

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

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In earlier laboratory investigations of thermal percolation at resinous fillings the duration of the heating periods was too long to be realistic. The aim of the present work was to investigate the effect of repeated heatings of realistic duration on the formation of marginal gaps between filling and tooth during a subsequent cooling below the minimum value in the temperature cycling process. Fillings made in extracted human teeth were studied. The brands investigated were Adaptic, Blendant, Concise, Opotow, Sevriton Simplified, and Swedon. After closure of the initial gaps by water absorption expansion the fillings were polished and subjected to thermal cycling. The specimens were cycled between either 37° and 50° C or 37° and 60° C, the duration of each immersion in the warmer bath was 2 or 5 seconds, and the number of cycles was 1, 10, 100 or 1000. The effect of the cycling was investigated by measuring the width of marginal gaps appearing at a temperature lower than 37° C. It was found that the width of the gaps was only little affected by thermal cycling between 37° and 50° C. Cycling between 37° and 60° C increased the gap widths only with Opotow, Sevriton Simplified, and Swedon. The data indicate that thermal percolation for a number of brands may be of no clinical importance.

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

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Resin fillings expand as a consequence of water absorption. In fillings expanded against the cavity walls elastic strain counteract the formation of marginal gaps during cooling. A certain degree of cooling is necessary to eliminate the elastic strain, and gaps appear only upon further cooling. On the other hand, a rise in temperature may cause a plastic deformation of the fillings and thereby a reduction of the elastic strain after returning to the initial temperature. This means that gap formation is less effectively counteracted during a subsequent cooling (Asmussen, 1973),

and that the risk of thermal percolation has increased. In the paper mentioned the effect of an initial rise in temperature on the gap formation during cooling was investigated by heating the filled teeth for two minutes to 50° or 60° C. In other investigations where the influence of temperature changes on the adaptation of resin fillings was studied (by measuring percolation intensity) the temperature to which the filled teeth were heated varied between 45° and 68° C, and the duration of the heating periods was 10 seconds (Lee & Swartz, 1970), 30 seconds (Guz-

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man, *et al.*, 1969), 1 minute (Tani & Buonocore, 1969) and 5 minutes (Going & Sawinski, 1966). But even a heating of 10 seconds' duration to e.g. 50° C is probably longer than the heating periods to which resin fillings are exposed in vivo.

The purpose of the present work was to investigate the effect of repeated heatings of realistic durations on the formation of marginal gaps during subsequent cooling on resin fillings that were 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 that they close the polymerization contraction gaps in the enamel region of the cavity by at most 8 days of water absorption expansion at 37° C. (Asmussen & Jørgensen, 1972).

A microscopic inspection was made of the enamel margins of 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 64 days before they were polished. Unpublished data suggest that the fillings were close to maximum compression against the cavity walls after 64 days of water absorption. Details in connection with the preparation and polishing of the fillings have been described previously (Asmussen & Jørgensen, 1972).

For each brand 6 fillings served as a control and were not thermally cycled. The fillings in the experimental groups were subjected to thermal cycling by transferring the specimens between two water baths, one maintained at $37 \pm 1^\circ\text{C}$, the other at $50 \pm 1^\circ\text{C}$ or at $60 \pm 1^\circ\text{C}$. The immersion time in the warmer bath was 2 or 5 seconds. The number of cycles was 1, 10, 100 or 1000. For each combination of 1) temperature of the warmer bath, 2) immersion time, and 3) number of thermal cycles, 6 fillings were investigated.

The filled teeth were cycled between two water baths by means of a device designed

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	Blendant®	032410 543	Kerr Manufacturing Company, Michigan, USA
C	Concise®	2160 F	3M Company, Minnesota, USA
D	Opotow®	720420	Opotow Dental MFG., New York, USA
E	Sevriton Simplified®	Powder: LJ3 Liquid: ML1 Adhesive: MH1	De Trey Frères, S.A., Zürich, Switzerland
F	Swedon®	Powder: 101 Liquid: 201 Reactor: 101	Svedia Dental Industri, Enköping, Sweden

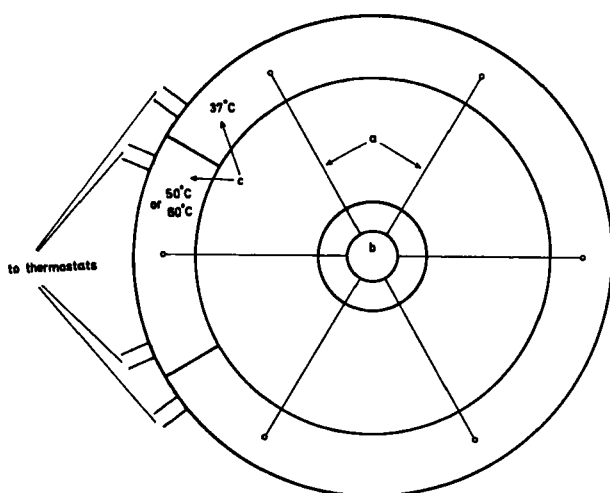


Fig. 1. Schematic presentation of device used for temperature cycling of the filled teeth (a.m. K. D. Jørgensen) a — rotating arms, b — synchronized, geared electro-motor, c — temperature baths.

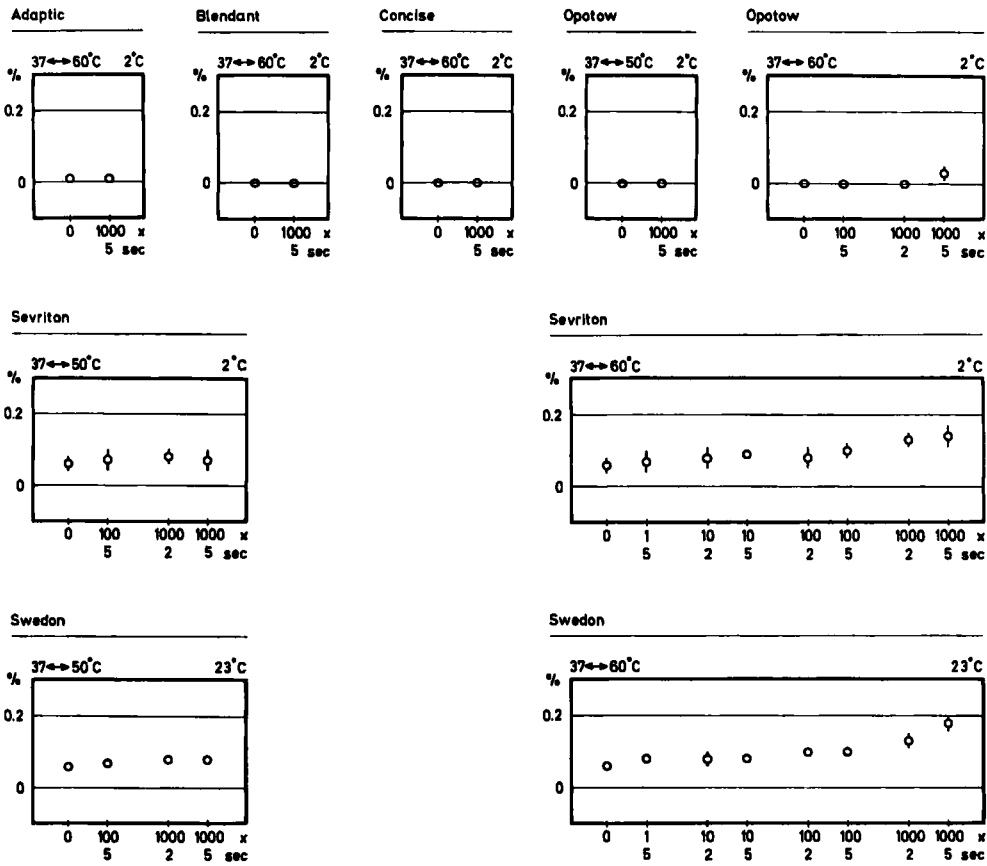
by K. D. Jørgensen, shown on Fig. 1. The teeth were suspended in sewing thread from the rotating arms (a) driven by the synchronized, geared motor (b) and were transferred from one bath to the other via two ramps. The two baths (c) were held at the desired temperatures by two thermostats, and the water levels of the baths were held constant. The length of the warmer bath was $1/6$ of the periphery of the device. By means of two gears the speed of the rotating arms could be set at 2 or 5 rpm, which made the immersion time in the warmer bath 5 or 2 seconds, respectively.

After the selected number of cycles the teeth were placed in a water bath at a temperature lower than 37°C . A measuring of gaps appearing between filling and tooth was commenced about two minutes later. A microscope fitted with a water immersion objective was used, and the maximum gap width was found and expressed in percent of the cavity diameter as described previously (Asmussen & Jørgensen, 1972). The gaps were measured at a bath temperature of $2 \pm 1^{\circ}\text{C}$ (brands A, B, C, D and E) or $23 \pm 1^{\circ}\text{C}$ (brand F).

After the gap measurement on the restored teeth in the control groups these teeth were subjected to a number of additional experiments: The fillings of brand A, B, C and D were placed in water at $60 \pm 1^{\circ}\text{C}$ continuously for 83 minutes ($\approx 1000 \cdot 5$ seconds) and the fillings of brand E and F for 2 minutes, whereupon the gaps were measured anew. For brand E and F the gaps were re-measured after storage of the specimens in water at $37 \pm 1^{\circ}\text{C}$ for 1 and 7 days.

RESULTS

The results of the investigation are presented in Figs. 2—16. The ordinate values show the mean of the measured gap widths in percent of the cavity diameter. The standard deviation is depicted in the cases where it exceeds 0.01 %. The temperature of the two water baths is stated in the upper left corner of the diagrams and the temperature at which the gap measurement took place, in the upper right corner. In Figs. 2—10 the abscissa gives the number of cycles and the duration of each immersion in the



Figs. 2—10. Gap width in percent of cavity diameter (ordinate) in relation to number of thermal cycles and immersion time in the warmer bath. The temperatures of the water baths are stated at the upper left corner and the temperature at which the gap measurement took place, at the upper right corner of the diagrams.

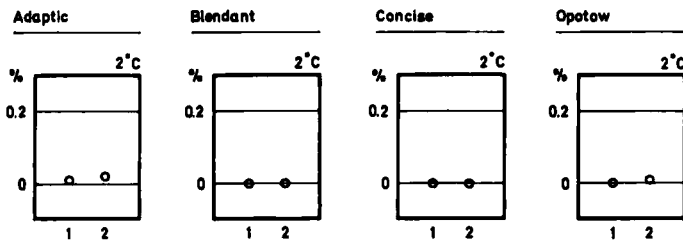
warmer bath. The gap widths of the control groups are given at the value zero on the abscissa.

With brand A, B and C (Figs. 2, 3 & 4) the marginal gaps were not influenced by temperature cycling between 37° and 60°C. With brand D temperature cycling between 37° and 50°C had no effect, whereas 1000 cycles between 37° and 60°C with a 5 seconds' immersion time did have a statistically significant effect ($p < 0.01$) on the marginal gaps (Figs. 5 & 6).

With the non-composite resins E and F

thermal cycling between 37° and 50°C (Figs. 7 & 9) had little effect. The effect was statistically significant ($p < 0.01$) only in the case of brand F. A constant gap width of 0.07 % and 0.08 %, respectively, seems to occur. On the other hand, cycling between 37° and 60°C influenced the gap widths markedly (Figs. 8 & 10). The widths of the gaps increased with the number of cycles.

Figs. 11—16 show how the gaps in the control groups were affected by the described heatings. Circle 1 shows the gap width after cooling from 37°C to $2 \pm 1^\circ\text{C}$;



Figs. 11—14. Gap width at 2° C in percent of cavity diameter. Circle 1 shows the gap width after cooling from 37° C. Circle 2 shows the gap width after heating for 83 minutes at 60° C.

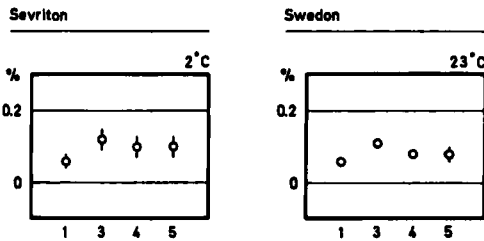


Fig. 15. Gap width at 2° C in percent of cavity diameter. Circle 1 shows the gap width after cooling from 37° C. Circle 3 shows the gap width after heating for 2 minutes at 60° C. Circles 4 and 5 show the gap width after heating at 60° C and subsequent storing in water at 37° C for 1 and 7 days, respectively.

Fig. 16. Gap width at 23° C in percent of cavity diameter. Circle 1 shows the gap width after cooling from 37° C. Circle 3 shows the gap width after heating for 2 minutes at 60° C. Circles 4 and 5 show the gap width after heating at 60° C and subsequent storing in water at 37° C for 1 and 7 days, respectively.

circle 2 (Figs. 11—14) the gap width after preceding heating to 60°C for 83 minutes; circle 3 (Figs. 15 & 16) the gap width after preceding heating to 60°C for 2 minutes; and circle 4 and 5 the width of the same gaps after storage of the fillings in water at 37°C for 1 and 7 days, respectively. With brand A, B, C and D the heating influenced the marginal gaps to a degree that was not statistically significant on the $p = 0.01$ level. With brand D the difference in gap width after heating for 83 minutes at 60°C (circle 2, Fig. 14), and after 1000 cycles between 37° and 60°C with a 5 seconds' immersion time (Fig. 6) was not statistically significant. With brand E and F the gaps were significantly increased ($p < 0.01$) by the heating.

After the storage in water for 1 day the gap widths were reduced, but they did not return to their size before the heating. Storage in water for a total of 7 days resulted in no further change in the gap widths.

DISCUSSION

The foregoing has demonstrated that repeated, short heating has a tendency to cause an increase in the size of the gaps formed during a subsequent cooling. The explanation is probably, as outlined in the introduction, that a permanent deformation of the filling takes place when it is pressed against the cavity walls during the heating. At the subsequent cooling the elastic strain in the filling at a given temperature below 37°C has been reduced and will, therefore, less effectively counteract the formation of marginal gaps.

Thermal cycling between 37° and 60°C as well as the longlasting heating to 60°C did not influence the marginal gaps at fillings of brands A, B and C.

This can be explained by the low coefficient of thermal expansion and the high limit of elasticity of these brands (Dennison & Craig, 1972). The gaps at fillings of brand D were affected by cycling between 37° and 60°C. The

coefficient of thermal expansion for this brand is of about the same magnitude as for brands A, B and C (unpublished data), but the limit of elasticity may well be lower, making this brand more susceptible to plastic deformation during heating. The possible low limit of elasticity can be explained by a less complete polymerization due to the unique mixing procedure: The catalyst is contained in the mixing pad and may be incorporated into the resin to an amount insufficient to produce a high degree of polymerization.

Thermal cycling had a more pronounced influence on the marginal gaps at fillings of the non-composite resins E and F, because the higher coefficient of thermal expansion and lower limit of elasticity lead to more plastic deformation during the heating.

Heating to 50°C had less effect on the gaps than heating to 60°C because 1) the fillings are less compressed against the cavity walls the less the rise in temperature and 2) the limit of elasticity is higher at 50° than at 60°C.

Figs. 15 and 16 suggest that at least part of the deformation that the fillings underwent during the heating was due to creep. The difference between circle 3 and circle 4 is (part of) the primary creep or elastic recovery, and the difference between circles 4 and 1 is the secondary creep or permanent deformation.

To evaluate the results clinically, the temperatures that resin fillings are exposed to in vivo have to be known. Reliable measurements have not been carried out, but on the basis of a number of observations of *Peterson et al.* (1966) it seems fair to assume that 15° and 50°C are the limits to these temperatures.

Taking 50°C as the upper limit it may be concluded that thermal cycling between

37° and 50°C of fillings of brands A, B and C has no influence on the marginal gaps formed during a subsequent cooling, since the gaps were not affected by cycling between 37° and 60°C. It follows that the gaps must be closed at the same temperatures as before the cycling, viz. at 10°C for brand A (*Asmussen*, 1973) and at 2°C for brands B and C. Cycling between 37° and 50°C followed by cooling to 2°C did not produce marginal gaps at fillings of brand D. With brands E and F temperature changes between 37° and 50°C increased the size of the gaps formed during subsequent cooling to 2° and 23°C, respectively. From the width of these gaps and by means of the coefficients of thermal expansion of the fillings the temperature where the gaps begin to open, can be calculated. However, *Asmussen* (1973) found that the dimensional change of fillings of brand F was smaller than expected from the value of the coefficient of thermal expansion taken from literature, possibly because of friction of the fillings against the cavity floor; microscopic observations showed that fillings of brand F frequently were in contact with the cavity floor. Similar observations on a number of fillings of brand E showed contact in all cases, indicating that the dimensional changes of these fillings may be restrained too. The change a in gap width per °C could be obtained for brands E and F by measuring the same marginal gap at both 2° and 23°C. In order to produce a gap at 23°C with brand E, the fillings were heated in water at 60°C for a number of minutes immediately prior to the measurements. For each brand marginal gaps were measured in 12 specimens. At 6 of the fillings the gaps were measured first at 2°C, then at 23°C; on the remaining 6 fillings the gaps were measured with the temperatures reversed. For both brands

no difference was found between the calculated α values of the two groups, so that the effect of a possible elastic recovery could be excluded. It was found that $\alpha = (56 \pm 13) \cdot 10^{-4} \% \text{ per } ^\circ\text{C}$ for brand E and $\alpha = (48 \pm 12) \cdot 10^{-4} \% \text{ per } ^\circ\text{C}$ for brand F. The latter value for α is in good agreement with the results previously obtained (Asmussen, 1973). Taking the gap widths after preceding thermal cycling between 37° and 50°C to be $0.07 \pm 0.03 \%$ at 2°C for brand E and $0.08 \pm 0.01 \%$ at 23°C for brand F and using the α values from above, the temperature at which the gaps begin to open when cooled from a higher temperature was calculated to be $15 \pm 6^\circ\text{C}$ for brand E and $40 \pm 6^\circ\text{C}$ for brand F.

To summarize, after preceding thermal cycling between 37° and 50°C marginal gaps at water saturated fillings of brands A, B, C and D will not be formed when the restored teeth are cooled to 15°C. With brand E the gaps appear at an average temperature of 15°C, and with brand F the gaps will be present at an average temperature of 40°C.

It must be born in mind that the above calculations are strictly valid only with the type of cavity used in this study. The dimensional changes of fillings subjected

to variations in temperature are no doubt to some degree dependant upon cavity size and shape and upon the use of a cavity base or liner. Thus, the calculated temperatures where the gaps begin to open should be considered only as approximations to the in vivo temperatures.

REFERENCES

- Asmussen, E. & Jørgensen, K. D. 1972. A microscopic investigation of the adaptation of some plastic filling materials to dental cavity walls. *Acta Odont. Scand.* 30, 3—21
- Asmussen, E. 1973. Temperaturændringers indflydelse på adapteringen af plastfyldninger. I. *Tandlægebladet* 77, 1072—1082
- Dennison, J. B. & Craig, R. G. 1972. Physical properties and finished surface texture of composite restorative resins. *J. Amer. Dent. Ass.* 85, 101—108
- Going, R. E. & Sawinski, V. J. 1966. Microleakage of a new restorative material. *J. Amer. Dent. Ass.* 73, 107—115
- Guzman, H. J., Swartz, M. L. & Phillips, R. W. 1969. Marginal leakage of dental restorations subjected to thermal stress. *J. Prosth. Dent.* 21, 166—175
- Lee, H. L. & Swartz, M. L. 1970. Scanning electron microscope study of composite restorative materials. *J. Dent. Res.* 49, 149—158
- Peterson, E. A. II, Phillips, R. W. & Swartz, M. L. 1966. A comparison of the physical properties of four restorative resins. *J. Amer. Dent. Ass.* 73, 1324—1336
- Tani, Y. & Buonocore, M. G. 1969. Marginal leakage and penetration of basic fuchsin dye in anterior restorative materials. *J. Amer. Dent. Ass.* 78, 542—548