Polymerization shrinkage of composite resins: Comparison with tooth deformation

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Polymerization shrinkage of two posterior composite resin restorative materials was measured by dilatometry. The results were compared with a decrease in cavity width of MOD preparations in extracted premolars restored with the composite resins. A highly filled hybrid composite exhibited greater free shrinkage and cuspal deformation than a hybrid composite with a lower filler content. Deformation of the cusps was less than the unrestricted shrinkage of the composite resins. Hydrated teeth exhibited less deformation than dehydrated teeth because of polymerization shrinkage. Greater cuspal deformations were measured with the microscopic technique than with interferometry because of differences in experimental design. (J Prosthet Dent 1994;71:7-12.)

Polymerization shrinkage is a critical limitation of dental composite resins. Shrinkage results in stresses in teeth restored with composite resin and also within the composite resin itself.[1-3] Stresses from shrinkage can cause clinical problems such as postoperative pain, fracture of the tooth, and opening of restoration margins that can result in microleakage and recurrent caries.[4-7]

In vitro measurements of polymerization contraction of composite resins range from 0.2% to 2% linear shrinkage,[1, 8-10] and from 1.7% to 5.7% volumetric shrinkage.[2, 4, 11-15] Stresses of 2 to 6 MPa caused by polymerization contraction have been measured in model systems.[2, 9, 16, 17]

Several studies demonstrated that the cusps of molars and premolars were deflected inward after placement of class II composite resin restorations.[3, 18-22] The amount of contraction reported ranged from 18 to 45 μm. Most of the deformation occurred in the first 15 minutes after placement of the composite resin, but in one study shrinkage continued for approximately 2 days.[18]

Polymerization shrinkage is compensated by flow of the composite resin in the initial stages of polymerization.[2] In later stages, water sorption with expansion of the composite resin partly compensates for polymerization shrinkage and reduces the marginal gap.[1, 23-27] Many factors have a direct effect on the polymerization shrinkage of composite resin: size of the restoration, cavity configuration, placement technique (incremental or bulk), and curing method (chemical or light-curing).[10, 17]

This study compared the unrestricted polymerization shrinkage of two posterior composite resin restorative materials with the cuspal deformation of extracted premolars with mesio-occluso-distal (MOD) surface restorations. Unrestricted polymerization shrinkage may not accurately predict cuspal deformation because of the flow of composite resin during curing and differences in elastic moduli of composite resins that influence stress accumulation. Clinically it is desirable to select composite resins that have the least polymerization shrinkage.

MATERIAL AND METHODS

Free polymerization shrinkage was measured with a water-filled dilatometer described by Bandyopadhyay[12] and used by Goldman[13] and Rees and Jacobsen.[14] The apparatus consisted of a 10 cm^3 density bottle with a calibrated capillary tube. The uncured composite resin was placed in the bottle filled with water and the decline in the water level in the capillary tube after the resin was cured was recorded.

Two light-cured composite resins used for posterior restorations with different inorganic fillers and properties were selected for the study: a highly filled hybrid with a filler loading of 85 wt% (P-50, 3M Co. Dental Products Division, St. Paul, Minn.; batch P900202) and a hybrid composite resin with a lower filler content of 62 wt% (Heliomolar Radiopaque, Vivadent-USA, Tonawanda, N. Y.; batch 260191). The filler content of these materials was analyzed in detail by Hosoda et al.[28]

The volume of the composite resin samples, 0.16 cm^3, was similar to a large cavity preparation in a maxillary premolar. The resin was placed in the density bottle filled with distilled water and covered with aluminum foil to prevent premature exposure to light. The assembled apparatus was allowed to stabilize for 20 minutes at 22° C. The foil was

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0022-3913/94/$1.00 + .10 **10/1/51430**

then removed from the bottom of the bottle and the resin was exposed to the curing light (Visilux, 3M Co.) for 120 seconds. The water level was recorded every 1 to 5 minutes for 1 hour. Measurements were repeated on five specimens of each resin.

A corrective factor was used to compensate for changes in water level resulting from temperature changes caused by the curing light or evaporation. The experiment was conducted without resin in the bottle. The drop in water level versus time fit a nonlinear regression curve, $y = 1.10 \exp(-0.0660\ t)$, and y was used to correct experimental readings.

The decline in water level represented the change in volume (dV) of the composite resin, provided water sorption had no substantial effect, which has been demonstrated by Bandyopadhyay[12] and by Rees and Jacobsen.[14] The percentage of volumetric shrinkage was calculated as vol% = $100\ (dV/(dV + V))$. The volume, V, of each specimen was measured by the water displacement technique using a density bottle. The volume percent of shrinkage was converted to linear percent by dividing by 3.

The inward cuspal deflection of extracted premolars in which MOD composite resin restorations were placed was measured with two techniques: microscopy and Michelson's interferometry.[29, 30] The same two posterior resins were selected. Standardized slot preparations were completed for 20 maxillary premolars. Tooth preparations were 2 to 3 mm wide faciolingually and 4 mm deep pulpally.

Each tooth was secured to the micrometer stage of a measuring microscope and cuspal indices were aligned with the eyepiece crosshair. The cavity preparations were etched for 30 seconds with Scotchbond etching gel (3M Co.), rinsed, dried, and treated with Scotchprep (3M Co.) resin for 60 seconds. This was followed by Scotchbond 2 (3M Co.) resin, which was cured for 20 seconds with a Visilux light unit. The cavity preparation was restored with one increment of composite resin without a matrix. The resin was cured for 120 seconds by application of the light to the mesial, distal, and occlusal surfaces for 40 seconds each. The intercuspal width was measured before and for 60 minutes after the cavity preparations were restored.

Half of the teeth were dry and half were wet during the study to determine the effect of hydration on cuspal deformation by polymerization shrinkage. Hydration of the wet teeth was maintained by physiologic hydrostatic pressure of 25 mm Hg (34 cm of H_2O) through a hypodermic needle bonded in the root canal and by a wet wick around the crown of the tooth during measurements.

The study was repeated with Michelson's interferometry used to measure tooth deformation. The lingual surface of each tooth was etched and bonded to an aluminum plate that was mounted on an optical bench. A 6 × 6 mm mirror was glued to the tip of the facial cusp, and movement of the facial cusp toward the secured lingual cusp was measured. Changes in the distance between a beam splitter and the sample mirror and a second reference mirror were measured by count of the number of fringes that passed a reference point on a target screen. The displacement (d) of the facial cusp was calculated from the formula $d = nl/2$, where n is the number of fringes and l is the laser wavelength (0.633 μm for helium-neon).

The teeth, half of them dry and half wet, were restored with identical materials. Hydration differed from the microscopic measurements because a wet wick could not be accommodated during interferometric measurements, but pulpal hydration pressure was maintained.

The data were analyzed with three-factor ANOVA to determine the effects of measurement method (microscopy, interferometry), material (P50, Heliomolar), and hydration (wet, dry) on cusp deformation. The level of significance was 0.05.

RESULTS

The unrestricted polymerization shrinkage at 22° C and 60 minutes for Heliomolar RO composite resin was 2.6 vol% (SD = 0.6) and it was 3.2 vol% (SD = 0.2) for P50 composite resin. In terms of linear shrinkage, the values were 0.9% and 1.1 "lin%," respectively. The free shrinkage of these materials during the initial 60 minutes is presented in Figs. 1 through 4.

Tooth deformations 60 minutes after placement of MOD composite resin restorations are shown in Table I. Decreases in the faciolingual direction were expressed as a percentage of cavity preparation widths. Unrestricted polymerization shrinkage of Heliomolar RO composite resin during the first 60 minutes was compared with restricted shrinkage (cuspal deformation) measured by microscopy in cavity preparations of hydrated and dehydrated teeth (Fig. 1). The same comparison was made by use of interferometric measurements of tooth deformation in Fig. 2. The microscopic and interferometric data for P-50 composite resin are given in Figs. 3 and 4.

Three-factor ANOVA showed that method of measurement, material, and hydration all significantly affected cuspal deflection ($p < 0.05$) (Table II). However, significant interactions between these variables indicated that the effects were not consistent across experimental groups (Table II). Consequently, the Duncan multiple range test (alpha 0.05) was performed to compare all eight experimental groups (Table I).

Less shrinkage was measured with interferometry than with microscopy in three of the groups shown in Table I. There was no statistical difference between the two methods in the dry Heliomolar group. There was less shrinkage when teeth and restorations were hydrated than when dry, except for the microscopic measurements of Heliomolar RO composite resin. The P-50 composite resin caused greater cuspal deformation than Heliomolar RO material under both wet and dry conditions and with both methods of measurement.

DISCUSSION

Polymerization shrinkage of the composite resins was rapid with considerable shrinkage during the 2 minutes that the materials were exposed to the curing light. This was followed by a period of slow contraction to 60 minutes.

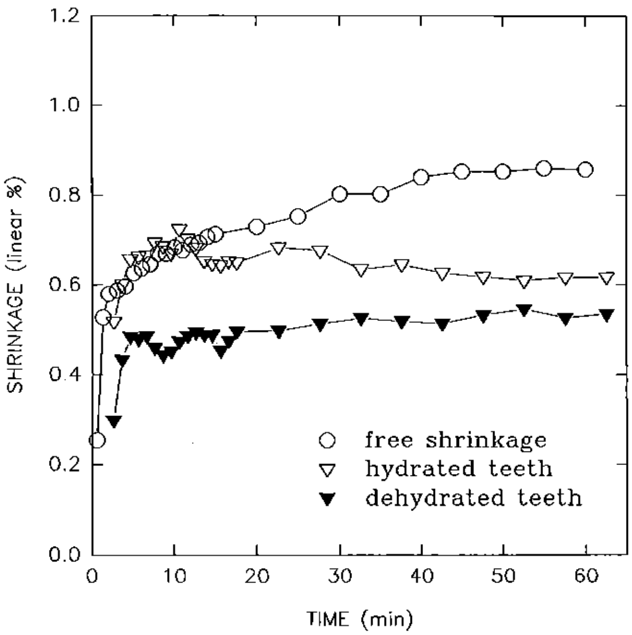

Fig. 1. Comparison of unrestricted (free) polymerization shrinkage of Heliomolar RO composite resin with decrease in cavity width of premolars with MOD restorations as measured microscopically. Teeth were hydrated or dry during and before measurements.

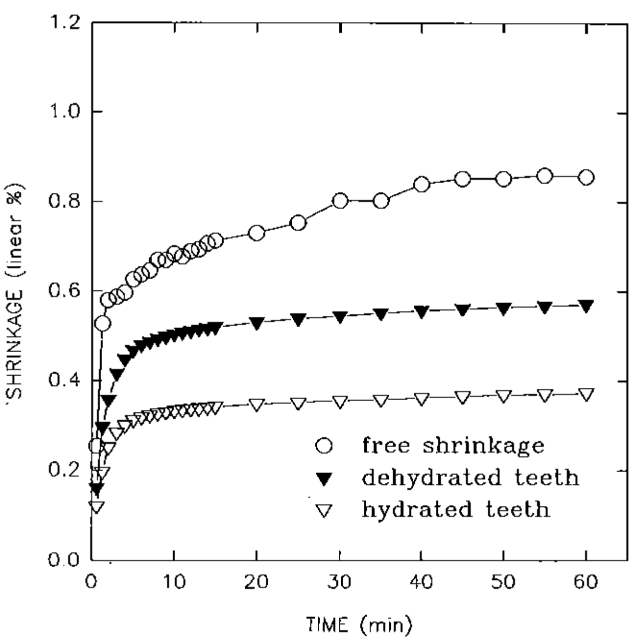

Fig. 2. Comparison of unrestricted (free) polymerization shrinkage of Heliomolar RO composite resin with decrease in cavity width measured with interferometry.

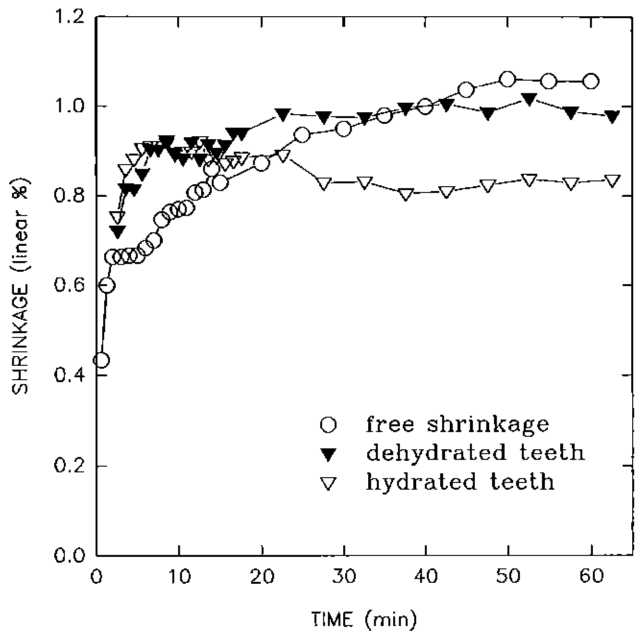

Fig. 3. Comparison of unrestricted polymerization shrinkage of P-50 composite resin with decrease in cavity width measured microscopically.

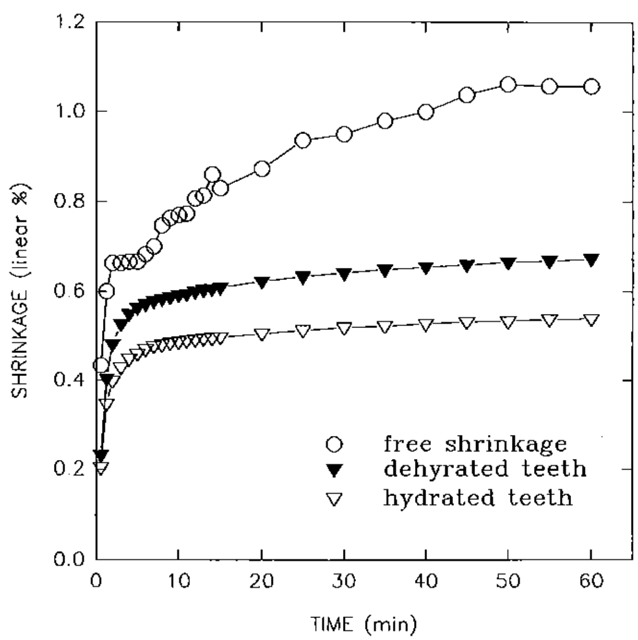

Fig. 4. Comparison of unrestricted polymerization shrinkage of P-50 composite resin with decrease in cavity width measured with interferometry.

The shrinkage curves are typical of the setting curves of light-cured composite resins, which exhibit rapid polymerization during the first minutes after activation.

Dilatometry measurements of unrestricted polymerization shrinkage of the composite resins are similar to values previously reported. Feilzer et al.[15] reported shrinkage of 2.8 vol% for Heliomolar RO composite resin compared with 2.6 vol% at 60 minutes in this study. This investigation recorded 3.2 vol% for P-50 composite resin compared with 3.6 vol% for P-30 material reported by Feilzer et al.[15] P-30 composite resin is also a highly filled hybrid with shrinkage similar to that of P-50 material. Although

Table I. Decrease in cavity width (%) 60 minutes after placement of MOD composite restorations in premolars as measured by microscopy and interferometry

Composite	Hydration	Microscopy		Interferometry	
		Mean*	SD	Mean*	SD
Heliomolar RO	Wet	0.62[a]	0.17	0.37	0.11
	Dry	0.53[a, b]	0.15	0.57[b, c]	0.07
P50	Wet	0.84	0.08	0.54[c]	0.08
	Dry	0.98	0.16	0.67	0.08

Means with the same superscript letters are statistically the same (alpha 0.05, Duncan test).
*Sample size 10.

Heliomolar RO composite resin was expected to have greater shrinkage than that of P-50 because of its lower filler content, 62 wt% versus 85 wt%, the opposite was discovered. The lower shrinkage of Heliomolar RO composite resin was attributed to its lower conversion rate.[31]

Cuspal deflection caused by composite resin shrinkage was measured by two different techniques. The interferometric technique was more precise than the microscopic method. This was demonstrated by less scatter of data points in Figs. 2 and 4 compared with Figs. 1 and 3 and by lower standard deviations in Table I. Less cuspal deflection was detected in the interferometric study and this was attributed to bonding of the lingual surfaces of the teeth to a support bracket so that movement of the facial cusp relative to the lingual cusp could be measured. This bond possibly reduced the flexibility of the teeth and resulted in less cuspal deflection. A double interferometry approach could be designed to measure the movement of each cusp separately. With the tooth supported by the root, results similar to microscopy could be expected.

Cuspal deflection in premolars with MOD restorations was less than the free shrinkage of the composite resins. The mean free shrinkage of the two resins was 0.96 lin%, and the decrease in cavity preparation width was 0.74 lin% for the microscopic study and 0.54 lin% for the interferometric study.

The difference between unrestricted shrinkage and cuspal movement or restricted shrinkage of composite resins might be attributed to gap formation between the composite resin and tooth or to flow of the composite. Because no gap formation was observed microscopically, the discrepancy was attributed primarily to flow.[2] The amount of flow, expressed as a percentage of free shrinkage, was estimated as 23% for the microscopic method and 44% for the interferometric method. These values should be regarded as rough estimates because of differences in geometry of the unrestricted specimens and the restorations in the teeth. Feilzer et al.[32] reported higher values, ranging from 65% to 92%, for flow of chemically cured composite resins. They anticipated that stress reduction because of flow would be appreciably less for light-cured composite resins because of their rapid initial polymerization reaction.

Stress reduction by flow also depends on configuration of the cavity preparation.[17, 32] Cavity preparations with fewer walls have a lower configuration (C) factor, which is the ratio of bonded to unbonded surface. Stress accumulation is less if there are fewer bonded surfaces, for example, a lower C factor. Flow can then more effectively compensate for polymerization shrinkage. The MOD tooth preparations that were used had a C factor of one. According to Feilzer et al.,[32] P-10 composite resin exhibited flow of 86.3% and 81.8% with C factors of 0.5 and 2.0, respectively. Measurements were not recorded for C = 1. In comparison, the values in this study were 23% to 44% for P-50 and Heliomolar RO composite resins.

Cuspal deformation was greater with P-50 than Heliomolar RO composite resin. In the microscopic study, cusp deformation was 0.91 lin% for P-50 and 0.58 lin% for Heliomolar RO composite resin. The corresponding values in the interferometric study were 0.60% and 0.47 lin%. These findings correlated with greater polymerization shrinkage of the P-50 material. The higher elastic modulus and reduced flow of P-50 relative to Heliomolar RO composite resin probably contributed to the greater cuspal deformation by P-50 composite resin. Highly filled hybrids, similar to P-50 material, have higher elastic moduli than hybrid or microfilled resins with less filler.[33] Stress buildup is high and stress relief by flow is less for composite resins with higher elastic moduli.[32] The values for flow in the microscopic study were 14% for P-50 and 32% for Heliomolar RO composite resin, whereas the corresponding values in the interferometric technique were 43% and 46%.

Hydration of the teeth significantly influenced the results and emphasized the importance of sustaining the moisture content of teeth during laboratory studies. Hydrated teeth had less cuspal deflection from composite resin shrinkage than did dry teeth, with the exception of one group, Heliomolar RO composite resin in the microscopic study. One possible explanation for the influence of moisture is the interference with bonding between composite resin and tooth structure, so that shrinkage is compensated by gap formation between them instead of deflection of the cusps. Another possible cause is that hygroscopic expansion of the resin compensated for some of

Table II. Analysis of variance for effect of the variables on decrease in cavity width after placement of composite restorations

Source	DF	SS	MS	F Value	pr > F
Model	7	2.5117	0.3588	25.19	0.0001
Error	69	0.9828	0.0142		
Corrected total	76	3.4946			
Method	1	0.8561	0.8561	60.10	0.0001
Material	1	1.0744	1.0744	75.43	0.0001
Hydration	1	0.1757	0.1757	12.34	0.0008
Method × material	1	0.1866	0.1866	13.10	0.0006
Method × hydration	1	0.0855	0.0855	6.01	0.0168
Material × hydration	1	0.0345	0.0345	2.42	0.1240
Method × material × hydration	1	0.0987	0.0987	6.93	0.0105

the polymerization contraction and reduced inward cuspal deflection. Other investigators have shown that hygroscopic expansion of composite resins can compensate for some of the polymerization contraction.[1, 23-27] This appeared to be the explanation in the microscopic study, where the hydration was easier to control because of a wet wick positioned around the crown of the tooth. Recovery of cuspal deflection between 10 and 60 minutes was evident in the curves of the hydrated teeth (Figs. 1 and 3) but recovery was not observed in the curves of the dry teeth.

In this study, cavity preparations were restored with one increment of composite resin and cured in bulk. The bulk-fill method is known to create maximal shrinkage, which was the intention of this study. Placing and curing composite resins in increments may partly diminish the shrinkage,[34, 3] but certain investigators recorded no effect.[35] However, in clinical practice an incremental technique is encouraged.

CONCLUSIONS

Some factors that affect stress in teeth restored with bonded composite resins were studied. Cuspal deformation in premolars with MOD composite resin restorations reflected the polymerization shrinkage measured by dilatometry. The composite resin with greater shrinkage caused more deflection of the cusps. Cuspal deformation was less than free polymerization shrinkage, and this was attributed to flow of composite resins bonded to the teeth, which restricted dimensional changes. There was less flow in the high filler, high elastic modulus composite resin and consequently it exhibited more cuspal deflection. Stress relief because of flow was considerably less for the light-cured composite resins in this study than previously reported for chemically cured composite resins that polymerize more slowly.

Hydration of the teeth influenced the amount of cuspal deformation. The decrease in intercuspal width was less with hydrated teeth because of possible hygroscopic expansion of the composite resin or marginal gap formation. Finally, the interferometric measurement of cuspal deformation was more precise than the microscopic technique.

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