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Amalgam dental fillings and hearing loss

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Key Words
dental amalgam
auditory thresholds
hearing loss
mercury
ototoxin
presbyacusis

Abbreviations
ASHA: American Speech-Language-Hearing Association

Abstract
In this study we investigated the effects of amalgam dental fillings on auditory thresholds. Participants (n = 39) were non-smoking women age 40 to 45. Regression and correlation analyses were performed between auditory thresholds, measured from 0.25 to 16 kHz, and the number/surface area of dental fillings, using the ASHA criteria for ototoxic change as a reference for comparison. No significant correlation ($p > 0.05$) was found between composite (non-amalgam) filling or drilling data and auditory thresholds. However, there was a significant positive linear correlation between amalgam filling data and auditory thresholds at 8, 11.2, 12.5, 14, and 16 kHz. The strongest association ($r = 0.587$, n = 39, $p < .001$, $r^2 = 0.345$) was at 14 kHz, where each additional amalgam filling was associated with a 2.4 dB decline in hearing threshold (*95% confidence interval [CI]*, 1.3–3.5 dB). The results suggest an association between more amalgam fillings and poorer thresholds at higher frequencies, which could contribute to presbyacusis in developed countries. This provides further argument for the use of amalgams to be phased out where suitable alternatives exist.

Sumario
En este estudio investigamos los efectos de los empastes dentales de amalgama en los umbrales auditivos. Los participantes (N=39) fueron mujeres no fumadores con edades de 40–45 años. Se realizaron análisis de regresión y correlación entre los umbrales auditivos medidos de 0.25 a 16 kHz y el número/superficie de los empastes dentales, usando el criterio ASHA para cambios ototóxicos como referencia para la comparación. No se encontró correlación significativa ($p > 0.05$) entre el empaste con compuesto (no amalgama) o los datos de fresado y los umbrales auditivos. No obstante, si hubo una correlación linear significativa positiva entre los datos del llenado con amalgama y los umbrales auditivos en 8,11.2, 12.5, 14 y 16 kHz. La asociación más intensa (r=0.587, n=39, $p < .001$, r^2=0.345) se observó en 14 kHz, mientras que cada llenado adicional de amalgama se asoció con una declinación de 2.4 dB en el umbral auditivo (95% de intervalo de confianza [C1], 1.3–3.5 dB). Los resultados sugieren una asociación entre más llenados con amalgama y umbrales más pobres en las frecuencias altas, lo que contribuye a la presbiacusia en los países desarrollados. Esto proporciona un argumento adicional para que el uso de amalgamas se escalone cuando existan otras alternativas apropiadas.

Introduction

The geriatric population from isolated communities has better hearing than the elderly in developed countries (Goycoolea et al., 1986). In addition, within developed populations, there is variability in hearing levels that cannot be wholly explained by noise exposure, ear infection or head injury rates, gender, or age (Tambs et al., 2003). Noxious substances such as cigarette smoke (Burr et al., 2005), lead (Schwartz & Otto, 1991), and carbon monoxide (Lacerda et al., 2005), as well as certain prescription drugs (Luxon et al., 2003), are known to have a detrimental effect on hearing and can thus explain some of these variations. Mercury can be released as vapour from amalgam dental fillings (Berlin, 2003; Clarkson et al., 2003; Goerling et al., 1992; U.S. Environmental Protection Agency, 1997); therefore, it is another potential ''environmental'' ototoxic agent. This type of dental restoration is commonly used in the developed world and represents the most continual and long-term environmental exposure to mercury in such countries (Berlin, 2003; Clarkson et al., 2003; Goerling et al., 1992).

As far back as the eleventh century, the polymath Avicenna noted that mercury vapour used to kill head lice damaged hearing (Schacht & Hawkins, 2006), and it is now known that acute exposure to high levels of mercury commonly results in hearing loss (U.S. Environmental Protection Agency, 1997). There are indications that ongoing low-level mercury exposure is also deleterious to parts of the auditory pathway (Anniko & Sarkady, 1978; Gopal, 2003; Liang et al., 2003; Letz et al., 2000; Wu et al., 1985; Carta et al., 2003). The auditory system may be particularly vulnerable to mercury in vapour form. The vapour from amalgam fillings is inhaled and transferred to the blood, the inhalation dose being a function of the size and number of amalgam surfaces (Berlin, 2003; Clarkson et al., 2003). With steady exposure, the vapours can gradually accumulate in the brain (Eggleston & Nylander, 1987) and other organs (Berlin, 2003), where distribution and localized concentrations can result in the alteration of cell function (Goerling et al., 1992). Certain sites of mercury-insensitive aquaporin 4 (AQP4) water channel expression (Preston et al., 1992), for example the brain, retina, and kidneys, have shown signs of localized concentrations of mercury (Berlin, 2003). The inner ear is also a site of AQP4 expression, where it plays a critical role in hearing function (Li & Verkman, 2001). In addition, because mercury vapour can cross the blood-brain barrier and cerebral blood flow and aerobic metabolism are highest in the auditory structures (Sokoloff, 1981), mercury is likely to accumulate and have the greatest effect in these structures.

Adults with amalgam fillings typically have blood mercury levels of 0.7–4.0 μg/l (Berlin, 2003; Abraham et al., 1984; Forsten, 1989). Auditory damage has previously been reported in Andean children exposed to mercury vapour from gold-mining activities, with mean blood mercury levels of 23 μg/l (Counter, 2003). Although this is a higher level than adult amalgam bearers, the duration of mercury vapour exposure is considerably longer for adults. One study specifically

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investigated amalgam fillings and hearing loss in patients with multiple sclerosis (Siblerud & Kienholz, 1997). The authors concluded that amalgams reduced hearing acuity in this patient group and suggested that amalgams might also be detrimental to auditory function in the general population. The objective of the current study was to investigate this possibility further in healthy subjects.

Materials and Methods

Detecting ototoxicity

When a medication with possible ototoxic side effects is administered, a patient normally acts as his/her own control, and repeated audiometric thresholds are recorded over time. Ototoxicity may be indicated, for example, if an audiometric threshold deteriorates by 20 dB or more at one frequency (ASHA, 1994) following the administration of the agent under investigation. However, it is difficult to investigate dental restoration materials in this manner because any deterioration due to a slow, long-term effect may be obscured by other age-related factors. In this study, audiometric thresholds were recorded for participants of similar age with a variable amount of amalgam fillings.

Study population

A power calculation indicated that the number of participants required was 33–44 if regression analysis is used to detect a 20 dB difference in auditory threshold (power .8, alpha .05, auditory threshold test/retest 10dB, maximum number of fillings 15–18, standard deviation 3.25–4.5). Participants were recruited by advertisement in a local newspaper and by e-mail to the staff of Manchester University. Participants were non-smokers who believed that their hearing was normal. Only females were included in the study to avoid having to take into account differences in gender; specifically, auditory thresholds differ slightly between men and women, and any effects of mercury may be subtly different between men and women. Participants were of a narrow age range (40–45), old enough to have long-term dental fillings, but unlikely to be on long-term medication. Potential participants were encouraged to participate by the offer of a free dental check-up, a free hearing test, paid expenses, and entry into a £100 prize draw. Ethical approval was obtained from the School of Psychological Sciences Ethics Committee, Manchester University, UK (reference number 299/05), and written consent was obtained from each participant.

Data collection

Each participant completed a questionnaire related to family history, medications/medical conditions, and lifestyle (e.g. noise exposure, past smoking, gum use, fish consumption, bruxism, use of lead water pipes at home), as such issues may affect hearing (Burr et al., 2005; Schwartz & Otto, 1991; Luxon et al., 2003; Berlin, 2003; Clarkson et al., 2003).

Three socio-economic measures were also collected using the following questionnaires:

Acorn (ACORN, 2007); based on postal-code, categories being (1) wealthy achiever, (2) urban prosperity, (3) comfortably off, (4) moderate means, and (5) hard pressed.

Qscore; based on highest qualification achieved, categories being (0) below UK GCSE level ("General Certificate of Education"; normally obtained at age 16), (1) UK GCSE level or equivalent, (2) UK 'A' level ("Advanced" level, usually obtained at age 18) or equivalent, (3) graduate or professional education, and (4) post-graduate education.

Employ (National Statistics, 2007); based on occupation, categories being (1) managerial or professional, (2) intermediate, (3) small employers and own account workers, (4) lower supervisory and technical, and (5) semi-routine and routine.

A qualified dentist assessed the number of each type of filling (amalgam versus non-amalgam) and produced a filling 'score' related to the surface area, as per Aposhian et al. (1992). Participants were also asked if and when they had replaced one type of filling with another type. The total number of drilling episodes was calculated as one episode per new filling or reported filling change.

The initial audiometric evaluation involved bilateral otoscopy and middle-ear testing (Luxon et al., 2003). The latter was performed using a GSI Tympstar tympanometer as per British Society of Audiology protocols (BSA, 1992). Air conduction auditory thresholds (in dB HL) to pure tones for conventional (0.25, 0.5, 1, 2, 4, and 8 kHz) and high frequencies (9, 10, 11.2, 12.5, 14, 15, and 16 kHz) were then measured blind (without knowledge of the dental numbers/scores) using a Kamplex KC50 Clinical Audiometer with TDH-39P (for frequencies up to 8 kHz) and KOSS R80 (for frequencies above 8 kHz) headphones. The BSA protocol for air-conducted sounds using the modified Hughson-Westlake technique of Carhart and Jerger (1959), in 5 dB steps, was used (BSA, 2004). This technique has been shown to be suitable for the detection of ototoxicity (Fausti et al., 1993). Thresholds were tested bilaterally, and an average value was calculated.

Inclusion criteria

Inclusion criteria for the initial analyses were: female, age 40–45, non-smoker, no known hearing problems, no family history of hearing loss, no current ear problems, no previous ear surgery, no clinically significant episodes of vertigo, normal otoscopy (Luxon et al., 2003), and normal middle-ear function (BSA, 1992).

Statistical analysis

Data were analyzed with SPSS (version 13.0). An alpha level of .05 was used in all statistical tests. Correlation and regression analyses were used between auditory threshold data (in dB HL) and the number of amalgam fillings, the number of composite fillings, and the total number of drilling episodes.

In quoted results, n is the number of participants in the statistical test; r_s is the Spearman's correlation coefficient; *r* is the Pearson's correlation coefficient; r^2 is the effect size (<0.01 small, 0.01 to 0.10 medium, >0.10 large); *p* is the p-value (level of significance); *M* is the mean; *95% CI* is the 95% confidence interval; and *F* is the ratio of the mean square for regression to the residual mean square.

Results

Participants satisfying the inclusion criteria

Forty-nine women were initially recruited for the study, and 39 satisfied the inclusion criteria. For the 10 excluded, two had a family history of hearing loss, two experienced occasional vertigo, one had a previously investigated unilateral hearing loss and a family history of hearing loss, and five had middle-ear function results outside the normal range. A variety of dental filling types was recorded, but all participants had had at least one amalgam filling at some time.

Amalgam fillings and auditory thresholds

An increase in the number of amalgams (range 0 to 16, mean = 7.1) was associated with poorer thresholds (expressed in dB HL) at 8, 11.2, 12.5, 14, and 16 kHz (Table 1, Figure 1). The greatest correlation was at 14 kHz (n = 39, $p < 0.001$, $r^2 = 0\ 35$, F = 19.5), where each amalgam was associated with a 2.4 dB decline in hearing sensitivity (95% CI 1.3–3.5 dB). Using ASHA's (1994) criteria of change (≥20 dB at a single frequency), an ototoxic effect was observed for women aged 40–45 with nine or more amalgam fillings. When ASHA's (1994) alternative criteria of ≥20 dB at one frequency and/or ≥10 dB at two adjacent frequencies was used, an ototoxic effect was observed with six or more amalgam fillings. Very similar results were obtained when considering the amalgam scores (taking into account the area of the fillings), but these results are not presented here.

In addition to the numbers and scores of the fillings at the time of testing, "adjusted" values were also calculated, taking into account estimated exposure differences due to a reported substitution of filling type. Using the adjusted calculation, the effect upon thresholds was more pronounced. The worsening in threshold per amalgam at 8, 11.2, 12.5, 14, and 16 kHz for adjusted dental numbers (recorded numbers in parentheses) was 0.97 (0.85), 1.31 (1.14), 1.98 (1.75), 2.75 (2.39), and 1.43 (1.0) dB, respectively. Regardless of these findings, the statistical analysis in this study concentrated mostly on the actual number of dental fillings and score values recorded, because adjusted values were derived using a common-sense but unproven calculation method.

Composite fillings/other dental data and auditory thresholds

Three tests of correlation were used: Kendall's tau_b, Spearman's rho, and Pearson's. There was no significant correlation ($p > 0.05$) between the number (range 0–9, $M = 2.4$) or score (range 0–43, $M = 10.1$) of composite fillings and auditory thresholds at any frequency. Participants had a mixture of dental filling types, and those with many amalgams generally had fewer composites ($r_s = -0.32$, n = 39, $p = 0.04$, $r^2 = 0.10$). There was no significant correlation ($p > 0.05$) between drilling episodes (range 4–25, M = 12.0) and auditory thresholds. Porcelain- and gold-filling data did not demonstrate a normal distribution and were not specifically compared with auditory thresholds; however, these data are included within the drilling episode data. Figure 2 shows the 14 kHz thresholds versus the number of amalgam fillings (upper panel), composite fillings (middle panel), and the number of drilling episodes (lower panel). The number of drilling episodes includes placement/removal of amalgam, composite, porcelain, and gold fillings.

Socio-economic data

Most participants were graduates or post-graduates (*Qscore* = 3.4; n = 30) and had a high-level occupation (*Emplo* = 1, n = 32). *Acorn* (postal-code) data were normally distributed. Participants with higher qualifications had fewer composites ($r_s = -0.39$, n = 39, $p = 0.02$, $r = 0.15$) and fewer drilling episodes ($r_s = -0.36$, n = 39, $p = 0.03$, $r^2 = 0.11$). Participants with high-level occupations had fewer amalgams ($r_s = 0.33$, n = 39, $p = 0.04$, $r^2 = 0.11$), fewer composites ($r_s = 0.36$, n = 39, $p = 0.03$, $r^2 = 0.13$), and fewer drilling episodes ($r_s = 0.45$, n = 39, $p = 0.004$, $r^2 = 0.20$).

To determine whether the association between amalgams and auditory thresholds was independent of socio-economic factors, those with high-level occupations and those with higher qualifications were examined. For the socio-economic group *Employ* = 1, there was a significant correlation between the number of amalgams and auditory thresholds at 12.5 kHz ($r = 0.47$, n = *32*, $p = 0.07$, $r^2 = 0.22$), 14 kHz ($r = 0.62$, n = 32, $p < 0.001$, $r^2 = 0.38$), and 16 kHz ($r = 0.53$, n = 32, $p = 0.002$, $r^2 = 0.28$). Many of these participants also had postgraduate qualifications (*Employ* = 1, *Qscore* = 4, n = 19). Even for this

Table 1. Correlation and regression analysis for auditory thresholds and the number of amalgam fillings (participants = 39).

Frequency	*Pearson's Correlation*		*Regression Analysis*	
	Auditory Thresholds versus Number of Amalgams		*Worsening of Threshold per Amalgam*	
kHz	*R*	*p*-value	(dB)	*95% CI* (dB)
0.25	−0.09	0.576	−.125	−0.6 to 0.4
0.5	0.00	0.998	0	−0.4 to 0.4
1	−0.16	0.343	−0.19	−0.6 to 0.2
2	−0.02	0.900	−0.06	−0.6 to 0.5
4	0.21	0.197	0.40	−0.2 to 1.0
8	0.33	0.039	0.80	0.1 to 1.6
9	0.22	0.182	0.44	−0.2 to 1.1
10	0.27	0.094	0.68	−0.1 to 1.5
11.2	0.33	0.044	1.14	0.1 to 2.3
12.5	0.44	0.005	1.75	0.6 to 2.9
14	0.59	<.001	2.39	1.3 to 3.5
16	0.41	0.010	1.00	0.3 to 1.8

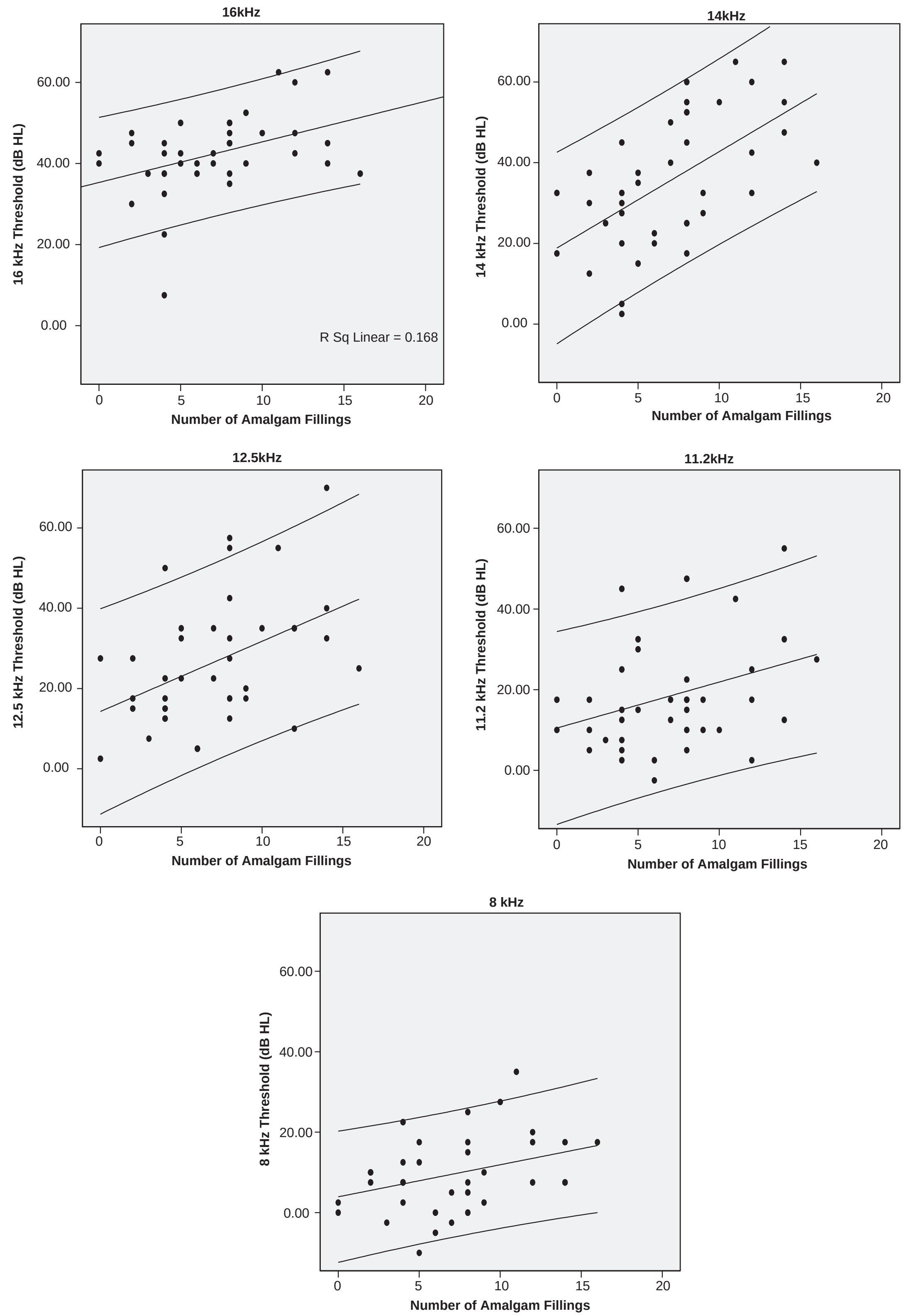

Figure 1. Auditory threshold (average L and R ears) versus number of amalgam fillings recorded by the dentist, with lines of best-fit and 95% confidence intervals.

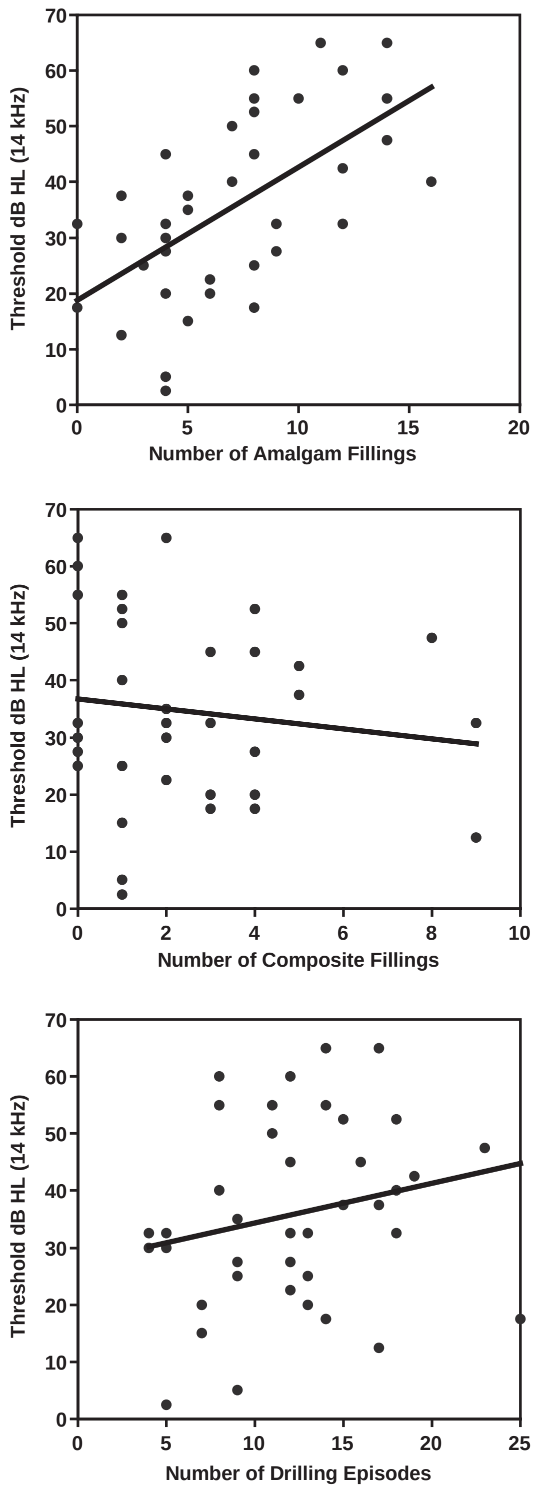

Figure 2. Threshold at 14 kHz (average left and right ears) versus number of amalgam fillings (top), number of composite fillings (middle), and number of drilling episodes (bottom). All participants had mixture of dental filling types. The number of drilling episodes includes placement/removal of amalgam, composite, porcelain, and gold dental fillings. Lines of best-fit are shown.

smaller sub-group, there was a significant correlation at 14 kHz ($r = 0.60$, n $= 19$, $p = 0.007$, $r^2 = 0.36$) and 16 kHz ($r = 0.51$, n $=$ 19, $p = 0.03$, $r^2 = 0.26$). The reduced number of frequencies at which an association was found was due to the reduced number of participants. A power calculation (power $= 0.8$, alpha $= 0.05$) showed a significant correlation was only possible at 14 kHz for these two sub-groups.

Age data

For this small age range (range $= 40$–45, M $= 42.5$, SD $= 1.83$), there was no correlation between age and auditory thresholds (n $= 39$, $p > 0.05$).

Auditory thresholds and questionnaire data

No participants reported any work-related noise exposure. Questionnaire data did not show any correlation with auditory thresholds.

Discussion

In this study, we compared the number and surface area of different types of dental fillings with auditory thresholds in the range of .25 to 16 kHz. For female participants taken from the local population, having more amalgam fillings was associated with a deterioration of high-frequency auditory acuity (8 kHz and above), independent of socio-economic factors. Thus, these results suggest a detrimental, dose-dependent effect of amalgams on hearing. There is also a likely duration-dependent effect.

For the study participants, age and questionnaire data were not confounding factors. Also, there was no correlation between total drilling episodes and thresholds or number of composite fillings and thresholds, which implies that the observed effect was not due to another related event such as noise damage caused by the drilling process.

It may be suggested that blood-mercury levels should have been recorded in order to determine the relationship between blood-mercury levels, amalgam numbers, and auditory thresholds; however, it was decided not to take this approach as blood-mercury levels have been shown to be a poor indicator of the levels that can accumulate in other parts of the body (Goerling et al., 1992).

"Presbyacusis" is the term generally used to describe the process by which hearing acuity reduces with age, starting in the high frequencies and gradually progressing towards lower frequencies (and becoming more clinically significant). There is considerable variability between individuals in the degree and rate of this hearing loss, which is presumed to be due to a variety of individual and environmental factors. Tambs et al. (2003) found that 31–64% of the variance in age-related hearing loss was linked to noise exposure, ear infections, head injury, and gender, and the remaining variance was postulated to be due, at least in part, to environmental toxins.

Regression data from this study indicate that women aged 40–45 with six or more amalgam fillings exhibit ototoxicity according to ASHA criteria (ASHA, 1994). With increasing age and, therefore, ongoing exposure, the percentage of participants exhibiting ototoxicity, as well as the degree of hearing loss, will gradually increase. Also, because ototoxicity progresses from high to low frequencies, it is probable that the detrimental effect will gradually become more apparent in speech frequencies, ultimately producing a clinically significant impairment. This may contribute to the hearing differences in older people between isolated and developed populations and the marked variations seen within developed populations. Indeed, it seems possible that the ototoxicity of amalgam fillings may be a component of what is currently labelled "presbyacusis" in developed countries.

The mechanisms of mercury ototoxicity were not the subject of the present study, but it is relevant to consider these here. Mercury has been shown to affect the auditory system at a wide range of levels, from the cochlea to the cortex, and there would appear to be scope for further audiological investigation into the effects of amalgam fillings. In particular, the use of Auditory Brainstem Responses (ABRs) could yield useful information. Counter (2003) noted a relationship between ABR measures and exposure to mercury vapour in gold-mining activities. Murata et al. (2004) reported increased latencies of ABR peaks in those exposed to long-term methyl mercury and suggested that the measures indicated both permanent and reversible components. Thus, further research is needed in this area. For the age group investigated in the present study, a high-frequency tone burst or a high-frequency band-limited click stimulus is likely to be more sensitive than a conventional ABR click stimulus because audiometric thresholds appear to be more readily affected at 8 kHz and above.

As far as we are aware, this is the first study that has shown a dose-dependent effect of amalgam fillings on health in the general population. In studies on children (Derouen et al., 2006; Bellinger et al., 2006), no adverse neurobehavioural, cognitive, or renal effect from exposure to amalgam was found. However, the children will inevitably have lower accumulated mercury levels due to the lower number of amalgam fillings and the shorter duration of exposure. In addition, auditory thresholds were not considered in these studies.

Based on the findings of this study, the use of alternative dental-filling materials, which do not show any evidence of ototoxicity, would be prudent; however, there is a dilemma regarding amalgam fillings already in place. Using a standard hearing test, Siblerud and Kienholz (1997) demonstrated improved audiometric thresholds six months after amalgam removal in a group of women with multiple sclerosis. However, although this is of considerable interest, the risk of complications due to removal of the amalgam may exceed the risk of long-term side effects (Berlin, 2003). Additional drilling can cause problems with existing teeth and causes a transient increase in blood mercury (Clarkson et al., 2003; Haikel et al., 1990), which may trigger a reaction in sensitive individuals, such as those with auto-immune conditions. Replacement of amalgam fillings (by another type) at the end of their useful life may be a sensible solution in the majority of cases. Furthermore, the use of certain precautionary techniques (such as high-volume air extraction) can minimize mercury vapour exposure to the patient, dentist, and dental staff during drilling.

In terms of public health and financial costs to health services (e.g. hearing aids), further research is clearly needed. The use of other dental filling materials, notably composites, has increased in recent years in many countries. However, the data from the current study provide an additional argument against the continued use of dental amalgam where suitable alternatives exist.

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