Estimating the Weight of Dental Amalgam Restorations

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Abstract

Aim: *Data on the weights of amalgam restorations are lacking. The aim of this study was to determine these weights and to develop criteria to facilitate their estimation.*

Methods: *Four separate regression models with 4 covariates in various combinations were used to estimate the weight of amalgam restorations. Model I, based on 514 restorations from both natural and anatomical replica teeth, contained 3 covariates: the number of restored surfaces (covariate A), the type of tooth (covariate B) and whether the restoration had been removed from a natural tooth or an anatomical replica tooth (covariate C). Model II, based on 359 restorations from anatomical replicas, contained 2 covariates: A and B. Model III, based on 155 restorations from natural teeth, contained 3 covariates: covariates A and B and whether the natural teeth had been extracted in 2002 or at least 15 years previously (covariate D). In model IV, covariate D was removed from model III.*

Results: *Model I explained 72% of the variation in the weight of restorations; the partial* R^2 *for covariates A, B and C in model I was 0.5818, 0.797 and 0.0579, respectively (*$p < 0.001$*). In model III, the weights of the restorations did not depend on covariate D (*$p = 0.93$*). The least square mean weight of amalgam restorations with 1, 2, 3, and 4 or more surfaces restored (and 95% confidence interval) was 0.31 g (0.28–0.34 g), 0.49 g (0.45–0.53 g), 0.81 g (0.76–0.86 g) and 1.38 g (1.31–1.45 g), respectively.*

Conclusion: *The number of surfaces restored (covariate A) accounted for at least 80% of the variation in the weight of restorations in all models and therefore provides the best estimate for the weight of amalgam restorations.*

MeSH Key Words: *dental amalgam/analysis; dental restoration, permanent*

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Other than rare reports[1–6] of contact hypersensitivity reaction, there is still no evidence that dental amalgam is a threat to the health of the general population. In fact, recent studies[7–9] have reported that adverse health effects in some individuals may be psychosomatic. Nevertheless, the use of amalgam remains controversial because of other safety concerns,[10–12] notably the fate of mercury that is bound in the waste dental amalgam that enters the environment through various waste streams.[13–17] Anthropogenic mercury from many sources contaminates the biosphere and the aquatic food chain,[18–22] and some authors[23,24] consider dentistry to be an important contributor to this problem.

Arenhölt-Bindslev[13,14] has described the cycle of mercury from amalgam used in dental practice. Bindslev and Larsen[25] and Arenhölt-Bindslev[13,14] have reported high concentrations of mercury in the waste water exiting dental clinics not equipped with high-efficiency amalgam particle separators. However, accurately calculating the total potential contribution from dentistry to the annual flux of anthropogenic mercury has been difficult because of the lack of reliable estimates of the weights of amalgam restorations.[23,24]

A literature search yielded just one study providing such estimates, and that study gave the weights of only 10 restorations from 5 subjects.[26] This number of restorations is far too small to yield reliable estimates. The aim of the

Table 1 **Summary of weights of dental amalgam restorations (g) placed in anatomical replica and natural teeth**

		Anatomical replica teeth			Natural teeth						Total		
					Old[a]			New[b]					
Tooth	No. of surfaces restored	*n*	Mean	(SD)	*n*	Mean	(SD)	*n*	Mean	(SD)	*n*	Mean	(SD)
Premolar[c]	1[d]	60	0.17	(0.12)	4	0.18	(0.09)	0	NA	NA	64	0.17	(0.12)
	2[e]	20	0.31	(0.07)	11	0.44	(0.22)	3	0.50	(0.14)	34	0.37	(0.15)
	3[f]	20	0.49	(0.13)	4	0.99	(0.52)	1	0.93	NA	25	0.59	(0.30)
	All	100	0.26	(0.17)	19	0.50	(0.39)	4	0.61	(0.34)	123	0.31	(0.24)
Mandibular molar[g]	1[d]	40	0.34	(0.17)	26	0.50	(0.38)	9	0.40	(0.29)	75	0.40	(0.28)
	2[e]	20	0.56	(0.17)	6	0.79	(0.29)	15	0.09	(0.46)	41	0.72	(0.35)
	3[f]	20	0.74	(0.17)	5	1.36	(0.23)	3	1.02	(0.30)	28	0.88	(0.31)
	≥4[h]	20	1.48	(0.20)	1	1.70	NA	1	1.63	NA	22	1.50	(0.20)
	All	100	0.69	(0.46)	38	0.69	(0.48)	28	0.78	(0.48)	166	0.71	(0.46)
Maxillary molar[i]	1[d]	93	0.17	(0.12)	2	0.27	(0.21)	12	0.43	(0.34)	130	0.21	(0.19)
	2[e]	30	0.22	(0.08)	12	0.60	(0.28)	4	0.49	(0.24)	4,627	0.34	(0.24)
	3[f]	19	0.65	(0.12)	5	1.22	(0.35)	3	0.90	(0.31)	22	0.78	(0.30)
	≥4[h]	17	1.14	(0.34)	5	1.35	(0.24)	0	NA	NA	0	1.19	(0.33)
	All	159	0.34	(0.34)	47	0.57	(0.47)	19	0.52	(0.34)	225	0.40	(0.39)
All		359	0.42	(0.39)	104	0.60	(0.46)	51	0.67	(0.43)	514	0.48	(0.42)

SD = standard deviation, NA = not applicable, CI = confidence interval
[a]Removed from natural teeth extracted 15 or more years ago
[b]Removed from natural teeth extracted recently (in April and May 2002)
[c]Mean weight (and 95% CI) of premolars = 0.31 g (0.27–0.36 g)
[d]Mean weight (and 95% CI) of amalgam restoration with 1 restored surface 0.26 g (0.23–0.28 g)
[e]Mean weight (and 95% CI) of amalgam restoration with 2 restored surfaces 0.50 g (0.43–0.56 g)
[f]Mean weight (and 95% CI) of amalgam restoration with 3 restored surfaces 0.77 g (0.70–0.85 g)
[g]Mean weight (and 95% CI) of mandibular molars 0.44 g (0.38–0.50 g)
[h]Mean weight (and 95% CI) of amalgam restoration with 4 or more restored surfaces 1.73 g (1.52–1.95 g)
[i]Mean weight (and 95% CI) of maxillary molars 0.86 g (0.75–0.97 g)

present study was to estimate the weights of dental amalgam restorations and to identify criteria to facilitate the estimation of these weights.

Materials and Methods

Amalgam restorations were removed from 3 groups of teeth. The first group (n = 368) consisted of restorations previously placed in anatomical replica teeth (Kilgore International Inc., Coldwater, Mich.) by dental students at the faculty of dentistry, University of Toronto, as part of the requirements for the preclinical operative course. The other 2 groups (total n = 162) consisted of restorations from natural teeth. One group of teeth had been collected at least 15 years previously and the other during April and May 2002.

The following procedure was used for removal of all restorations. After being cleaned and dried at room temperature for 24 hours, each tooth was weighed (on a TR-602 scale, Denver Instrument Company, Arvada, Colo.) to a precision of 0.01 g with the restorations in situ. Then, the restorations were removed with a water-cooled Star 430K high-speed handpiece (Star Dental, Lancaster, Penn.) and conventional high-volume suction. After removal of the amalgam restorations, the teeth were again cleaned and dried at room temperature for 24 hours, and each tooth was reweighed. The difference in the weight of each tooth with and without the restoration was the weight of the amalgam restoration.

The mean weight (and standard deviation [SD]) was 0.55 g (SD 0.59 g) for all 530 restorations, 0.48 g (SD 0.58 g) for the restorations from anatomical replicas and 0.71 g (SD 0.60 g) for the restorations from natural teeth. A Tukey-style stem-and-leaf plot[27] revealed that the weights of the restorations did not exhibit a normal distribution. Sixteen outliers, 9 from anatomical replicas and 7 from natural teeth, were omitted from subsequent analysis (see **Table 1** for detailed information about the teeth that were included in the study).

To determine the amount of tooth material lost during the removal of restorations, preparations with 1, 2, 3, and 4 or more surfaces were made in 4 groups of 10 teeth each. The prepared teeth were cleaned, dried, weighed and restored with amalgam. One week later, the amalgam restorations were removed and the teeth were cleaned, dried

Table 2 Weights of anatomical replica teeth before and after removal of restorations

Type of amalgam restoration	n	Weight of tooth (g): Before placement of restoration	After placement of restoration	After removal of restoration	Net change (g)
1 surface	10	19.05	21.54	19.04	–0.01
2 surfaces	10	19.83	24.47	19.81	–0.02
3 surfaces	10	11.01	16.75	10.02	+0.01
≥ 4 surfaces	10	18.21	31.86	18.16	–0.05

and reweighed. The total weight of material lost from each group was 0.05 g or less (**Table 2**).

All data were entered and analyzed with SAS version 8.02 software (SAS Institute Inc., Cary, N.C.) Means, standard deviations, confidence limits and Tukey-style stem-and-leaf plots[27] were used to examine the distribution of weights of amalgam restorations. One-way analysis of variance (ANOVA) was used to compare differences in means among the 3 sets of teeth and the 4 classes of restorations, and a post hoc evaluation of these differences was performed with Tukey's test. The PROC GLM procedure in the SAS software was used to produce estimates for the weights of amalgam restorations through regression of various combinations of 4 covariates on the weights of amalgam restorations. The covariates tested in model I, which was based on all 514 teeth, were the number of tooth surfaces restored (covariate A), the type of tooth (premolar, maxillary molar or mandibular molar) (covariate B) and whether the restoration had been removed from a natural or an anatomical replica tooth (covariate C). In model II, which analyzed only restorations from anatomical replicas, covariates A and B were used. Model III, which analyzed the restorations from natural teeth, used covariates A and B, along with whether the natural teeth had been collected recently or at least 15 years ago (covariate D). This model examined whether the weights of the 2 groups of natural teeth were significantly different from each other. Model IV used covariates A and B, but not D, to predict the weight of all restorations in natural teeth.

Results

The mean weight of all 3 sets of restorations combined (514 teeth) was 0.48 g (SD 0.42 g) (**Table 1**). Within the 3 subgroups, the mean weight was 0.42 g (SD 0.39 g) for the 359 restorations from anatomical replicas, 0.60 g (SD 0.46 g) for the 104 restorations removed from natural teeth at least 15 years ago and 0.67 g (SD 0.43 g) for the 51 restorations removed from natural teeth recently.

The mean weights of the 3 sets of teeth were significantly different from each other (ANOVA, $p < 0.001$). Although the mean weights of restorations from old and new natural teeth were similar (Tukey's test, $p > 0.05$), the restorations from each set of natural teeth differed significantly from those removed from anatomical replicas (Tukey's test, $p \leq 0.05$). As well, the mean weights of restorations with 1, 2, 3, and 4 or more surfaces differed significantly from each other (ANOVA, $p < 0.001$); Tukey's post hoc test also showed the mean weights were significantly different ($p \leq 0.05$). The mean weight of restorations increased with number of restored surfaces (**Table 1**).

Model I

Model I used covariates A, B and C to estimate the weights of restorations with 1, 2, 3, and 4 or more restored surfaces in all 514 teeth. The 3 covariates jointly accounted for 72% of the variation in the weights of restorations (model $R^2 = 0.7194$) (**Table 3**). Hence, the model failed to account for 28% of the variation in weight of the amalgam restorations. Covariate A, the most important explanatory covariate, independently accounted for 58% of the weight of restorations (partial $R^2 = 0.5818$) ($p < 0.001$) or 81% of the total variation explained by all 3 covariates in this model. Covariate B, the next highest ranking explanatory factor, independently explained 8% of the variation in the weights of restorations (partial $R^2 = 0.0797$) ($p < 0.001$), while covariate C independently accounted for 6% of the variation in the weight of restorations (partial $R^2 = 0.0579$) ($p < 0.001$).

Table 3 also presents the least square mean weights[28] of the amalgam restorations, adjusted for other covariates.

Model II

Model II was based on restorations from anatomical replica teeth and used only covariates A and B. The overall R^2 (0.8397) ($p < 0.001$) was greater than for model I, and 93% of this was derived from covariate A (**Table 3**). However, the partial R^2 of covariate B was marginally smaller than the 0.0579 reported in Model I, at 0.0612.

Model III

This model explored the similarity between the weights of restorations in the 2 sets of natural teeth. The R^2 of the model was 0.5351 ($p < 0.001$). The contribution of covariate D to the variation in the weights of restorations was minimal (partial $R^2 < 0.0001$), and not statistically significant ($p = 0.93$). However, the partial R^2 of covariate A was 0.4569 ($p < 0.001$) or 85% of the explained variation, and covariate B had a partial R^2 of 0.0782 ($p < 0.001$). The

Table 3 Summary of results of ordinary least square regressions and the least square mean weights (and 95% confidence limits [CI]) of amalgam restorations

Model characteristics and estimated weights	Summary of regression models		
	Model I: for all teeth (n = 514)	**Model II: for anatomical replica teeth (n = 359)**	**Model IV: for all natural teeth (n = 155)**
Overall			
• F value	216.65	369.89	34.30
• Probability > F	< 0.001	< 0.001	< 0.001
• R2	0.7194	0.8397	0.5351
Partial R^2 (and p value) for covariates			
• No. of surfaces restored (covariate A)	0.5818 (< 0.001)	0.7785 (< 0.001)	0.4569 (< 0.001)
• Type of tooth (covariate B)	0.0797 (< 0.001)	0.0612 (< 0.001)	0.0782 (< 0.001)
• Natural tooth or anatomical replica (covariate C)	0.0579 (< 0.001)	Not tested	Not tested
Least square mean weight (and 95% CI) of amalgam restorations (g)			
No. of surfaces restored (covariate A)			
• 1 surface	0.31 (0.28–0.34)	0.23 (0.20–0.26)	0.31 (0.24–0.40)
• 2 surfaces	0.49 (0.45–0.53)	0.35 (0.32–0.39)	0.64 (0.55–0.73)
• 3 surfaces	0.81 (0.76–0.86)	0.62 (0.58–0.66)	1.10 (0.96–1.23)
• ≥ 4 surfaces	1.38 (1.31–1.45)	1.28 (1.22–1.33)	1.40 (1.16–1.64)
Type of tooth (covariate B)			
• Premolar	0.67 (0.62–0.71)	0.55 (0.52–0.59)	0.70 (0.56–0.85)
• Mandibular molar	0.90 (0.86–0.93)	0.77 (0.74–0.80)	1.05 (0.95–1.14)
• Maxillary molar	0.68 (0.64–0.72)	0.55 (0.52–0.57)	0.85 (0.76–0.94)
Natural tooth or anatomical replica (covariate C)			
• Natural teeth	0.86 (0.82–0.90)		
• Anatomical replica teeth	0.64 (0.61–0.66)		

CI = confidence interval

results of this model are not included in Table 3 because no significant differences were observed between the weights of the 2 sets of natural teeth. Hence, the results from the 2 sets of natural teeth were pooled for analysis in another regression model (Model IV).

Model IV

Model IV used covariates A and B to assess the variation in the weights of all natural teeth and explained 54% of this variation (**Table 3**). Again, covariate A accounted for more than 80% of the total variation explained by the model (partial R^2 = 0.4569, p < 0.001), whereas covariate B accounted for the remaining 15% (partial R^2 = 0.0782, p < 0.001). The contribution of covariate A was 12 percentage points less than its independent contribution in model I.

Weights of Restorations According to Number of Surfaces Restored

In all 4 models, covariate A alone accounted for at least 80% of the explained variation in the weight of restorations. The adjusted least square mean weights of restorations from anatomical replica teeth obtained with model II were generally lower than those obtained with the other models. Given the narrow confidence intervals of the estimated weights, the estimates derived from model I were considered the most precise.

The least square mean weights of amalgam restorations with 1 and with 4 or more restored surfaces were very similar in models I and IV. However, the estimates from model IV were less precise. The least square mean weights of restorations with 2 and 3 restored surfaces were significantly different in these 2 models (indicated by non-overlap of the 95% confidence intervals).

Discussion

The weights of restorations were progressively greater from premolars to maxillary molars and then to mandibular molars; however, among the restorations taken recently from natural teeth, those from premolars were heavier than those from maxillary molars. In addition, the weight of restorations increased as the number of surfaces restored with amalgam increased. The restorations from natural teeth were heavier than those from anatomical replicas. All of these trends were expected. The occlusal surface area of a premolar is less than that of a molar, and the occlusal surface area of mandibular molars is the largest.[28] However, unlike the situation for mandibular molars, the anatomic structure of maxillary molars facilitates the placement of smaller restorations, especially if the transverse ridge is preserved. Restorations in anatomical replicas were expected to weigh less than their counterparts in natural

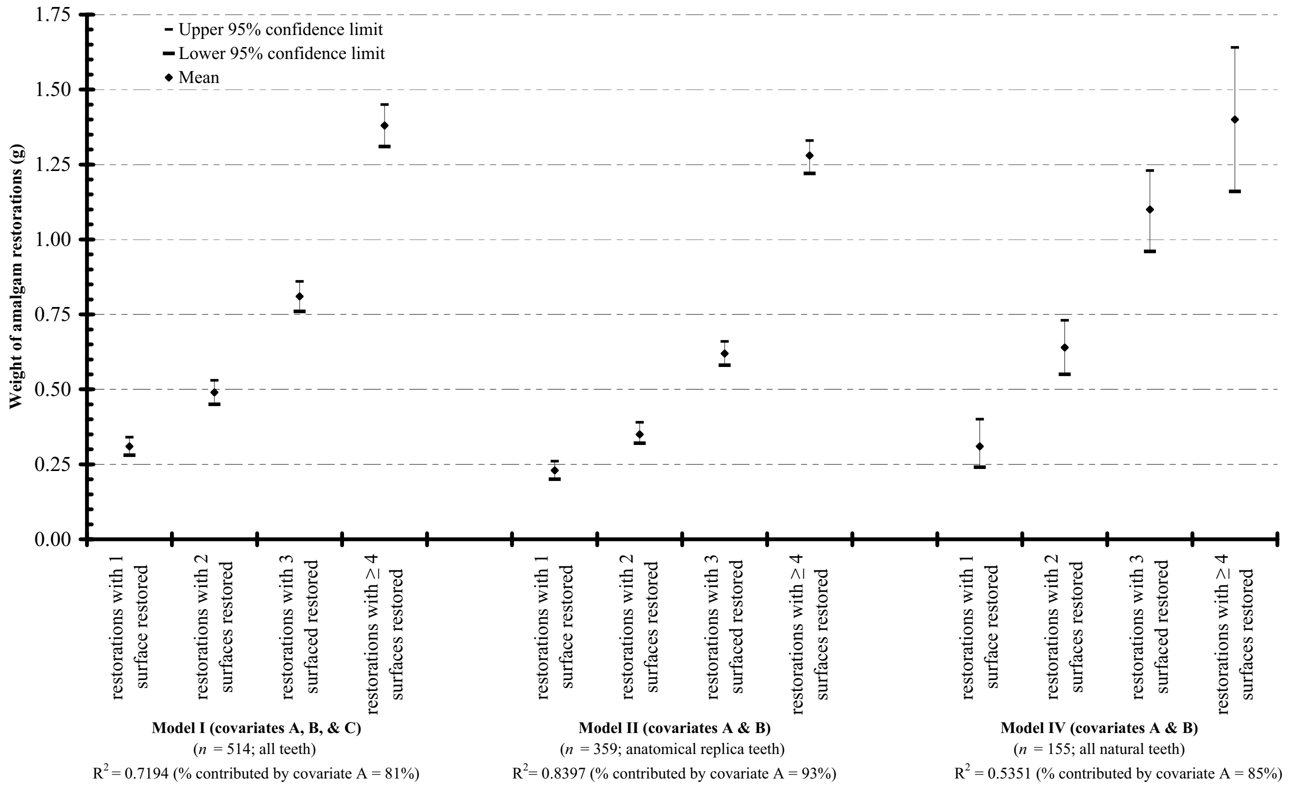

Figure 1: *Estimated mean weights of amalgam restorations (and 95% confidence intervals), according to number of restored surfaces.*

teeth, for which removal of caries often leads to more extensive restorations.

In the ordinary least squares (OLS) model, 3 of the 4 covariates tested (A, B and C) significantly influenced the weight of restorations. However, whether the restored natural tooth was extracted more recently or longer ago (covariate D) did not influence the weight of restorations.

A limitation of this study is that the restored teeth — anatomical replica and natural — were not selected randomly. In the case of anatomical replicas, a pool of all teeth restored by dental students is not available. Students prepare teeth to a standardized conservative form related to a theoretical disease. This form can vary among dental schools. Hence, limiting the selection of teeth to one dental school reduced the variability in the study sample. The precision of the estimates of weights of restorations from anatomical replicas may reflect students' conformity to the "gold standard" in the school, rather than true precision in the measurement of the population mean.

A relatively small number of restorations from natural teeth were used in this study, which might have limited the external validity of the estimates derived from natural teeth alone. The confidence intervals for the estimated weights of restorations from natural teeth were very wide (**Table 3** and **Fig. 1**). Another limitation is related to the use of restorations from a nonrandom pool of extracted teeth to the exclusion of newly placed and functioning restorations. A test of the hypothesis that the source population influences the weights of restorations (model III) showed that the 2 sets of natural teeth were not significantly different from one another. However, this does not eliminate the possibility that only large restorations recovered from extracted teeth were included. The possibility of a bias toward smaller restorations in anatomical replicas is the reverse of the potential bias toward larger restorations in natural teeth. The real differences in the predicted weights of amalgam restorations between models I and IV were in estimating the weights of restorations with 2 and 3 restored surfaces; for these restorations, the confidence intervals of the estimates derived from the 2 models did not overlap. This was an expected trend with natural teeth, given the more apical gingival margins often required for treating interproximal caries and the possibility that some of the restorations were extensions or enlargements of previously existing restorations due to secondary caries or other causes of amalgam failure. Therefore, by deriving estimates from all teeth, this study achieved a reliable basis from which to estimate the weights of amalgam restorations. It is believed that the estimates of weights derived from model I most accurately represent the weight of amalgam restorations in natural teeth.

Given the somewhat ordered variation in the surface area of teeth and the number of tooth surfaces,[28] these variables — type of tooth and number of surfaces — might have been treated as ordinal variables. However, to assure development of a model that would predict values within a clinically feasible range, these variables were deliberately treated as class variables, providing the least square mean weights of restorations.

The mean weights for the small and large restorations removed by Reinhardt and others,[26] were 0.53 g and 1.69 g, respectively. However, these authors used only 10 restorations in total.

In the present study the weight of a restoration with 1 restored surface was estimated to range from 0.28 to 0.34 g and that of a restoration with 4 or more restored surfaces from 1.31 to 1.45 g (model I, **Table 3**). Therefore, studies that estimate the flux of mercury in dentistry should account for the number of surfaces restored with amalgam rather than the type of tooth from which the dental amalgam is removed. In addition, upper and lower limits of the estimate should be provided.

Obenauf and Skavroneck[23] as well as O'Connor Associates Environmental Inc.[29] reported that the lack of reliable data on the weights of amalgams limited their ability to determine the flux of mercury associated with dental uses. This study provides data that should assist others to develop reliable estimates of mercury flux in dentistry. ◆

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