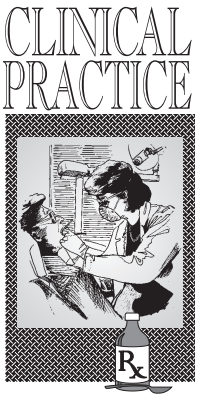

Exposure or Absorption and the Crucial Question of Limits for Mercury

Derek W. Jones, PhD, FIM, CChem., FRSC(UK), FBSE

ABSTRACT

Health Canada recently lowered the recommended maximum daily exposure of mercury from all sources for women of child-bearing age and for children less than 10 years. This new exposure guideline does not seem to be based on any new scientific finding of human toxicity. The average daily intake of methylmercury (mainly from fish) that may cause demonstrable health effects in the most sensitive individual is 300 μg/day, or 4.3 μg Hg/day/kg body weight. The new, lower Health Canada limit is 95% below the level that may cause health effects. A number of studies have looked at methylmercury in human breast milk (where maternal consumption of fish is high), but no strong evidence of toxicity has been reported. The amount of mercury released from dental amalgam is minimal; a person would have to have 490 amalgam surfaces for there to be enough mercury vapour and ionic mercury given off from amalgam fillings to meet the maximum exposure guidelines. The uptake of food-related organic mercury is six times higher than the uptake of mercury from amalgam; moreover, food-related mercury is significantly more toxic. Many studies of amalgam-related mercury are flawed by confusion between exposure and absorption for the various forms of mercury, a limited selection of data, the ignoring of confounding variables or the misclassification of data.

MeSH Key Words: absorption; dental amalgam/adverse effects; environmental exposure; mercury/adverse effects.

This article has been peer reviewed.

Introduction

In April 1998, Health Canada lowered the maximum daily exposure of mercury from all sources for women of child-bearing age and for children less than 10 years by 57% from 0.47 μg/kg/day down to 0.2 μg/kg/day. This new exposure guideline does not seem to be based upon any new scientific finding of human toxicity. The average daily intake of methylmercury (mainly from fish) that may cause demonstrable health effects in the most sensitive individual is 300 μg/day, or 4.3 μg Hg/day/kg body weight.[1] The new, lower Health Canada limit is 95% below the level that may cause health effects. This recommended lower mercury exposure has raised questions about the dental amalgam issue once again.

It is extremely misleading to look only at the exposure levels without considering the absorption levels, particularly if we consider the different chemical forms of mercury. Lipid soluble organic mercury is much more bioavailable than metallic inorganic mercury, ionic mercury or mercury vapour from dental amalgam. The organic form in food is much more insidious due to its ability to traverse lipid membranes and penetrate the central nervous system.[2] Unlike inorganic or metallic mercury, organic mercury readily crosses the blood-brain barrier.[3]

Health Canada and Environment Canada have stated that they are concerned about industrial pollution; however, it is important to note that about 50% of environmental mercury comes from natural sources due to volatilization from the ocean and erosion of rocks. The atmosphere deposits about 2 million kg/year of mercury into oceans, and the rivers are estimated to contribute a further 200,000 kg/year.[4] Regardless of the source of environmental mercury, a major question that science has not yet answered is what

effect mercury in the food chain has on human health.

Mercury in the Food Chain

A 20-year retrospective analysis of methylmercury in fish involving over 38,000 individuals in Canada did not find any identifiable health problems related to mercury.[5] No negative health effects from eating contaminated fish have been established; no clinical cases of methylmercury poisoning from fish have been found in Canada or Sweden.[6]

Two important scientific studies that are currently under way aim to address the effect of mercury in the food chain; these are the Seychelles study and the Faroe Islands study. Of the two studies, the double-blind study in the Seychelles has by far the best design and has the potential to yield the most valid scientific data.

The Seychelles study. Controversy exists concerning the fetal risk associated with exposure to low-dose methylmercury from maternal fish consumption.[7] Previous studies of the effects of acute prenatal mercury exposure identified delays in achieving developmental milestones among exposed children. This led to public health concerns that prenatal low-dose exposure from fish consumption could also adversely affect the fetus.

The extensive Seychelles Child Development Study that began in 1986 is examining the association between fetal methylmercury exposure from a maternal diet high in fish and subsequent child development. The study is double blind and uses maternal hair mercury as the index of fetal exposure. No definite effects have been detected through 29 months of age in the main study.[8] Toddlers who had prenatal exposure to methylmercury are achieving the developmental milestones of walking and talking at normal ages.[9] The authors do say that more detailed studies in older children are needed to determine if there are adverse effects in fish-eating populations.

The Faroe Islands study. Human milk as a source of methylmercury exposure in infants has been studied by Grandjean and others.[10] In a community in the Faroe Islands, high maternal consumption of pilot whale meat and blubber and other seafood had the potential to cause a considerable transfer of neurotoxicants during breast-feeding. The researchers followed 583 children from a birth cohort. Three developmental milestones that are usually reached between 5 and 12 months of age, i.e., sitting, crawling and standing, were examined. It was found that infants who reached the milestone criteria early had significantly *higher* mercury concentrations in the hair at 12 months of age. This association is contrary to what would be expected from possible neurotoxic effects of mercury. The authors point out that early milestone development is clearly associated with breast-feeding, which suggests that, if methylmercury exposure from human milk had any adverse effect on milestone development in these infants, the effect was compensated by the advantages associated with breast-feeding.

Other studies on mercury in breast milk. A study by Oskarsson and others[11] looked at the total and inorganic mercury content in breast milk that is related to fish consumption. In the milk, 51% of the mercury was in the inorganic form; in the blood, only 26% was present in the inorganic form. The authors found no significant correlation between the mercury levels in milk in any chemical form and the methylmercury intake. The results indicated that there was an efficient transfer of inorganic mercury from blood to milk. The researchers claimed that the exposure from amalgam fillings was the main source of mercury in milk. They reported that the exposure of the infant to mercury from breast milk ranged up to 0.3 μg/kg/day, of which approximately 50% was inorganic. The exposure was said to be one-half the tolerable daily intake for adults recommended by the World Health Organization (WHO). They concluded that efforts should be made to decrease mercury burden in fertile women.

In contrast, a study by Smith and others[12] reported that methylmercury in the U.S. population is quite low, and that it is not likely that maternal hair methylmercury levels in the range found in their study would be associated with adverse health effects in children. In addition, a study by Drexler and Schaller[13] concluded that the additional exposure to mercury of breast-fed babies from maternal amalgam fillings is of minor importance compared to maternal fish consumption.

Thus, although a number of studies have looked at methylmercury in human breast milk, no strong evidence of toxicity has been reported. Dose-response relationships are not clearly established for developmental neurotoxicity under conditions of chronic exposure (exposure for 365 days or more) to methylmercury; shorter periods of time such as the duration of breast-feeding are even more challenging. In light of these findings it is difficult to understand the recent change in the guidelines from Health Canada.

Biotransformation of mercury. Since organic mercury presents a greater health hazard than metallic or inorganic mercury, a suggestion has been made that exposure to mercury vapour may result in metallic mercury (or perhaps ionic mercury) being transformed into highly toxic lipid soluble organo-mercury compounds by micro-organisms in the oral cavity and gastrointestinal tract. A study by Chang and others[14] evaluated the blood mercury concentrations of dentists and non-dentists; sources of mercury exposure were identified through a questionnaire at the time of sampling. Concentrations of total and inorganic blood mercury were significantly higher in dentists; however, organo-mercury concentrations of the two groups were not statistically different ($p \geq .05$), suggesting that biotransformation of inorganic mercury to organo-mercury does not occur *in vivo*. The study does not exclude the possibility that some degree of non-significant biotransformation may occur. However, -

organo-mercury in blood was positively correlated with the frequency of fish consumption.

Dental Amalgam

An item of news causing some confusion recently was the announcement from the United Kingdom that pregnant women should avoid treatment involving amalgam fillings to limit the possibility of mercury reaching the fetus. Having produced this new guideline, the U.K. government then stated that it had no evidence that there was a risk from amalgam. The British Dental Association issued a press release on April 29, 1998, stating,

"The BDA accepts the Department of Health's view that:

- Pregnant women (or new mothers) should not be alarmed by this announcement. There is no evidence of harm to children whose mothers have undergone dental amalgam placement or removal during pregnancy. COT [Committee on Toxicity of Chemicals in Food, UK Consumer Products and Environment] is issuing precautionary advice pending further research.
- There is no evidence that placement or removal of amalgam during pregnancy affects the fetus. Studies show small amounts of mercury in fetuses but no adverse health effects have been shown and it is also not known whether the mercury found came from the diet or from amalgam fillings."

A publication of WHO by Mjõr and Pakhomov[15] recently endorsed the safety of amalgam, pointing out that the use of amalgam, especially during placement and removal, has not been shown to cause any adverse health effects. This 1997 WHO consensus statement does not suggest restrictions in the use of dental amalgam.

Mercury release is associated with the removal of an oxide layer from the surface of the amalgam alloy. Only inorganic and ionic forms of mercury are released from amalgam restorations. Release of mercury from restorations is time-dependent and proportional to the surface area of the restorations.[16] Mackert and Berglund[17] have reported that the rate of unstimulated mercury release from amalgam averages 0.4 μg per amalgam surface per day; higher rates occur during the eating of some foods and during tooth-brushing. (A number of reports have assumed that meals and snacks affect mercury release to a degree similar to gum-chewing and tooth-brushing. This is, however, an erroneous assumption, which leads to serious overestimations in calculating release of mercury from restorations.[18,19]) If we assume that the stimulated condition occurs during a period of 4 hours and that it is three times higher than the unstimulated rate, it can be calculated that the 4-hour stimulated release during the day would be:

$$0.4\ \mu g\ Hg/day \div 24\ hours = 0.0167 \times 4 = 0.067 \times 3 = 0.2\ \mu g/day$$

The unstimulated rate for 20 hours would be:

$$0.4\ \mu g\ Hg/day \div 24\ hours \times 20 = 0.334\ \mu g\ Hg/day.$$

The combined 24-hour stimulated and unstimulated rate would thus be:

$$0.2\ \mu g\ Hg/day + 3.34\ \mu g\ Hg/day = 0.534\ \mu g\ Hg/day$$

Many researchers studying the release of mercury from amalgam have made use of a Jerome 401 instrument for sampling mercury in air. It takes the instrument 40 seconds to aspirate 500 mL of air; this amount of air (500 mL) is typical for an ordinary inhalation into the lungs, but the lungs inhale that much air in just 2.5 seconds. The mercury vapour taken in by the instrument in 40 seconds compared with the 2.5 seconds needed by the lungs produces a mercury-in-air value (40 ÷ 2.5) that is 16 times too high. Mackert and Berglund[17] point out that several publications misinterpret mercury in air by a factor of 16; when used to make further calculations, these incorrect values compound inaccuracy.

Berglund[18] developed a model based upon available literature that estimates the total mercury released from amalgam restorations. About 25% is released as vapour from the saliva-covered amalgam; about half of this 25% is exhaled and the other half is inhaled (12.5%), and of this latter amount 80% is absorbed through the lungs. Thus, only about 10% of mercury vapour released is absorbed (i.e., 80% of 12.5%). It is further estimated that the other 75% of mercury vapour is dissolved in saliva, swallowed and converted to the ionic form. Only about 5.25% of this ionic mercury ends up being absorbed from the gastrointestinal tract (7% of 75%). Thus only 15.25% (10% + 5.25%) of the total mercury given off from dental amalgam is absorbed; most inorganic mercury released from amalgam is excreted.

WHO standards for occupational exposure to inorganic mercury are currently 50 $\mu g/m^3$ in air and 50 μg/g creatinine in urine.[20] The mean total mercury level in urine for 1,073 male subjects with a mean of 8.2 amalgam restorations has been reported as 3.1 μg/L.[21]

WHO's maximum acceptable daily intake (ADI) for mercury is 40 μg/day. An individual can be exposed to 44 μg/day of organic mercury in food, of which about 90% is absorbed,[22] and still keep within the limit of 40 μg/day:

$$44\ \mu g/day \div 100 \times 90 = 39.6\ \mu g/day$$

An individual can be exposed to 262 μg/day of inorganic mercury from amalgam fillings with only 15.25% absorption and be within the same limit of 40 μg/day:

$$262\ \mu g/day \div 100 \times 15.25 = 39.95\ \mu g/day$$

Assuming a combined stimulated and unstimulated release of 0.535 μg/day per amalgam surface, this 262 μg/day of mercury vapour and ionic mercury given off from amalgam fillings would be equivalent to the mercury released from 490 amalgam surfaces. How many patients do you know who have 490 amalgam surfaces?

A woman weighing 54 kg under the old Health Canada maximum exposure limit of 0.47 μg/kg/day would be permitted to be exposed to 25.38 μg/day Hg. Assuming no mercury being contributed from food, this 54-kg woman would have to have 47 amalgam surfaces (assuming an average mercury release per surface of 0.534 μg/day) to reach the maximum level of mercury permitted. With the new lower Health Canada maximum exposure limit, the number of amalgam surfaces would be reduced to 20, again assuming no mercury intake from other sources such as food; this would be equal to an absorption of 1.6 μgHg/day. In other words, with the new Canadian exposure limit of 0.2 μg/Hg/kg/day, a 54-kg woman would be permitted to be exposed to:

54 kg × 0.2 μg/kg/day =
10.8 μg Hg/day

The resultant absorbed dose differs greatly with the form of mercury. If all of the mercury is food-related, then the absorbed dose would be 90% of 10.8, i.e., 9.7 μg. Alternatively, if the mercury is all contributed from dental amalgam fillings, then the absorbed dose would be

10.8 μg Hg ÷ 15.25% =
1.65 μg Hg/day

Thus, the uptake of food-related organic mercury is *six times* higher than the uptake of mercury from amalgam; moreover, food-related mercury is significantly more toxic. The constantly repeated statement that most mercury is derived from amalgam fillings is puzzling.

Exposure and Absorption

The science of toxicity is complex. However, the absorbed dosage is by far the most important critical factor in determining if a substance is an acute or chronic toxicant or if it has no toxic effect at all. As demonstrated above, exposure to organic mercury from food results in an absorption six times greater than the same amount of inorganic or ionic mercury. The ability to be absorbed is an essential prerequisite for systematic toxicity to occur. The lipid soluble organic mercury is readily absorbed from the gastrointestinal tract, while inorganic ionic mercury is only very sparingly absorbed.

Confusion between exposure and absorption for the various forms of mercury and the overestimation of mercury vapour using the Jerome instrument are two of many areas of misinformation that have confused facts relating to dental amalgam. Many studies suffer from a limited selection or choice of data, the ignoring of confounding variables or the misclassification of data. The resulting misinformation has been propagated and sensationalized by the media and by those with vested interests. Many well-meaning environmental activists subscribe to these scare stories that are often based on poorly designed experiments and epidemiological surveys.[23] We are faced with a constant stream of half-truths and anti-chemical alarms that ignore and undermine basic scientific principals.

A major concern with neurobehavioural testing has to be the danger of measuring effects that are due to an activity or substance other than the one being evaluated. At least 750 toxicants have the potential to cause neurotoxic effects in humans after a short-term or long-term exposure or latent period.[24] It is too simplistic to lay blame on any one toxic element or compound in the absence of scientific proof.

Ongoing Research

A longitudinal, randomized, prospective clinical trial in Portugal involves placement of amalgam and composite restorations in a group of 500 children aged 8 to 10 years.[21] The test population selected had little or no exposure to mercury combined with a relatively high rate of caries. Supported by the National Institute of Dental and Craniofacial Research (NIDR), this study may finally provide solid data to confirm or disprove the potential for subtle and long-term effects from dental amalgam.

Another study initiated by the NIDR, in 1992, is the so-called Ranch Hand study, based on U.S. Air Force personnel who served in Vietnam from 1962 to 1971. The study was originally designed to evaluate the health effects attributable to exposure to Agent Orange. The study design had a matching comparison group of non-exposed individuals. The database of these individuals contains comprehensive health data such as exposure to heavy metals and clinical measurements evaluating the central nervous and renal systems. The database also contains full dental records, including the type of restorations. This all-male (age 40 to 78 years) 1,127-man cohort cannot be said to represent a cross-section of the general population. Additionally, the design of the study limits its usefulness, because it will not be possible to infer cause and effect based simply on association. However, the database should be able to provide some useful information. Thus far, data indicate that each 10-fold increase in amalgam surfaces is associated with an increase of 1 μg/L of mercury in urine.[25] It is hoped that further data studying the possible linkages between mercury levels and health outcomes will become available as the study proceeds.

Conclusions

Recent announcements in Canada and the United Kingdom raise the question, Should governments be developing limits and issuing precautionary advice for exposure to mercury from food or dental amalgam in the absence of new, definitive scientific data? Do such announcements themselves create unease and stress that can affect the health of the population? The public should not be misled about the difference between exposure to mercury and the absorbed dose of mercury, or about the different chemical forms in which it exists. When the public see an item reported in the media they assume that it is true. If governments change position statements or guidelines regarding health and safety, the public assume that the situation has become worse. That assumption holds even if, as in the case of the

British government and dental amalgam, the new guidelines are introduced with the qualifying statement that there is no evidence on the health risk.

According to some people who view dental amalgam as causing a variety of health problems, no level of mercury is acceptable in the human body. The concept that an actual tolerance may exists for low levels of mercury in the human body can, however, be rationalized. The prevalence of naturally occurring mercury in the Earth's crust, coupled with the relative ease with which it can be chemically modified, transported and exchanged among land, aquatic and air environments, suggests that living organisms have been in contact with mercury and mercury compounds throughout the long evolution of biological systems leading up to human development.[26,27] Given the epidemiological evidence we have, it seems likely that humans may have evolved with a threshold level for mercury below which there is no response or observable adverse health effects. ■

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PRATIQUE CLINIQUE

Exposure or Absorption and the Crucial Question of Limits for Mercury

(Différence entre exposition et absorption et la question cruciale des limites relatives au mercure)

Derek W. Jones, PhD, FIM, CChem., FRSC(UK), FBSE

SOMMAIRE

Santé Canada a récemment abaissé le taux maximal recommandé d'exposition quotidienne au mercure (toutes sources confondues), pour les femmes en âge de procréer et les enfants de moins de 10 ans. Cependant, cette nouvelle directive ne semble s'appuyer sur aucune donnée scientifique nouvelle concernant la toxicité du mercure chez les humains. En moyenne, l'ingestion quotidienne de méthylmercure (provenant essentiellement du poisson) qui peut causer des effets démontrables sur la santé des personnes les plus sensibles est de 300 μg par jour, ou 4,3 μg de Hg par jour, par kilogramme de poids corporel. Or la nouvelle limite à la baisse établie par Santé Canada est de 95 % inférieure au seuil nuisible à la santé. Les études qui ont été faites sur le méthylmercure dans le lait maternel (chez les mères qui consomment beaucoup de poisson) n'ont révélé aucune preuve solide de toxicité. La quantité de mercure qui se dégage des amalgames dentaires est minime; il faudrait en effet qu'une personne ait 490 surfaces d'amalgame pour que la quantité de vapeurs de mercure et d'ions mercure libérés par les obturations à l'amalgame atteigne l'exposition maximale prescrite. La quantité de mercure organique qui provient des aliments est six fois plus élevée que l'apport provenant des amalgames; qui plus est, le mercure d'origine alimentaire est beaucoup plus toxique. Un grand nombre d'études sur le mercure dans les amalgames dentaires présentent des lacunes dues à la confusion qui existe entre l'exposition aux diverses formes de mercure et l'absorption de ce dernier, à la sélection limitée de données, ainsi qu'à l'erreur de classification des données ou à l'abstraction qui est faite des variables confusionnelles dans l'analyse.

Mots clés MeSH : absorption; dental amalgam/adverse effects; environmental exposure; mercury/adverse effects.

Cet article a fait l'objet d'une révision par des pairs.

Introduction

In April 1998, Health Canada lowered the maximum daily exposure of mercury from all sources for women of child-bearing age and for children less than 10 years by 57% from 0.47 μg/kg/day down to 0.2 μg/kg/day. This new exposure guideline does not seem to be based upon any new scientific finding of human toxicity. The average daily intake of methylmercury (mainly from fish) that may cause demonstrable health effects in the most sensitive individual is 300 μg/day, or 4.3 μg Hg/day/kg body weight.[1] The new, lower Health Canada limit is 95% below the level that may cause health effects. This recommended lower mercury exposure has raised questions about the dental amalgam issue once again.

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In contrast, a study by Smith and others[12] reported that methylmercury in the U.S. population is quite low, and that it is not likely that maternal hair methylmercury levels in the range found in their study would be associated with adverse health effects in children. In addition, a study by Drexler and Schaller[13] concluded that the additional exposure to mercury of breast-fed babies from maternal amalgam fillings is of minor importance compared to maternal fish consumption.

Thus, although a number of studies have looked at methylmercury in human breast milk, no strong evidence of toxicity has been reported. Dose-response relationships are not clearly established for developmental neurotoxicity under conditions of chronic exposure (exposure for 365 days or more) to methylmercury; shorter periods of time such as the duration of breast-feeding are even more challenging. In light of these findings it is difficult to understand the recent change in the guidelines from Health Canada.

Biotransformation of mercury. Since organic mercury presents a greater health hazard than metallic or inorganic mercury, a suggestion has been made that exposure to mercury vapour may result in metallic mercury (or perhaps ionic mercury) being transformed into highly toxic lipid soluble organomercury compounds by microorganisms in the oral cavity and gastrointestinal tract. A study by Chang and others[14] evaluated the blood mercury concentrations of dentists and non-dentists; sources of mercury exposure were identified through a questionnaire at the time of sampling. Concentrations of total and inorganic blood mercury were significantly higher in dentists; however, organo-mercury concentrations of the two groups were not statistically different ($p \geq .05$), suggesting that biotransformation of inorganic mercury to organo-mercury does not occur *in vivo*. The study does not exclude the possibility that some degree of non-significant biotransformation may occur. However, -

organo-mercury in blood was positively correlated with the frequency of fish consumption.

Dental Amalgam

An item of news causing some confusion recently was the announcement from the United Kingdom that pregnant women should avoid treatment involving amalgam fillings to limit the possibility of mercury reaching the fetus. Having produced this new guideline, the U.K. government then stated that it had no evidence that there was a risk from amalgam. The British Dental Association issued a press release on April 29, 1998, stating,

"The BDA accepts the Department of Health's view that:

- Pregnant women (or new mothers) should not be alarmed by this announcement. There is no evidence of harm to children whose mothers have undergone dental amalgam placement or removal during pregnancy. COT [Committee on Toxicity of Chemicals in Food, UK Consumer Products and Environment] is issuing precautionary advice pending further research.
- There is no evidence that placement or removal of amalgam during pregnancy affects the fetus. Studies show small amounts of mercury in fetuses but no adverse health effects have been shown and it is also not known whether the mercury found came from the diet or from amalgam fillings."

A publication of WHO by Mjõr and Pakhomov[15] recently endorsed the safety of amalgam, pointing out that the use of amalgam, especially during placement and removal, has not been shown to cause any adverse health effects. This 1997 WHO consensus statement does not suggest restrictions in the use of dental amalgam.

Mercury release is associated with the removal of an oxide layer from the surface of the amalgam alloy. Only inorganic and ionic forms of mercury are released from amalgam restorations. Release of mercury from restorations is time-dependent and proportional to the surface area of the restorations.[16] Mackert and Berglund[17] have reported that the rate of unstimulated mercury release from amalgam averages 0.4 μg per amalgam surface per day; higher rates occur during the eating of some foods and during tooth-brushing. (A number of reports have assumed that meals and snacks affect mercury release to a degree similar to gum-chewing and tooth-brushing. This is, however, an erroneous assumption, which leads to serious overestimations in calculating release of mercury from restorations.[18,19]) If we assume that the stimulated condition occurs during a period of 4 hours and that it is three times higher than the unstimulated rate, it can be calculated that the 4-hour stimulated release during the day would be:

$$0.4\ \mu g\ Hg/day \div 24\ hours = 0.0167 \times 4 = 0.067 \times 3 = 0.2\ \mu g/day$$

The unstimulated rate for 20 hours would be:

$$0.4\ \mu g\ Hg/day \div 24\ hours \times 20 = 0.334\ \mu g\ Hg/day.$$

The combined 24-hour stimulated and unstimulated rate would thus be:

$$0.2\ \mu g\ Hg/day + 3.34\ \mu g\ Hg/day = 0.534\ \mu g\ Hg/day$$

Many researchers studying the release of mercury from amalgam have made use of a Jerome 401 instrument for sampling mercury in air. It takes the instrument 40 seconds to aspirate 500 mL of air; this amount of air (500 mL) is typical for an ordinary inhalation into the lungs, but the lungs inhale that much air in just 2.5 seconds. The mercury vapour taken in by the instrument in 40 seconds compared with the 2.5 seconds needed by the lungs produces a mercury-in-air value (40 ÷ 2.5) that is 16 times too high. Mackert and Berglund[17] point out that several publications misinterpret mercury in air by a factor of 16; when used to make further calculations, these incorrect values compound inaccuracy.

Berglund[18] developed a model based upon available literature that estimates the total mercury released from amalgam restorations. About 25% is released as vapour from the saliva-covered amalgam; about half of this 25% is exhaled and the other half is inhaled (12.5%), and of this latter amount 80% is absorbed through the lungs. Thus, only about 10% of mercury vapour released is absorbed (i.e., 80% of 12.5%). It is further estimated that the other 75% of mercury vapour is dissolved in saliva, swallowed and converted to the ionic form. Only about 5.25% of this ionic mercury ends up being absorbed from the gastrointestinal tract (7% of 75%). Thus only 15.25% (10% + 5.25%) of the total mercury given off from dental amalgam is absorbed; most inorganic mercury released from amalgam is excreted.

WHO standards for occupational exposure to inorganic mercury are currently 50 $\mu g/m^3$ in air and 50 μg/g creatinine in urine.[20] The mean total mercury level in urine for 1,073 male subjects with a mean of 8.2 amalgam restorations has been reported as 3.1 μg/L.[21]

WHO's maximum acceptable daily intake (ADI) for mercury is 40 μg/day. An individual can be exposed to 44 μg/day of organic mercury in food, of which about 90% is absorbed,[22] and still keep within the limit of 40 μg/day:

$$44\ \mu g/day \div 100 \times 90 = 39.6\ \mu g/day$$

An individual can be exposed to 262 μg/day of inorganic mercury from amalgam fillings with only 15.25% absorption and be within the same limit of 40 μg/day:

$$262\ \mu g/day \div 100 \times 15.25 = 39.95\ \mu g/day$$

Assuming a combined stimulated and unstimulated release of 0.535 μg/day per amalgam surface, this 262 μg/day of mercury vapour and ionic mercury given off from amalgam fillings would be equivalent to the mercury released from 490 amalgam surfaces. How many patients do you know who have 490 amalgam surfaces?

A woman weighing 54 kg under the old Health Canada maximum exposure limit of 0.47 μg/kg/day would be permitted to be exposed to 25.38 μg/day Hg. Assuming no mercury being contributed from food, this 54-kg woman would have to have 47 amalgam surfaces (assuming an average mercury release per surface of 0.534 μg/day) to reach the maximum level of mercury permitted. With the new lower Health Canada maximum exposure limit, the number of amalgam surfaces would be reduced to 20, again assuming no mercury intake from other sources such as food; this would be equal to an absorption of 1.6 μgHg/day. In other words, with the new Canadian exposure limit of 0.2 μg/Hg/kg/day, a 54-kg woman would be permitted to be exposed to:

54 kg × 0.2 μg/kg/day =
10.8 μg Hg/day

The resultant absorbed dose differs greatly with the form of mercury. If all of the mercury is food-related, then the absorbed dose would be 90% of 10.8, i.e., 9.7 μg. Alternatively, if the mercury is all contributed from dental amalgam fillings, then the absorbed dose would be

10.8 μg Hg ÷ 15.25% =
1.65 μg Hg/day

Thus, the uptake of food-related organic mercury is *six times* higher than the uptake of mercury from amalgam; moreover, food-related mercury is significantly more toxic. The constantly repeated statement that most mercury is derived from amalgam fillings is puzzling.

Exposure and Absorption

The science of toxicity is complex. However, the absorbed dosage is by far the most important critical factor in determining if a substance is an acute or chronic toxicant or if it has no toxic effect at all. As demonstrated above, exposure to organic mercury from food results in an absorption six times greater than the same amount of inorganic or ionic mercury. The ability to be absorbed is an essential prerequisite for systematic toxicity to occur. The lipid soluble organic mercury is readily absorbed from the gastrointestinal tract, while inorganic ionic mercury is only very sparingly absorbed.

Confusion between exposure and absorption for the various forms of mercury and the overestimation of mercury vapour using the Jerome instrument are two of many areas of misinformation that have confused facts relating to dental amalgam. Many studies suffer from a limited selection or choice of data, the ignoring of confounding variables or the misclassification of data. The resulting misinformation has been propagated and sensationalized by the media and by those with vested interests. Many well-meaning environmental activists subscribe to these scare stories that are often based on poorly designed experiments and epidemiological surveys.[23] We are faced with a constant stream of half-truths and anti-chemical alarms that ignore and undermine basic scientific principals.

A major concern with neurobehavioural testing has to be the danger of measuring effects that are due to an activity or substance other than the one being evaluated. At least 750 toxicants have the potential to cause neurotoxic effects in humans after a short-term or long-term exposure or latent period.[24] It is too simplistic to lay blame on any one toxic element or compound in the absence of scientific proof.

Ongoing Research

A longitudinal, randomized, prospective clinical trial in Portugal involves placement of amalgam and composite restorations in a group of 500 children aged 8 to 10 years.[21] The test population selected had little or no exposure to mercury combined with a relatively high rate of caries. Supported by the National Institute of Dental and Craniofacial Research (NIDR), this study may finally provide solid data to confirm or disprove the potential for subtle and long-term effects from dental amalgam.

Another study initiated by the NIDR, in 1992, is the so-called Ranch Hand study, based on U.S. Air Force personnel who served in Vietnam from 1962 to 1971. The study was originally designed to evaluate the health effects attributable to exposure to Agent Orange. The study design had a matching comparison group of non-exposed individuals. The database of these individuals contains comprehensive health data such as exposure to heavy metals and clinical measurements evaluating the central nervous and renal systems. The database also contains full dental records, including the type of restorations. This all-male (age 40 to 78 years) 1,127-man cohort cannot be said to represent a cross-section of the general population. Additionally, the design of the study limits its usefulness, because it will not be possible to infer cause and effect based simply on association. However, the database should be able to provide some useful information. Thus far, data indicate that each 10-fold increase in amalgam surfaces is associated with an increase of 1 μg/L of mercury in urine.[25] It is hoped that further data studying the possible linkages between mercury levels and health outcomes will become available as the study proceeds.

Conclusions

Recent announcements in Canada and the United Kingdom raise the question, Should governments be developing limits and issuing precautionary advice for exposure to mercury from food or dental amalgam in the absence of new, definitive scientific data? Do such announcements themselves create unease and stress that can affect the health of the population? The public should not be misled about the difference between exposure to mercury and the absorbed dose of mercury, or about the different chemical forms in which it exists. When the public see an item reported in the media they assume that it is true. If governments change position statements or guidelines regarding health and safety, the public assume that the situation has become worse. That assumption holds even if, as in the case of the

British government and dental amalgam, the new guidelines are introduced with the qualifying statement that there is no evidence on the health risk.

According to some people who view dental amalgam as causing a variety of health problems, no level of mercury is acceptable in the human body. The concept that an actual tolerance may exists for low levels of mercury in the human body can, however, be rationalized. The prevalence of naturally occurring mercury in the Earth's crust, coupled with the relative ease with which it can be chemically modified, transported and exchanged among land, aquatic and air environments, suggests that living organisms have been in contact with mercury and mercury compounds throughout the long evolution of biological systems leading up to human development.[26,27] Given the epidemiological evidence we have, it seems likely that humans may have evolved with a threshold level for mercury below which there is no response or observable adverse health effects. ■

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