The effect of temperature changes on adaptation of resin fillings. I

ERIK ASMUSSEN

Department of Technology, Royal Dental College, Copenhagen, Denmark

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Thermal percolation has been considered a cause of a number of the flaws occurring in connection with resin fillings. However, in fillings expanded against the cavity walls by water absorption, elastic stresses counteract the formation of marginal gaps. The purpose of the present work was 1) to study the relationship between temperature reduction and size of marginal gaps and 2) to investigate the effect of a rise in temperature on the gaps formed under subsequent cooling. Fillings made in extracted human teeth were studied. The brands investigated were Adaptic, Blendànt, Concise, Opotow, Sevriton Simplified, and Swedon. After closure of the initial gaps by water absorption expansion the fillings were polished and examined microscopically under water. Marginal gaps between filling and tooth were measured between 37 and 2°C. The effect of a rise in temperature was investigated by heating the fillings to 50 or 60°C, with subsequent measurement of gap size at 2°C. It was found that the fillings could be cooled through a certain temperature range without marginal gaps being formed. The size of the gaps at 2°C was but little affected by previous heating to 50°C. Heating to 60°C increased the gap size at 2°C only in unfilled resins.

Key-words: Dental restoration, permanent; resins; composite filling materials; dental materials

Erik Asmussen, Department of Technology, Royal Dental College, Jagtvej 160, DK-2100 Copenhagen Ø, Denmark

The coefficient of thermal expansion is approximately $90 \cdot 10^{-6}$ cm per cm per °C for non-composite resin materials and $30—50 \cdot 10^{-6}$ cm per cm per °C for composite resin materials (*Dennison & Craig*, 1972). Tooth structure has a coefficient of thermal expansion of approximately $10 \cdot 10^{-6}$ cm per cm per °C (*Souder & Paffenbarger*, 1942). The difference in expansion between resin and tooth means that a change in temperature of a resin filling will cause a flow of liquid in gaps present between filling and tooth, i.e. »thermal percolation» occurs. The percolation involves risks of marginal discoloration and of damage both to the hard tissues and the pulp.

Thermal percolation was demonstrated for the first time on fillings in extracted teeth by *Nelsen, Wolcott & Paffenbarger* (1952) and has later been the subject of numerous laboratory investigations. The intensity of the percolation has been studied, e.g. by means of dyes and radio-

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Table I. *List of brands used in the investigation*

No.	Name	Batch No.	Manufacturer
A	Adaptic®	11 H 035	Johnson & Johnson, New Jersey, USA
B	Blendànt®	1212 2341 3	Kerr Mfg. Co., Michigan, USA
C	Concise®	2160 F	3M Company, Minnesota, USA
D	Opotow®	72 04 20	Opotow Dental Mfg., New York, USA
E	Sevriton Simplified®	powder: LJ4 liquid: ML1 adhesive: LC9	De Trey Frères, S.A., Zürich, Switzerland
F	Swedon®	powder: 925 liquid: 105 reactor: 101	Svedia Dental Industri, Enköping, Sweden

active tracers the penetration of which between filling and tooth could be recorded. *Guzman et al.* (1969) examined a composite and a non-composite resin material and found that changes in temperature between 15 and 45°C did not cause percolation. This finding confirmed the results of *Petersen et al.* (1966). At somewhat larger changes in temperature thermal percolation was observed (*Lee & Swartz*, 1970; *Petersen et al.*, 1966; *Tani & Buonocore*, 1969), but it was characteristic that the results did not reflect the differences in coefficient of thermal expansion between the examined composite and non-composite resins. These findings were difficult to explain because the effect of the water absorption of the resin materials on the percolation had not been taken into account. In resin fillings expanded against the cavity walls by water absorption elastic stresses counteract the formation of marginal gaps during cooling. Thermal percolation thus depends not only on the thermal properties of the filling material and on the magnitude and duration of the temperatures to which the filling is exposed, but also on the degree of elastic compression against the cavity walls.

The purpose of the present work was 1) to investigate the relationship between temperature reduction and the size of marginal gaps and 2) to study the effect of an initial rise in temperature on the formation of gaps during subsequent cooling on resin fillings that were more or less expanded against the cavity walls by water absorption.

MATERIALS AND METHODS

The brands listed in Table I were used in the investigation. The first four are composite, the last two are non-composite resin filling materials. The brands are characterized by the fact they close the initial polymerization contraction gaps sooner or later by water absorption expansion (*Asmussen & Jørgensen*, 1972). In the enamel region of the cavity the gap is closed after 12 hours of water absorption for brand E and after 8 days of water absorption for the brands A, B, C, D, and F.

A microscopic inspection was made of the enamel margins of resin fillings with the initial contraction gaps closed by water absorption. The fillings were made

in extracted human teeth and stored in water at 37°C for a varying number of days before they were polished. Details in connection with the preparation and polishing of the fillings have been described previously (*Asmussen & Jørgensen*, 1972). The duration of the storage in water of the filled teeth before polishing was 1, 8 or 64 days for brand E, and 8 or 64 days for brands A, B, C, D, and F.

Five fillings of each brand were examined if the polishing took place after 1 or 8 days, ten if the fillings were polished after 64 days. Immediately after the polishing the marginal area of the filling was inspected under microscope, and it was in all cases confirmed that the gap between filling and tooth was closed. The inspection was made in a thermostat room at 37 ± 1°C and lasted approximately 2 minutes. A Reichert MeF Universal Camera Microscope with dry objective was used at a nominal magnification of 12.5 × 63 times. The fillings were thereafter placed under water in a heat insulated container and removed from the thermostat room. The fillings were now successively placed in water at 23 ± 1°C, 15 ± 1°C, 10 ± 1°C and 2 ± 1°C. At each temperature possible gaps appearing between filling and tooth were measured, and the maximum gap width was found and expressed in per cent of the cavity diameter as previously described (*Asmussen & Jørgensen*, 1972). The fillings were kept for about 2 minutes at each temperature before the measuring was commenced.

The filled teeth were thereafter placed in water at 50 ± 1°C for 2 minutes and later again in water at 60 ± 1°C for 2 minutes. After each heating the marginal gaps were measured under water at 2°C.

Each measuring of the gap around a filling lasted approximately 10 minutes; in this period of time no change in the width of the gap was observed. The last gap measuring of each individual filling took place about 90 minutes after its removal from the thermostat room.

The gaps were measured by means of a Leitz Panphot microscope fitted with water immersion objective and measuring ocular. The nominal magnification of objective and ocular was 90 times and 12.5 times respectively. Gaps as narrow as 0.4 μm could be measured.

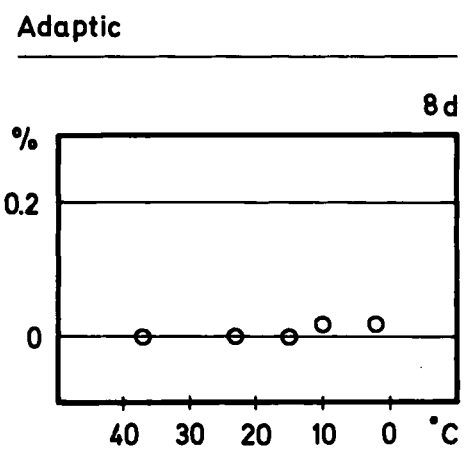


Fig. 1

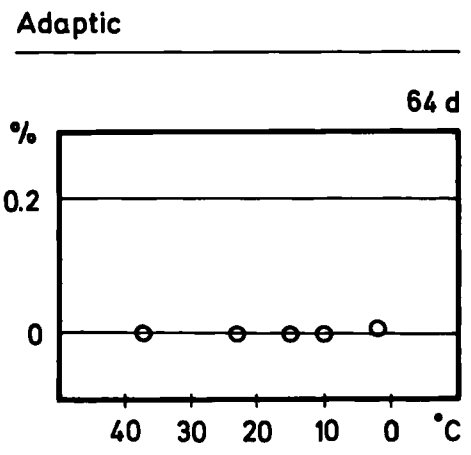
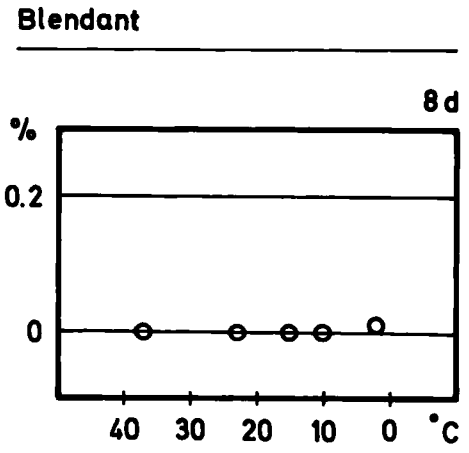


Fig. 2



Fig, 3

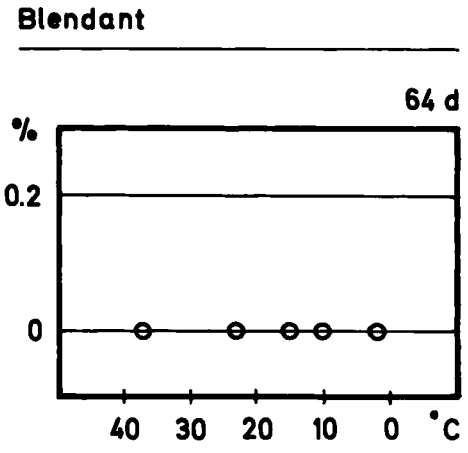


Fig. 4

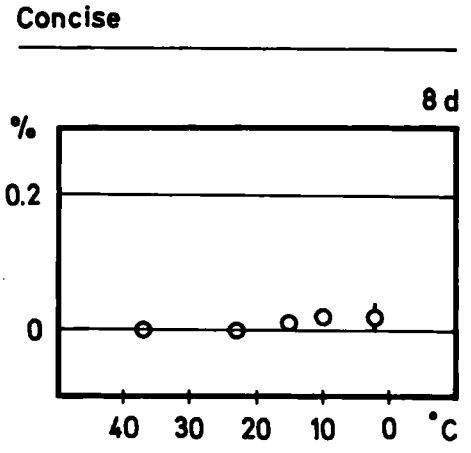


Fig. 5

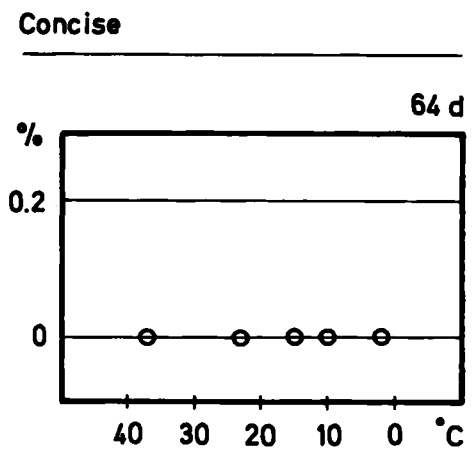


Fig. 6

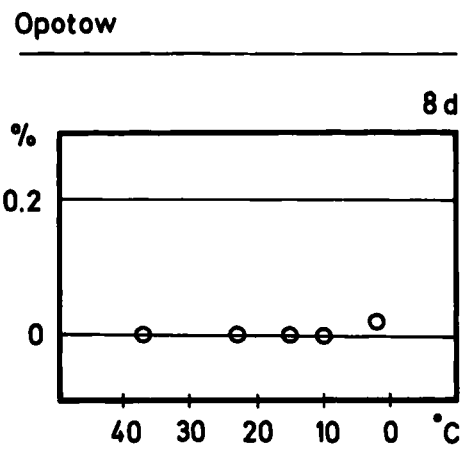


Fig. 7

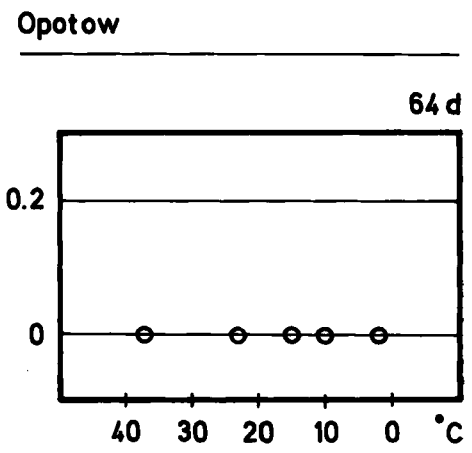


Fig. 8

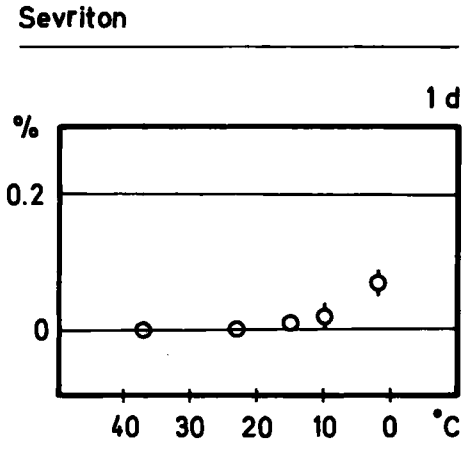


Fig. 9

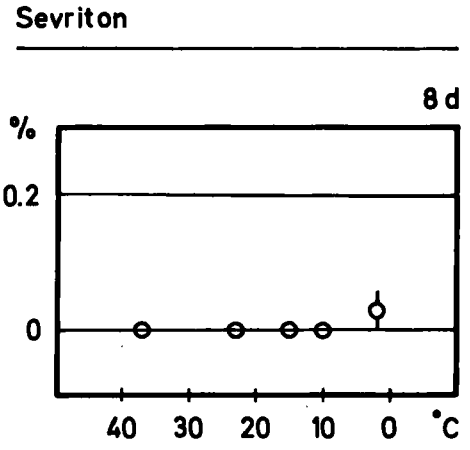


Fig. 10

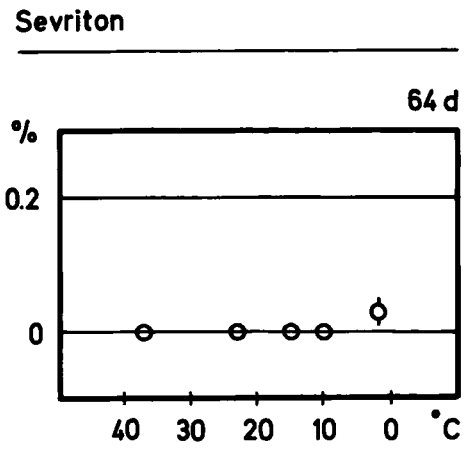


Fig. 11

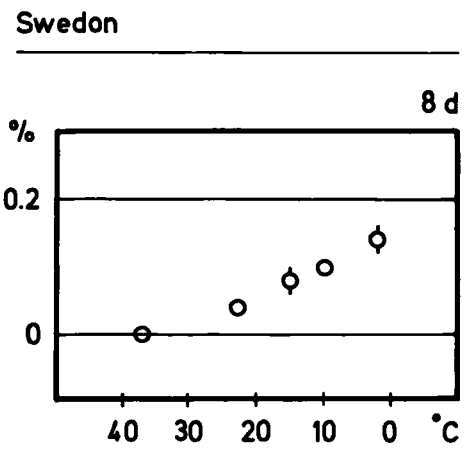


Fig. 12

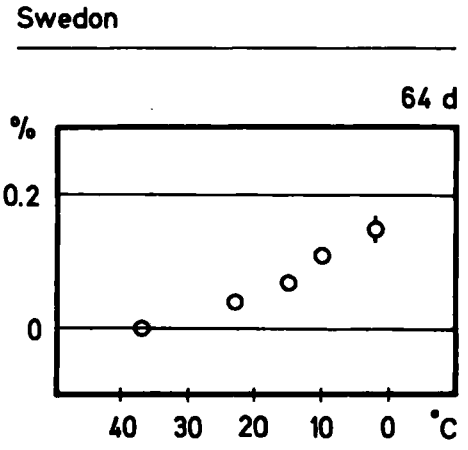


Fig. 13

Figs. 1—13. Gap width in relation to temperature. Brand, and number of days during which the fillings were stored in water at 37°C are stated at the top of each diagram.

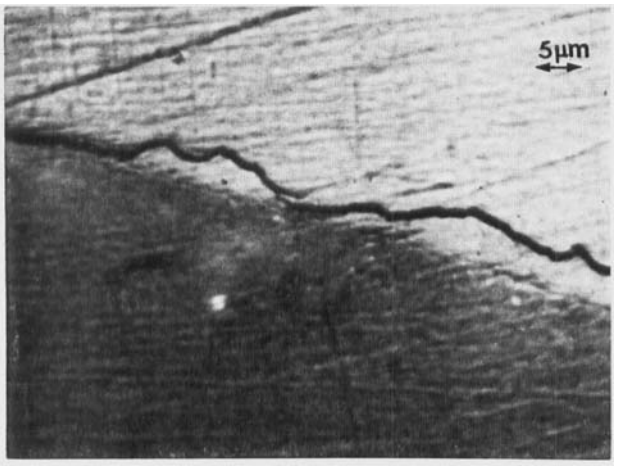


Fig. 14. Filling of brand E with marginal gap. The gap was formed by cooling of the filling from 37 to 2°C. The enamel is seen in the upper part, the filling in the lower part of the picture (×1560).

RESULTS

The results of the investigation are presented in Figs. 1—13 and Figs. 16—21. Figs. 1—13 show the relationship between temperature and mean value of the observed gap widths. The standard deviation is given in the cases where it exceeds 0.01 %. The age in days of the fillings is stated above the diagrams. It is seen that the filled teeth could be cooled through a certain temperature range without marginal gaps being formed, the temperature range depending on the age of the fillings. After 64 days of water absorption fillings made of brands A, B, C, D, and E could be cooled from 37 to 10°C without gaps being formed. With brand F gaps were already present when the filled teeth were cooled to 23°C.

The described heat treatment of fillings and teeth had a tendency to increase the width of the gaps formed during the subsequent cooling. This phenomenon is illustrated in Figs. 14 and 15. Fig. 14 shows a gap at the margin of a filling of brand E formed after cooling from 37 to 2°C. Fig. 15 shows the same place of the same filling which after heat treatment at 60°C

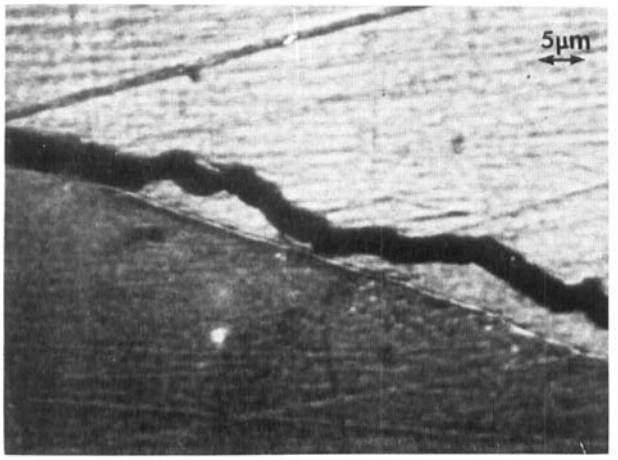


Fig. 15. Marginal gap at the same filling as shown in Fig. 14. After heating to 60°C the filling was again cooled to 2°C. The enamel is seen in the upper part, the filling in the lower part of the picture (×1560).

has again been cooled to 2° C. The gap width has now increased from about 1 μm to about 3 μm. In Figs. 16—21 the ordinate gives the width of the gaps measured at 2°C in per cent of the cavity diameter. Circle 1 shows the gap width at 2°C after cooling from 37°C, circle 2 shows the gap width after the preceeding heating to 50°C, and circle 3 shows the gap width at 2°C after heating to 60°C. The standard deviation is given in the cases where it exceeds 0.01 %. It appears that heating to 50°C had but little effect on the gap sizes. Heating to 60°C likewise had very small effect on the gaps with fillings made from brands A, B, C and D; but the effect on the gaps with fillings of brands E and F was considerably greater.

The gaps were located along the fillings' margins except with fillings of brand E. With this material the gaps were often found in the enamel as seen in Figs. 14 and 15. The average distance of the gap from the filling margin was about 3 μm.

DISCUSSION

The foregoing has demonstrated that resin fillings made from the examined brands can be cooled through a certain temperature range without marginal gaps being formed. As already indicated this is no doubt due to the fact that the fillings are elastically compressed against the cavity walls because of expansion caused by water absorption. A certain degree of cooling is necessary to eliminate the elastic stresses, and gaps appear only upon further cooling. The adaptation and consequently the thermal percolation are thus dependent not only on the coefficients of thermal expansion but also on the state of stress of the fillings. The state of stress is in its turn determined by the relation between the size of the initial contraction gap and the degree of water absorption.

The examined composite resins showed only small differences as regards formation of gaps during cooling because of the fact that the initial contraction gap (*Asmussen & Jørgensen*, 1972), the coefficient of thermal expansion (*Dennison & Craig*, 1972), and the water absorption of the materials (unpublished results) are of about the same magnitude. The considerable differences in formation of gaps during cooling between the two non-composite resins must be due to the fact that the two materials are pressed to a different degree against the cavity walls. The coefficients of thermal expansion are of nearly the same magnitude, but brand E has a somewhat larger water absorption (unpublished results), and with fillings of this brand the initial contraction gap is smaller (*Asmussen & Jørgensen*, 1972). This may explain why these fillings were pressed more strongly against the cavity walls and therefore could be cooled more before marginal gaps were formed.

It is seen that Figs. 10 and 11 are almost identical. The same applies to Figs. 12 and 13. This is due to the fact that fillings of brands E and F are near water saturation after 8 days of water absorption and hence maximum pressed against the cavity walls. By comparing Figs. 1 and 2, Figs. 3 and 4, Figs. 5 and 6, Figs. 7 and 8, and Figs. 9 and 10, it is seen that the more water a filling of a given brand has absorbed, the smaller are the gaps formed by cooling. The reason is that the compressing of the filling against the cavity walls increases with the water absorption.

In Figs. 12 and 13 the slope α of the straight line through the points can be calculated by means of the method of

Adaptic

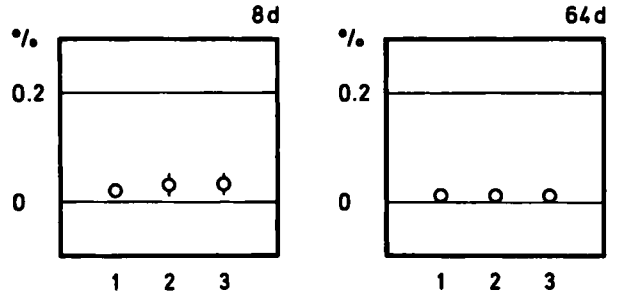


Fig. 16

Blendant

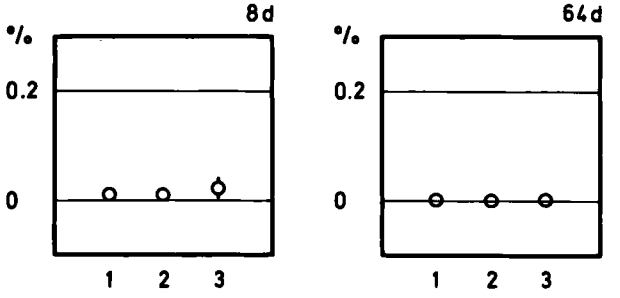


Fig. 17

Concise

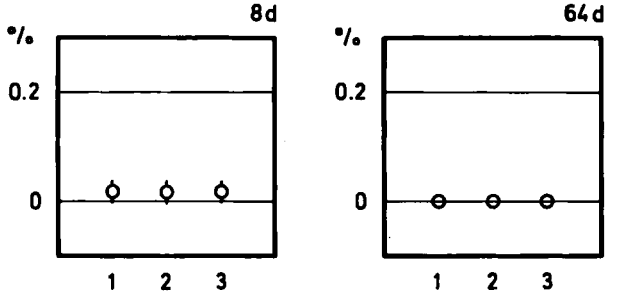


Fig. 18

Opotow

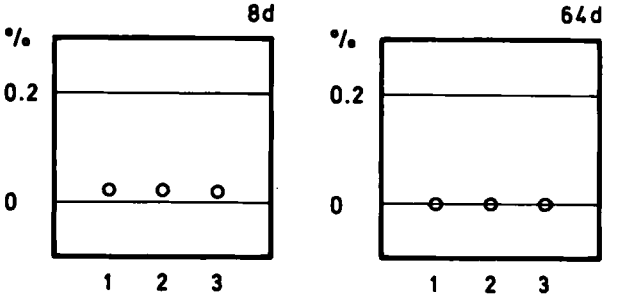


Fig. 19

Sevriton

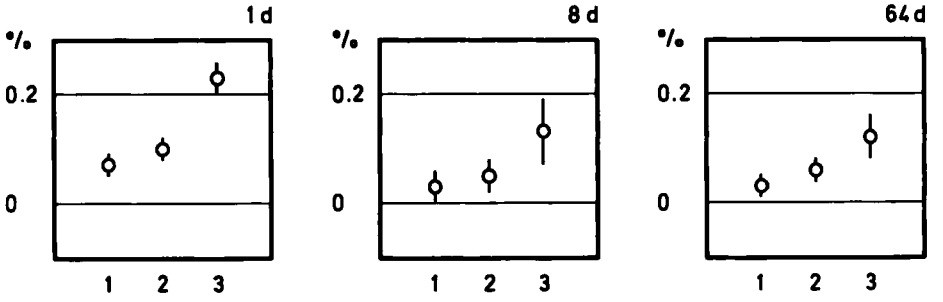


Fig. 20

Swedon

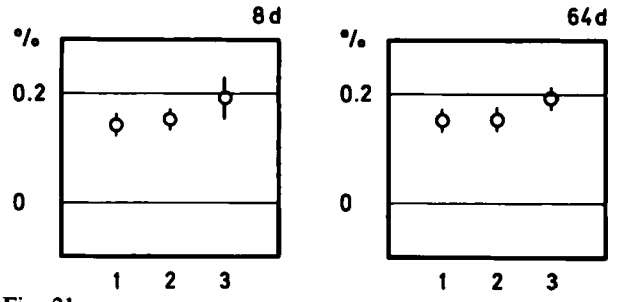


Fig. 21

Figs. 16—21. Gap width in per cent of cavity diameter. Circle 1 shows the gap width at 2°C after cooling from 37°C. Circle 2 shows the gap width at 2°C after heating for 2 minutes at 50°C. Circle 3 shows the gap width at 2°C after heating for 2 minutes at 60°C. Brand. and number of days during which the fillings were stored in water at 37°C are stated at the top of each diagram.

least squares. In Fig. 12 $\alpha = (47 \pm 12) \cdot 10^{-4}$ % per °C, and in Fig. 13 $\alpha = (50 \pm 8) \cdot 10^{-4}$ % per °C. These figures deviate significantly from the difference in coefficient of expansion between resin and tooth which in this case is approximately $80 \cdot 10^{-4}$ % per °C. Assuming that the fillings are near complete water saturation this deviation may be explained in one of the following two ways: 1) By cooling a gap appears between filling and tooth. Hereafter an expansion due to elastic recovery may take place in the filling material during the hour that elapses from the removal of the filling from the thermostat room until the gap is measured at 2°C. The recovery will tend to reduce the width of the gaps, and consequently the calculated slope will be smaller than the difference in coefficient of expansion between resin and tooth. 2) The contraction of the fillings in the enamel area may be restrained e.g. by friction against the cavity floor.

In order to examine the first possibility, a number of fillings were quickly cooled from 37 to 2°C at which temperature the gap immediately was measured. A possible elastic recovery can then take place only for a short time whereby its effect on the gap sizes at 2°C would be reduced. But no difference in gap sizes at 2°C was found between fillings quickly and slowly cooled. To examine the other possibility, a number of filled teeth were polished in a plane perpendicular to the surface of the fillings until approximately one third of the filling had been removed. It was then possible in a microscope to observe the adaptation of the filling to the cavity floor, and in 11 cases out of 16 the examined section showed contact between filling and cavity floor. On the basis of this observation, it seems fair to assume that the contraction of the fillings during cooling is restrained by friction against the cavity floor, and that this, at least partly, is the cause of the low value of the slope in Figs. 12 and 13.

In order to investigate the effect of the recommended adhesive on the location of the gaps formed by cooling of fillings of brand E, a number of fillings were made with this material without the use of the adhesive. Inspection of the gaps at 2°C then showed that they in all cases were located along the filling margin. Therefore, it is likely that when the adhesive is used, the resin is bonded (chemically or mechanically) so well to the enamel that this will fracture when the resin contracts during the cooling.

As mentioned it was found that heating of a resin filling had a tendency to cause an increase in the size of the gaps formed during a subsequent cooling. The explanation is probably that a permanent deformation of the filling takes place when it is compressed against the cavity walls during the heating. At the subsequent cooling the elastic stresses in the filling at a given temperature below 37°C will have been reduced and will, therefore, less effectively counteract the formation of gaps. Heating affected the composite fillings less than the non-composite fillings because 1) the smaller coefficient of thermal expansion of the composite resins results in less compression against the cavity walls during heating, and 2) the examined composite resins have higher elastic limits (*Dennison & Craig*, 1972).

The present experiments support and explain previous observations on thermal percolation of resin fillings. As mentioned in the introduction, temperature changes between 15 and 45°C gave no marginal penetration of isotope when fillings of brand E and a composite resin were investigated (*Guzman et al.*, 1969). The

cause must be that the elastic stresses in the fillings are not eliminated in this temperature range. At somewhat larger variations in temperature percolation occurred, but no relationship between the percolation and the coefficient of thermal expansion of brand E and a number of composite resins was found (*Lee & Swartz*, 1970; *Peterson et al.*, 1966; *Tani & Buonocore*, 1969). In these studies the duration of the heating and cooling periods was 10, 30 and 60 seconds, respectively. When the duration of the change in temperature is short, the thermal diffusivity of the filling materials may have an influence on percolation. *Peterson et al.* found that the temperature of the cavity floor beneath the restorations reached that of the surroundings within 15 seconds. Thus, the lack of correlation between percolation and coefficient of thermal expansion may to some degree be accounted for by differences in thermal diffusivity of the filling materials. It is, however, most probably also due to the fact that the size of gaps formed by a certain degree of cooling is dependent on the internal state of stress of the fillings as well as on the thermal properties of the filling materials. By variations in temperature between 2 and 68°C of 5 minutes' duration *Going & Sawinski* (1966) found a greater percolation intensity with fillings of brand E than with fillings of a composite resin. This result is no doubt explainable by the greater tendency of the non-composite resin to become plastically deformed when the fillings are compressed against the cavity walls during the heating process.

To evaluate the results, estimates have to be made of the temperatures that resin fillings will be exposed to in vivo. 15 and 50°C are probable limits to these temperatures. After 64 days of water absorption heating to 50°C of fillings of brand A, B, C and D did not influence the marginal gaps at 2°C. It can therefore be assumed that the gaps are closed at the same temperature as before the heating, viz. at 10°C for brand A and at 2°C for brand B, C and D. Heating to 50°C of fillings of brand E increased the gap widths at 2°C to 0.06 ± 0.02 %. From this value and from a determination of the change α in gap width per °C it can be calculated at which temperature the gaps begin to open. α was determined by measuring the gap width at two different temperatures. Details in connection with this procedure is described in part II of this paper (to be published). $\alpha = (56 \pm 12) \cdot 10^{-4}$ % per °C was found. The temperature where the gaps begin to open then becomes 13 ± 4°C. Heating to 50°C of fillings of brand F did not influence the marginal gaps at 2°C. As above it can be assumed that the gaps at a given temperature are of the same size before and after the heating. At 23°C the width of the gaps was 0.04 ± 0.01 %. $\alpha = (50 \pm 8) \cdot 10^{-4}$ % per °C was found above. The temperature where the gaps begin to open then becomes 31 ± 2°C.

Consequently, it is probable that the adaptations of brands A, B, C, D and possibly E is not impaired by temperature fluctuation under oral conditions and that thermally conditioned percolation with these brands may not be of clinical importance. However, it must be born in mind that the heating periods used in this study deviate from those to which resin fillings are exposed in vivo. In the mouth the length of heating and cooling periods is normally much shorter, but on the other hand they are repeated many times. The effect of repeated, short heating on the formation of gaps during cooling will be discussed in a following article.

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