and (iii) validate the calculated score by relating it to mercury urine values measured earlier.

Mercury in dental amalgam and determinants of exposure

Dental silver amalgam contains 50% metallic mercury by weight and a metal alloy composed of silver (about 70%), tin (about 25%), copper (1–6%) and zinc (0–2%). Copper amalgam was a special kind of amalgam that was previously commonly used for the restoration of deciduous teeth in many countries. It consisted of 70% metallic mercury and 30% copper. During preparation, solid tablets of this material had to be heated above the melting point of the alloy. Inhalation of metal vapor during this process resulted in a possible source of significant exposures. After the preparation of all the types of amalgam, it was also common that surplus mercury was removed, usually by pressing it through a rag, before the amalgam was used as a filling material.

Throughout the years, different methods for the preparation of dental amalgam have been applied. Initially, amalgam was mixed in a mortar after the manual weighing of each component; later it was prepared in self-made capsules or in semi-automatic amalgamators. Eventually, pre-produced capsules were used. Each of these methods are briefly described below.

In the 1950s and 1960s, the most commonly used method was the preparation of dental amalgam in a mortar, where metallic mercury and metal powder were weighed separately and mixed together manually. We have also been told that the amalgam was often further processed in the palm of the hand to keep it smooth and malleable until it was to be used.

Some clinics also employed self-produced capsules during this period. These were filled with mercury and metal alloy that were mixed and shaken before use. The process entailed a significant risk for spills when the capsules were filled, broke during shaking, or became otherwise leaky during filling and mixing.

Another method, often used in Norwegian dental clinics in the 1970s and 1980s, was the preparation of amalgam in a so-called "Dentomat" or similar semi-automatic mixing devices. In this process, mercury and metal powder were added separately to individual chambers where

dosage and mixing took place automatically in a closed system. The mix could be adjusted to be either wet or dry amalgam. There was a risk of spillage during the filling of the Dentomat or when the amalgam was too wet.

During the late 1980s, pre-produced amalgam capsules became available in Norwegian dental healthcare, where proper dosages of mercury and metal powder had been mixed by the manufacturer and were delivered in a closed and solid system. In this method, the quantities of metallic mercury and alloy were so precise that squeezing out excess mercury eventually became unnecessary.

The use of copper amalgam, which was applied in some countries, entailed a source of significant exposure to mercury vapor. Copper amalgam was easier to insert as a filling as it was smooth. It was also considered to have a better antibacterial effect, which reduced the need for excavation of the affected tooth, and it was, therefore, commonly used for the treatment of deciduous teeth. When preparing copper amalgam from a solid form, tablets were heated over a spirit burner until liquefied at temperatures up to 225 °C (16). The melted metal was then transferred to a mortar, and finally to a textile rag, where excess mercury was squeezed out. In most Norwegian dental clinics, the use of copper amalgam was stopped in the early 1980s, but, according to local registers, some dentists still purchased copper amalgam as late as 1987.

Previous studies have aimed at elucidating which factors could be the main determinants for mercury exposure in dental personnel. There have been, however, substantial differences in conditions, equipment, and routines for dental treatment among countries. Therefore, such factors are not necessarily the same everywhere.

There are only a few reliable fulltime exposure measurements from air samples in dental clinics. From studies conducted before 1970, one study of 50 dental clinics in New York City, USA, showed mean mercury vapor concentrations of 0.02 mg/m³ in the breathing zone of the dentists. Only 2% of the measurements were >0.1 mg/m³. When particulate mercury was included, the mean air level was 0.045 mg/m³ and 14% of the measurements were >0.1 mg/m³ (17). Another study from the US incorporating 59 clinics reported that exposure in the breathing zone reached as much as 0.18 mg/m³. Approximately 10% of the dentists had exposure levels >0.1 mg/m³ while 80% had exposure levels <0.01 mg/m³ (18).

The literature refers to the work of Frykholm (19), who performed measurements in Swedish dental clinics before 1970 using direct reading instruments over a period of 25 minutes. He showed that the mercury exposure levels for dentists and dental nurses varied from <0.01 mg/m³, for normal amalgam work in well-ventilated rooms, to 0.4 mg/m³ when copper amalgam was used in small rooms.

In the years between 1970 and 1980, one study

covering 23 dental clinics in Alberta, Canada, reported concentrations in the breathing zone of $<0.055 \text{ mg/m}^3$ in 22 clinics. The median level of mercury vapor in the operating room was found to be 0.023 mg/m^3 (20). A Norwegian study of 15 clinics reported a mean level of 0.043 mg/m^3 ; the level was $<0.020 \text{ mg/m}^3$ in 50% of the clinics. In one clinic, the mean exposure level in the operating room was found to be 0.4 mg/m^3 (9).

After 1980, there is one report from Sweden where the median level of mercury vapor in 82 clinics was $<0.002 \text{ mg/m}^3$ in public service clinics and $<0.0036 \text{ mg/m}^3$ in private clinics. The measurements were taken in the breathing zone of the dentists (11).

All the aforementioned studies seem to have used short-time measurements with direct reading instruments for mercury vapor detection. Measurement times were mentioned in only two of the five studies.

One Swedish study from the 1990s did, however, report time-weighted average air mercury levels during normal 8-hour working days. Measurements were performed by use of "hydrar tubes" and showed a median air level of mercury of $1.8 \mu\text{g/m}^3$ for the dentists and $2.1 \mu\text{g/m}^3$ for the dental nurses (21).

The most recent study measuring mercury in dental clinics is from 2004 in Great Britain. It reported results from 153 dosimeters worn by dentists. The mean concentration was 0.029 mg/m^3 ; 29% of the measurements were $>0.025 \text{ mg/m}^3$ (22).

However, most available studies that have looked at determinants for exposure to metallic mercury in dental clinics have used mercury levels in urine as an indicator of exposure.

For this purpose, a complete 24-hour urine sample is preferable, but in practice it is difficult to obtain. As a surrogate for timed samples, spot samples of the first morning urine, corrected for creatinine or specific gravity, are recommended. After short-term exposure, the maximum mercury level in urine is not reached until several weeks after exposure, and the half time of mercury is 40–60 days when a one compartment model is assumed (23). The time of the day when the urine is collected is a significant factor for both the level of mercury in urine and the creatinine-corrected values (24). In Norway, the reference value from objects with no occupational exposure to metallic mercury has been 100 nmol/l (8); while the new biological limit value in Norway today is $30 \mu\text{g}$ mercury/g creatinine, which corresponds to $150\text{--}200 \text{ nmol/l}$. The mean background concentration of urinary mercury has, however, been reported to be 20 nmol/l with a 95th percentile of 100 nmol/l (8).

Important factors that may influence exposure and, thus, also the levels of mercury in urine include: (i) the use of a textile rag to squeeze out excess mercury, (ii) the number of years a clinic has used the same premises, (iii) the number of amalgam treatments per

week, (iv) whether a mercury spill has occurred in the clinic, and (v) whether Dentomat or capsules were used (4, 5, 10, 11, 13, 25).

Some studies have also reported that the number of amalgam surfaces that were removed or polished has had an effect on measured mercury in urine (10) and that the removal of amalgam fillings can give dental personnel an equally high mercury exposure as when new fillings are put in place (26). Others have, however, not shown any relationship between the number of removed fillings and urinary mercury levels among the dental staff (4, 25).

Method

This study was conducted as a questionnaire survey during the spring of 2006 among individuals who had worked in the dental health services in three counties forming the central part of Norway. We obtained lists of previous and current employees from both private and public service dentists. In this way, we identified 2247 dental personnel, born between 1913 and 1985, who were asked to participate in the study by responding to a comprehensive questionnaire on both exposure and health.

In order to learn about previous methods for preparing amalgam and design a suitable questionnaire, we interviewed both dentists and dental nurses who had worked in dental healthcare as early as the 1950s and 1960s. These individuals also demonstrated to us how the work was done in earlier days. Combining this acquired knowledge with previous knowledge about exposure and the factors that influence it, we developed a detailed questionnaire on working conditions at the dental clinics throughout the professional life of the respondents. The questionnaire was tested in a small group of dental personnel before the main study was performed.

In the questionnaire, the participants were asked about their vocational title, at which clinics they had worked, and during what time periods. The participants were also asked if they had ever worked with copper amalgam and, if yes, when they started and stopped using it and how many patients they treated each week using the substance. Similar questions were asked with respect to the various treatment methods (ie, the preparation of amalgam in a mortar, the production of self-produced capsules, and the use of a Dentomat or pre-produced capsules). When the participants had used a Dentomat or similar mixing device, they were also asked how often it was filled, if there had been frequent spills of mercury, whether the amalgam was soft or firm, and whether they had been the ones who filled the Dentomat with mercury and alloy. The questionnaire also inquired about spills of mercury in general, and about flooring, ventilation, and other characteristics of their workplace.

All questionnaires were read optically using the Teleform software, and the registered data were subsequently checked for scanning and logical errors.

Model for exposure assessment

Using the questionnaire data, we calculated a total relative exposure score for each participant. A sub-score was constructed for each relevant treatment method that entailed the use of mercury and other features that could influence exposure. The sub-scores included the weekly number of patients treated with the particular method, the number of years the method was used, and an adjustment factor that reflected our assumptions concerning the relative degree of exposure in connection with that particular treatment method. These adjustment factors were based on crude estimates of relative exposure levels – when taking temperature, surface area and frequency of contact with mercury into consideration – and levels reported in the literature. In addition, we developed a clinic sub-score based on: (i) how long there had been a dental clinic on the premises, (ii) what the floor covering had been on the premises, and (iii) if there had been any serious spills of mercury in the clinic. All these sub-scores were then summed up to a relative exposure score for the cumulative exposure to mercury vapor throughout the individual's career in dental healthcare.

The individual total relative scores were calculated by the following formula as the sum of the five different

sub-scores for treatment methods and the clinic scores as described in table 1:

$$\text{Relative exposure score} = \sum_{i=1}^5 (N_i \times Y_i \times A_i) + \text{clinic score}$$

(N_i = number of patients per week for sub-score i , Y_i = number of years for sub-score i , A_i = adjustment factor for sub-score i). In addition, the sub-scores 1–5 were adjusted by a factor of 0.5 for each of the years where local air extraction was used.

This relative exposure score is cumulative. To obtain a so-called “intensity score” more suitable for comparison with urine levels of mercury, the relative exposure score was divided by the number of years with exposure to dental amalgam.

For some of the treatment methods, a substantial number of respondents were missing details on the number of patients treated each week. In such cases, and if the number of years for that particular treatment method was given, we replaced the missing number of patients with the median number for the whole study group.

Mercury in urine

During the period 1955–2000, the Norwegian National Institute of Occupational Health (STAMI in Norwegian) conducted voluntary monitoring of mercury levels in urine for dental personnel in Norway. During this time,

Table 1. Adjustment factors for the different sub-scores for the treatment method and clinic sub-score.

Score	Treatment method	Adjustment factor	Comments
Sub-score (i)			
1	Use of copper amalgam	10	A study conducted in Norwegian dental clinics in 1974 showed levels of mercury ranging from <0.01–0.4 mg/m ³ . The measurements were done with a Mercury Vapor Sniffer and in standardized locations in the clinics. All measurements >0.05 mg/m ³ were found in clinics using copper amalgam(9)
2	Mixing amalgam in a mortar	0.4	Metallic mercury and metal powder were weighed separately and mixed together manually. This will give an enhanced surface area of mercury.
3	Production of self-made capsules	0.3	The process entailed a significant risk for spills both when the capsules were filled, when they broke during shaking, or in other ways became leaky during filling and mixing
4	Use of an amalgamator (dentomat)	0.2, 0.3, or 0.4	Factor 0.2 was given as base value for the use of a dentomat, factor 0.3 was given if the respondent reported that the amalgam was wet or if the dentomat was filled ≥1 week or if there was a spill ≥1 month when filling the dentomat or if it was most often the respondent who filled the dentomat. If all 4 factors were fulfilled, the factor 0.4 was given. A Swedish investigation has shown high levels of mercury vapor in the front of the amalgamators. Visible droplets of mercury are seen in some cases. The level of mercury as mean of 1–3 minutes registration in the breathing zone at the amalgam preparation area varied between <1.0–18.7 µg/m ³ (11)
5	Use of pre-produced capsules	0.1	Delivered in a closed and solid system. By this method, the quantities of metallic mercury and alloy were so precise that squeezing out excess mercury eventually became unnecessary. Exposure was supposed to be low but was not totally eliminated
Clinic score		1, 5, 8, or 10	If there had been poor routines for the handling of mercury leftovers and spills in the clinic, the adjustment factor was set to 5, if there was a floor covering of wooden panels or carpets, the adjustment factor was 8 and if there have been poor routines for handling mercury leftovers, major spills and there was floor covering of wooden panels or carpets, the adjustment factor was 10. A Norwegian study has shown that it is possible to keep the exposure level <0.01 mg/m ³ , but that some clinics without any obvious reason had levels in the range 0.1 mg/m ³ (9)

STAMI analyzed a total of 4030 samples from 2028 individuals. The results showed a decrease of about 90% in urine mercury levels from the 1960s to the 1990s. The concentration among dentists showed a median of 240 nmol/l (range 83–528) in the 1960s and 22 nmol/l (range 6–76) in the 1990s. The corresponding figures for dental nurses were 160 nmol/l (range 7.5–3100) and 21 nmol/l (range 5–133). The urine samples were analyzed using flameless atomic absorption (8).

In the questionnaires, we requested written permission from each participant to access results from any previously collected urine tests available at STAMI. Of the 273 respondents with available urine values, most respondents had one sample, but there were up to ten samples for one person. The urine values were not creatinine corrected. These urinary values were later collated to two variables: one for the average urinary value for each person and the other for the highest observed value for each person. The urine data were used as a crude measure of former exposure and compared to the individually calculated relative exposure scores. The urine values were given as urine mean, (ie, the mean urine value of all samples from the same person) and urine maximum (ie, the highest value measured for each individual).

Statistical analysis

We used the SPSS version 14.0 to analyze data (SPSS Inc, Chicago, IL, USA). Most analyses were performed with descriptive statistics, and univariate analysis of variance. We performed correlations between the urinary mercury values and the calculated exposure score using a non-parametric method (Spearman's rho).

Ethical considerations

The ethical committee for medical research in Central Norway approved the study; the Norwegian Social Science Data Services provided a license for personal registrations.

Results

Out of the 1224 dental nurses who were invited to participate, 690 (56.4%) responded and 655 confirmed having worked as a dental nurses. The response rate for the dentists was 452 out of 922 (49%). The mean age of the participating dental nurses and dentists was 53.3 [standard deviation (SD)=11.0] and 54.3 (SD=13.8) years, respectively. Figure 1 shows the distribution of the years of first employment in dental care for the participating dental nurses and dentists. The mean duration of their employment in dental care was 21.9 (SD=13.3) and 24.0 (SD=13.4) years, respectively. For the dental nurses, a mean of 18.1 (SD=9.3) of the employed years had been before 1990. For dentists, the corresponding figure was 18.7 (SD=8.6) years.

Table 2 shows the main factors assumed to have influenced exposure to mercury as reported by the dental nurses and dentists themselves (eg, use of copper amalgam, mixing amalgam in a mortar, production of capsules, use of the Dentomat, mercury spills, or frequent handling of amalgam in the hands). The dental nurses reported more of all of these features than the dentists, in particular with respect to spills and the handling of amalgam in the palm.

Of the dental nurses, 201 reported having used copper amalgam for a mean of 8.3 (SD 7.6) years while 108 dentists reported using it for an average of 6.6 (SD 5.4) years. At the most, the two groups reported having had 16.7 (SD 19.2) and 7.7 (SD 9.3) patients a week who were treated with the use of copper amalgam. Only 0.5% of the dental nurses and 0.9% of the dentists reported having used any kind of ventilated hoods when heating copper amalgam.

The use of ordinary amalgam – either prepared in a mortar, by the Dentomat, or in capsules – was stable from the 1960s onwards. Typically, 40–50 patients a week were treated with amalgam while, from the 1990s, the use of ordinary amalgam decreased to 25–30

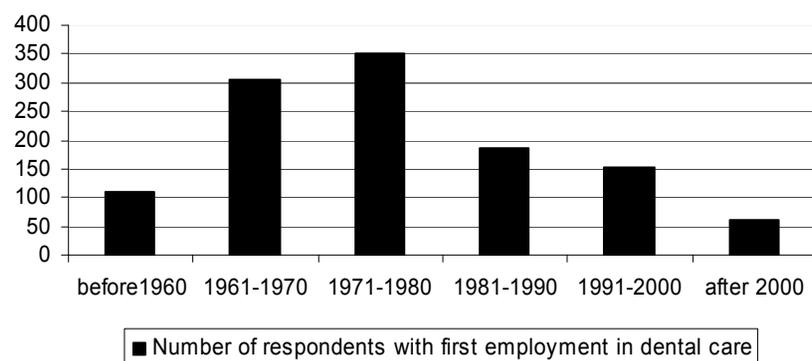


Figure 1. The distribution of the years of first employment in dental care for the 1079 respondents.

Table 2. Factors assumed to have influenced exposure to mercury among dental personnel, and the proportion of the 655 dental nurses and the 452 dentists who reported having used the different working methods. All numbers are given as the percentage of positive answers in each occupational group.

Variable	Dental nurses (%)	Dentists (%)
Used copper amalgam	41.6	30.7
Used a mortar	42.6	34.1
Produced own capsules	13.8	9.6
Often used the Dentomat	82.1	54.2
Wet amalgam	54.9	22.6
Filled the Dentomat >1/week	12.9	8.8
Often filled the Dentomat on your own	79.4	9.0
Experienced a spill each time the Dentomat was filled	32.8	7.0
There was a great spill of mercury in the room at least once	7.7	3.6
Often handled the amalgam in the palm	67.4	9.1

treatments a week. Figure 2 shows a decrease in the reported use of copper amalgam from 69.5%, for those who had started as a dental nurse before 1970, to 5.7% for those who had started after 1990. The use of a mortar shows the same strong decrease, while the Dentomat was used most frequently by those who started to work between 1970–1980. Figure 3 shows the same trends for the dentists’ use of the different methods. The dental nurses and dentists, who started to work before 1970, reported the same degree of work with a mortar; for all other methods and start-up years, the dental nurses reported greater use of all treatment methods.

Table 3 gives the 95th and 75th percentiles for the

year reported for the termination of the use of the four treatment methods that are assumed to have contributed to the highest exposure to mercury. This means that, by 1991, 95% of both dental nurses and dentists had terminated the use of copper amalgam.

When we entered the relevant elements from the above information into the formula for the cumulative exposure assessment, the scores showed a wide distribution for both dental nurses and dentists, with a clear tendency for higher scores in the former. Table 4 shows core statistics on the calculated relative exposure scores for both groups. Even if we substituted the missing number of patients each week with the group median, only 713 (64%) of the respondents answered the most important questions necessary for a valid, relative exposure score (ie, those regarding the years of commencement and termination of the use of copper amalgam and the Dentomat).

Figure 4 shows the development of the relative exposure scores with their SD for both groups, dependent on the year when they started their employment in dental care. We gained access to the results from previous measurements of mercury in urine for 143 (22%) of the participating dental nurses and 130 (29%) of the dentists. Figure 5 shows the distribution of the years when the urine values were analyzed. Table 5 shows available urinary mercury values for the respondents. More than one urine measurement was available in the registry for 37% of the dental personnel. When looking at the whole data set, we found a weak positive correlation between the urinary mercury values and both the relative exposure and intensity scores. For the relative exposure score, Spearman’s Rho was 0.24 (P=0.001) and 0.19 (P=0.008) for the maximum and average urine

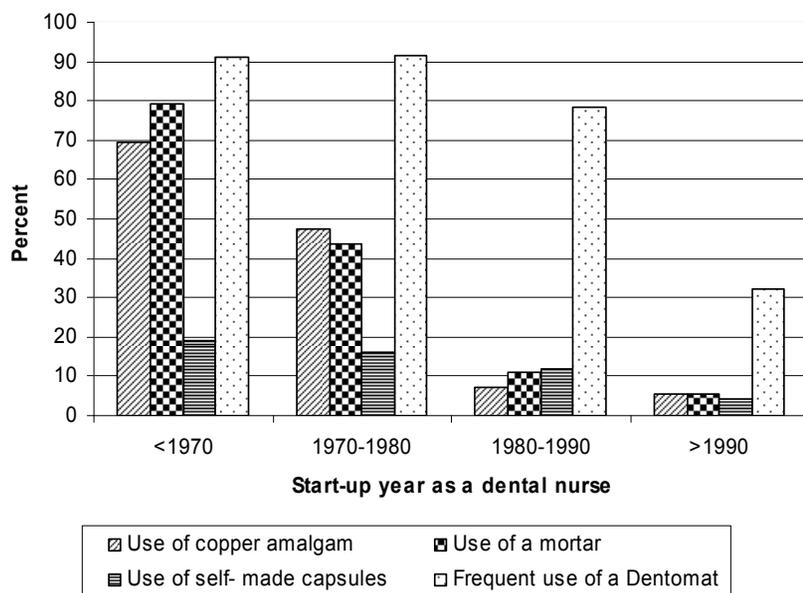


Figure 2. Percent of the 655 dental nurses who reported using the different methods in relation to start-up year as a dental nurse

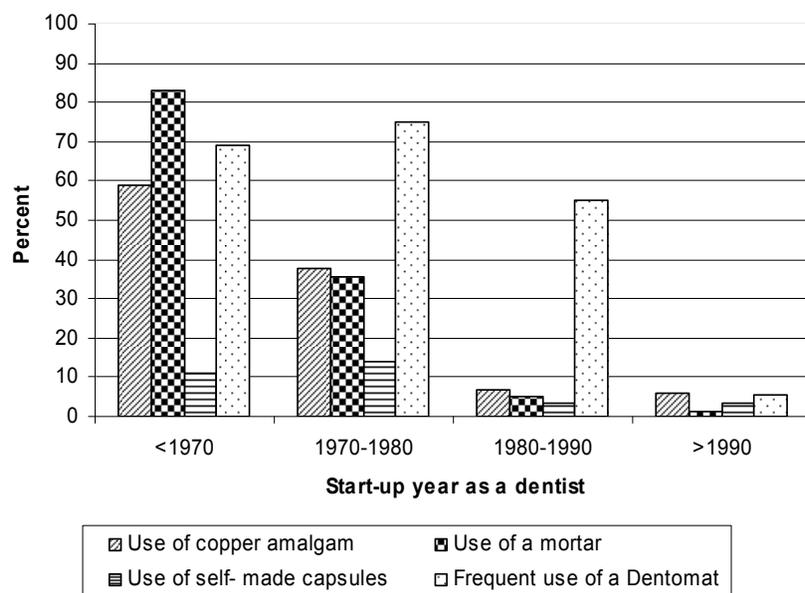


Figure 3. Percent of the 452 dentists who reported using the different methods in relation to start-up year as a dentist.

Table 3. The 95th and 75th percentiles for the years reported for the termination of the four treatment methods that are assumed to give the highest exposure to mercury. The results are given for the dental nurses and the dentists.

Variable	Dental nurses			Dentists		
	Number of respondents	95 th percentile	75 th percentile	Number of respondents	95 th percentile	75 th percentile
In what year did you terminate the use of a mortar?	216	1996	1981	153	1990	1980
In what year did you terminate the use of copper amalgam?	226	1991	1984	146	1991	1982
In what year did you terminate the use of self-made capsules?	58	2006	1995	36	2005	1992
In what year did you start using the Dentomat?	486	1993	1983	289	1995	1981
In what year did you terminate the use of the Dentomat?	458	2005	1999	280	2005	1999

levels, respectively. For the intensity score, the corresponding Spearman's Rho were 0.27 ($P=0.000$) and 0.20 ($P=0.004$). Table 6 shows the correlation between the relative exposure score in four groups for the participants with a valid score and the available urinary mercury values. The group mean urinary level increases as the grouped relative exposure score increases, although not in a statistically significant manner.

Discussion

The results of this study are in concordance with earlier studies that have shown that dental nurses have been more severely exposed to mercury than dentists (10). Both the answers to our questionnaire and the previous measurements of mercury in the urine samples from our participants reveal higher exposures among dental nurses. But, the results also show a wide distribution,

both in the calculated individual relative exposure scores and the previously measured mercury values in urine. Though most of our respondents seem to have had rather low exposures to mercury, the data showed that some of the respondents probably had been more extensively exposed. Even for dental personnel who were first

Table 4. Core statistics for the calculated relative exposure score for the dentists and the dental nurses who had a valid answer on all important determinants (year of starting and terminating the use of copper amalgam and a Dentomat or had never used these methods). [SD=standard deviation.]

	N	Mean	SD	Median	Minimum	Maximum	Geometric mean
Dental nurses	440	829	1371	381	9	12120	374
Dentists	272	561	926	270	9.3	7170	255
Total	712	726	1227	331	9	12120	323

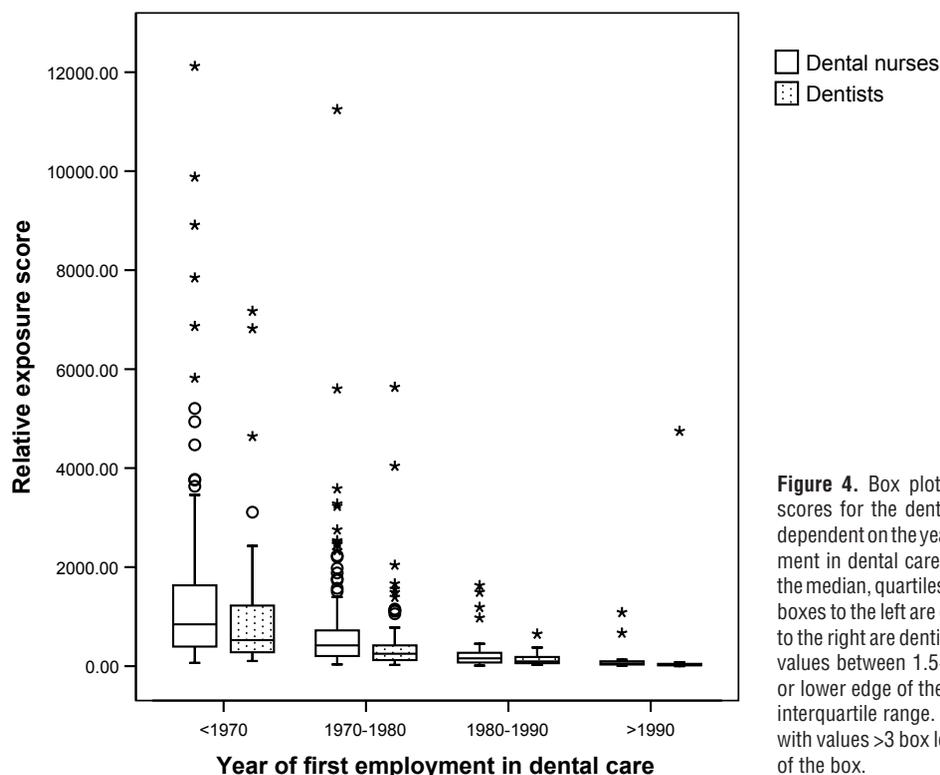


Figure 4. Box plots of the relative exposure scores for the dental nurses and the dentists dependent on the year they started their employment in dental care. The box plot summarizes the median, quartiles, and extreme values. White boxes to the left are dental nurses, dotted boxes to the right are dentists. Circles are outliers with values between 1.5–3 box lengths from upper or lower edge of the box. The box length is the interquartile range. Crosses are extreme cases with values >3 box lengths from the upper edge of the box.

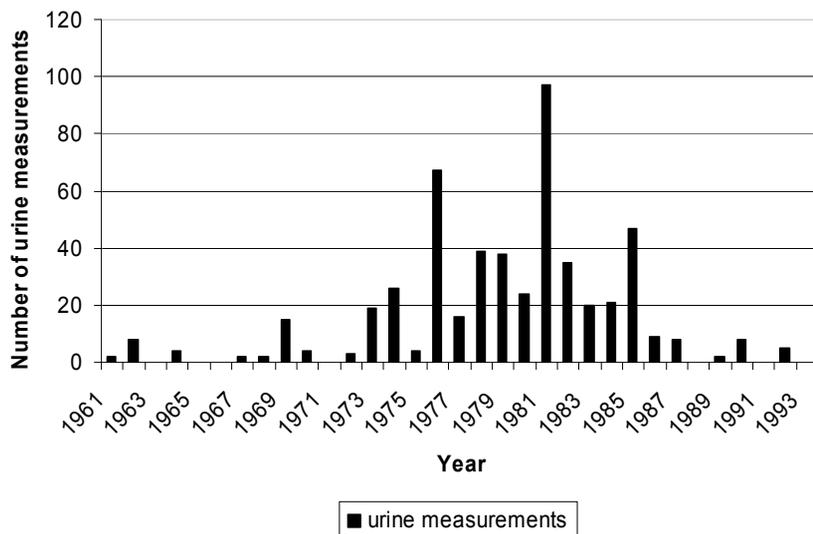


Figure 5. Distribution of the year when the urine mercury measurements were taken for the study group.

Table 5. Median, maximum value, 25th and 75th percentiles, and number of respondents or respondents with urine samples (N) for the calculated exposure score for the two groups, the urine values for the groups, and the highest single urine value measured in each group. Both parameters are statistically significantly different between the dental nurses and the dentists with P<0.005.

	Dental nurses (N=143)				Dentists (N=130)			
	Median	Maximum value	25 th percentile	75 th percentile	Median	Maximum value	25 th percentile	75 th percentile
Urine mean (nmol/l)	49	298	30	85	42	258	30	61
Urine maximum (nmol/l)	59	1065	31	100	51	305	30	75

Table 6. Results from the univariate analysis with maximum urine value as dependent variable and relative exposure score in four groups as grouping variable. [SD=standard deviation.]

Relative exposure score	N ^a	Mean urine max (nmol/l)	SD
Low (N= 176)	21	53	29.5
Medium (N= 176)	39	61	64.6
High (N= 177)	51	69	61.1
Very high (N= 184)	82	90	122.0
Total	193	74	91.4

^a Number of available urine mercury values in each exposure group.

employed in the same decade, the exposure varied substantially. The median levels of mercury in urine, both for dental nurses and dentists, were below the reference value regarding occupational exposure to mercury. The 75th percentile for the maximum urine value for the dental nurses was, however, 100 nmol/l.

The exposure was at its highest for those who started to work in the 1960s and 1970s and decreased gradually thereafter. However, the use of treatment methods that are supposed to result in high exposure to mercury remained frequent in certain clinics up to 1980. It might, therefore, be that some individuals were still substantially exposed to mercury despite the decrease in overall mean exposure. The highest exposures were clearly connected to the heating of copper amalgam. Mercury levels as high as 3 mg/m³ (3000 µg/m³) have been reported when using copper amalgam (27). The risk of adverse health effects resulting from such exposures should not be disregarded. The use of copper amalgam started as early as the 1800s and continued far into the second half of the last century. While one source claimed that the use of copper amalgam was terminated in the 1950s (16), the use of heated copper amalgam has been described in Sweden up to 1987 (28), in New Zealand until 1975 (27) and in Germany up to 1940 and maybe as late as the 1980s (29).

Though copper amalgam can be regarded as the strongest source of exposure to metallic mercury, another substantial source could be spills on the floor, deposited under the furnishings and in slits in the floor covering (9). The handling of mercury in the palm of the hand may also have entailed a risk of metallic mercury vapor exposure, as such handling increases the temperature of the amalgam to above room temperature, leading to higher vaporization. When measuring mercury vapor on the skin right after handling copper amalgam in the bare palm and following hand washing, levels up to 0.2 mg/m³ have been measured (9). Handling amalgam in the palm of the hand was, however, not a factor that was regarded as a significant source of exposure when we started the study and was, therefore, not incorpo-

rated in the exposure score when, on second thoughts, it should have been.

From our data, we see that the dental nurses reported having had twice as many patients each week who were treated with the use of copper amalgam compared to the dentists. In regard to the other treatment methods, the dental nurses and the dentists reported the same number of patients each week. This discrepancy is not easy to understand. As there were more dental nurses than dentists who answered, there may be a selection of dental nurses in our study with an extensive use of copper amalgam. The share of the dental nurses who reported having used copper amalgam (42%) was also higher than that of the dentists (31%). This is in agreement with a recently published study where 42% of dental nurses in public service clinics, and 30% in private clinics reported that they had used copper amalgam (30).

Our respondents' answers as to what year they stopped using the different treatment methods was somewhat confusing. Some of both the dentists and dental nurses reported using copper amalgam as late as 2000 and thereafter. This is probably due to a misunderstanding as a *high copper alloy amalgam* has been in use in recent times and differs from the copper amalgam that had to be heated over a flame. The same phenomenon was seen for the use of the mortar. We supposed the use of this method was terminated in the early 1980s, but some dentists and dental nurses reported the use of mortars as late as 2000. These results may indicate that the wording of the questionnaire was not optimal in spite of our efforts to perfect the questions. Another more worrisome interpretation could be that some dental clinics still use the old fashioned methods for some purposes.

Our calculated exposure score is a relative figure that does not give the exact exposure level, but is aimed at expressing the cumulative exposure during work as a dentist or dental nurse. The model includes numerous factors that were assumed to be of relevance for exposure. The adjustment factors which were used to assess relative exposure intensity were roughly based on available results, measurements and empirical knowledge. The levels measured in Swedish public dental clinics in the early 1980s (11) and the mean levels from Norwegian clinics in the 1970s (9) showed that there was reason to apply a factor of 100 between clinics with good versus bad hygienic practice (including the use of copper amalgam). The values given for the adjustment factors might seem arbitrary, but a typical rise in mercury concentration (0.01–0.1 mg/m³) was found in Norwegian clinics in the 1970s when heating copper amalgam; all clinics with measured levels >0.05 mg/m³ in standardized locations used copper amalgam. The highest level measured was 0.4 mg/m³ and, at the same time, 16% of the clinics had levels <0.01 mg/m³ (9). In the Swedish study, the concentration level varied

between <0.001 – 0.024 mg/m³, and no copper amalgam was used in the clinics under scrutiny (11). Thus one can say that exposure based on location, work practice, ventilation, and other working conditions has varied considerably.

One of the weak points in our approach was that we based our calculations on the responses regarding the years of commencement and termination of the different treatment methods and the number of patients treated each week. As was seen from the answers about the year of termination of the different treatment methods, the results were hampered not only by possible misunderstandings, but also from missing information, resulting in a low response rate for the relative exposure score. It has been shown that missing information on exposure, and not erroneous reporting, is the most important cause of misclassification of the determinant in occupational epidemiological studies (31).

Another potential problem was that, before we started our study, the Norwegian media had focused attention on dental nurses' possible health problems stemming from mercury exposure. As a result, some recall bias overstating the exposure among the dental nurses cannot be ruled out. As many of the dentists were the employers of these dental nurses, a "recall" bias in the opposite direction may have occurred among them.

The group mean urine maximum level increased as the relative exposure score increased, although not in a statistically significant manner. The urine value and the score were two different features. The exposure score was a measure of cumulative exposure that entailed both intensity and duration; while the measured urine mercury value was just a spot value at one point in time and, thus, not a measure on cumulative exposure. In addition, the urine samples were collected on a voluntary basis, and although there was some guidance on the collection of the samples (they were asked to take the sample in the morning), there is no guarantee that the samples were taken in a standardized way. In addition, the urine values were not corrected for creatinine or specific gravity and thus not a good measure of exposure. The measured level of urinary mercury only reflects the exposure level for a relatively short period of the working life. Still, this is the only objective measure on exposure that exists, and we think that a measured urine level may give an indication on the working conditions in the clinic at the time of the measurement. Therefore, we find it interesting that we found a positive correlation between the urinary mercury values and both the relative exposure and intensity scores. The correlation for the intensity score was, as expected, slightly better than that of the relative exposure score, which is a cumulative score.

The model to calculate the exposure score was based on Norwegian habits and constructed on the basis of how dental work was performed in Norway. It may,

however, be used in other countries as well but should be adjusted to local dental treatment practices.

When assigning individual exposure measures to dental nurses and dentists, it is important to take into consideration all the different conditions of their work in order to identify individual differences in the exposure to mercury. Detailed job-specific questionnaires are supposed to be able to differentiate between high- and low-exposed workers (32), and we believe that our relative exposure score, based on a detailed questionnaire, reflects the cumulative exposure to mercury. From both empirical knowledge, and our calculated relative exposure score, it seems evident that the exposure to mercury among dental personnel varies substantially even within the year intervals for first employment in dental care, which is important to take into account when making exposure assessments for this group of workers.

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