Marginal adaptation of restorative resins in acid etched cavities

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The purpose of the present work was to investigate the wall-to-wall polymerization contraction of restorative resins placed in acid etched cavities and to study the effect of water absorption and temperature changes on the formation of marginal gaps on such fillings. Fillings made in extracted human teeth were examined microscopically. Before filling the cavities including 1.5–2 mm peripheral enamel were etched with 35% H_3PO_4. When polished and examined immediately after setting, fillings of a number of brands showed no marginal gaps. Gaps due to continued polymerization were formed around some of these fillings after 1 day's storage in water at 37°C. These gaps did not close as a consequence of hygroscopic expansion of the fillings. Around fillings of the brands where no gaps were present immediately after setting, gaps were formed by cooling from 37 to 23°C. One day's storage in water at 37°C before polishing generally reduced the frequency of marginal gaps both directly and after cooling. Heating of the fillings increased the risk of gaps being formed by a subsequent cooling.

Key-words: Dental restoration; in vitro dental materials

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The acid etching technique has proved to be an effective means of increasing the bonding between restorative resins and etched enamel. The technique has primarily been used in connection with fractured incisors; but also acid etching of cavities has been investigated. *Buonocore, Sheykholeslam & Glena* (1973) and *Baharloo & Moore* (1974) studied the effect of acid etching on the marginal seal of composite fillings. *Buonocore et al.* (1973) found 1) that application of a low-viscous, non-composite resin as an intermediate layer between filling material and etched enamel, and 2) that extension of resin and filling material over etched, peripheral enamel in a «featheredge» was necessary to prevent marginal penetration of a dye. The observed effect of the low-viscous resin is difficult to understand because it has been demonstrated that composite resins adapt themselves to etched enamel surfaces equally well as do low-viscous resins (*Jørgensen & Shimokobe*, 1975). Furthermore, it has been shown that the retention of composite resins increases only insignificantly, if at all, with the use of an intermediate layer of low-viscous resin

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(Mitchem & Turner, 1974). *Baharloo & Moore* (1974) studied fillings that had been subjected to thermal cycling between 4 and 60°C. It was found that marginal leakage was reduced but not eliminated with the use of acid etching. In this work only the cavity walls were etched, and the fillings were investigated shortly after setting. However, if also the peripheral enamel adjoining the cavity margins is etched, the resistance to leakage will probably increase (*Buonocore et al.*, 1973). Furthermore, it has been demonstrated with fillings in unetched cavities that the expansion by water absorption reduces the risk of «thermal percolation» (*Asmussen*, 1974). Fillings expanded against the cavity walls can be cooled through a certain temperature range without marginal gaps being formed. It is very probable that marginal leakage during thermal changes will be reduced as a consequence of hygroscopic expansion also in the case of fillings in etched cavities.

The purpose of the present work was to investigate the wall–to–wall polymerization contraction of restorative resins placed in acid etched central cavities prepared in extracted human teeth, and to study the effect of water absorption and temperature changes on the formation of marginal gaps on such fillings.

MATERIALS AND METHODS

The brands listed in Table 1 were used in the study. A microscopic inspection was made of the enamel margins of fillings placed in acid etched, cylindrical cavities prepared in extracted human teeth. Before the preparation the teeth were cleaned with an aqueous slurry of pumice by means of a toothbrush. The etching and the filling of the cavities were carried out in a thermostat room at 37°C. Immediately prior to filling, the cavities were dried by compressed air whereafter the cavity walls and a zone peripheral to the cavity margins were etched with a 35% phosphoric acid. The acid was applied with a cotton pellet, the width of the peripheral zone of etched enamel was 1.5–2 mm, and the etching time was 90 seconds. The cavities were then rinsed with demineralized water and dried. The materials were mixed at room temperature and immediately hereafter carried into the thermostat room where the cavities were filled. The filling materials were extended over the etched, peripheral enamel and covered with a matrix band during setting. Ten minutes after start of mixing the fillings were either polished or placed under water at 37°C for subsequent polishing. The polishing was conducted at 37°C. After polishing the teeth were wiped with lens tissue and were now ready for the microscopic examination. Further details in connection with the preparation of the cavities, the filling procedure, and the polishing technique have been described previously (*Asmussen & Jørgensen, 1972*).

Wall-to-wall polymerization contraction

Five fillings of each brand were investigated. The fillings were polished 10 minutes after mixing of the materials. The microscopic inspection was carried out in the thermostat room 15 – 20 minutes after mixing and lasted about two minutes for each filling. A Reichert MeF Universal Camera Microscope with dry objective was used at a nominal magnification of 12.5 x 63 times. The wall–to–wall contraction was assessed by the presence or the abscence of marginal gaps. Gaps as narrow as 0.5 μm could be observed. Fillings of brands with no marginal gaps were stored in water at 37°C after being examined. These fillings were re-examined after 1 day and after 16 days in water.

Effect of water absorption and temperature changes on marginal gaps

The fillings were polished either 10 minutes after mixing or after being stored in water at 37 °C for 24 ± 1 hours. After polishing the cavity margins were inspected in the microscope as described above. Immediately

Table 1. *List of brands used in the investigation*

No.	Name	Batch No.	Manufacturer
A	Sevriton Simplified	powder: NH1 liquid: OE1	De Trey Frères, S.A., Zürich, Switzerland
B	Opotow	720 420	Opotow Dental Mfg. New York, USA
C	Adaptic	3E 019	Johnson & Johnson, New Jersey, USA
D	Concise	42 91 15	3M Company, Minnesota, USA
E	Compact	cat: 74 0121 uni: 740422	Svedia Dental Industri, Enköping, Sweden
F	Smile	cat: 330.05 uni: 923125.73	Kerr Manufacturing Company, Michigan, USA
G	Cosmic	cat: SG1 base: SG8	Amalgamated Dental, London, England
H	HL72	powder: HLR0006 liquid: HLR 0005	Lee Pharmaceuticals, California, USA
I	Concise cap-c-rynge	31 761 G 212	3M Company, Minnesota, USA
J	Estic Pasta	41016	Kulzer & Co., Hamburg v.d.H., Germany
K	Compocap	220374	Vivadent, Schaan, Liechtenstein
L	Prestige	cat: HPR 0063 uni: HPR 0059	Lee Pharmaceuticals, California, USA

after the microscopic examination fillings of brands without marginal gaps were subjected to temperature changes. The fillings polished after 10 min were successively placed in water at 23 ± 1 °C, 15 ± 1 °C and 2 ± 1 °C. At each temperature possible marginal gaps were measured. Five fillings of each brand were investigated. The fillings polished after 24 hours were placed in water at either 23 ± 1 °C, 15 ± 1 °C, 10 ± 1 °C, or 2 ± 1 °C. At each temperature possible marginal gaps were measured on 5 fillings of each brand. After the measuring the fillings were placed in water at 50 ± 1 °C for 60 min, and thereafter cooled in water to the same temperature as before the heating. Again, possible marginal gaps were measured.

The gaps were measured under water by means of a Leitz Panphot microscope fitted with a water immersion objective and a measuring ocular. The nominal magnification was 90 x 12.5 times. Gaps as narrow as 0.4 µm could be measured. At each filling the maximum gap width was found and expressed in percent of the cavity diameter as previously described (*Asmussen & Jørgensen,* 1972). Further details in connection with the measuring of the gaps have been described by *Asmussen* (1974).

RESULTS

Wall-to-wall polymerization contraction

The presence or abscence of marginal gaps at fillings examined 15–20 min after mixing is shown in Fig. 1. The brands are arranged in order of increasing wall-to-wall polymerization contraction in the dentin part of unetched cavities, as measured by the method described by *Asmussen & Jørgensen* (1972). It appears from Fig. 1 that no gaps were observed with brands A – F. With brands G – L gaps were found in two or more of the cases. When a contraction gap was observed, it was invariably accompanied by enamel fractures caused by the polishing (*Asmussen & Jørgensen*, 1972). It was characteristic that the gaps as well as the polishing defects were located in the enamel. The distance of the defects from the cavity margins varied from a few microns up to about 30 microns. Tags in the etched enamel walls were observed with all brands. Fig. 2 shows the gap at the margin of a filling of brand L.

Re-examination after 1 day's storage in water of the fillings of brands A-F showed for all brands the presence of gaps in one or more of the cases. The gaps were located in the enamel, their width being 0.5–1 μm. The inspection after 16 days' storage in water showed that the gaps did not close as a consequence of hygroscopic expansion.

Effect of temperature changes on marginal gaps

As mentioned above no initial marginal gaps were observed at 37°C at the fillings of brands A–F. For all these brands gaps were formed by cooling at some of the investigated fillings. Figs. 3 – 8 show the mean percentage gap width (ordinate) in relation to temperature (abscissa). The range is represented by the vertical lines. The mean of the gap widths is seen to increase with decreasing temperature. The gaps were all located in the enamel at a distance from the cavity margin that varied from a few microns to about 50 microns. Fig. 9 shows the gap at the margin of a filling of brand C formed by cooling from 37 to 23 °C.

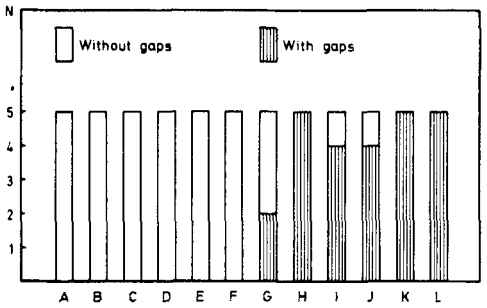

Fig. 1. Occurrence of initial marginal gaps due to polymerization contraction. Unhatched columns indicate absence, hatched columns presence of gaps. The ordinate gives the number of fillings.

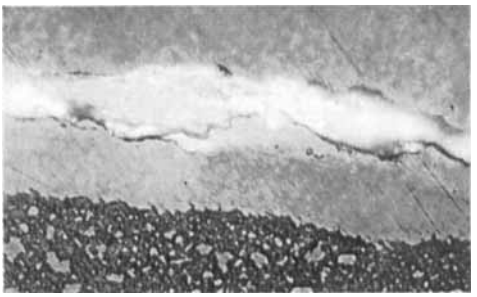

Fig. 2. Polymerization contraction gap at the margin of a filling of brand L. The gap is located in the enamel. x425.

When the fillings were polished after 24 hours' storage in water, no gaps were observed at 37°C at the fillings of brands A–G, I and J. With these brands it was found that the filled teeth could be cooled through a certain temperature range without marginal gaps being formed. In Figs. 10–18 the unfilled circles give the mean percentage gap width (ordinate) in relation to temperature (abscissa). The filled circles represent the mean of the gap widths after heating to 50°C for 60 min and recooling to the same temperature as before the heating. The range is shown by the vertical lines. It appears that the heat treatment affected the gaps at the fillings of brand A to a higher degree than was the case with the other brands. The gaps were all located in the enamel.

Fig. 3-8. Brands A-F. Gap width in percent of cavity diameter at different temperatures. The fillings were polished and examined immediately after setting. For each brand five fillings were investigated. The range is represented by the vertical lines.

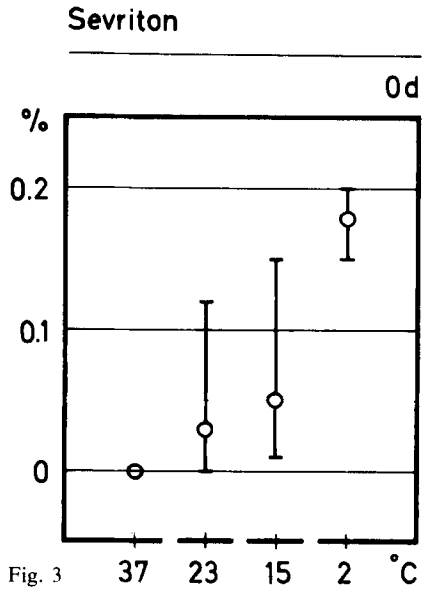

Fig. 3

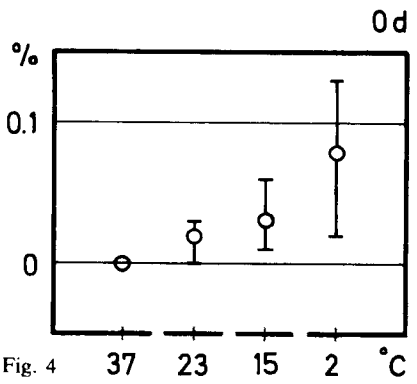

Fig. 4

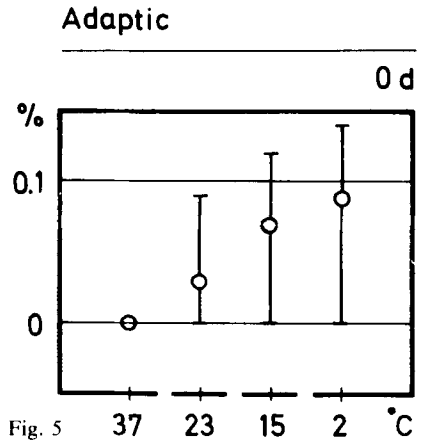

Fig. 5

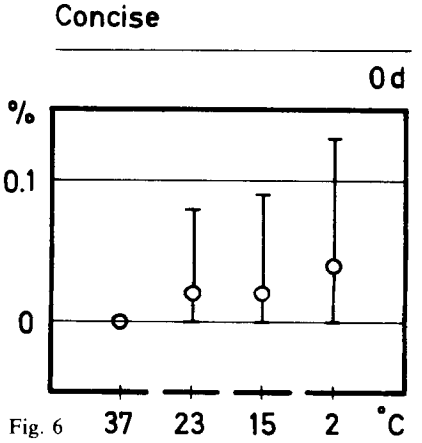

Fig. 6

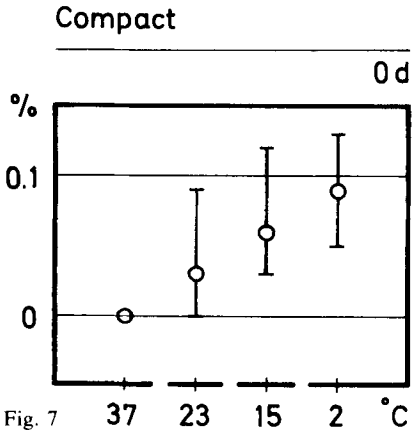

Fig. 7

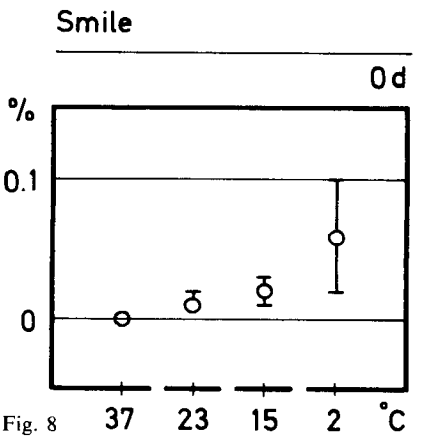

Fig. 8

Figs. 10-18. Brands A-G, I and J. Gap width in percent of the cavity diameter at different temperatures. The unfilled circles show the gap width after cooling from 37 °C. The filled circles show the gap width after a preceding heating to 50°C for 60 min. The fillings were polished and examined after 1 day's storage in water at 37 °C. For each brand five fillings were investigated at each temperature below 37°C. The range is represented by the vertical lines.

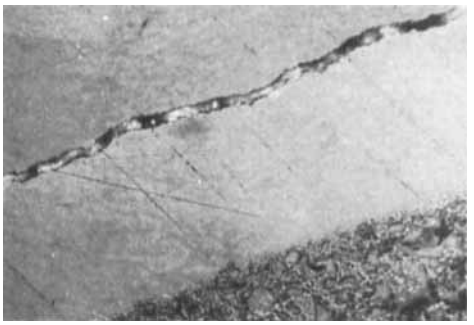

Fig. 9. Marginal gap caused by thermal contraction of a filling of brand C. The gap was formed by cooling from 37 to 23°C and is located in the enamel. x425.

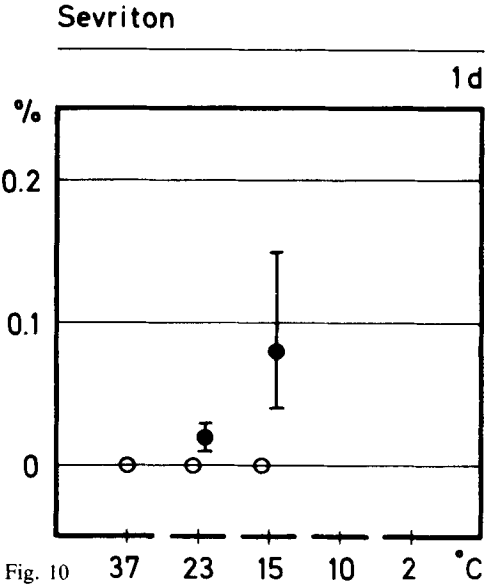

Fig. 10

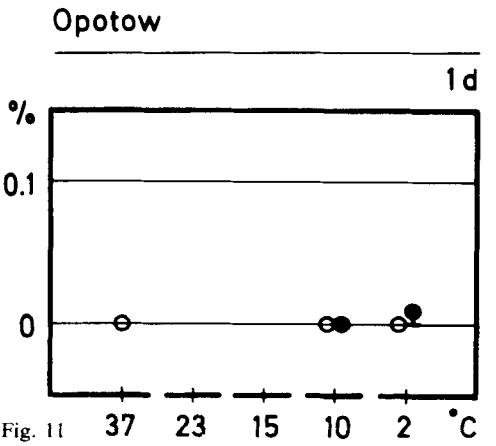

Fig. 11

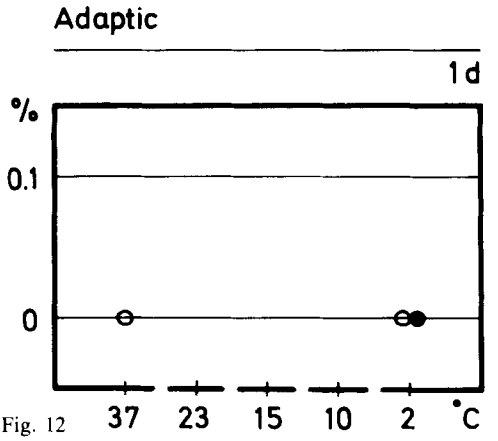

Fig. 12

DISCUSSION

The results obtained with regards to wall-to-wall contraction can be discussed on the basis of the following considerations: When a restorative resin polymerizes in a cylindrical cavity, contraction forces are developed that tend to pull the material away from the cavity walls. With the use of the described acid etching technique the wall-to-wall contraction is counteracted by the bond 1) between the resin and the etched cavity walls, and 2) between the resin and the etched peripheral enamel. As long as the contraction forces are smaller than the bonding forces, the material will remain in contact with the cavity walls, and the polymerization shrinkage will appear either as a sinking-in of the free surface of the filling or it will cause fractures in the enamel surrounding the cavity. The flow of material

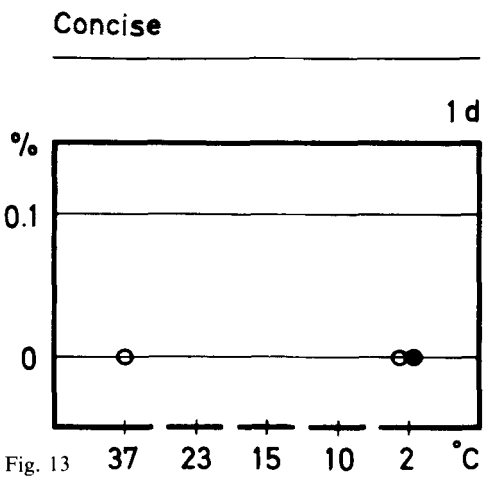

Fig. 13

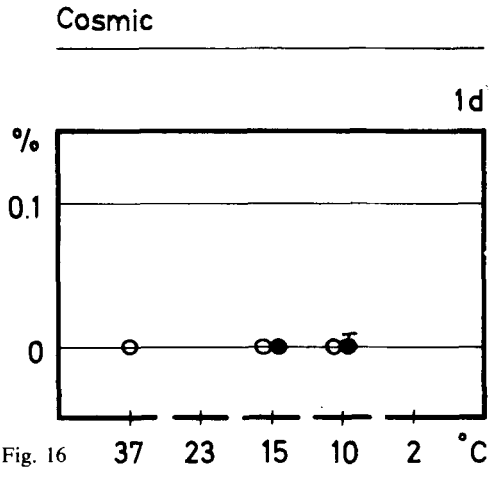

Fig. 16

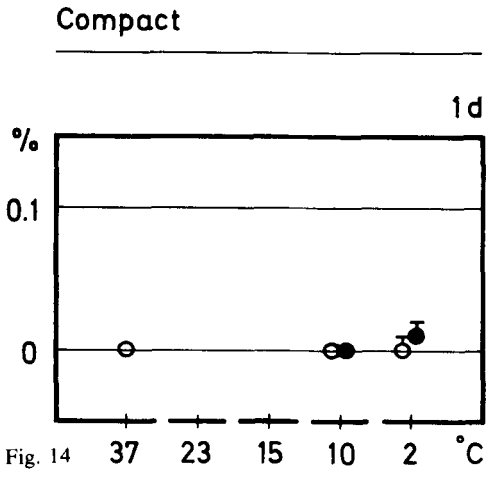

Fig. 14

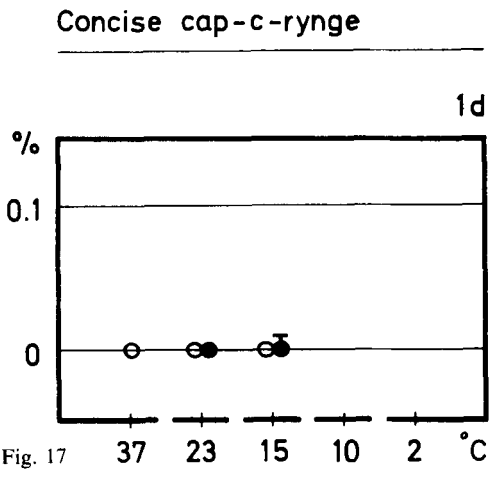

Fig. 17

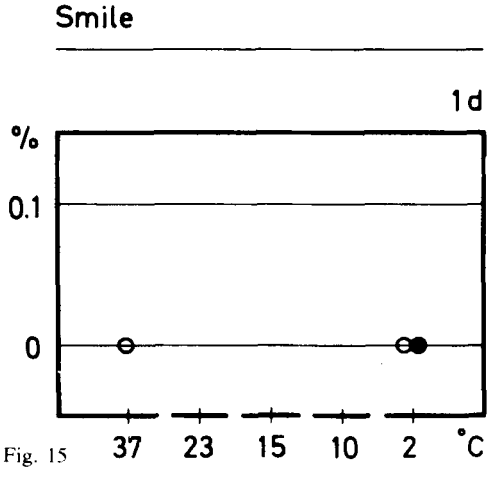

Fig. 15

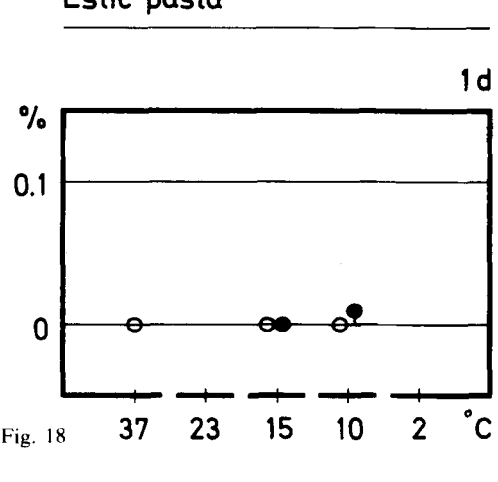

Fig. 18

into the cavity will cause a reduction of the contraction forces. After initial setting a certain amount of residual stresses will probably be present in the filling. When the excess material has been removed by polishing, these residual stresses are counteracted only by the adhesion to the cavity walls.

On this basis it follows from Fig. 1 that the stresses due to polymerization contraction developed in fillings of brands A-F were so small that no marginal gaps were formed immediately after polishing. The stresses in fillings of brands G-L, however, were so large that initial gaps occurred. It may be added that with fillings in unetched cavities the bonding forces have been found with all brands to be too small to prevent wall-to-wall polymerization contraction (*Asmussen & Jørgensen*, 1972 and unpublished results). It is interesting to note that the differences between the brands as regards contraction tendency in etched cavities also manifest themselves with fillings in unetched cavities. According to the method of *Asmussen & Jørgensen* (1972) brands A–F are characterized by a wall-to-wall polymerization contraction in the dentin part of unetched cavities that is less than 0.40%, whereas this contraction for brands G–L exceeds 0.40%.

At the time when the wall–to–wall polymerization contraction was assessed, the polymerization had most probably not yet completed terminated. The continued polymerization leads to an increase in the stresses in the fillings where no initial marginal gaps could be observed. As a consequence the risk that marginal gaps will occur later on also increases. The gaps formed at fillings of brands A-F after 1 day's storage in water may be explained by the continued polymerization contraction. When the fillings were re-examined after 16 days' storage in water, these gaps were still present. Using the method of *Asmussen & Jørgensen* (1972) the polymerization contraction gaps at fillings of brands A-F in unetched cavities have been found to have closed by hygroscopic expansion at this time. The fact that the very narrow gaps in the present experiments did not close is probably due to the minute irregularities of the opposing walls of the gaps. The results show that a replacement of corresponding positive and negative relief elements in these walls during the hygroscopic expansion of the restorations is not possible.

In the second part of the investigation the influence of temperature changes and of hygroscopic expansion on the formation of marginal gaps was studied. The coefficient of thermal expansion of restorative resins is 3-8 times as high as that of the enamel and the dentin which means that a reduction in temperature of a resinous filling involves the risk of formation of marginal gaps. This is demonstrated in Figs. 3-8 with fillings that had absorbed only a minimum of water.

The hygroscopic expansion of the fillings stored in water before polishing will reduce the polymerization contraction stresses present in the fillings after the initial setting. In time the fillings may become elastically strained against the cavity walls. Thus, as a consequence of water absorption the risk of marginal gaps caused by polymerization and thermal contraction is reduced. This explains the finding that when polished also fillings of brands G, I and J, at which gaps were found on examination immediately after setting, showed no marginal gaps after 1 day's storage in water at 37°C. On the other hand, the polymerization contraction tendency of fillings of brands H, K and L is so high that the hygroscopic expansion after 1 day's storage in water could not prevent the formation of gaps.

As regards thermal contraction a comparison of Figs. 3–8 with Figs. 10–15 shows that after 1 day's storage in water at 37°C marginal gaps do not form as readily upon cooling. This may be explained by the hygroscopic expansion of the fillings. As mentioned above the hygroscopic expansion results in a reduction of the tensile stresses present in the fillings immediately after initial setting, and later on possibly in an elastic compression against the cavity walls. This compression together with the bond between the restorative and the etched cavity walls has

the effect, as can be seen from Figs. 10-18, that the fillings can be cooled through a certain temperature range without marginal gaps being formed. The temperature range is dependent upon the polymerization contraction tendency, the hygroscopic expansion and the coefficient of thermal expansion (*Asmussen*, 1974).

As shown by *Asmussen* (1974) heating of resinous fillings in unetched cavities with closed marginal gaps causes a compression against the cavity walls which may result in a plastic deformation of the fillings. At a subsequent cooling to a give temperature below 37°C the elastic strain against the cavity walls caused by the hygroscopic expansion has been reduced and will, therefore, less effectively counteract the formation of marginal gaps. It appears from Figs. 10-18 that the heat treatment had the same effect on fillings in etched cavities: In several cases gaps at a given temperature were wider after the heating than before. Fig. 10 shows that the heat treatment of fillings of the non-composite brand A affected the gap widths to a higher degree than was the case with the composite brands. A probable explanation is that the higher coefficient of thermal expansion and the lower limit of elasticity of the non-composite brand causes a larger plastic deformation during the heating.

The polymerization contraction gaps and the gaps due to thermal contraction were always located in the enamel. Thus it seems that a possible increase of the bonding between restorative resin and etched enamel by the use of an intermediate layer of low-viscous, non-composite resin will not reduce the risk of formation of marginal gaps. The results indicate that the bonding between restorative resin and etched enamel is sufficiently strong, and that it is the enamel itself that is the weaker link in the chain.

To summarize, the study has demonstrated that marginal gaps caused by polymerization contraction did not occur around fillings of several of the restoratives investigated, when the described acid etch technique was used and if the fillings were polished only after 1 day's storage in water at 37°C. The study has further demonstrated that such fillings could be cooled from 37 to 15°C or to a still lower temperature without gaps being formed. After 1 day's storage in water the fillings are not yet water saturated, and the continued hygroscopic expansion will further lower the critical temperature at which the gaps begin to occur. Heating to 50°C for 60 minutes was found to increase the risk of gaps being formed at a subsequent cooling. However, a heating period of 60 minutes is much longer than those to which the fillings will be exposed in vivo. It is possible that heating to 50°C of a realistic duration will not influence the temperature at which the gaps begin to form, as demonstrated by *Asmussen* (1974) with fillings in unetched cavities.

Consequently, the results indicate that if 1) the described acid etching technique is used, 2) the polishing is postponed at least 24 hours, and 3) 15°C and 50°C are taken as the limits of the temperatures that resin fillings experience under oral conditions, marginal gaps due to polymerization contraction and temperature changes may not be formed around fillings of several of the investigated brands.

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