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DELAYED EXPANSION OF DENTAL AMALGAMS IN RELATION TO PREAMALGAMATION OF THE ALLOY

by

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INTRODUCTION

Most dental filling materials are very sensitive to moisture that enters during handling. This applies in a high degree to silver-tin amalgams. *Worner* (1941) found that amalgam contaminated by moisture during manipulation began to expand strongly several days later. *Skinner & Phillips* (1960) called this expansion delayed or secondary expansion. This expansion did not coincide in time with the setting of the amalgam that usually takes place during the first 8—12 hours after its condensation. Thus there was a period of time between these two processes during which the volume of the amalgam remained practically constant. The primary dimensional changes occurred during the first twenty-four hours and were connected with the setting reaction. Further dimensional changes were insignificant unless the amalgam was contaminated by moisture.

It has been established that the mechanical properties of amalgams deteriorate greatly when delayed expansion occurs as a result of moisture contamination. *Healey & Phillips* (1949) found that 16.6 per cent of 1521 defective dental fillings had deteriorated owing to secondary expansion. *Phillips* (1954) showed that the compressive strength of one amalgam decreased about 25 per cent on contamination with moisture.

In addition, the delayed expansion of amalgam fillings has often led to severe pain. This was pointed out first by *Rommes & Skinner* (1938), who concluded that the pain was due to a strong pressure exerted on the pulp by the expanding filling retained by undercutting. *Nachlin* (1954) has suggested that the pain caused by a contaminated amalgam filling ”is due to an electrical phenomenon in which the filling produces enough electrical energy to produce pain in the tooth”. He admits, however, that ”there are many questions raised by this observation which are unanswerable at the present time”.

Schoonover et al. (1942) showed that the delayed expansion resulting from moisture contamination was caused by the reaction of water with zinc. Following this observation, several investigations were concentrated mainly on this problem. *Liebig* (1942) found that the extent of the secondary expansion rapidly increased with the zinc content of the alloy in the range from 0.3 to 1.5 per cent. Amalgams containing less than 0.3 per cent zinc did not show delayed expansion. *Van Gunst & Hertog* (1957) observed that the delayed expansion increased with the zinc content when this varied from 0.01 to 0.06 per cent. *Kanatake & Takahashi* (1960) showed that excessive expansion occurred when the zinc content was more than 0.5 per cent, but was not proportional to the amount of zinc present in the original alloy. When zinc powder was mixed with a zinc-free alloy, the delayed expansion increased with increasing zinc content. They also observed secondary expansion when the alloys contained as scavenger silicon, manganese or nickel-magnesium instead of zinc.

The fact that no delayed expansion occurred with zinc-free amalgams led several manufacturers to produce such alloys. *Sweeney* (1941), *Schoonover et al.* (1942) and *Liebig* (1942) have, however, considered these alloys more difficult to handle. The opinion of *Jendersen & Ryge* (1961) and *Wilson & Ryge* (1963) was that the zinc-free alloys had poorer properties than alloys containing zinc. In contrast, *Skinner's* (1960) view was that modern zinc-free alloys were fully equivalent to zinc-containing alloys. Zinc added as a scavenger facilitated the manufacture of the alloy by preventing the formation of oxidation products.

Several other factors besides the zinc content of the alloy determine the delayed expansion of an amalgam. *Van Gunst & Hertog* (1957) found that at zinc contents exceeding 0.06 per cent, the secondary expansion varied inversely as the copper content of the alloy. *Kanatake & Takahashi* (1960), on the contrary, did not find any correlation between the copper content and the delayed expansion. They observed that the secondary expansion increased with diminishing particle size of the alloy and that the expansion was three times greater at + 37° C than at room temperature. According to *Ray* (1942) the delayed expansion was mainly determined by the composition of the alloy, trituration, condensing procedure and the environment of the specimen, whereas the annealing process and the particle size were of lesser importance. *Holst & Jørgensen* (1963) found that the delayed expansion decreased with increasing condensing pressure, was less marked with fine-grained than with coarse-grained alloys, and was almost independent of whether the specimen was stored in air at room temperature or at + 37° C. The delayed expansion was marked when the specimen was in a cavity, and also when the sample was stored in a one per cent sodium chloride solution.

The contaminating liquid employed in most investigations has been a one per cent sodium chloride solution. It has been found (*Skinner & Phillips,* 1960) that the nature of the aqueous solution is of no great importance since only water reacts with zinc. *Kanatake & Takahashi* (1960) were not able to detect excessive expansion when they contaminated amalgam with oil.

In most of these studies the liquid was added to the amalgam before condensation during either trituration or kneading. The results of the earlier investigations led the American Dental Association (1941, 1942, 1948 and 1960) and the Fédération Dentaire Internationale (1959) to draw definite conclusions. Detailed instructions were subsequently included in textbooks and manufacturers' pamphlets. For these reasons and as contamination by moisture can easily be avoided before amalgamation, the problem is no longer of any greater interest. On the other hand, contamination by saliva during the condensing procedure is more difficult to avoid. In a preliminary study, *Forsten* (1964) discussed the delayed expansion that was caused by moisture introduced after trituration. This expansion was, however, less marked than that referred to above. In the same study a definite difference was found between the secondary expansion that occurred in standard* and preamalgamated alloys. A further observation was

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*The author of the present paper terms amalgams which are prepared from mercury-free alloys standard amalgams. The preamalgamated amalgams are prepared from alloys which contains mercury (less than 3 per cent).

that the expansion was less marked and proceeded more slowly at room temperature than at + 37° C.

As apparent from the review of literature concerning the delayed expansion of amalgams, preamalgamated amalgams have not been studied in this respect, with the exception of the preliminary report mentioned above. The effect of the zinc content of the alloy has been investigated in most of the studies, but the results have been divergent. The influence of some other important factors on the delayed expansion has been discussed to a minor extent only. Such factors are, for example, the moment of contamination, the composition of the contaminating liquid and the storage environment of the amalgam.

The purpose of the present investigation was to carry out a more profound study of the behavior of amalgams generally used in the Scandinavian countries.

MATERIALS AND METHODS

1. Material

The material examined in the present investigation comprised seven different dental alloys which are in general use in Scandinavia. Five of the alloys were obtained in both preamalgamated and standard forms. In order to avoid the commercial exploitation of the results, the commercial names of the alloys will not be divulged and they will be designated by letters. The standard forms of alloys D, E, and F were not commercial products, but were ordered specially for this investigation. According to the manufacturer, the standard alloy D II was from the same ingot as the preamalgamated alloy. The same applies to the standard and preamalgamated alloys E II and F II.

The zinc contents of the alloys are given in Table I. The analyses were performed at the Valtion Teknillinen Tutkimuslaitos (The State Institute for Technical Research) in Helsinki, Finland.

As controls, four zinc-free alloys employed in Scandinavia were studied.

Table I

Percentages of zinc in the alloys

Alloy	
Standard	Zn
A	0.7
B	0.7
D	0.5
E II	<0.1
F II	0.4
H1	1.4
H2	0.8

Alloy	
Preamalg.	Zn
A	0.8
B	0.2
C	0.4
D	0.4
E II	<0.1
F II	0.3

2. Preparation of Specimens

The alloy and mercury were weighed with a Dentatus amalgam balance. The amalgam was triturated as recommended by the manufacturer in a mortar, model DAB, or in an electric amalgamator, Torit model, without the pestle in the capsule. The mixed amalgam was divided into 4—5 approximately equal portions. Free mercury was pressed out manually from each portion using a linen squeeze cloth immediately before the amalgam was condensed.

The amalgam was condensed at room temperature (+ 22° C ± 2° C) in a steel mold in which the cavity was 10 mm deep and had a diameter of 5 mm in accordance with the recommendations of the American Dental Association (1960) and Fédération Dentaire Internationale (1959) for the preparation of amalgam specimens for the measurement of dimensional changes. The mold was placed on a balance (Fig. 1) adjusted to 4 kg. The head of the condensing instrument was smoothfaced, circular and 2 mm in diameter. The amalgam was condensed using 10—15 condenser thrusts on each piece of amalgam. The mold was overfilled and the excess was trimmed even with the mold top. The specimen was removed from the mold immediately after the condensation and stored at + 37° C. The two plane surfaces of the

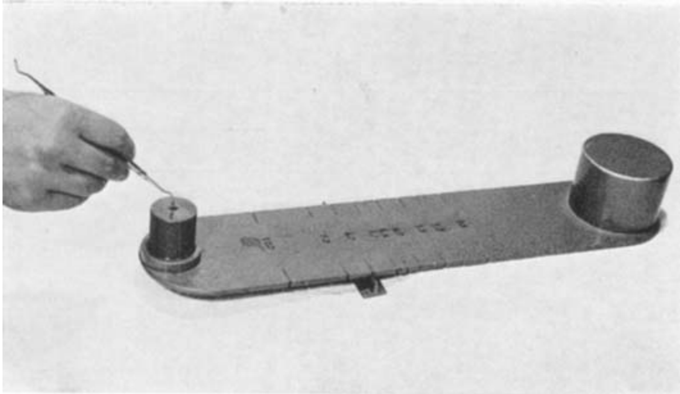


Fig. 1. The mold placed on a balance adjusted to 4 kg.

amalgam cylinder were polished after the amalgam had hardened for 24 hours.

Although the contamination of amalgam by moisture before trituration is exceptional nowadays in clinical work, also the effect of such contamination was investigated. The reason was that differences between the various alloys and techniques then became more clearly evident.

The contamination before amalgamation was effected by adding one drop (about 0.04 gm) of one per cent sodium chloride solution to the weighed alloy in the mortar or in the Torit capsule. This volume of the solution was sufficient to thoroughly wet the amalgam.

A number of experiments were also carried out in which distilled water or fresh saliva was added instead of the sodium chloride solution.

When the contamination was effected after trituration, each portion of amalgam was immersed, after free mercury had been pressed out, in a one per cent sodium chloride solution. The amalgam was not really kneaded in these cases. Each portion was only made plastic in the squeeze cloth using a minimum of kneading.

A number of specimens were contaminated during the kneading process. The triturated, standard amalgam B was kneaded with two drops of the one per cent sodium chloride solution in a rubber finger stall for 10 seconds. This method was not used further since the results exhibited considerable variation ($n = 6$, mean expansion during 12 weeks was 224 microns/cm and the standard deviation was 72 microns/cm).

In order to obtain information on how much the mercury contents of specimens prepared by one person vary, the amalgam and mercury that had been weighed on the amalgam balance were reweighed on an analytical balance (accuracy 0.005 gm). Also the mercury removed in connection with condensation was collected. As all of the amalgam was not used to prepare the specimen, the free mercury in the remaining amalgam was pressed out with pliers by hand. All of the recovered mercury was weighed and the weight was subtracted to find the mercury content of each specimen. The variations in mercury contents of some specimens are shown in Table II.

Table II

Percentage of mercury in some test specimens.
I = not contaminated specimens, II = specimens contaminated with one per cent sodium chloride solution before trituration

Alloy	Trituration	Mercury content		
Standard		Mean	Min.	Max.
A	by hand I	50.5	50.3	50.6
H2	by hand I	48.6	47.0	49.6
H2	in Torit I	48.2	47.6	48.6
H2	in Torit II	48.8	47.9	49.5
H zinc-free	in Torit I	50.1	49.7	51.1
H zinc-free	in Torit II	49.7	48.8	50.8
Preamalgamated				
A	by hand I	42.1	41.6	42.7
B zinc-free	by hand I	45.5	44.5	46.6
B zinc-free	by hand II	44.2	43.7	44.9
E	by hand I	41.3	41.0	41.7
E	by hand II	40.9	39.0	43.1
E	in Torit I	42.3	41.5	43.0

3. Measurement of Specimens

To determine when the delayed expansion began, two microcators (model S 510-5, C. E. Johansson, Sweden) with a scale divided in half microns were employed. The measuring load was between 1.0 and 1.6 grams. The instruments were located in an incubator at $+37° C \pm 1° C$ which rested on a stable foundation. The temperature was regulated by a contact thermometer and checked in the immediate vicinity of the specimens. Although the measurement of dimensional changes of amalgams should begin 15 minutes after the beginning of trituration according to the recommendations of the American Dental Association (1960) and the Fédération Dentaire Internationale (1959), the measurements of the present study were begun when 5 minutes had elapsed from the beginning of the mixing.

The progress of the delayed expansion was measured in one direction with a Microfix (Steinmeyer) screw micrometer accurate to 2 microns according to the manufacturer. Control measurements showed that also the amalgam specimens were measured with the same accurancy. The specimens were first measured one day after condensation, once a week during the first two months, after 12, 18, 26 and 52 weeks and after 18 months had elapsed from the date of the initial measurement. In a few cases the measurements were carried out more frequently and in a few cases less frequently. The specimens were allowed to cool to room temperature before the measurements. If the specimens were stored in a liquid, the liquid and any loose layers were wiped off with a cloth. In order to avoid the specimens from becoming warm during the measurements, they were not handled with the fingers.

RESULTS

1. The Primary and Secondary Dimensional Changes of Amalgams Contaminated by Moisture

The results in Table III and Figure 2 indicate that when the amalgam was moistened during the manipulation, its volume remained constant several days after the primary dimensional changes before the delayed expansion began. The values for the

Table III

The onset of delayed expansion of amalgams contaminated with sodium chloride solution

Dimensional changes (μ/cm) when contaminated before trituration							
Alloy	Controls after		Contaminated specimens after				
Standard	24 h	5 days	24 h	2 days	3 days	4 days	5 days
A	7.5	5.0	6.0	6.0	6.0	6.5	7.5
B	7.0	6.6	3.0	6.5	11.0	16.0	
D	11.4	12.8	12.5	12.7	13.1	13.6	14.0
E	8.2	7.6	19.0	19.0	19.5	20.0	
H1	6.0	5.6	9.5	11.0	14.0	17.5	
H2	1.3	0.2	9.0	14.0	21.0	29.0	
H zinc-free	0.7	0.0	1.1				0.9
Preamalgamated							
A	8.4	7.8	23.0	24.0	26.5		
B	18.2	17.7	35.0	36.0	37.0	38.5	
B zinc-free	7.8	7.0	—2.0				—2.0
C	10.3	10.1	42.0	44.0	45.5	46.5	
D	—0.2		—0.5	—0.5	—0.2	0.0	0.2
E*	15.5	15.0	38.6	39.4	40.4	41.6	42.8
F	4.7	3.7	7.2	7.2	7.1	7.1	7.4

Dimensional changes (μ/cm) when contamin. after trit. (controls above)							
Alloy	Contaminated specimens after						
Standard	24 h	2 days	3 days	4 days	5 days	6 days	7 days
A	6.0	5.5	5.5	6.0	6.5	7.2	
B	5.0	7.7	11.0	14.1	15.3		
D	17.0	17.1	17.2	17.4		17.9	
E	16.0	16.0	16.0	16.0		17.0	17.4
H1	8.8	10.6	14.0	17.0		28.5	36.7
H2	7.4	7.8	8.8	10.2	13.5	15.1	
Preamalgamated							
A	10.6	10.5	10.7	11.1		12.1	12.7
B	25.8	25.6	25.7	25.9		26.8	27.2
C	18.7	18.6	18.7		19.1	19.6	
D	2.7	2.3	1.8	1.6		1.7	
E	25.0	24.9	25.1		25.7	26.4	27.2
F	6.9	6.5	6.3	6.3	6.3	6.3	6.5

* Mean value from five tests

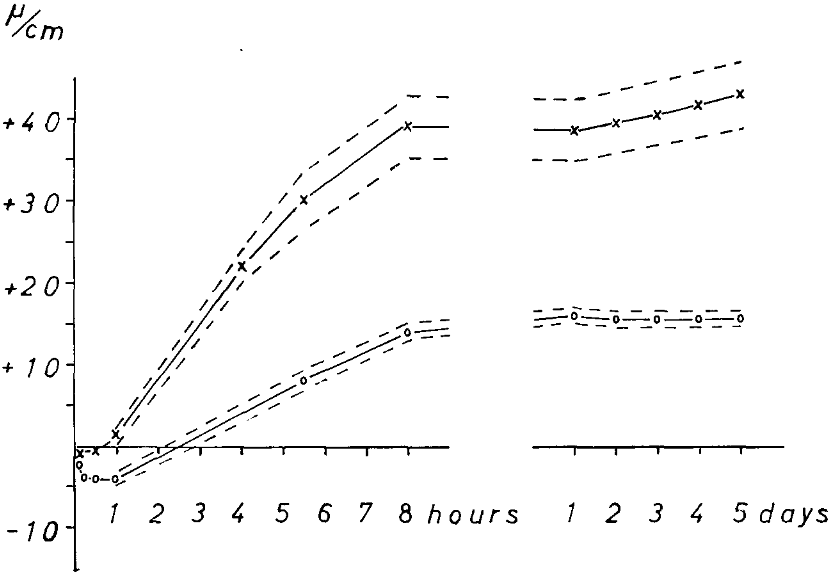


Fig. 2. Dimensional change of the preamalgamated amalgam E triturated *by hand*.

—x—x— = mean values when contaminated before trituration

—o—o— = mean values when the amalgam had not been contaminated

— — — = standard deviation

controls in Table III are means of values from two experiments which in each case differed less than two microns. The other values are based on only one experiment. The curves in Figure 2 represent means of five experiments.

The moisture caused not only the secondary expansion but also influenced the primary dimensional changes in certain cases. It will be seen from Table III that the total expansion after 24 hours was definitely greater for several of the preamalgamated amalgams if the amalgams had been contaminated. The curves in Figure 2 are typical and show clearly that the primary expansion was greater if the amalgam had been contaminated before amalgamation than if it had been handled dry. In contrast the preamalgamated zinc-free alloy B (Table III) underwent contraction when contaminated by moisture.

Figure 3 shows the later progress of the delayed expansion

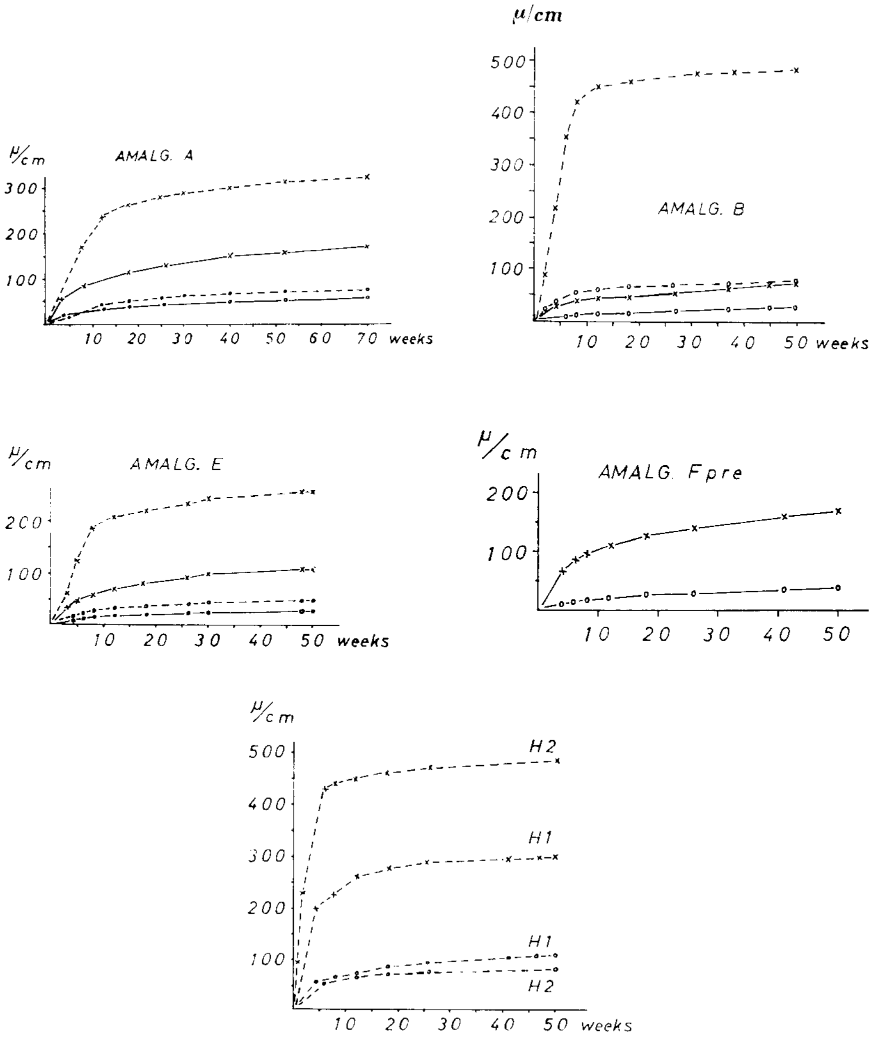


Fig. 3 Delayed expansion of dental amalgams contaminated with 1 per cent sodium chloride solution. Storage in air at 37°C. Amalgams D, E and F were triturated mechanically (Torit). Amalgams A, H1 and H2 were triturated by hand.

— — — = standard amalgams
——— = preamalgamated amalgams
—x—x— = mean values when contaminated *before* trituration
—o—o— = mean values when contaminated *after* trituration

as measured with the screw micrometer. The curves plot mean values from five experiments. The scatter of the results expressed as the standard deviation (S.D.) after 12 weeks is shown in Tables IV and V. The expansion curves for the standard forms of amalgams D and F and for the preamalgamated forms of amalgams C and D are not presented because the expansion was insignificant.

The delayed expansion took place in two stages. The contaminated amalgam first expanded rapidly during 4—12 weeks depending on the alloy and the method of contaminating the amalgam. This initial rapid expansion was followed by a slow and slightly decelerating expansion which was very limited after one year if the contamination had taken place before the trituration. An expansion was no longer detected with the micrometer screw if the contamination had occurred after the mixing of the amalgam. The division of the expansion curve into two parts was very marked if a strongly expanding amalgam was contaminated before amalgamation. The greatest differences between the various amalgams and contamination procedures became evident in the first stage of the delayed expansion. The slow second stage was closely similar for all amalgams.

2. The Effect of Various Factors on the Delayed Expansion of Amalgams

The values given in all the tables except Table III are means of values from five experiments; the scatter of the values is given as the standard deviation (S.D.). The data in Tables IV and V and in Figure 3 reveal the following. The standard alloys with the exception of alloys D and F gave amalgams that on contamination with moisture underwent secondary dimensional changes that were from 2 to 8 times as great as the excessive expansion of the preamalgamated amalgams. When contamination occurred after the amalgamation, the expansion was only from 15 to 30 per cent of the expansion that resulted when the amalgams were contaminated before the trituration. The scatter of the values was in general greater when contamination occurred after than before the trituration.

Mixing and contamination in the Torit amalgamator resulted

Table IV

Delayed expansion during 12 weeks of dental amalgams contaminated with sodium chloride solution before trituration. Storage in air at 37°C

Trituration by hand (mortar)					
Standard alloys			Preamalgamated alloys		
Alloy	Exp. μ/cm	S.D.	Alloy	Exp. μ/cm	S.D.
A	238	12	A	100	5
B	400	28	B	47	8
			C	35	5
			D	3	2
			E	55	15
			F	111	15
H1	264	16			
H2	447	38			
Mechanical trituration (Torit)					
Standard alloys			Preamalgamated alloys		
Alloy	Exp. μ/cm	S.D.	Alloy	Exp. μ/cm	S.D.
A	313	18	A	200	31
B	452	12	B	45	6
D II	114	5	D II	50	7
E II	204	12	E II	68	9
F II	19	2	F II	81	9
H2	477	11			

generally in a slightly greater delayed expansion and less divergent results than trituration by hand.

A comparison of the results and the zinc contents of the alloys (Table I) revealed no correlation between the zinc content and the magnitude of the excessive expansion.

Alloy H2, which was the most fine-grained of the studied standard alloys (Figure 4), gave an amalgam which underwent the greatest delayed expansion when the contamination took place before the mixing. Alloy H1, which was from the same

Table V

Delayed expansion during 12 weeks of amalgams contaminated with sodium chloride solution after trituration. Storage in air at 37°C

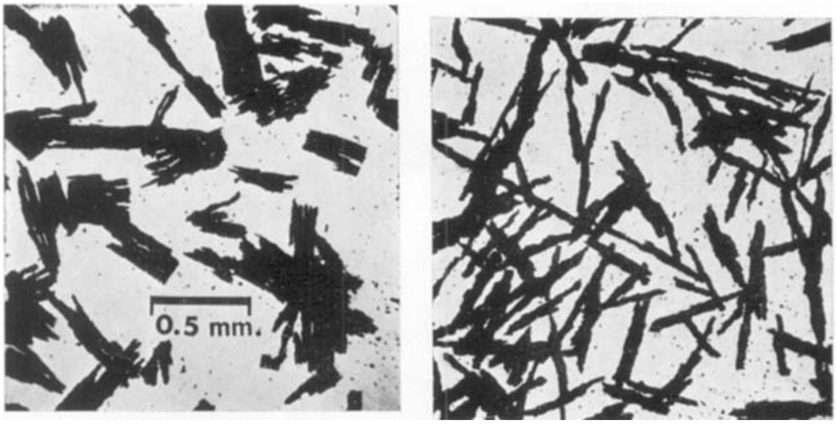
Standard alloys				Preamalgamated alloys			
Alloy		Exp. μ/cm	S.D.	Alloy		Exp. μ/cm	S.D.
A	M	41	8	A	M	33	10
B	M	75	23	B	M	12	4
B	T	61	16	B	T	13	3
				C	M	14	1
D	T	12	4	D	M	3	1
				E	M	17	3
E II	T	32	4	E II	T	18	6
				F	M	23	8
F II	T	13	2	F II	T	12	6
H1	M	74	18				
H2	M	66	31				
H2	T	62	25				

M = trituration by hand. T = mechanical trituration (Torit)

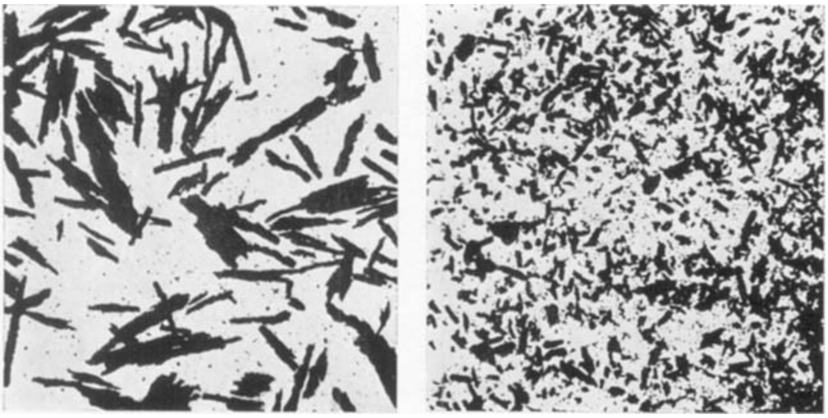
manufacturer, but coarse-grained, expanded only slightly more than half as much. The standard alloys A and B were also coarse-grained, and they expanded definitely less than alloy H2.

The results in Table VI were obtained when the amalgams were contaminated with various liquids. Water led to approximately the same expansion as the one per cent sodium chloride solution. A slightly smaller delayed expansion resulted when saliva was added to the amalgam. Only a few experiments of this type were carried out as the results were similar to those obtained earlier (*Skinner & Phillips*, 1960).

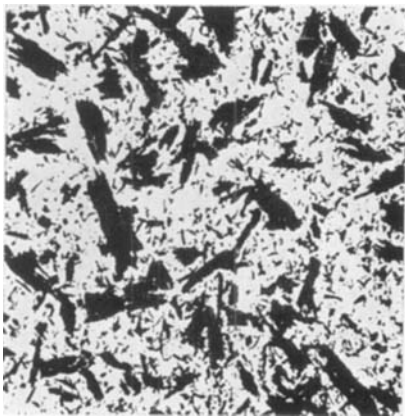
Measurements on the control specimens that were kept in air revealed an increase in length of a few microns during 12 weeks in a few cases, but in all except one case this increase was less than 10 microns; for this reason the results are not tabulated. Control specimens prepared from alloy H1 underwent an average increase in length of 15 microns (number of specimens was 10 and S.D. was 9 microns) during 12 weeks.



Alloy A Alloy B



Alloy H1 Alloy H2



Alloy E

Fig. 4. The grains of the standard alloys A, B, E, H1 and H2. The magnification is the same in all five pictures.

Table VI

Delayed expansion during 12 weeks of two standard amalgams contaminated with different solutions before trituration in Torit. Storage in air at 37°C

Contaminated with	Alloy	Exp. μ/cm	S.D.
1 per cent NaCl	B	452	12
solution	H2	477	11
Water	B	431	11
Saliva	B	399	17
	H2	393	17

3. The Effect of the Environment upon the Delayed Expansion

A series of amalgam specimens which were moistened before trituration were stored separately in air, distilled water and 0.3 and 0.9 per cent sodium chloride solutions at + 37° C. The magnitude of the expansion is shown in Table VII.

The delayed expansion of the specimens stored in water was the same as the expansion of the specimens stored in air.

The standard amalgam B stored in 0.3 per cent sodium chloride solution underwent a greater increase in length than the same amalgam stored in air. Also the control specimens increased slightly in length. The standard amalgam H2 and the preamalgamated amalgam E did not increase in length more on storage in 0.3 per cent sodium chloride solution than on storage in air.

On storage in the 0.9 per cent solution the standard amalgam H2 increased slightly more in length, while the contaminated preamalgamated amalgam E underwent a much larger increase in length and a radical change in colour. Its surface also was roughened by corrosion products. Control specimens of this amalgam triturated mechanically increased slightly in length, but the colour change was very slight and no surface roughness was visible. Control specimens triturated by hand increased more in length and showed marked corrosion.

Both the contaminated and uncontaminated specimens of the zinc-free amalgams B (preamalgamated) and H (standard) increased in length and underwent marked surface corrosion on storage in the 0.9 per cent sodium chloride solution. The me-

Table VII

Delayed expension during 12 weeks of dental amalgams contaminated with sodium chloride solution before trituration. Storage in different media at 37°C

			Controls		Contamin.spec.	
Storage medium	Alloy		Exp. μ/cm	S.D.	Exp. μ/cm	S.D.
Air	B	T	<10		457	12
	B zinc-free	T	<10		<10	
	E pre	T	<10		68	9
	H2	T	<10		477	11
	H zinc-free	T	<10		<10	
Water	B	T			463	27
	H2	T			468	7
0.3 per cent NaCl solut.	B	T	39	15	491	26
	E pre	T	9*	7	41	16
	H2	T	19	16	465	17
0.9 per cent NaCl solut.	B zinc-free	T	86	18		
	B zinc-free	M	13	8	27	12
	E pre	T	12*	14	120	49
	E pre	M	54	14		
	H2	T	30	17	503	25
	H zinc-free	T	57	20	35	18

* Mean value of 10 tests with varied trituration time
T = mechanical trituration, M = trituration by hand

chanically mixed control specimens of alloy B increased much more in length than the specimens mixed by hand.

The scatter of the values for specimens stored in the 0.9 per cent sodium chloride solution was fairly large.

DISCUSSION

With the exception of the preliminary study of *Forsten* (1964), none of the above-mentioned publications has dealt with the influence of liquids on preamalgamated alloys that have been generally employed in the Scandinavian countries. Neither has the contamination by moisture which occurs after trituration been discussed to any greater extent.

As the material examined in the preliminary study was limited and the experiments few in member, the aim of the present study was to continue the investigation to obtain more reliable evidence from a larger material that would reveal the differences in the delayed expansion of standard and preamalgamated amalgams. Another aim was to take into consideration the influence of the following factors on the secondary expansion; the moment of the contamination, zinc content of the alloy, the grain size of the alloy, the composition of the contaminating liquid and the storage environment of the amalgam.

The delayed expansion on storage of the specimens at room temperature was not studied in the present investigation because storage at + 37° C is closer to the clinical conditions.

The method which was used in the present study to determine the mercury content of the amalgam specimens was crude, but was considered accurate enough for the purpose of the investigation. A similar method has been described by *Jørgensen et al.* (1964), but this latter method was more accurate as the condensation was carried out in a standardized apparatus and all the weighed alloy was used to prepare the specimen.

The reason why the measurements of the primary dimensional changes were begun in the present study when 5 minutes had elapsed from the start of the mixing of the amalgam was that in this way the initial contraction could be more accurately defined. This has been pointed out by *Rantanen* (1961, 1963) and *Fusayama et al.* (1964). In *Wing's* (1964) opinion, however, the early measurement of initial contraction was not so much due to real dimensional change as to flow and compression of the amalgam specimen.

The influence of moisture contamination on the primary dimensional changes found in the present study has not been reported in earlier investigations. The mechanism of this phenomenon has not yet been clarified.

The most pronounced delayed expansion of amalgams was observed to take place during the first 2—3 months; the subsequent expansion was so slow that it can hardly be of any practical significance.

With two exceptions, the standard amalgams underwent a much more marked secondary expansion than the preamalgamated amalgams. No explanation can be proposed at this stage for the absence of excessive expansion in the case of the two standard amalgams, which, although they contained 0.4 and 0.5 per cent zinc, expanded so little that one can hardly speak of any delayed expansion caused by moisture contamination. These alloys are not commercially available but the results obtained with these alloys are of interest as they show that the influence of zinc has not been completely clarified. Although both forms of amalgam E containing only traces (0.1 per cent) of zinc exhibited marked secondary expansion, the standard forms of amalgam D containing 0.4 and amalgam F containing 0.5 per cent zinc failed to show any delayed expansion. It may be noted that also *Kanatake & Takahashi* (1960) reported a "nonexpanding" amalgam which contained 0.5 per cent zinc.

It may be noted further that it was not possible in the present study to find any correlation between the extent of secondary expansion and the zinc content. This is in agreement with the finding of *Kanatake & Takahashi* (1960). It should be kept in mind, however, that a zinc-free amalgam has never been found to expand excessively when contaminated with moisture.

The observation that the alloy of the smallest particle size studied in this investigation gave an amalgam that underwent the greatest delayed expansion is in agreement with the findings of *Kanatake & Takahashi* (1960), but not with those of *Holst & Jørgensen* (1963). The results were probably divergent because in Holst & Jørgensen's study the amalgam was contaminated during the mulling procedure and in Kanatakes & Takahashi's and the present study before the trituration. If the amalgam is contaminated before the mixing the greater reaction surface of a fine-grained alloy obviously has an influence on the delayed expansion.

Although uncontaminated specimens of one amalgam increased in length to some extent on storage in air, this can hardly be considered true delayed expansion. The specimens of this amalgam became darker than the specimens of the other amalgams, evidently because the surface layers of the specimens had reacted with atmospheric components and this led to the increase in length.

The experimental conditions in this investigation differed from the conditions in clinical practice in respect of the method of storage of the specimens. In clinical practice, the amalgam filling is for the most part enclosed in a tooth, which in turn is covered by an electrolyte solution (saliva). In addition to the galvanic activity, which may occur in a particular filling, potential differences between dissimilar metals may give rise to galvanic currents in the mouth which may influence the delayed expansion. Other factors such as biting stresses, abrasion and temperature variations may also exert an influence. It is difficult to reproduce these conditions in vitro.

When an attempt was made in this direction by storing the specimens individually in electrolyte solutions, the results were very difficult to interpret. When the specimens were stored in sodium chloride solution a marked discoloration was observed as a sign of surface corrosion which presumably resulted from a galvanic activity between the various metals in the amalgam. None of the three contaminated amalgams increased in length much more on storage in the 0.3 per cent sodium chloride solution than on storage in air. The greater increase in length noted on storage in the 0.9 per cent sodium chloride solution was probably due to the formation of corroded layers which were visually discernible. This is confirmed by the observation that also the zinc-free amalgams increased in length. When the corrosion became greater, the measurement of the specimens became less reliable. These observations show that the storage in electrolyte solution did not affect the delayed expansion, although it induced surface corrosion which was much greater in one of the contaminated amalgams (E pre) than in the uncontaminated amalgams. Further experiments are required to clarify this problem.

When the amalgams were contaminated, attention was paid mostly to the ensuing delayed expansion. If an amalgam becomes contaminated by moisture or other impurities during its manipulation, the result will be poor not only because of the excessive expansion, but also because the amalgam filling becomes inhomogeneous. Contamination by saliva during condensation leads to a porous filling with interfaces between successive condensation layers and may also cause leakage of the restoration. When a zinc-free alloy is employed, contamination does not cause excessive expansion, but owing to the above-mentioned factors the filling will not be satisfactory. Moreover, these alloys may give the dentist a false sense of security.

Further studies have been carried out in order to determine the influence of moisture contamination on the compressive and transverse strength of amalgams. These results will be presented in a later paper.

SUMMARY

The aim of the investigation was to study the delayed expansion of amalgam types after their contamination by moisture and the effect of various factors on this expansion. These amalgams are generally used in the Scandinavian countries.

Moisture contamination increased the primary setting expansion of certain amalgams. The delayed expansion began some days after the specimen was prepared, and the greatest dimensional changes occurred during the first months.

With two exceptions, standard amalgams underwent greater delayed expansion than the preamalgamated amalgams. Two standard amalgams expanded only slightly although they contained zinc.

The delayed expansion was definitely greater when the contamination occurred before than after trituration and somewhat greater when the trituration was carried out in a Torit amalgamator than when it was done by hand.

No correlation was found between the zinc content of the amalgams and the magnitude of the delayed expansion.

The alloy having the smallest particle size gave an amalgam with the greatest delayed expansion after it was contaminated before trituration.

The nature of the contaminating liquid had no significant influence on the extent of the delayed expansion.

Storage of the amalgam specimens in air, water and sodium chloride solutions gave results that indicated that the storage environment does not affect the delayed expansion.

RÉSUMÉ

RAPPORTS ENTRE L'EXPANSION SECONDAIRE DES AMALGAMES DENTAIRES ET LA PRÉAMALGAMATION DE L'ALLIAGE

Le but du présent travail a été d'étudier l'expansion secondaire de différents types d'amalgames après leur contamination par l'humidité, ainsi que l'action de divers facteurs sur cette expansion. Ces amalgames sont couramment utilisés dans les pays scandinaves.

La contamination par l'humidité augmentait l'expansion de prise primaire de certains amalgames. L'expansion secondaire commençait quelques jours après la préparation des échantillons, et les changements de dimension les plus importants se faisaient pendant les premiers mois.

A deux exceptions près, les amalgames ordinaires ont subi une expansion secondaire plus importante que les amalgames préamalgamés. Deux des amalgames ordinaires n'ont subi qu'une légère expansion, bien que contenant du zinc.

L'expansion secondaire était nettement plus grande lorsque la contamination se produisait avant la trituration que si elle se produisait après la trituration, et un peu plus grande lorsque la trituration était faite dans un vibreur automatique Torit que si la trituration était faite à la main.

Aucune corrélation n'a été trouvée entre la teneur en zinc de l'amalgame et l'importance de l'expansion secondaire.

L'alliage dont les particules avaient les dimensions les plus fines donnait l'amalgame ayant l'expansion secondaire la plus importante lorsque la contamination avait lieu avant la trituration.

La nature du liquide par lequel l'amalgame était contaminé n'avait pas d'influence significative sur l'importance de l'expansion secondaire.

La conservation des échantillons d'amalgame dans l'air, dans l'eau et dans des solutions de chlorure de sodium a donné des résultats indiquant que le milieu dans lequel se fait la conservation n'a pas d'influence sur l'expansion secondaire.

ZUSAMMENFASSUNG

DIE SEKUNDÄRE EXPANSION DER AMALGAME IM VERHÄLTNIS ZUR PREAMALGAMIERUNG DES ALLOYPULVERS

Die Absicht dieser Arbeit war es, die sekundäre Expansion der verschiedenen in Skandinavien benutzten Amalgame bei Flüssigkeitskontamination (Flüssigkeitseinmischung) zu untersuchen. Ausserdem wurde die Einwirkung gewisser Faktoren auf die Expansion untersucht. Die Ergebnisse ergaben folgendes:

Die Flüssigkeitskontamination vergrösserte die primäre Erhärtungsexpansion einiger Amalgame.

Die Nachexpansion begann einige Tage nach der Herstellung des Probekörpers, und die grösste Volumenveränderung trat während der ersten Monate auf.

Die nicht praeamalgamierten Amalgame zeigten mit zwei Ausnahmen eine grössere sekundäre Expansion als die praeamalgamierten. Zwei nicht praeamalgamierte Amalgame expandierten nur gering trotz des Zinkinhaltes. Die Nachexpansion war erheblich grösser bei der Kontamination vor als nach dem Anrühren, und etwas grösser beim Anrühren im Torit Amalgamator als beim Anrühren im Mörser.

Eine Korrelation zwischen dem Zinkgehalt und der Grösse der sekundären Expansion wurde nicht festgestellt.

Das feinkörnigste Alloypulver ergab Amalgam mit der grössten Nachexpansion.

Die Beschaffenheit der Kontaminationsflüssigkeit hatte keine nennenswerte Einwirkung auf die Expansion.

Bei der Verwahrung der Probekörper in Luft, Wasser oder Natriumchloridlösung konnte eine Einwirkung der Verwahrungsumgebung auf die Nachexpansion nicht festgestellt werden.

REFERENCES

American Dental Association, 1960—1961: Specifications for Dental Materials. Fourth ed. Chicago.

American Dental Association Council on Dental Research, 1948: Effects of contaminating of amalgam with moisture. J. Amer. dent. Ass. *37*: 239.

American Dental Association Research Commission, 1941: Palming amalgam. J. Amer. dent. Ass. *28:* 830.

—»— 1942: Excessive expansion of amalgam. J. Amer. dent. Ass. *29:* 292.

Fédération Dentaire Internationale, 1959: Specification for alloy for dental amalgam. Int. dent. J. *9:* 421—423.

Forsten, L., 1964: Sekundär expansion av dentala amalgam vid vätskekontamination. Odont. Tidskr. *72:* 94—100.

Fusayama, T. & al., 1964: Early and transversal measurement of amalgam expansion. J. dent. Res. *43:* 194—205.

Van Gunst, Ir. C. A. & H. J. P. M. Hertog, 1957: On the relation between delayed expansion of amalgam and the composition of amalgam alloys. Brit. dent. J. *88:* 428—430.

Holst, K. & K. D. Jørgensen, 1963: Kondenseringstrykkets og andre faktorers indflydelse på forsinket ekspansion i sølvamalgam. Tandlægebladet *67:* 493—502.

—»— 1964: The influence of condensing pressure and other factors on delayed expansion of silver amalgam. Acta Odont. Scand. *22:* 311—321.

Jendersen, M. D. & G. Ryge, 1961: Effects of particle thickness of zinc and nonzinc alloys. D. Prog. *1:* 24.

Jørgensen, K. D. & al., 1964 a: Sølvamalgams kviksølvindhold i afhaengighed af kondenseringens begynnelse efter udrøringen. Tandlægebladet *68:* 3—8.

—»— 1964 b: Mercury content of silver amalgam. Acta Odont. Scand. *22:* 207—214.

Kanatake, T. & S. Takahashi, 1960: Some factors affecting the delayed expansion of amalgam. J. Japan Soc. dent. Apparat. & Materials *1:* 28—33.

Liebig, E. O., 1942: Excessive expansion of dental amalgam and its relationship to the zinc contents of the alloy. (Abstract.) J. dent. Res. *21:* 307.

Nachlin, J. J., 1954: A type of pain associated with restoration of teeth with amalgam. J. Amer. dent. Ass. *48:* 284—293.

Phillips, R. W. & al., 1954: Effect of moisture contamination on compressive strength of amalgam. J. Amer. dent. Ass. *49:* 436—438.

Rantanen, A. V., 1961: On the initial contraction of dental amalgams. Odont. Revy *12:* 166—173.

—»— 1963: Amalgaamitäytteiden supistumiseen johtavista tekijöistä. Suom. hammaslääk. toim. *59:* 459—468.

Ray, K. W., 1942: Long continued expansion of amalgams. (Abstract). J. dent. Res. *21:* 307.

Rommes, A. F. & E. W. Skinner, 1938: A report of a study concerning postoperative pain following restoration with amalgam. Northwest. Univ. Bul. *38:* 19—22.

Schoonover, I. C. & al., 1942: Excessive expansion of dental amalgam. J. Amer. dent. Ass. *29:* 1825—1832.

Skinner, E. W. & R. W. Phillips, 1960: The Science of Dental Materials, Fifth ed, W. B. Saunders Company, Philadelphia & London.

Sweeney, J. T., 1941: Delayed expansion in nonzinc alloys. J. Amer. dent. Ass. *28:* 2018—2019.

Wilson, C. J. & G. Ryge, 1963: Clinical study of dental amalgam fillings. J. Amer. dent. Ass., *66:* 763—771.

Wing, G., 1964: The measurement of dimensional change of dental amalgam Austral. dent. J. *9:* 426—430.

Worner, H. K., 1941: Excessive expansions in dental amalgams. Austr. J. Dent. *45:* 161—163.

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