Interferometric Measurements of Cusp Deformation of Teeth Restored with Composites

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A Michelson interferometry apparatus was used for measurement of the displacement of the buccal cusps of premolars after restoration of MOD preparations with composites. The effects of composite type, cavity size, and hydration conditions were examined. Interferometry permitted real-time measurement of cusp movement as it occurred. Contraction occurred very rapidly, about 1/3 of the 60-minute amount within the two-minute period of exposure to the curing light. Cusp movement was smooth rather than interrupted, indicating lack of microfracturing at deformations of 11-46 µm. Contraction, 0.94% for Heliomolar and 1.2% for P-50, was similar to the linear polymerization shrinkage of the resins. Less cusp movement occurred in small cavities than in large cavities. Hydrated teeth had less cusp movement than dehydrated teeth.

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Introduction.

Polymerization shrinkage is one of the most important limitations of dental composites. Shrinkage results in stresses in teeth restored with composites (Jensen and Chan, 1985) and in the material itself (Bowen *et al.*, 1983; Davidson and De Gee, 1984). Shrinkage stresses may cause such clinical problems as post-operative pain, fracture of the tooth, and opening of the margins of restorations, which may result in microleakage of fluids as well as recurrent caries (Bausch *et al.*, 1982; Eick and Welch, 1986; Kemp-Scholte and Davidson, 1988; Torstenson and Odén, 1989).

Polymerization contraction of composites ranges from 0.6 to 2 linear % (Bausch *et al.*, 1982) and from 1 to 6 volume % (Dennison and Craig, 1972; Goldman, 1983; Walls *et al.*, 1988; Feilzer *et al.*, 1990a). Stresses of 2 to 6 MPa due to polymerization contraction have been measured in model systems (Hegdahl and Gjerdet, 1977; Bowen *et al.*, 1983; Davidson and De Gee, 1984; Feilzer *et al.*, 1987).

Several studies have demonstrated that the cusps of molars and premolars are deflected inward after placement of class II composite restorations (Causton *et al.*, 1985; Jensen and Chan, 1985; McCullock and Smith, 1986; Pearson and Hegarty, 1987; Smith and Caughman, 1988; Lutz and Barbakow, 1991). The amount of contraction ranged from 18 to 45 µm in these studies and was similar to the linear setting shrinkage of the composites. Most of the deformation occurred in the first 15 min after placement of the composite; however, in one study (Causton *et al.*, 1985), shrinkage continued for at least for two days.

Cusp movement was sporadic in two of the studies (Causton *et al.*, 1985; Pearson and Hegarty, 1987), indicating stress relief in the tooth due to microfracturing; however, movement was smooth in a third study (McCullock and Smith, 1986). Cutting of the composite restoration caused partial recovery of the tooth and indicated that stress relief was not complete and that only a small amount of permanent deformation of the tooth had occurred (Jensen and Chan, 1985).

Hygroscopic expansion of composites as they absorb water has been found to offset some of the polymerization contraction (Bowen *et al.*, 1982; Hirasawa *et al.*, 1983; Soltèsz *et al.*, 1986; Hansen and Asmussen, 1989). Only a few composites have sufficient hygroscopic expansion to compensate completely for polymerization contraction. Water sorption affects the mechanical properties of composites, *e.g.*, it lowers the elastic modulus and decreases creep resistance. These factors influence the build-up and relief of stresses caused by polymerization shrinkage. Causton *et al.* (1985) found no difference in cusp deflection due to composite shrinkage when the teeth were stored wet or dry over a one-week period. They concluded that water sorption did not offset polymerization shrinkage during the first week.

This investigation was initiated to answer the following questions: (1) What amount of cusp movement results from composite polymerization shrinkage? (2) Does the size of the cavity preparation influence the amount of cusp deflection? (3) Does the choice of composite influence cusp deflection? (4) Does hydration influence deformation?

Materials and methods.

Two composites with substantial differences in inorganic filler loading and properties were selected. The low-resin composite, P-50 (3M Co. Dental Products Division, St. Paul, MN), has a filler loading of 87 wt% (77 vol%). The high-resin composite, Heliomolar R.O. (Vivadent-USA, Tonawanda, NY), has a filler content of 77-79 wt% (65-67 vol%).

TABLE 1

CAVITY DIMENSIONS (mm)

Specification	Small Cavity mean* (SD)	Large Cavity mean* (SD)
Occlusal width	1.94 (0.12)	3.38 (0.15)
Pulpal depth	2.02 (0.06)	NA
Gingival depth	3.89 (0.08)	3.94 (0.11)
Proximal width	2.04 (0.12)	3.29 (0.08)
Axial depth	1.51 (0.08)	NA

*n = 20.

NA = not applicable.

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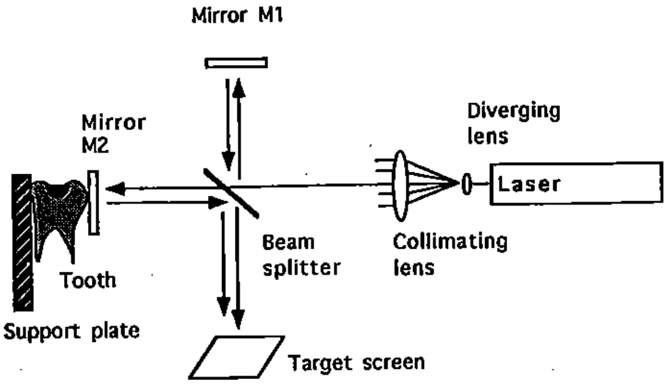

Fig. 1—Michelson's interferometry set-up.

Forty extracted non-carious maxillary premolars were randomly assigned to eight experimental groups. The experimental variables were cavity size (small, large), hydration (dry, wet), and composite (P-50, Heliomolar). Small (approximate volume = 0.10 cm^3) and large (approximate volume = 0.16 cm^3) standardized mesio-occlusal-distal (MOD) cavities (Table 1) were prepared with #55 fissure burs in a high-speed handpiece with water spray. The apical third of the root was removed with a fissure bur. The pulpal tissue was removed, and the canal was enlarged with endodontic files to facilitate the implantation of a 21-gauge disposable needle (Monoject, St. Louis, MO) to supply the tooth with water and to simulate intrapulpal fluid pressure (Terkla *et al.*, 1987). Panavia dental adhesive (Kuraray Co. Ltd, Osaka, Japan) was used to seal the needle to the apex of the tooth. The tooth was tested under pressure for an adequate seal before the root was embedded in acrylic resin.

The lingual cusp of each tooth was etched for 10 s, rinsed, and air-dried. The etched cusp was fixed with Scotchbond 2 dental adhesive (3M Co.) to a sandblasted aluminum plate. The movement of the buccal cusp relative to the fixed lingual cusp was measured in this study. The root of the tooth with its acrylic block was left unrestricted. A small notch was prepared at the tip of the buccal cusp, to which a 6 X 6 mm mirror was glued with cyanoacrylate adhesive. The aluminum plate was attached to a stand fixed to an optical bench.

A Michelson interferometry set-up was used for measurement of the movement of the buccal cusp after the tooth was restored with composite. Changes in the distance between a beam splitter and two mirrors (M1 and

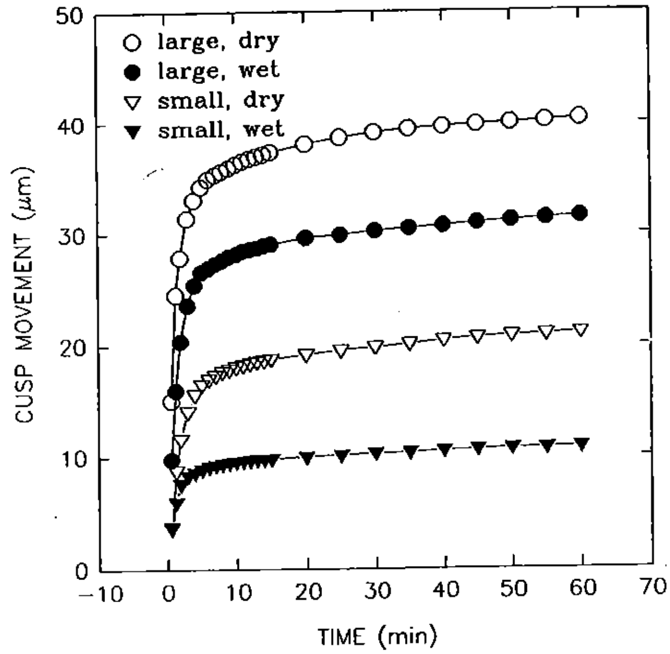

Fig. 2—Cusp movement *vs.* time caused by polymerization shrinkage of Heliomolar MOD restorations in premolars.

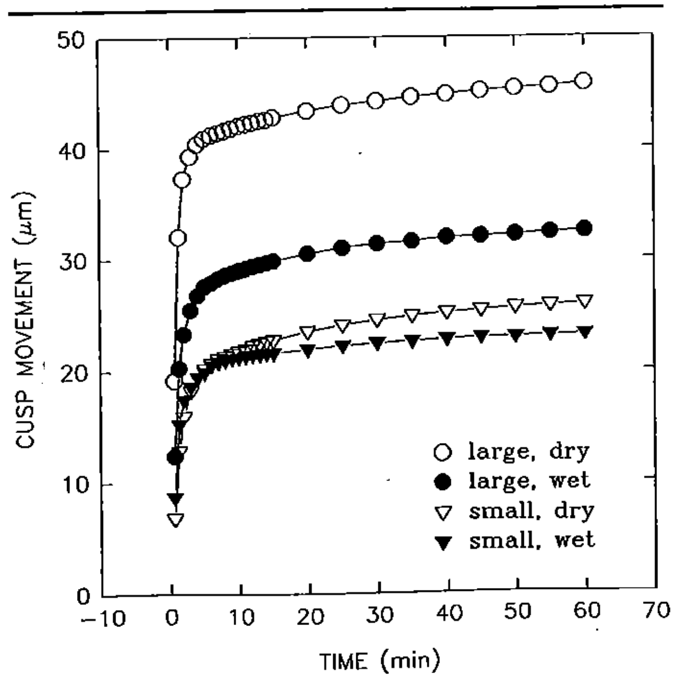

Fig. 3—Cusp movement *vs.* time caused by polymerization shrinkage of P-50 MOD restorations in premolars.

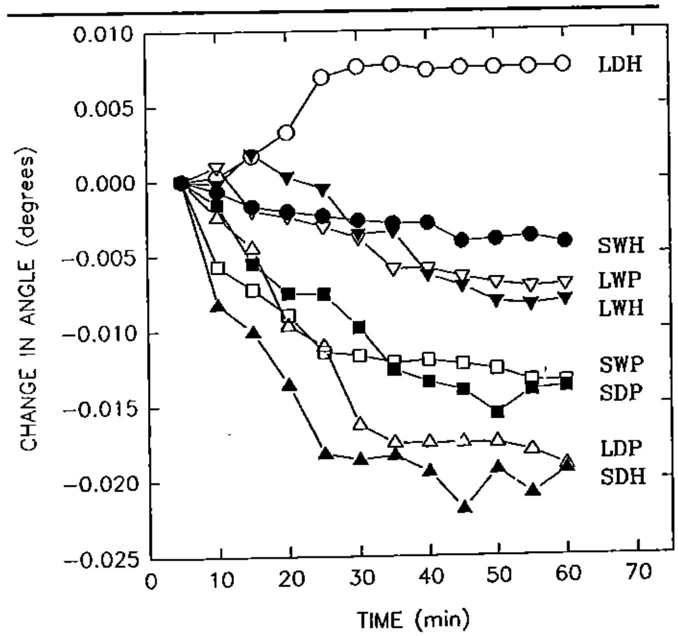

Fig. 4—Changes in angle of tilt *vs.* time of the buccal cusp relative to the lingual cusp in the bucco-lingual direction. Labels: S = small cavity, L = large cavity, W = wet tooth, D = dry tooth, H = Heliomolar, and P = P-50.

M2 in Fig. 1) were measured by counting the number of fringes that passed a reference point on a target screen. The Michelson method does not give the sign of the displacement. The direction of movement, which was from the buccal cusp toward the lingual cusp, was determined by microscopic measurement of the intercuspal distance. Tilting of the cusp was determined from the fringe spacing in either the horizontal or vertical direction.

Once fringes were located on the target screen, the composite was cured, and fringe counting was started. The number of fringes passing the reference point on the screen was counted for 60 min. Fringe spacing in both horizontal and vertical directions was measured every 5 min. The number of fringes counted was converted into cusp displacement in μm. The average displacement (d) of the buccal cusp was calculated from the formula $d = nl/2$ (Dyson, 1970), where n is the number of fringes and l is the laser wavelength (0.633 μm). The tilt (ϕ) of the cusp in a bucco-lingual direction and a mesio-distal direction was obtained by the formula $\phi = l/2D$ (Dyson, 1970), where D is the distance between fringes.

All cavities were restored in the same manner. The enamel was etched for 30 s with Scotchbond etching gel (3M Co.) and rinsed and dried with an air stream. Scotchprep (3M Co.) was applied to dentin for 60 s with a brush and dried with an air stream. Scotchbond 2 (3M Co.) was applied to the cavity with a brush and then air-dried for 5 s and cured for 20 s. One increment of composite was placed and cured for a total of 120 s (40 s each on the mesial, distal, and occlusal aspects of the cavity) by means of a Visilux curing unit (3M Co.).

The dry samples were not allowed to come into contact with water during the course of the experiment, except for a very brief time (approximately 30 s) when water was used to rinse the etchant from the cavity. Similarly, none of the wet sampleswas allowed to dry except briefly during placement and curing of the resin composite. Moreover, physiological hydrostatic pressure (25 mm Hg) was maintained on all wet samples during resin placement and measurements.

Statistical analysis consisted of testing for significant displacement of the buccal cusp relative to the lingual cusp at 60 min after the composite was placed. Analysis of variance was used to determine the influence of the factors cavity size, hydration condition, and type of composite. The Duncan multiple-range test was used for *a posteriori* contrasts following F-tests that were significant. An alpha value of 0.05 was used for all statistical tests.

Results.

Movement of the buccal cusp was detected in all experimental groups during the first 60 min after placement of the resin composite. The mean cusp movement after 1 h was statistically significant in all experimental groups ($p < 0.05$). Most of the deformation took place within the first 5 min. Fig. 2 shows cusp movement for teeth restored with Heliomolar, while Fig. 3 shows those with P-50. From these illustrations, it is seen that large cavities restored with either Heliomolar or P-50 under dry conditions had the largest displacement of the buccal cusp (40-45 μm). The least amount of movement (10 μm) was found in small cavities in hydrated teeth restored with Heliomolar.

TABLE 2
CUSP MOVEMENT AT 60 MIN AFTER RESTORATION
(ANOVA AND DUNCAN MULTIPLE-RANGE TESTS)

ANOVA Summary Table (Alpha = 0.05)

Source	df	SS	F value	Pr > F
Group	7	3871.51	55.65	0.0001

Duncan Multiple-range Test
(Alpha = 0.05, df = 31, ms = 9.94175)

Source	Mean (μm)*	Grouping+
Small wet Heliomolar	10.8	A
Small dry Heliomolar	21.1	B C
Small wet P-50	23.2	C
Small dry P-50	26.0	C
Large wet Heliomolar	31.5	D
Large wet P-50	32.5	D
Large dry Heliomolar	40.3	E
Large dry P-50	45.7	F

*n = 5.
+Means with the same letter are not significantly different.

TABLE 3
CUSP MOVEMENT (μm) AFTER 60 MIN
CAUSED BY COMPOSITE POLYMERIZATION SHRINKAGE

Material	Hydration	Large Cavities mean* (SD)	Small Cavities mean (SD)
P-50	Wet	32.5 (3.6)	23.2 (2.5)
	Dry	45.7 (4.8)	26.0 (3.7)
Heliomolar	Wet	31.5 (2.5)	10.8 (1.8)
	Dry	40.3 (2.6)	21.1 (3.2)

*n = 5.

One-way analysis of variance showed that there were significant differences among the experimental groups at the end of the observation period (Table 2). Results of the Duncan multiple-range test are also presented in Table 2. Small cavities had less cusp movement than large cavities; teeth restored with Heliomolar were not statistically different from those restored with P-50; and hydrated teeth had less cusp movement than dry teeth. Mean cusp displacements and standard deviations for the experimental groups are summarized in Table 3.

The tilt of the buccal cusp relative to the lingual cusp in the x-direction (bucco-lingual direction) was found, as expected, to be more than that in the y-direction (mesio-distal direction). The changes in the angle of tilt in the bucco-lingual direction are shown for the experimental groups in Fig. 4.

Discussion.

Interferometry permitted real-time measurement of cusp movement as it occurred. Contraction occurred very rapidly; about 1/3 of the 60-minute amount occurred during the first 2 min while the composite was exposed to the curing light. Measurements were begun when the curing light was turned on.

The amounts of deformation measured, 10.8-45.7 μm, were similar to those found by other methods in previous studies. Movement of cusps was smooth rather than interrupted and indicated no microfracturing at these deformations. This agrees with some previous work (McCullock and Smith, 1986) but disagrees with others (Causton *et al.*, 1985; Pearson and Hegarty, 1987).

Cusp movements expressed as a percentage of cavity width were very similar to literature values of linear shrinkage of the resins: Heliomolar, 2.8 vol% (0.93 lin%), and P-30 (forerunner of P-50), 3.6 vol% (1.2 lin%) (Feilzer *et al.*, 1988). Our values were 0.94% and 1.21%, respectively, and were obtained by dividing mean values of cusp movement from Table 3 by the cavity widths in Table 1.

Several factors may influence the displacement of the cusps by the setting contraction of the composite: (1) the elastic modulus and flow of the composite, (2) bonding between the composite and tooth, and (3) the flexibility of the tooth. Feilzer *et al.* (1990b) have shown that stress build-up is higher and stress relief by flow is less with composites with high elastic moduli. Consequently, P-50, with its higher filler loading and stiffness, was expected to result in more cuspal deformation than Heliomolar. This trend was seen, though it was not statistically significant.

Bonding between the composite and tooth will transmit shrinkage stresses in the composite to the tooth and result in cusp deformation. In the absence of bonding, composite shrinkage results in gap formation between the composite and tooth (Hansen and Asmussen, 1989). In this study, gap formation was not determined; however, effective bonding was presumed, since cusp deformations approximated linear shrinkage values of the composites.

The larger the cavity size, the greater was the cusp movement. This can be explained by two points: First, there was less tooth structure left in large cavities, which meant more flexibility of the cusps and more compliance with composite shrinkage. As the cavity preparation becomes wider and deeper, the strength of the prepared tooth is considerably reduced and the tooth becomes more flexible (Blaser *et al.*, 1983; Douglas, 1985).

Second, the greater total volume of composite needed for restoration of large cavities results in higher shrinkage force (Goldman, 1983). Although large restorations might be expected to permit more flow than smaller ones, this did not offset the factors contributing to higher cusp deformation.

Restoring large cavities in several increments has been shown to distribute the contraction strain among the increments, reduce the stress on the cusps, and result in less cusp deformation (Jensen and Chan, 1985). Due to the experimental set-up used for interferometry, which requires undisturbed mirrors for observation of fringes produced by cusp movement, an incremental technique was not possible. Consequently, the results obtained in this study represent the extreme.

Hydration of teeth may potentially influence in several ways the deformation of teeth restored with composites. A hydrated tooth may be more flexible, and this would lead to higher deformation. Hydration interferes with bonding to dentin of some bonding agents. Lack of bonding to dentin may permit contraction of the composite without deformation of the tooth by formation of a gap between composite and dentin. If this is the case, hydration would decrease deformation of the tooth. Finally, absorption of water by composite is known to offset polymerization shrinkage to some extent. Since the hydrated teeth deformed less than dry teeth, it is hypothesized that this was due to decreased bonding between the composite and wet teeth and to absorption of water by composite.

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