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Review Article

A Review of Mercury Exposure and Health of Dental Personnel

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ABSTRACT

Considerable effort has been made to address the issue of occupational health and environmental exposure to mercury. This review reports on the current literature of mercury exposure and health impacts on dental personnel. Citations were searched using four comprehensive electronic databases for articles published between 2002 and 2015. All original articles that evaluated an association between the use of dental amalgam and occupational mercury exposure in dental personnel were included. Fifteen publications from nine different countries met the selection criteria. The design and quality of the studies showed significant variation, particularly in the choice of biomarkers as an indicator of mercury exposure. In several countries, dental personnel had higher mercury levels in biological fluids and tissues than in control groups; some work practices increased mercury exposure but the exposure levels remained below recommended guidelines. Dental personnel reported more health conditions, often involving the central nervous system, than the control groups. Clinical symptoms reported by dental professionals may be associated with low-level, long-term exposure to occupational mercury, but may also be due to the effects of aging, occupational overuse, and stress. It is important that dental personnel, researchers, and educators continue to encourage and monitor good work practices by dental professionals.

1. Introduction

Dental caries remains an international public health challenge for many countries despite an increased focus on prevention of dental caries worldwide [1,2]. Despite periodic safety concerns, dental amalgam has remained one of the most cost effective and durable dental restorative materials for 150 years [1,2]. The World Health Organisation has encouraged "phasing down" of dental amalgam use and the introduction of alternative dental restoration materials [3], but the alternatives to amalgam may be technically more difficult to place, more expensive, and not as durable as amalgam. Research on alternative dental materials has grown significantly in the past decade and their use has increased in high-income countries, but dental amalgam remains the preferred restorative material in low- and middle-income nations and for the disadvantaged in high-income countries [2].

There have been numerous studies over the last 20 years designed to measure the effects of mercury in many occupational groups. Dental personnel are at risk of exposure to metallic mercury when handling amalgam for restorations. Early reports of toxicological risk analysis of occupational diseases in dentists showed that work practices were associated with mercury exposure in dental personnel, and that symptoms associated with renal function, reproductive processes and allergies were related to chronic mercury exposure [4]. Other reports found an association of occupational mercury exposure with memory loss, severe depression, and behavioral and personality changes [5,6] and a decline in fecundability (probability of conception each menstrual cycle) amongst female dental assistants [7].

Mercury is of global concern and due to health and environmental risks linked to mercury exposure, 128 signatories and 25 parties have supported a United Nations treaty from the Minamata Convention on Mercury [8]. The world dental body, Fédération Dentaire International, has established guidelines for dental amalgam use to ensure safety for those in practice, the general population and the environment [9] and encourages further research into possible adverse effects of dental amalgam. Norway, Sweden, and Denmark have legislated to ban the use of mercury in amalgams due to environmental health concerns [10–12].

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It is important to evaluate any adverse effects of the use of dental amalgam on the health of dental personnel so that clinicians, policy makers, and legislators can take the appropriate actions to minimize any health risk to dental personnel. The aim of this review was to synthesize the best available evidence on mercury exposure due to the use of dental amalgam and its health impacts on dental personnel.

2. Materials and methods

The selection criteria included studies published in English between 2002 and 2015 that evaluated the health impacts on dental personnel from occupational exposure to mercury. Non-English articles were excluded to prevent linguistic bias in translation.

Search terms including dental amalgam, mercury silver amalgam, occupational expos*, occupational diseases were combined with terms relating to dental personnel, which included the terms: dentists, dental therapists, dental nurses, dental hygienists, dental assistants, but excluded dental students. Dental students were not considered to have had the time in clinical practice to be able to develop significant mercury exposure or associated health symptoms. Boolean operators and truncation (*) were used. The searches were carried out using four large and comprehensive electronic databases (CINAHL, Pubmed, Web of Science, and Embase) for literature published between 2002 and 2015. Reference lists were also searched for relevant studies and reviews and digital dissertation databases. Citations were reviewed by two of the authors (NN and SB) and the individual paper references searched to identify any missed reports or citations. The original research articles were then critically appraised using the Quantitative Review Form as a standardized means to assess study quality, synthesis, and knowledge [13]. The search process is described in Fig. 1.

3. Results

The search yielded 286 citations, 66 of which were screened based on the review of titles or abstracts (Fig. 1). The citations review and the search to identify any missed reports or citations yielded 15 published quantitative articles; 13 from the database search and two from searching related citations and reference lists. This left 15 original research articles for critical appraisal. There were 10 cross-sectional, four cohort studies (3 of which were retrospective), and one nested cohort study. The studies represented dental personnel in countries from Denmark, Egypt, Iran, New Zealand, Norway (4), Scotland, Turkey (3), Sweden, and the USA. Exposed groups included dentists, dental nurses, dental assistants, or a combination of these occupations.

The studies focused on mercury levels in biological fluids and tissues of dental personnel, the impact on the health of dental personnel from exposure to mercury, the working environment, dental practices, and personal characteristics.

3.1. Mercury levels in biological fluids and tissues of dental personnel

The specimens used as biomarkers of mercury exposure were urine, whole blood, hair, and toe nails [14–24]. Only one study used the indicators of renal function of albumin and α_1 microglobulin, and the enzymes glutathione peroxidase and superoxide dismutase [21]. The most common techniques to analyze mercury levels were cold vapor atomic absorption spectrometry, atomic absorption spectrometry, and neutron activation analysis. The threshold guidelines for the biological exposure index were 35 μg/g creatinine for urine and 15 μg/L for blood as set by the American Conference of Governmental Industrial Hygienists (ACGIH) [25]. Two studies reported mercury levels in both urine and blood [15,21], while four studies reported levels only in urine [17,18,23,26].

Four studies indicated a higher than average mercury level in the urine of dental personnel. Scottish dentists had mean urinary mercury levels four times higher than control individuals, although all but one dentist had mercury levels below the UK Health and Safety value [14]. A study of dental practices in Turkey detected higher urinary mercury levels in dental nurses (dental assistants) than dentists [15]. Higher urine mercury levels in dental personnel than the control individuals were detected in Iran [17,22], and Egypt [21]. A prospective Norwegian study [20] noted a gradual

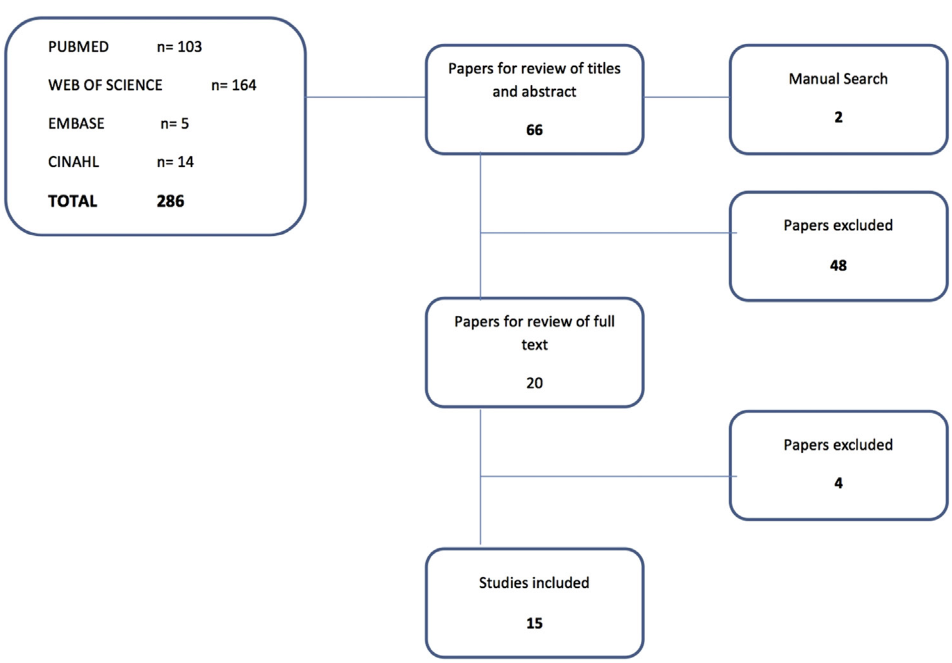

Fig. 1. Flowchart of literature search in Pubmed, Web of Science, Embase and CINAHL.

decrease in urine mercury levels from 1960 to 1990 in dentists, but identified higher mercury values in dental nurses than dentists.

In Egypt, blood mercury levels were 1.5 times higher in dental staff in Cairo than controls [21], and in Turkey plasma mercury levels were significantly higher in dental personnel than control groups [24]. Two studies [14,22] strongly suggested a possible association between airborne and urinary concentrations. A nested control study by Joshi et al [16] noted the mean toenail mercury levels for dentists (0.94 ppm) was twice as high as the nondentists (0.45 ppm) and 60% higher levels than for specialist dentists (0.59 ppm).

The results in the majority of the remaining studies reported higher biomarker levels in dental personnel than the control group. Longer work hours, work place characteristics, and lower standards of safety and hygiene in some countries were key predisposing factors to higher levels of biomarkers. However, none of these studies recorded mercury levels that exceeded recommended levels.

3.2. Health effects of occupational mercury exposure on dental personnel

All of the studies used questionnaires, neurophysiological tests, or a combination of both, to determine the health effects on dental personnel from occupational mercury exposure. Cognitive and neurophysiologic symptoms varied between the cross-sectional studies [14,15,18,22,23,27].

Neghab et al [22] reported that after adjusting for potential confounding factors, there was a significant association between the number of amalgam fillings done per day with neuropsychological and muscular disorders. Reports of hyperpigmentation, respiratory disorders, irregular pulse, hand tremor, spasm of the upper extremities, moodiness, nervousness, anxiety, insomnia, erethism, memory deficit, depression, and chronic fatigue were significantly more prevalent in dentists than control groups. However, a confounding factor could be the report by dentists of exposure to other harmful chemicals.

In Norway, Moen et al [27] noted that dental assistants reported neurological symptoms, psychosomatic symptoms, memory loss, and difficulty with concentration, fatigue and sleep disturbance. In the Danish retrospective study, Thygesen et al [28] found a significant association between the years of dental work experience and symptoms, but when participants age was included in the model, the association between work experience and symptoms became nonsignificant. Aydin et al [15] analyzed the relationship between duration of employment with the combination of mercury in urine and neuropsychological findings, controlling for age, ability, education, alcohol consumption, and previous head injury, they found that urine mercury concentrations were associated with the decreased performance on logical memory and total memory retention. Sletvold et al [26] reported a statistically significant relationship between the urine mercury value and visual long-term memory. Ritchie et al [14] noted significantly more dentists than controls reported memory disturbance, and this remained significant after adjusting for age and sex, but not after adjusting for urinary mercury concentration. Occupational overuse syndrome or repetitive strain injury, a type of injury to fingers, hands, wrists, and elbows, was reported by 32.5% of the dental nurses and attributed to medium- to long-term mercury exposure [28]. However, mechanical vibration from the use of vibrating hand equipment was considered a confounding variable in the case of physical injuries or peripheral nerve damage.

Ritchie et al [14] reported that after adjusting for age and sex, urinary mercury concentration was not significantly associated with kidney problems in dentists. Thygesen et al [28] noted that dentists were significantly more likely than control individuals to suffer renal disorders, but the results were not significantly associated with levels of mercury exposure.

A study of dental nurses reported reproductive health issues at a ratio of 2:1 in comparison to controls [29]. Dental nurses perceived themselves to be in very good reproductive health, but higher incidences of early-age hysterectomy were experienced at the rate of 4:1 in comparison to controls.

3.2.1. The working environment

Several studies collected information on clinic design, area of work rooms, type of ventilation, floor covering, daily cleaning procedures [14–17,20,21,29]. Aydin et al [15] noted mechanical ventilation (laminar flow or heap-filter systems), special floor covering (plastic carpet) and special daily cleaning methods were not recorded in all dental working areas. Kasraei et al [19] detected higher blood mercury levels in dentists working in offices with nylon flooring and wall coverings, but no figures were provided to support this contention.

3.2.2. Dental practices

The equipment/instruments used for amalgam preparation, storage and placement/removal of amalgam restorations in dental patients by dental practitioners in dental offices were investigated by several studies. Blood mercury levels in all studies increased with lower standards of safety and hygiene.

Karahalil et al [17] examined the work practice behavior in dental personnel who were detected with higher urinary mercury levels. One exposed practitioner did not wear a mask and gloves when handling dental amalgam. There were reports of lack of proper ventilation systems and improperly cleaned amalgam spills. The study concluded that the working environment played a crucial role in mercury exposure of dental personnel. Svendsen et al [20] noted that a decrease in mercury exposure over the years was due to improvement in hygiene practices, better method of preparation, and development of improved amalgam alloys. Reports of self-made capsules, use of mortar, and handling of amalgam in the palms were reported during professional practice which dated from 1960 to 1990.

Aydin et al [15] contended that metallic mercury within dental operatories was a major source of mercury exposure, and that the type of equipment used, ventilation, and floor coverings in the dental offices all contributed to mercury exposure. Yilmaz et al [24] explained that the higher mercury exposure in their study correlated with the work place characteristics of dental personnel.

Ritchie et al [14] indicated that in 25% of dental surgeries, the breathing zone of dental staff reported concentrations above the mercury vapor occupational exposure standard (25 $\mu g/m^3$ for 8 hours/day, 40 hours/week). The number of amalgam fillings placed and removed by dentists and urinary mercury in a week showed high significant correlation.

Kasraei et al [19] reported higher blood mercury levels associated with increased working hours per day, the number of restorations per day, amalgam removals per week, and the use of dry sterilization process for amalgam contaminated instruments. Mercury blood levels were also associated with the age of the dental office, greater levels of work experience, the use of diamond burs for removing amalgam, the use of powder/mercury amalgamators, and hand triturating of amalgam. Cleaning unit basins and larger office rooms were not associated with lower blood mercury levels. No studies reported on the methods used for disposing of excess amalgam.

3.3. Personal characteristics

Most studies compared one or more personal characteristics such as age, personal amalgam fillings, smoking, alcohol

Table 1
Study details reporting the association of mercury exposure and health of dental personnel

Study details	Dental personnel	Controls	Measurement of exposure biomarker & mercury levels (mean ± SD) other	Workplace characteristics	Dental practice characteristics
Cross sectional					
Ritchie et al 2002 [14] Scotland	Dentists ($n = 180$) Recruited random sampling (71.7%) & self-selected volunteers (28.3%) Mean age = 39.9 y (SD = 9.7; range 23–62 Sex: male 60%, female 40% Mean years of practice = 15.6 (9.5, 0.5–39) Mean hours/wk 32.8 (6.4, 6–43)	Control ($n = 180$) Matched by academic ability recruited from the University of Glasgow Mean age = 32.1 y (SD = 9.7); range 21–63 Sex: male 47%, female 53%	Questionnaire Urine sample collection and analysis cold vapor atomic absorption spectroscopy Hair and nails sample Health & Safety Lab, Sheffield Air mercury level analysis Jerome 431: X gold film mercury vapor analyzer and personal dosimeter Psychomotor performance: Cognitive Drug Research Participant response rate 92% dentists and 99% controls Urine Hg nmol Hg/mmol creatinine dentists: 2.58 ± 2.76, controls: 0.67 ± 0.68 Toenail mass Hg/g dentists: 0.71 ± 1.38, controls: 0.24 ± 0.19	–	No. of amalgam fillings Removal ($r = 0.29$, $p < 0.001$) Placement ($r = 0.38$, $p < 0.001$) Working h/d in the clinics $r = 0.24$, $p < 0.05$
Aydin et al 2003 [15] Turkey	Dentists ($n = 33$), dental nurses ($n = 6$), dental technicians ($n = 4$) Mean age = 32 y (23–54) Sex: male 53.5%, female 46.5% Average duration of exposure = 10 y (range 4–27) Exclusion criteria	Controls ($n = 43$); Categorical matching Mean age = 31 y Sex: male 53.5 %, female 46.5%	Questionnaire with oral examination Venous blood (for plasma) and morning urine sample collection and analysis (UNICAM 929 atomic absorption spectrophotometry) Neuropsychological testing Background characteristics Alcohol (cL/wk), Smoking (no./d), fish (meals/wk), Number of amalgam surfaces Urine Hg nmol Hg/mmol creatinine (mean) dental personnel: 1.17, controls: 0.64 Blood Hg nmol/L (mean) dental personnel: 2.18, controls: 1.50	Passive ventilation in all clinics Daily Wet cleaning Cobblestone floor 10–70 m^2 average area of working rooms	"All Mixer" amalgam mixer used
Karahalil et al 2005 [17] Turkey	Dentists ($n = 20$) Mean age = 29 ± 6.1 y Sex: male 65%, female 35% Mean years of practice = 7.0 ± 5.3 y (range 1–23)	Controls ($n = 9$) Mean age = 30.1 ± 3.6 y; Sex: unknown	Questionnaire based on practice characteristics, personal habits and health conditions. 24 h urine sample collection and analysis UNICAM model 939 atomic absorption spectrometer and cold vapor atomic absorption spectrometer Urine Hg μg/L; dentists: 6.2 ± 3.5, Male: 6.9 ± 3.9, female: 4.9 ± 2.4 Controls: 1.97 ± 0.9	No specialized ventilation in dental clinics Mercury spills not properly cleaned	90% Dentists wore both gloves & masks
Hilt et al 2009 [18] Norway	Dental assistants ($n = 608$) Mean age = 51.7 y (± 9.7) Sex: female 100% Mean years of practice = 18.1 y (± 11.7)	Controls ($n = 425$). Random selection; Categorical matching Mean age = 49.4 y (± 10.8) Sex: female 100% Worked outside home > 5 y after 1960	Primary questionnaire EUROQUEST included. Secondary questionnaire – Background characteristics Urine sample collection and analysis cold vapor flameless atomic absorption spectrophotometry The participation rate was 56.4% dental assistants and 42.9% controls Urine Hg nmol/L dental assistant 91.2 ± 114.5 Previously recorded data	Serious spills of Hg in their working environment	Copper amalgam mainly used before 1990 Occasional use after 1990.

Kasraei et al 2010 [19] Iran	Dentists ($n = 43$) Mean age = 37.3 y; Mean years of practice = 11 y Average duration of mercury exposure $p = 0.427$	Controls: no controls recorded	Questionnaire: on demographics and factors affecting the blood mercury levels. Venous blood sample collection and analysis cold vapor atomic absorption analyzer system VAV-440 Blood Hg: μg/L Dentists: 6.3 ± 1.31 Male: 6.73 ± 1.20 Female: 5.13 ± 0.95	–	No. of amalgam removal ($p = 0.278$) Placement ($r = 0.474$, $p = 0.002$) Working h/d in the clinics = 0.529, $p < 0.001$
Samir and Aref 2011 [21] Egypt	Dentists ($n = 12$) Sex: male 66.7%, female 33.3% Dental nurses ($n = 20$) Sex: male 35%, female 65% Mean age = 43.2 y (SD = 10.75; range 28–67) Mean years of exposure = 17.18 y (± 5.93)	Control ($n = 37$) Sex: male 47%, female 53% Mean age = 41.3 y (SD = 10.78; range 25–66)	Questionnaire Blood and urine sample collection and analysis cold vapor atomic absorption spectrometry Glutathione activity Blood Level Cayman Glutathione Peroxidase kit Superoxide Dismutase Blood SOD Assay Kit WST Renal Function Behring BN II Nephelometer Urine Hg: μg Hg/g creatinine Dental personnel: 10.02 ± 1.36 Controls: 4.74 ± 0.84 Blood Hg: μg/L Dental staff: 7.74 ± 1.03 Controls: 4.79 ± 0.84	Lack of hygiene measures and proper exhaust ventilation	Working with amalgam on daily basis during at least 2 y, at least 4 h/d Use of high speed rotary instruments Lack of use of safety measures (gloves, masks) when handling mercury amalgam
Neghab et al 2011 [22] Iran	Dentists ($n = 106$) Recruited random sampling Mean age = 38 y (± 8) Sex: male 59.4%, female 40.6% Mean years of practice = 11.7 y (± 7.3)	Control ($n = 94$) Random sampling General Practitioners Mean age = 40.8 y (± 7.7) Sex: male 60.6%, female 39.4% Mean years of practice = 11 y (± 5.9)	Questionnaire – Three parts atmospheric mercury levels mercury vapor level analysis: 3,000 mercury analyzer, Seefelder Messtechnik, Germany Urinary concentration analysis Atomic absorption spectroscopy technique (model CTA 3000) Urine Hg μg/g creatinine median and range. Dentists: 3.16 (0.01–18.1) Control: 2.18 (0.33–5.08) Hg levels in ambient air μg/m^3 Dentists: 3.35 (0.4–7.7) Control: not detectable	–	No. of amalgam fillings/d 5.8 (± 2.7) No. of amalgam replacements/d 2 (± 1.5)
Hilt et al 2011 [23] Norway	Dentists ($n = 406$) Mean age = 52.1 y (± 12.4) Sex: male 57.4%, female 42.6% Mean years of practice = 26.3 (±12.6)	Controls ($n = 217$) Random selection; Categorical matching Mean age = 48.4 y Sex: male 51.6%, female 48.4% Mean years of Practice = 24.0 (± 10.5)	Primary questionnaire EUROQUEST included Secondary questionnaire Urine sample collection and analysis cold vapor flameless atomic absorption spectrophotometry participation rate 57.2% for dental assistants & 42.9% controls Urine Hg nmol/L Dentists Male: 58.7 ± 37.4 Female: 57.3 ± 35.4	–	Copper amalgam reportedly used in practice by females 28.1%, males 35.2%

(*continued on next page*)

Table 1 (*continued*)

Study details	Dental personnel	Controls	Measurement of exposure biomarker & mercury levels (mean ± SD) other	Workplace characteristics	Dental practice characteristics
Moen et al 2008 [27] Norway	Dental assistants (n = 41) Mean age = 57.8 y (± 6.7) Sex: female 100% Mean years of practice = 29.7 (± 8.2) Alcohol units in a month = 2.6 (± 3.0) Smoking: cigarettes smoked/d = 3.7 (± 5.6)	Controls (n = 64) Mean age = 52.5 y (± 8.3) Sex: female 100% Mean years of practice = 17.5 (± 11.8) Alcohol units in a month, 4.8 (± 3.8) Smoking: cigarettes smoked/d = 7.2 (± 6.3)	Questionnaire: (for both groups) and EUROQUEST Background characteristics The response rate was 68% for dental assistants and 87% for the assistant nurses Dental assistants had significantly higher occurrence of neurological symptoms, psychosomatic symptoms, memory, concentration, fatigue, and sleep disturbance than the reference group. Adjusting for age, education level and lifestyle factors, as well as personality traits Musculoskeletal symptoms reported	–	Copper amalgam reportedly used in practice
Yilmaz et al 2013 [24] Turkey	Dentists (n = 67) Mean age = 38.5 y (± 5.95) Sex: male 29.9%, female 70.1% Mean years of practice = 14.9 (± 5.75) Smoking – 28.4% Dental personnel (n = 21) Sex: male 38%, female 61% Mean age = 36.1 y (± 9.29) Mean years of practice = 9.69 (± 6.26) Smoking – 42.9%	Non dental personnel (n = 27) Mean age = 39.6 y (± 7.80) Sex: male 55.5%, female 44.5% Mean years in practice = 18.6 (± 7.09) Smoking – 14.8%	Blood sample collection and analysis cold vapor atomic absorption spectrometry (CVAAS) Blood Hg: µg/L Dentists Group1: 3.76 ± 1.84; Dental personnel Group 2: 3.54 ± 1.83 Control–non dental personnel Group 3: 2.69 ± 0.97	N/A	Average no. of amalgam fillings made in the previous year 861 ± 391
Cohort study					
Sletvold et al 2012 [26] Norway	Dentists (n = 16) Dental assistants (n = 69) Other occupational groups within health care (n = 6) Mean age = 57 y (± 6.4) Sex: female 100% Mean years of practice = 15.6 (± 7.2)	Controls – no controls recorded	Questionnaire preliminary standardized & EUROQUEST Background characteristics recorded Interview with one of the three occupational physicians Blood pressure and venous blood sample analysis for thyroid hormones, alanine transaminase vitamins and serum creatinine CNS tests and neuropsychologist profile Urine mercury levels – nmol/L Previous results for 28 exposed individuals 86.7 ± 86.7 Only statistical significant relationship was between urinary mercury levels and visual long term memory	N/A	Previous exposure to metallic mercury
Retrospective cohort					
Svendsen et al 2010 [20] Norway (1960–1990)	Dentists (n = 452) Mean age = 54.3 y Mean years of practice = 24 Dental nurses (n = 655) Mean age = 53.3 y Mean years of practice 21.9	Controls – no control groups	Questionnaire survey Detailed working conditions from 1950-60s. Registered data scanned Teleform software Participant response rate 56.4% dental nurses and 49% dentists Urine Hg nmol/L Dentist and dental nurses 74 ± 91.4 [from Norwegian National Institute of Occupational Health (STAMI)]	Mercury spill reported in room at least once Workplace flooring, ventilation Consistency of amalgam, spills of mercury reported	Use of copper amalgam Use of Dentomat Use of self-made capsules Use of mortar Handling of amalgam in palm

Thygesen et al 2011 [28] Denmark (1964–1969; 1970–1979; 1980–1989; 1990–2006)	Dentists ($n = 5,371$) Mean age = 30.2 y Sex: male 49.9%, female 50.1% Dental assistants ($n = 33,858$) Mean age = 23.8 y Sex: male 5%, female 95%	Controls ($n = 83,961$) GPs, nurse medical secretary lawyer legal secretary Mean age range = 27.6 –37.3 y	Sourced registers: Supplementary Pension Fund Register (ATP); Authorization of Health-Care Personnel (RAHP), Danish Civil Registration System (CRS), Labor Market Module (LMM) &Danish National Patient Cases and age-standardized incidence rates of neurological, Parkinson's disease, and renal disease.	Proxy measure for excess cumulative mercury exposure calculated Dates reflect year of employment termination	Included only people employed for more than 8 h per week in dental clinics
Jones et al 2007 [29] New Zealand (1968–1971)	Dental nurses ($n = 43$) Mean age = 52.19 y (± 1.20) Sex: female 100% Mean years of practice = 2–10	Controls ($n = 32$) Matched controls Mean age = 51.39 y (± 4.54) Sex: female 100%	Preliminary Questionnaire CNS tests Participant response rate = 40.2% Occupational overuse syndrome Dental nurses-32.5%; control group-.66% Reproductive health Early-age hysterectomy rate of 4:1; Neurobehavioral test battery cognitive tests	Use of methylated spirits for cold sterilization of surfaces Repeated washing of hands throughout the working day Operated in standing upright position with patient seated upright	Unprotected skin contact with elemental Hg, copper amalgam, manual mixing
Nested case control					
Joshi et al 2003 [16] USA	General dentists ($n = 169$) Mean age = 60.9 y (± 8.4) Dental specialists ($n = 45$) Mean age = 60.1 y (± 7.2)	Non dental health personnel ($n = 196$) Mean age = 61.5 y (± 7.8)	Questionnaire – every two years, follow-up questionnaires sent to update information on newly diagnosed diseases original HPFS cohort study All participants from Health Professionals Follow-up Study (HPFS) 1986. Randomly selected matched to coronary heart disease cases on age, smoking status and time (month of return of their toenail clippings). Confounders adjusted for tuna consumption, saltwater fish consumption and occupational status Number of teeth, amalgam restorations, tooth brushing frequency Response rate was 71% from 410 respondents Nail sample collection and analysis –neutron activation analysis toenail parts per million (ppm) General Dentists: 0.94 ± 0.95; Dental Specialists: 0.59 ± 0.59; Non dental health personnel: 0.45 ± 0.38	Amalgam mixing methods Scrape amalgam storage Dry cutting vs. high speed handpiece and water spray	No. of amalgam restorations placed/wk (100+) (1.74 ± 1.18) No. of amalgam restorations removed /wk (30 +) (0.81 ± 0.87)

consumption, fish consumption, chewing gum, brushing, and bruxism of dental personnel to the control groups to exclude lifestyle habits from possible occupational mercury exposure from dental amalgam.

Personal amalgam restorations were not a source of occupational mercury exposure in the studies reported by Aydin et al [15], Karahalil et al [17], and Joshi et al [16]. Joshi et al [16] found a significant relationship between the frequency of fish consumption and increasing toenail mercury levels in general dentist, dental specialist, and control groups. Kasraei et al [19] also identified higher blood mercury levels with increasing fish consumption, but the relationship remained higher in dental professionals than in the control group. Moreover, the neuropsychological tests were not affected by fish consumption among the dental staff. Karahalil et al [17] reported that smoking habits were associated with the increased urinary mercury levels of dental personnel. Aydin et al [15] stated that current smoking habits were positively correlated with reduced immediate memory (see Table 1).

4. Discussion

In this review of 15 studies of over 40,000 dentists and personnel, dental personnel had higher mercury exposure than the control groups, but the exposure levels were below the American Conference of Governmental Industrial Hygienists (ACGIH) threshold-limiting guidelines. The correlations between dental amalgams and mercury levels were much stronger when urine mercury levels were used compared to serum or whole blood mercury levels. Authors could not distinguish between mercury levels from fish consumption or other food sources, inorganic mercury vapors in dental practice or from an individual's own amalgam restorations. The most commonly reported health conditions that aligned with mercury exposure involved the central nervous system, but these conditions may also be aligned with other aspects of clinical work and it was difficult to attribute them only to mercury exposure from amalgams.

Work practices were associated with mercury exposure in dental personnel, but there has been an improvement in work and hygiene practices since 1990 compared to earlier years. It is difficult to establish what guidelines or mercury hygiene recommendations are followed by dental personnel in most of the countries highlighted in these studies, and even more difficult in developing economies. We note that Denmark, Iran, Turkey, UK, USA, New Zealand, and Norway are signatories to the Minamata Convention on Mercury, but Egypt is not yet listed [8]. In 2007, Lynch et al [30] reported that surveys of educational curricula in the area of restorations in the United Kingdom, Ireland, and North America, demonstrated variations both within and between dental schools. This statement may be relevant for most countries but at the same time, there are guidelines and statements on dental amalgam use and replacement from the American Dental Association, Canadian Dental Association (CDA), Australia, and Germany. Overall, it is clearly stated by these groups that dental amalgam is a durable material with recorded safety and effectiveness. Similarly, it is considered unnecessary and ill-advised to replace functional or amalgam restorations for safety concerns of the patient. The Australian guidelines as well as the CDA, suggest clinicians provide patients with appropriate information particularly on alternative material. There are no German guidelines for the use of amalgam but a consensus statement of 1997 by the German Ministry of Health and other dental associations, including the German Institute for Drugs and Medical Devices, the German Dental Association, the National Association of Statutory Health Insurance Dentists, the German Society for Dental and Oral Medicine, the German Society for Operative Dentistry, and the German Association of dentists practicing naturopathy. The consensus statement on "Restorative Materials in Dentistry" highlights key recommendations, but also responsibilities of dental practitioners in its use on patients that are pregnant, who have renal dysfunction, a known allergy, and children. A summary of these examples are available in Table 2.

While most reported mercury levels remained below threshold values, some dental professionals were failing to follow guidelines produced by organizations such as the Fédération Dentaire International, which includes reducing the potential of occupational exposure to mercury. This includes avoiding direct skin contact with mercury or freshly mixed dental amalgam, and avoiding exposure to potential sources of mercury vapor due to accidental mercury spills, malfunctioning amalgamators, leaky amalgam capsules, malfunctioning bulk mercury dispensers, during trituration, during placement and condensation of amalgam, during polishing or removal of amalgam, vaporization of mercury from contaminated instruments, and open storage of amalgam scrap or used capsules [9]. It is important that dental personnel are encouraged to undertake good mercury hygiene work practices.

The main limitation of the study was the heterogeneity of the papers. The validity of many of the studies is limited due to the cross sectional design and there were reports of low participation rates and subjective reporting of exposure and symptoms. The health effects could be associated with the aging process or factors unrelated to the work environment. Despite this the review article provides an insightful synthesis of the 15 quantitative research articles selected by a rigorous screening method.

Future researchers in this field are encouraged to determine the most appropriate biomarker to use in their study design and consider how the results will be interpreted, as there are advantages and limitations for each test. The urine test is mainly used to

Table 2
The guidelines/statements on dental amalgam

Country/association (reference)	Guidelines/statement on dental amalgam
American Dental Association (ADA) [31]	Dental amalgam is considered a safe, affordable and durable material that has been used to restore the teeth of more than 100 million Americans. It contains a mixture of metals such as silver, copper, and tin, in addition to mercury, which binds these components into a hard, stable, and safe substance. Dental amalgam has been studied and reviewed extensively, and has established a record of safety and effectiveness.
Canadian Dental Association (CDA) [32]	It is considered unnecessary and ill-advised to replace functional or serviceable dental amalgam fillings (restorations) for safety concerns or perceived health needs. A conservative approach to filling replacement, combined with effective decay prevention, is strongly advised to help maintain the dentition over a lifetime.
Australia [33]	Dental amalgam is a safe, useful, and long lasting dental restorative material. It is particularly useful for restoring larger cavities in permanent posterior teeth. However, clinicians should provide their patients with appropriate information on the risks and benefits of all dental materials.
Germany [34]	Alternatives to amalgam should only be recommended if sufficient knowledge concerning the safety of the alternatives for the individual is available. The dentist is responsible for the individual "right choice" of the material. Use of amalgam contraindicated for children, pregnant women, those with allergies, and renal dysfunction.

detect the presence of metallic mercury and other inorganic forms of mercury. Urine tests are reliable and simple but cannot be used to determine exposure to methyl mercury and correlate better with exposure following long-term occupational exposure of elemental mercury vapor. This test is also useful to determine the individual's ability to remove mercury from the body. Analytical approaches often employ urine creatinine during the modelling process to correct for urine dilution effects [35]. Blood is primarily tested to detect the presence of methyl mercury and monitor an acute exposure to mercury. It is limited in detecting the body's burden of mercury or other forms of mercury (metallic and inorganic). The amount present does decrease as the mercury moves into organs such as the brain and kidneys, therefore, blood testing needs to be performed within days of suspected exposure [36]. Toenail mercury is a reliable, well-validated biologic marker of long-term exposure to mercury [37]. The process of hair testing is relatively complex, yet hair is a useful biomarker to detect methyl mercury exposures that occurred several months previously, but an inappropriate biomarker of inorganic mercury exposure [38].

Although arguments have been made that the presence of urine mercury concentrations in some dental personnel explains memory disturbances and anxiety, lowered memory performance, and total retention, these symptoms could also be attributed to the effects of aging and stress. It is important that dental personnel, researchers, and educators encourage and monitor good work practices by dental professionals. Future research should focus on improving sampling strategies and use of standard biomarkers to collect data from developing economies, as well as monitoring the use of mercury hygiene guidelines by dental personnel and the professional's transition in the use of nonamalgam restorative materials.

Conflicts of interest

All Authors have no conflict of interest to declare.

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References

[1] American Dental Association. Dental Amalgam: Update on safety concerns [Internet]. 2010 [cited 2015 Feb 12]. Available from: http://www.ada.org/~/media/ADA/Member%20Center/FIles/safety.pdf.
[2] World Health Organization. Future use of material for dental restorations [Internet]. 2012a [cited 2015 Feb 12]. Available from: http://www.who.int/oral_health/publications/dental_material_2011.pdf.
[3] World Health Organization. Exposure to mercury: A major public health concern [Internet]. 2012b [cited 2014 Mar 1]. Available from: http://www.who.int/phe/news/Mercury-flyer.pdf.
[4] Bjorklund G. Mercury in the dental office. Risk evaluation of the occupational environment in dental care. Tidsskr Nor Laegeforen 1991;111:948–51 [in Norwegian].
[5] Ngim CH, Foo SC, Boey KW, Jeyaratnam J. Chronic neurobehavioral effects of elemental mercury in dentists. Br J Ind Med 1992;49:782–90.
[6] Echeverria D, Heyer NJ, Martin MD, Naleway CA, Woods JS, Bittner AC. Behavioural effects of low levels exposure to Hg0 among dentists. Neurotoxicol Teratol 1995;17:161–8.
[7] Rowland AS, Baird DD, Weinberg CR, Shore DL, Shy CM, Wilcox AJ. The effect of occupational exposure to mercury vapour on the fertility of female dental assistants. Occup Environ Med 1994;51:28–34.
[8] United Nations Environmental Program "INC7". Minamata Convention on Mercury [Internet]. [cited 2016 Jan 1] Available from: http://www.mercuryconvention.org/Countries/tabid/3428/Default.aspx.
[9] FDI Policy Statement. Mercury Hygiene Guidance [Internet]. 2007 [cited 2015 Oct 1]. Available from: http://www.fdiworldental.org/media/11271/Mercury-hygiene-guidance-2007.pdf.
[10] National Health Federation. Press release: NORWAY-Minister of the Environment and International Development Erik Solheim: Bans Mercury in Products [Internet]. 2010 [cited 2015 Oct 1]. Available from: https://www.thenhf.com/norway-minister-of-the-environment-and-international-development-erik-solheim-bans-mercury-in-products/.
[11] The Swedish Government Chemicals Policy. Sweden will ban the use of mercury on 1 June 2009 [Internet]. [cited 2014 Mar 1]. Available from: http://www.government.se/contentassets/12c4d85c2ca64d05827fc131f1a47ab9/sweden-will-ban-the-use-of-mercury.
[12] Food and Drug Administration. Banning mercury amalgam [Internet]. 2013 [cited 2015 Oct 1]. Available from: http://www.fda.gov/downloads/.../medicaldevices/.../ucm236379.pdf.
[13] Law M, Stewart D, Pollock N, Letts L, Bosch J, Westmorland M. Critical Review Form — Quantitative Studies [Internet]. 2012 [cited 2015 Nov 1]. Available from: https://www.unisa.edu.au/Global/Health/Sansom/Documents/iCAHE/CATs/McMasters_Quantitative%20review.pdf.
[14] Ritchie KA, Gilmour WH, Macdonald EB, Burke FJT, McGowan DA, Dale I, Hammersley R, Hamilton R, Binnie V, Collington D. Health and neuropsychological functioning of dentists exposed to mercury. Occup Environ Med 2002;59:287–93.
[15] Aydin N, Karaoglanoglu S, Yigit A, Keles SM, Kirpinar I, Seven N. Neuropsychological effects of low mercury exposure in dental staff in Erzurum, Turkey. Int Dent J 2003;53:85–91.
[16] Joshi A, Douglass CW, Kim HD, Joshipura KJ, Park MC, Rimm EB, Carino MJ, Garcia RI, Morris JS, Willett WC. The relationship between amalgam restorations and mercury levels in male dentists and non dental health professionals. J Public Health Dent 2003;63:52–60.
[17] Karahalil B, Rahravi H, Ertas N. Examination of urinary mercury levels in dentists in Turkey. Hum Exp Toxicol 2005;24:383–8.
[18] Hilt B, Svendson K, Syverson T, Aas O, Qvenild T, Sletvold H, Melo I. Occurrence of cognitive symptoms in dental assistants with previous occupational exposure to metallic mercury. Neurotoxicology 2009;30:1202–6.
[19] Kasraei S, Mortazavi H, Vahedi M, Vaziri PB, Assar MJ. Blood mercury levels and its determinants among dental practitioners in Hamadan, Iran. J Dent 2010;7:55–62.
[20] Svendsen K, Syversen T, Melø I, Hilt B. Historical exposure to mercury among Norwegian dental personnel. Scand J Work Environ Health 2010;36:231–41.
[21] Samir AM, Aref WM. Impact of occupational exposure to elemental mercury on some antioxidative enzymes among dental staff. Toxicol Ind Health 2011;27:779–86.
[22] Neghab M, Choobineh A, Hassan Zadeh J, Ghaderi E. Symptoms of intoxication in dentists associated with exposure to low levels of mercury. Ind Health 2011;49:249–54.
[23] Hilt B, Svendson K, Syverson T, Aas O, Qvenild T. Occurrence of cognitive and neurological symptoms in Norwegian dentists. Saf Health Work 2011;2:176–82.
[24] Yılmaz H, Tutkun E, Demiralp KO, Yılmaz FM, Aliyev V, Soylemezoglu T. Exposure to mercury among dental health workers in Turkey: Correlation with amalgam work and own fillings. Toxicol Ind Health 2013:1–4.
[25] ACGIH. TLVs and BEIs. Threshold limit values for chemical substances and physical agents and biological exposure indices. Cincinnati (OH): American Conference of Governmental Industrial Hygienists; 2003. Report No.: ISBN 1-882417-49-6.
[26] Sletvold H, Svendsen K, Aas O, Syverson T, Hilt B. Neuropsychological function and past exposure to metallic mercury in female dental workers. Scand J Psychol 2012;53:136–43.
[27] Moen BE, Hollund BE, Riise T. Neurological symptoms among dental assistants: a cross sectional study. J Occup Med Toxicol 2008;18:3.
[28] Thygesen LC, Flaschs EM, Hanehoj K, Kjuus H, Juel K. Hospital admissions for neurological among dentists and dental assistants occupationally exposed to mercury. J Occup Environ Med 2011;68:895–901.
[29] Jones L, Bunnell J, Stillman J. A 30-year follow up of residual effects on New Zealand School Dental Nurses, from occupational mercury exposure. Hum Exp Toxicol 2007;26:367–74.
[30] Lynch CD, Shortall AC, Stewardson D, Tomson PL, Burke FJ. Teaching posterior composite resin restorations in the United Kingdom and Ireland: Consensus views of teachers. Br Dent J 2007;203:183–7.
[31] American Dental Association. Statement on Dental Amalgam: American Dental Association [Internet]. 2009 [cited 2016 Oct 05]. Available from: http://www.ada.org/en/about-the-ada/ada-positions-policies-and-statements/statement-on-dental-amalgam.
[32] Canadian Dental Association. Position on Dental Amalgam [Internet]. 2005 [cited 2016 May 15]. Available from: https://www.cda-adc.ca/_files/position_statements/amalgam.pdf.
[33] Australian Dental Association (ADA) Policy Statement 5.15 on Amalgam Waste Management — Best Practice Guide [Internet]. 2007 [cited 2016 May 15]. Available from: http://155.187.2.69/wastepolicy/consultation/submissions/pubs/134-attachmenta.pdf.
[34] Consensus statement of the German Federal Ministry of Health, the German Institute for Drugs and Medical Devices (BfArM), the German Dental Association (BZÄK), the National Association of Statutory Health Insurance Dentists (KZBV), the German Society for Dental and Oral Medicine (DGZMK), the German Society for Operative Dentistry and the German Association of dentists practicing naturopathy. Consensus statement on restorative materials in dentistry [Internet]. 1997 [cited 2016 May 15]. Available from: http://www.agz-rnk.de/agz/download/3/broschuere_amalgame.pdf.

[35] Dye BA, Schober SE, Dillon CF, Jones RL, Fryar C, McDowell M, Sinks TH. Urinary mercury concentrations associated with dental restorations in adult women aged 16–49 years: United States, 1999–2000. Occup Environ Med 2005;62:368–75.
[36] Mahaffey KR. Mercury exposure: medical and public health issues. Trans Am Clin Climatol Assoc 2005;116:127–54.
[37] Mordukhovich I, Wright RO, Hu H, Amarasirlwardena C, Baccarelli A, Litonjua A, Sparrow D, Vokonas P, Schwartz J. Associations of toenail arsenic, cadmium, mercury, manganese, and lead with blood pressure in the normative aging study. Environ Health Perspect 2012;20:98–104.
[38] Nutall KL. Interpreting hair mercury levels in individual patients. Ann Clin Lab Sci 2006;36:248–61.