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RESEARCH ARTICLE

Mercury Vapor Release from Amalgam Restorations: An *In Vitro* Study

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ABSTRACT

Dental amalgam has served as an excellent and versatile restorative material for more than 150 years despite periods of controversies. If we were to believe the opinions of some of the last decade, dental amalgam would not survive as a restorative material into the 21st century. Various forces at work seemed to doom it to extinction.

The aim of the present study is to further characterize the factors that contribute to elemental mercury vapor exposure and to recommend how the practicing dentist can best minimize exposure in the practice setting.

Keywords: Dental amalgam, Mercury toxicity, Mercury vapor.

INTRODUCTION

Amalgam, as a dental restorative material, has sparked controversy several times during its 150- year history. Amalgams are alloys of various metals with mercury, and so, in the broadest sense, the material used in the early 1800s in France- D'Arcets Mineral Cement could be considered the first dental amalgam.[1] This alloy of bismuth, lead, tin and mercury used plasticized at 100°C and poured directly into the cavity.

The first use of a room temperature mixed amalgam, as a restorative material, is attributed to Bell in England (1819) and Taveau in France (1826), who advocated a mixture of silver and mercury as a filling material.

Although amalgam has inferior esthetics to tooth colored material, it continues to be the preferred restorative material for direct applications (Berry and others, 1998),[2] Leinfelder (1993) attributes the success of amalgam to factors that traditionally have been the limitations of resin-based materials; durability, sealing of the restoration/tooth interface, ease of manipulation and finishing and low-technique sensitivity.[3]

Improvements in the physical properties of dental amalgam during the past 30 years have been instrumental in its persistence. Two major developments in the early 1960s were primarily responsible for the improvement in amalgam characteristics. The copper content was increased in the alloy to produce an amalgam free of gamma-2 phase. The increase in copper provides more substrate for the copper tin reaction, greatly reducing or eliminating the tin mercury (gamma-2) phase, which is the weakest and the most corrosive product of amalgam reaction. Also, a spraying technique used in manufacturing alloys for jet engines was implemented in the manufacture of dental amalgam alloy.[5]

Despite the improvements in physical properties, and use of the most reliable bonding agents for direct posterior resin-based composites; fracture of restorations, marginal ditching, discoloration, formation of secondary caries, insufficient wear characteristics resulting in loss of anatomic form, and inter-proximal contacts are still the main reasons limiting the longevity of resin-based composites.

However, amalgam is still considered to be a superior restorative material attributed to its good clinical performance overtime when compared to resin-based composites.

During all phases of manipulation, it is well documented that mercury vapor is released from dental amalgam.[6,7] Both atomic absorption flameless spectrophotometer and detection of elemental mercury vapor by thin gold film sensors have measured and evaluated the amount of mercury vapor release from dental amalgam.[8,9]

This study investigates operator—controlled variables that may affect mercury vapor release from dental amalgam and suggests possible techniques to reduce exposure. An in vitro method for measuring mercury vapor release from amalgam was used to evaluate the variables: Alloy morphology and various cavity designs with and without external surface coating of amalgam restorations with an intermediary varnish.

MATERIALS AND METHODS

For each study in this investigation, the preparation of amalgam samples was carried out at room temperature on bench top. Amalgam was triturated according to manufacturer's directions in an automatic amalgamator. Following condensation and carving, amalgam samples prepared from the rubber base (putty) impression molds in cylindrical form and various cavity designs

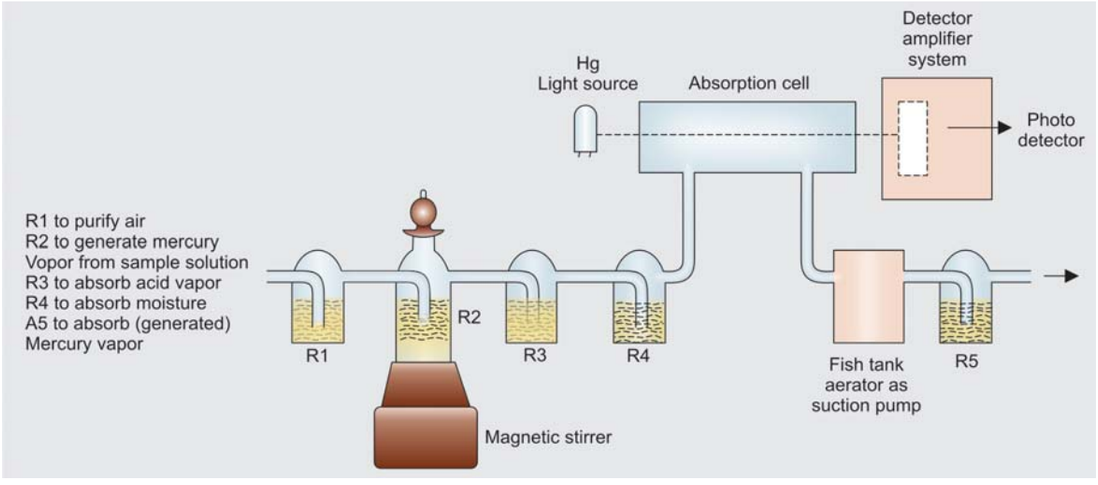

Fig. 1: The vapor generating system with the reaction vessel, four traps and magnetic stirrer is compactly mounted on a sturdy wooden stand with laminated finish

were stored in 25 ml glass bottle sealed with a rubber stopper. The bottles were undisturbed at room temperature until mercury vapor measure was taken at predetermined times.

The mercury vapor analyzer measured the mercury content in each vapor sample. Mercury vapor concentrations were standardized against calibrated temperature readings that compared actual and expected mercury vapor for a given temperature.

The mercury analyzer MA 5800E (Fig. 1) consists of:

1. *Vapor generating system*: This consists of the reaction vessel (R2) where atomic mercury vapor is generated by stirring with a magnetic stirrer. A strap to purify incoming air of mercury vapor and prevent its escape into the air (R5). Traps (R3) and (R4) are for purifying the generated mercury vapor of acid vapors and moisture before it enters the absorption cell. Various traps are connected by latex tubings.
2. Electronic unit:
    1. *The optical part*: Consists of a light tight box enclosing the 20 cm long glass absorption cell fixed with quartz windows at both ends. It has an inlet and outlet for the mercury vapor. On one side of this box is the mercury lamp source with the slit arrangement and the highly sensitive photo detector.
    2. *The suction pump*: This draws the mercury vapor from the vapor generating system through the absorption cell and out through trap R5 to the air in securely mounted inside the electronic unit.
    3. *The electronic circuitry*: This fully solid state design is conveniently and securely mounted to give the best performance and easy accessibility for servicing.
        i. The electronic unit front panel as is seen in the photograph comprises of wide diameter graduated in % transmittance and absorbance units and controls for mains ON/OFF, " filter" "pump" ON/OFF hold-normal for meter, "Zero" and 100% T' adjustments.
        ii. Peak hold facility is provided to facilitate reading of the peak value at ease. As the mercury vapor passes through the absorption cell, the absorbance rises, attains a maximum and falls back (Fig. 2). This happens within seconds. It, being difficult to observe the peak of a transient reading, an electron "peak hold" facility has been provided in the 'hold' position whereby the needle sticks at the maximum point for a sufficiently long time to enable noting of the reading.

The variables tested in this study are:

1. Alloy morphology
2. Different cavity designs with and without external surface coating of amalgam restoration with an intermediary varnish.

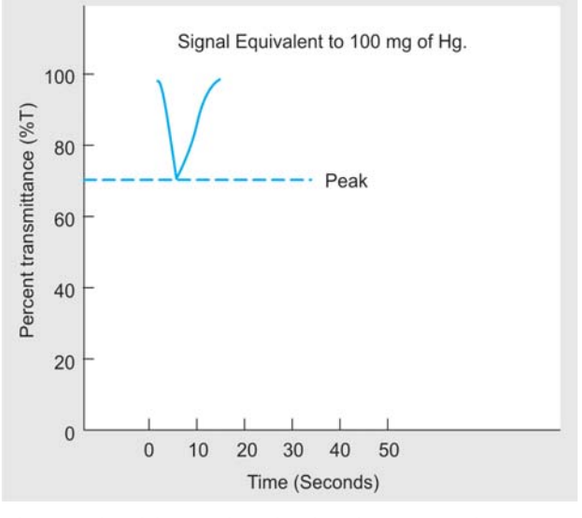

Fig. 2: A plot of the transient signal on the meter as the mercury vapor passes through the absorption cell

Alloy Morphology

Three amalgam alloys with similar chemistry and different morphology (Fig. 3) were analyzed and grouped as follows:

Group A: High copper spherical particle

Group B: High copper admixed particle

Group C: High copper lathe-cut particle

30 amalgam samples, 10 each from three different alloy morphologies were prepared. Each amalgam sample was prepared to make uniform cylindrical specimens (Fig. 4) measuring 7 mm in depth and 5 mm in diameter. Ten minutes after preparation, each sample was immersed individually in a sealed test tube containing 0.9% NaCl.

Vapor was extracted and analyzed (Fig. 5) at 1, 3, 5 and 24 hours then daily for 14 days.

DIFFERENT CAVITY DESIGNS WITH AND WITHOUT EXTERNAL SURFACE COATING OF AMALGAM RESTORATION WITH AN INTERMEDIARY VARNISH

Three standardized cavities fabricated from the elastomeric rubber base impression materials were grouped as follows:

Coated samples	Noncoated samples
Group I: Class I (5 mm diameter × 3 mm depth)	Group Ia-class I
Group II: Class II (5 mm diameter × 3 mm depth)	Group IIa-class II
Group III: MOD (5 mm diameter × 4 mm depth)	Group IIIa-MOD

30 amalgam samples, 10 samples of each preparation type were filled with a spherical alloy and half of the samples from each cavity designs were coated with two uniform layers of copalite varnish with a sable brush. Vapor was sampled and analyzed at 1, 3, 5 and 24 hours then daily for 14 days until vapor levels were below the detection level of the instrument.

The average mercury vapor release levels and the total amount of vapor released were calculated and the data was analyzed by ANOVA and Tukey HSD ($\alpha = 0.05$).

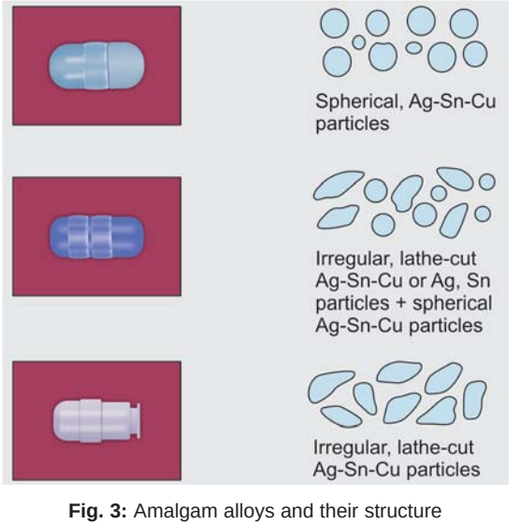

Fig. 3: Amalgam alloys and their structure

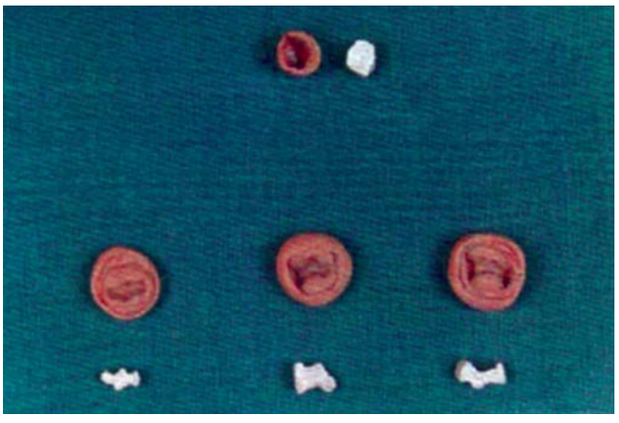

Fig. 4: Amalgam samples prepared to uniform cylindrical specimens

Fig. 5: Mercury vapor analyzer

RESULTS

For each system investigated, mercury vapor release decreased with time. Also, a significant reduction in measurable mercury vapor was reported within the first five hours following trituration for each system.

A statistically significant reduction in measurable mercury vapor was determined after varnish coverage of amalgam restoration.

1. *Alloy Morphology*: It (Fig. 6) presents the average mercury vapor released from the three alloy morphologies in nanograms (ng). A significant difference was determined among alloys by time with a material/time interaction. A significant difference in mercury release between initial reading and 24 hours reading was determined for each alloy. The alloy with greatest initial reduction in vapor release (spherical alloy) resulted in the least amount of overall mercury vapor followed by admixed and lathe-cut alloys. The spherical alloy yielded the least total mercury vapor (4.5 ng) over 14 days collection followed by the admixed

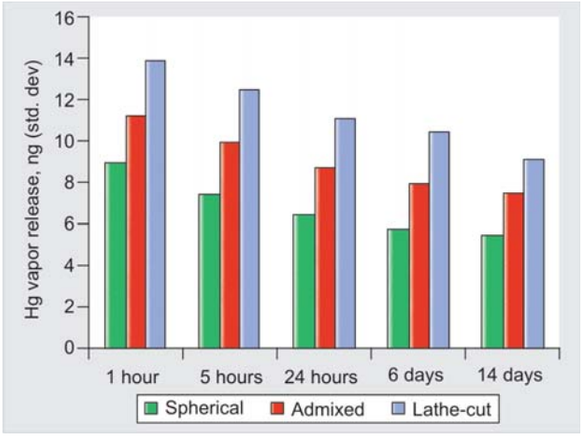

Fig. 6: Alloy morphology

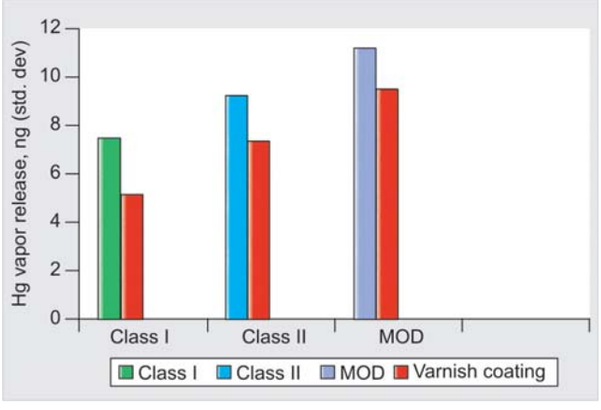

Fig. 7: Cavity design with and without varnish coating

(6.5 ng) and the atomized irregular particle alloy (8.5 ng).

2. Different cavity designs with and without external surface coverage of amalgam restoration with an intermediary varnish.

The cavity design graph (Fig. 7) presents the average daily and total amount of mercury vapor released in nanograms over a 14-day period in three different cavity designs with a spherical alloy, with and without external surface coverage of amalgam restoration with an intermediary varnish.

ANOVA and pair-wise comparisons demonstrated a statistically significant difference among all three restoration designs ($P \leq 0.05$). The class I design yielded the least total mercury vapor over 14 days collection followed by the class II design and the MOD.

A statistically significant difference among the three restoration designs was demonstrated with varnish coating of amalgam when compared to the noncoated amalgam restorations.

DISCUSSION

The safety of dental amalgam, as a material for dental restoration, has been debated since its introduction in the 19th century.[4]

The main contention centers on whether mercury is released in sufficient quantities to pose a health hazard. Most scientists agree that current evidence is not sufficient to show that amalgam restorations pose a general health threat. But researchers on both sides of this debate agree that much remains to be learned about any potential toxicity of dental amalgam—an issue serious enough to merit additional research.

Workers in the dental practice using amalgam can be exposed to mercury either in form of vapor or as particulate amalgam dust, which can be inhaled from the air.[11]

This can result from poor mercury hygiene within the practice as a result of:

- Incorrect storage of mercury or waste amalgam.
- Spillage of mercury or waste amalgam used in dental procedures.

It can also result from dental procedures like:

- Preparation of amalgam restorations
- Placement of amalgam restorations
- Removal of amalgam restorations
- Polishing of amalgam restorations.

The amount of mercury released from all procedures has been quantified:
(JH Engle, JL Ferracane, J Wichmann, and T Okabe in 1992)[8]

- Trituration: 1-2 ug
- Placement of amalgam restoration: 6-8 ug
- Dry polishing: 44 ug
- Wet polishing: 2-4 ug
- Removal of amalgam restoration under water spray and high volume suction: 15-20 ug
- Additional evacuation for 1 minute to remove residual amalgam dust: 1.5-2.0 ug.

Patients can be exposed to Hg from amalgam filling during dental procedures, such as the placement, polishing or removal of amalgam fillings: During its functional life, corrosion affects amalgam restorations and the mechanism of this process is limited by three factors.[12]

1. Formation of a pacifying layer of corrosive products on its surface.
2. Formation of additional gamma-1 and gamma-2 phases from the action of released mercury on the residual gamma phase (Ag3 Sn).
3. The preferential corrosion of the n (Cu 6 Sn5) phase of high copper amalgams.

The factors, which disrupt the surface-pacifying layer, such as tooth brushing and chewing can increase mercury release. Thus, mercury release from amalgam is phasic and consists of a very low baseline release and increased stimulated release as a result of tooth brushing or chewing.

The mercury emitted from amalgam by these processes may be in one of two forms:[10]

1. Mercury Vapor (Hg0), which passes into the oral air and from here may be either inspired into the lungs or expired into the outside air.
2. Mercuric ions (Hg2+), which pass into the saliva and from there to the gastrointestinal (GI) tract.

The release of mercury vapor from dental amalgam restorations has been widely researched and reported over 15 years and many attempts to measure and estimate the release of mercury from amalgam fillings and its absorption by the body have been made.[13]

In the present study, total mercury release from amalgam samples was measured. The alloys evaluated in this investigation represent varying morphologies and chemistries. Alloys were chosen for each of the individual studies based on their unique characteristics. To test the effect of morphology on mercury vapor release, alloys with similar chemistry yet different alloy particles shape, were evaluated (spherical, admixed, and an atomized irregular particle). For the other individual study, different cavity designs with and without external surface coating of amalgam restoration with an intermediary varnish were tested to evaluate possible trends in mercury vapor release.

A consistent finding among all variables tested in this study was a typical pattern of mercury vapor release from setting dental amalgam. This pattern is characterized by higher levels of mercury release early in the setting reaction, steadily decreasing over time until the release rate is undetectable.[15,17] This suggests that mercury is released throughout the initial amalgamation reaction and continues to be released until the material mass reaches a steady state (okabe, 1987).[14] However, the results also demonstrate that mercury vapor release from amalgam is affected by many variables and challenges some basic concepts regarding amalgam technique.

The findings that alloy morphology consistently demonstrated significant differences when evaluated alone and with other variables suggest that it is important in predicting mercury vapor release. There are several possibilities for this finding. First, the differences in mercury vapor release over time between the spherical and admixed alloy may, in part, be determined by the dynamics of amalgamation reaction related to the particle morphology.

The spherical alloy has an increased surface area for immediate reaction with liquid mercury.[18] The more irregular surfaces of the admixed particle may not be as accessible to the liquid mercury initially, and therefore free mercury remains in the mass for a larger period of time during the reaction.[19]

Secondly, differences in chemical composition between materials may affect mercury vapor release, especially with regard to tin content (Mahler Adey and Fleming, 1994; Ferracane and others, 1995).[23] The more the tin content, the less is the mercury vapor released, as the dissolved tin forms a protective film of oxide on the surface and effectively reduces the dry evaporation rate of mercury to a very low value. This is in accordance to the study done by JL Ferracane et al in the year 1995—"Mercury vaporization from amalgams with varied alloy compositions."

Comparing vapor release by preparation design suggests that the larger mass of amalgam presented in the final restoration, the more mercury vapor will be released. However, the most important factor for predicting mercury vapor release from amalgam restorations does not appear to be volume, but the square area of the restoration exposed to air.

The most important factor in the preparations designs can be external surface coverage of amalgam restoration with an intermediary varnish. The varnish coating, which forms an impermeable protective barrier demonstrated significant reduction in mercury vapor release, especially within the first five hours after trituration, which is supposed to be the most crucial period. This is in accordance to the study done by I. Rotstein et al[22] in the year 2000 – " Protective effect of copalite surface coating on mercury release from dental amalgam following treatment with Carbamide peroxide" and by R Ahmad and JG Stannard in the year 1990—Mercury release from amalgam: A study *in vitro* and *in vivo*.[1]

Mercury in its many forms is widely distributed throughout the environment and trace levels are present in air, water and food.[20] Mercury vapor (monoatomic gas, HgO, released by metallic liquid mercury) is probably the most important form of mercury that determines human exposure from dental amalgam fillings.[24] The World Health Organization (WHO) in 1991 established that the absorption of elemental mercury via the respiratory organs is approximately 80%. It is important to clarify whether an amount of elemental mercury is large enough to create adverse biological effects.[21] Estimates of inhaled elemental mercury from ambient air range from 40 to 120 mg per day (Clarkson and Others, 1998; US EPA, 1984).[16] The amount of mercury vapor released from amalgam restorations tested I, the present study ranged from less than 1.0 mg per day to 11.4 mg per day.

The results of this investigation demonstrate some consistent patterns for mercury vapor release *in vitro*. Although clinical evaluation is necessary to evaluate the relation between the amount of mercury vapor released *in vitro* to that released in the oral cavity, the results of this study indicate that mercury vapor release can be affected by alloy morphology and restoration designs with and without intermediary varnish coating over amalgam restorations.

CONCLUSION

Dentists should be aware of the broad parameters of mercury's toxic properties, and specifically their hygiene and vapor hazard in the dental office. Dentists should examine the forthcoming technology for reducing mercury discharge from their offices. They should also understand the complex aspects of medical/psychological profiles of patient with "amalgam illness" and the needs of such patients for proper treatment.

The variables tested in this *in vitro* investigation demonstrated interesting findings.

1. Regardless of alloy type or manipulation, mercury vapor release decreased with time.
2. Spherical alloys consistently released less mercury vapor than admixed alloys except when the spherical alloy had its remaining mercury rich layer present.

3. Variables, including alloy morphology, operator skill and technique, and cavity design influence total mercury vapor release *in vitro*.
4. As with other physical and chemical properties of materials, overall operator handling techniques can influence mercury vapor release from dental amalgam.

CLINICAL RELEVANCE

Mercury vapor release from dental amalgam can be influenced by variables controlled by the clinician. However, there is no rationale for alteration in clinical behavior based on mercury vapor release alone.

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