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Effect of Using Silorane-based Resin Composite for Restoring Conservative Cavities on the Changes in Cuspal Deflection

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Clinical Relevance

After five minutes of curing, the change in the organic matrix of the resin composite using silorane has a positive effect on controlling the cumulative cuspal deflection.

SUMMARY

Objective: **To investigate the effect of using two resin-composite materials for restoring conservative mesio-occluso-distal (MOD) cavities on the changes (incremental and cumulative) in cuspal deflection.**

Methods: **Forty extracted sound human maxillary second premolars were subjected to standardized MOD cavity preparation and then divided into two groups (n=20). The first group of teeth was restored with Filtek Z250 (3M ESPE, St Paul, MN, USA), and Filtek P90 (3M ESPE, St Paul, MN, USA) was used in the second group. Incremental cuspal deflection was calculated by measuring the intercuspal distance between the indexed cusp tips before the restoration and at five-minute intervals up to 30 minutes using a stereomicroscope connected to a digital camera. Cumulative cuspal deflection for both materials was also calculated.**

Results: **Comparing the incremental cuspal deflection of the tested groups at each time interval, it was found that there was no significant difference immediately after curing and at five, 15, 20, and 25 minutes. However, a significant difference was recorded at 10 and 30 minutes. For the cumulative cuspal deflection, Filtek P90 showed significantly lower deflection values than Filtek Z250 only after five minutes.**

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Conclusions: **Incremental cuspal deflections of both materials over the tested intervals were almost comparable. However, after five minutes of curing, silorane-based resin composite surpassed the methacrylate-based resin composite in controlling the cumulative cuspal deflection.**

INTRODUCTION

Restorative resin composites have been used in dentistry for 41 years.[1] Notwithstanding the indisputable technological advances introduced during these decades, the volumetric shrinkage of methacrylate-based resin composite remains a major concern.[2] The development of the stresses in tooth structure can be manifested clinically as cuspal deflection. Teeth with mesio-occluso-distal (MOD) cavities have recorded the highest cuspal deflection values when direct resin composite restorations are used.[3] Thus, several approaches have been taken to diminish polymerization shrinkage.[4-6] One such approach incorporated 40 wt% of pre-cured composite particles to reduce the volume of shrinking matrix available during polymerization; however, this was found to increase the material's stiffness.[5] Clinically, the use of different modes of curing has been recommended, yet this did not significantly reduce the shrinkage.[6]

Silorane-based resin composite has been on the market since 2007. A silorane molecule contains a siloxane core with four attached oxirane rings that open upon polymerization and bond with other monomers.[4] The oxirane ring opening leads to a volumetric expansion that, to a certain degree, counteracts the volumetric shrinkage resulting from monomers bonding. [4] Previous studies confirmed that silorane-based resin composite has a total volumetric shrinkage of 1% or less compared with the methacrylate-based composites that resulted in 2%-3.5% shrinkage.[4,7] This low shrinkage property of silorane-based resin composite might lessen the need to control the negative effects that occur when restoring cavities with a high configuration factor (C-factor) and diminish the need for using the incremental application technique. Consequently, restoration of complex cavities in posterior teeth would become easier. Meanwhile, low shrinkage does not necessarily result in low contraction stress, which may manifest itself clinically by cuspal deflection.[8] Therefore, it is important to verify the behavior of this new composite in this term. The null hypothesis tested was that there is no difference between the two materials in regards to the incremental changes and the cumulative changes in cuspal deflection.

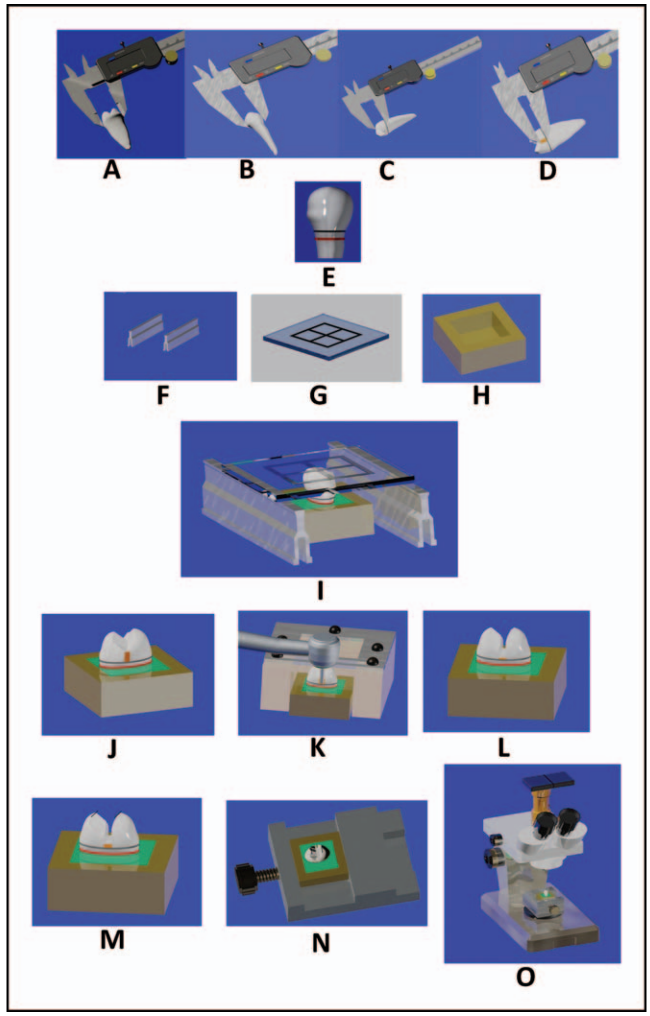

Figure 1. *Schematic drawing illustrating the study setup. (A, B, C, and D): Measurement of the premolars to select those that do not vary more than 5%. (E): A specimen with the root apex trimmed. (F, G, H, and I): The metallic stands, glass slab, and mold used for the specimen mounting. (J and K): The embedded specimen and specially constructed setup used to stabilize the handpiece and fix the distance during the cavity preparation. (L): The prepared embedded specimen. (M): The prepared embedded specimen with the two horsehairs fixed to the cusp tips. (N): The specimen stabilized to the specially constructed holder during measuring the cusp deflection. (O): The stereomicroscope to which a digital camera was attached.*

Materials and Methods

Selection and Standardization of Teeth

Freshly extracted non-carious human maxillary second premolars, extracted for orthodontic purposes from patients aged from 15 to 18 years, were collected. The teeth were inspected using a magnifying lens (6×) (Bausch and Lomb, Rochester, NY, USA) to confirm the absence of visible hypoplastic defects or cracks. The maximum buccopalatal width and the maximum mesiodistal width were measured using a digital caliper (Mitutoyo Corp, Kawasaki, Japan) as shown in Figures 1A and 1B. The cementoenamel junction (CEJ) was demarcated with an indelible pen. The height of the palatal cusp was measured from the cusp tip to the demarcated CEJ (Figure 1C). For the distal proximal surface, the mid-proximal line extending from crest of the marginal ridge to the CEJ was also demarcated and measured (Figure 1D). From the collected premolars, 40 teeth that showed less than 5% variation in the measured dimensions were selected. A second line was drawn so that the height of the crown segment left above its level was standardized to 10 mm for all specimens. The level of this line varied by 2 ± 0.5 mm apical to the CEJ to accommodate the 5% difference in cusp height. The apical one third of each selected tooth was trimmed using an Isomet saw (Buehler Ltd, Lake Bluff, IL, USA) to aid in the specimen mounting (Figure 1E). Teeth were stored in a phosphate buffer solution (pH=7) with 0.02% sodium azide at 4°C. Teeth were kept moist except when the study protocol required isolation from moisture.[9]

Fabrication of the Mold and Supporting Stands

To standardize the height of the specimen after mounting, two metallic stands 25-mm long were fabricated to support the glass slab (50 mm × 50 mm) to which the specimen was fixed during mounting (Figures 1F and 1G). A square split metal mold was constructed with the following dimensions: the external dimension was 30 mm long and 15 mm high, and the internal dimension was 20 mm long and 10 mm high (Figure 1H). The two metal stands were designed to guarantee that the palatal cusp tip of the mounted specimen was 10 mm higher than the upper edge of the metal mold.

Mounting of the Specimens

A square (30 mm × 30 mm) with two perpendicularly intersected lines was drawn on each glass slab. Each specimen was fixed from its occlusal surface to the center of the drawn square using fast-set glue (Jip, Axxon, Belgrade, Serbia). A chemically activated polyester material (polyester #2121, ETERNAL CHEMICAL CO., LTD., Hsien, Taiwan) was mixed according to the manufacturer's instructions in a disposable plastic cup. The resin/activator ratio was 5:1. The mixture was poured to fill the mold up to the second drawn line (2 ± 0.5 mm below the CEJ) as presented in Figure 1I. Thus, the height of crown segment left above the level of the embedding material was standardized to 10m m for all specimens (Figure 1J).

Cavity Preparation

The cavities were prepared using a cylindrical diamond stone (#015, Komet Gebr, Brasseler, Lemgo, Germany) operated at low speed with continuous water coolant application. A specially constructed set was used to ensure control of the proper depth, width, and parallelism between the buccal and lingual walls (Figure 1K). The set comprised two metal slides fixed to a hollow plastic U-shaped frame (30 mm high, 30 mm wide). The two metal slides allowed the head of the handpiece to rest upon it at a total height of 30 mm. This height was planned to accommodate the height of the embedded specimen (from the base of the mold to the cusp tip) as shown in Figure 1K. In each specimen, a standardized centralized MOD slot cavity with parallel lingual and buccal walls was prepared (Figure 1L). The prepared cavity was proposed to have the following dimensions: buccopalatal width of 1.5 mm and 2 mm depth of the pulpal floor from the top of the demarcated mid-proximal lines. The final cavity dimensions were checked using a digital caliper (Mitutoyo Corp, Kawasaki, Japan). Dimensions for each cavity were measured, and means and standard deviations were calculated. The C-factor (bounded area/unbounded area) was also calculated.

Grouping of Specimens and Restoration Placement

The prepared specimens were divided into two main groups of 20 specimens each, according to the resin composite material used. The materials used in the current study are presented in Table 1. A methacrylate-based microhybrid resin composite Filtek Z250 (3M ESPE, St Paul, MN, USA) was used in group 1, whereas a low shrinkage silorane-based microhybrid resin composite Filtek P90 (3M ESPE, St Paul, MN, USA) was used in group 2. The cuspal deflection of each specimen (n=20/group) was recorded using a stereomicroscope before curing, just after curing (within 30 seconds), and every five minutes over a period of 30 minutes. The end result was eight records for each specimen and a total of 40 × 8 = 320 readings for both tested groups. Clearfil SE Bond (Kuraray Medical Inc, Osaka, Japan) was used for the Filtek Z250 resin composite group, whereas the P90 System Adhesive (3M ESPE, Seefeld, Germany) was used for the Filtek P90 resin

Table 1: *Resin Composite Restorative Materials and Adhesive Systems Used in the Study*

Brand name/ Manufacturer	Description	Compositions	Lot No.
Filtek Z250 (shade A3), 3M ESPE, St Paul, MN, USA	Methacrylate-based microhybrid resin composite	*Organic resin*: Bis-GMA, UDMA, and Bis-EMA *Inorganic filler*: Silica/zirconia (60% by volume); the filler particle-size distribution is 0.01 μm to 3.5 μm with an average particle size of 0.6 μm	N137859
Filtek P90 (shade A3), 3M ESPE, St Paul, MN, USA	Low shrinkage silorane-based microhybrid resin composite	*Organic resin:* 3,4-epoxycyclohexylethylcyclopolymethylsiloxane, bis-3,4-epoxycyclohexylethylphenylmethylsilane, camphorquinone, stabilizers, and pigments. *Inorganic filler*: Quartz/yttrium fluoride (53% by volume), average particle size of 0.47 μm	8BP
Clearfil SE, Bond, Kuraray Medical Inc, Osaka, Japan	Two- step self-etch adhesive system	*Primer*: MDP, HEMA, hydrophilic dimethacrylate, photoinitiator, ethanol, water	*Primer*: 00999A
		Bond: MDP, HEMA, Bis-GMA, hydrophobic dimethacrylate, photoinitiators, silanated colloidal silica	*Bond*: 01486A
P90 System Adhesive, 3M ESPE, Seefeld, Germany	Two-step self-etch adhesive system	*Primer*: phosphoric acid methacryloxyhexyl esters mixture, 1,6-hexanediol dimethacrylate, copolymer of acrylic and itaconic acid, phosphine oxide, (dimethylamino) ethyl methacrylate, BisGMA and HEMA, water and ethanol, camphorquinone, silane-treated silica filler with a primary particle size of about 7 nm	*Primer*: N139733
		Bond: Substituted dimethacrylate, TEGDMA, phosphoric acid methacryloxyhexyl esters, 1,6-hexanediol dimethacrylate camphorquinone, silane-treated silica fillers	*Bond*: N139734
Scotchbond, 3M ESPE St. Paul, MN, USA.	Etchant gel	37% phosphoric acid, thickening agents	N149102

Abbreviations: Bis-EMA, bisphenol A ethoxylate dimethacrylate; Bis-GMA, Bisphenol-A-glycidyl-dimethacrylate*; HEMA, 2-hydroxyethyl methacrylate; MDP, 10-methacryloxydecyl dihydrogen phosphate; TEGDMA, triethylene glycol dimethacrylate; UDMA, urethane dimethacrylate.*

composite group. Both adhesive systems were applied according to the manufacturer's instructions as shown in Table 2. The cavities were thoroughly washed with distilled water to remove any debris found during preparation. Before any of the adhesive systems were applied, the enamel was etched for 15 seconds with Scotchbond etchant gel (3M ESPE, St Paul, MN, USA) followed by thorough washing with water for 10 seconds and drying for five seconds. Each prepared specimen was bulk filled (one increment) with the proposed resin composite.[10] The resin composite increments were weighed using a sensitive digital balance (0.0875 ± 0.002 g). The resin composite was light-cured with a light-emitting diode (LED) light curing unit (Satelec Acteon Group, Mérignac Cedex, France). The intensity of the light curing unit (1250 mW/cm^2) was checked using an LED radiometer (Kerr Dental Specialties, Orange, CA, USA). Light curing was done from the distal, mesial, and occlusal sides for 40 seconds each, resulting in a total curing time of 120 seconds.[11]

Measurement of Cuspal Deflection

A stereomicroscope was used to precisely measure the cuspal deflection. It consisted of a stereomicroscope (Labomed CZM4, Fremont, CA, USA) to which a digital camera (Nikon Coolpix P5100, Melville, NY, USA) was attached. Two equal lengths of horse hair[12] (0.13 mm diameter**;** Shanghai Vidaware Co Ltd, Shanghai, China) were fixed on the cusp tips of both cusps (Figure 1M) using Clearfil SE Bond. The prepared specimens were held by a specially constructed metal holder to ensure their stability and to retain the same position under the stereomicroscope

Table 2: *Mode of Application of the Adhesive Systems Used in the Study*

Adhesive System	Mode of Application
Clearfil SE Bond	• Apply primer using a microbrush.
	• Leave for 20 seconds.
	• Dry gently with oil-free air stream for 10 seconds.
	• Apply bond and distribute evenly.
	• Dry gently with oil-free air stream for five seconds.
	• Light cure for 10 seconds.
P90 System Adhesive	• Apply primer using microbrush with agitation.
	• Leave for 15 seconds.
	• Dry gently with oil-free air stream for five seconds.
	• Light cure for 10 seconds.
	• Apply bond and distribute evenly.
	• Dry gently with oil-free air stream for five seconds.
	• Light cure for 10 seconds.

during curing and photographing (Figure 1N).[13] The specimens were viewed under a trinocular stereomicroscope at 40× magnification (Figure 1O). ImageJ software (NIH, version v1.45e, National Institutes of Health, Bethesda, Maryland, USA) was calibrated, and each image was viewed on the computer screen for preanalysis adjustments. Images were processed for brightness adjustment and color enhancement. The processed images were then converted into eight-bit grayscale images. The distance between the two hair lengths was registered before tooth restoration, immediately after light-curing, and after five-minute intervals over 30 minutes.

Statistical Analysis

A paired *t*-test was used to compare groups for the two restorative materials regarding teeth dimensions (buccopalatal width, mesiodistal width, distal proximal height, and palatal cusp height), as well as cavity dimensions and C-factor. One-way analysis of variance (ANOVA) was used to compare changes in cuspal deflection and cumulative changes over time intervals for the two tested materials. Conover-Inman was used for pairwise comparison. A *t*-test was used to compare cuspal changes and cumulative changes for both restorative materials at each time interval.

RESULTS

Statistical analysis using *t*-tests revealed that there was no significant difference between the tooth dimensions ($p = 0.1$), cavity dimensions ($p=0.1$), or C-factor ($p \geq 0.4$) in both groups. The descriptive statistics and test of significance of the mean changes in the cuspal deflection (μm) for Filtek Z250 and Filtek P90 are presented in Table 3. Statistical analysis comparing the change in cuspal deflections over time using one-way ANOVA revealed significant differences for both groups as shown in Table 3. Statistical analysis comparing the cumulative change in cuspal deflection over time using one-way ANOVA revealed significant difference for both groups, as shown in Table 4. Comparing the two groups at each time interval using a *t*-test revealed that there were significant differences at 10, 15, 20, 25, and 30 minutes.

DISCUSSION

The thickness of the remaining cusps plays an important role in determining the degree of cuspal deflection. Cusps of teeth with large cavity preparations displayed greater deflection than those of teeth with small cavities.[14] It has been reported that one of the major constraints that influences cuspal deflection measurements is the difference in cusp thicknesses among natural teeth.[15,16] Therefore, in the current study, the problem of possessing different cusp thicknesses was eliminated by keeping the size differences between the teeth less than 5%[9,10,17-20] and by standardizing the cavity preparation and restoration methods. A stereomicroscope was used to measure the cusp deflection without contacting the teeth.[12] In contrast, other methods that come in contact with the teeth, such as transducers, may stiffen the cusps, thereby interfering with their free movement.[12]

The statistical analysis demonstrated a significant difference between the two materials; thus, the null hypothesis was rejected. The finding could be explained based on the different polymerization

Table 3: *Descriptive Statistics and Test Significance of the Mean Changes in the Cuspal Movement (μm) for the Filtek Z250 and Filtek P90 Groups*

Time	Filtek Z250, Mean (SD)	Filtek P90, Mean (SD)	*P Value*
Immediate	–5.90 (2.8)^{aA}	–4.733 (1.6)^{aA}	0.23
5 minutes	–4.04 (1.7)^{aA}	–3.93 (1.9)^{bA}	0.88
10 minutes	–2.45 (1.7)^{bA}	–1.078 (0.7)^{cB}	0.007
15 minutes	–3.31 (2.5)^{cA}	–3.34 (2.5)^{bA}	0.92
20 minutes	–1.85 (2.6)^{dA}	–1.23 (0.9)^{cA}	0.92
25 minutes	–1.79 (1.2)^{dA}	–1.17 (1.2)^{cA}	0.048
30 minutes	–0.72 (0.8)^{dA}	–1.80 (1.6)^{cB}	0.040
P value	<0.0001	<0.0001	

Within rows, means with different capital letters are statistically significantly different ($p \leq 0.05$, t-test); Within columns, means with different small letters are statistically significantly different ($p \leq 0.05$, Conover-Inman test).

Table 4: *Descriptive Analysis and Test of Significance of Cumulative Change in Cuspal Movement (μm) of Filtek Z250 and Filtek P90 at Different Time Intervals*

Time	Filtek Z250, Mean (SD)	Filtek P90, Mean (SD)	*P* Value
Immediate	–5.90 (2.8)^{aA}	–4.7 (1.6)^{aA}	0.23
5 minutes	–9.95 (3.9)^{bA}	–8.67 (2.6)^{bA}	0.25
10 minutes	–12.39 (3.6)^{cA}	–9.75 (2.9)^{cB}	0.01
15 minutes	–15.70 (3.6)^{dA}	–13.09 (3.7)^{dB}	0.02
20 minutes	–17.56 (3.0)^{eA}	–14.33 (3.5)^{eB}	0.003
25 minutes	–19.35 (2.3)^{fA}	–15.49 (3.2)^{fB}	0.0001
30 minutes	–20.08 (1.7)^{gA}	–17.29 (2.0)^{gB}	0.0001
P value	<0.0001	<0.0001	

Within rows, means with different capital letters are statistically significantly different ($p \leq 0.05$, t-test); Within columns, means with different small letters are statistically significantly different ($p \leq 0.05$, Conover-Inman test).

processes of the two materials. The cationic ring opening of oxirane moieties in the silorane-based composite yields a reduced volumetric shrinkage[21,22] in contrast to the free radical addition reaction of the double bonds of the dimethacrylate-based composite.[4,7,23] When acidic cations attack the oxirane rings, the cleavage and opening of these rings gain space, thus counteracting the loss of volume occurring in the subsequent step when covalent bonds are formed.[7] The lower shrinkage of silorane-based material due to its alternative resin formulation was confirmed by other authors.[24] Nevertheless, there was a difference in the obtained values between both studies, which may be related to the difference in the testing conditions, approaches, and time intervals at which the cuspal deflections were recorded.[15,25,26]

Concerning the incremental changes in cuspal deflection, the recorded measurements of each restoration were not consistent over the tested intervals. Additionally, both restorations exhibited no significant difference in cuspal deflection values at all recorded time intervals, except at 10 minutes and 30 minutes. This indicates that the amount of change in the cuspal deflection was not consistent for each restoration and the amount of change for Filtek P90 was not constantly lower than that of Filtek Z250. The high initial nonsignificant cuspal deflection shown by Filtek P90 may indicate its high polymerization stress value in spite of its low volumetric shrinkage. Previous research supports this point in that low volumetric shrinkage does not necessarily correspond to a low polymerization stress development.[2,5] Marchesi and others[22] support this assumption, as they have revealed no significant difference between Filtek P90 and Filtek Z250 in the recorded shrinkage stresses after five minutes. Additionally, the microtensile results recorded by Van Ende and others[27] failed to confirm that silorane resin composite (Filtek P90) induces less stress at the adhesive interface compared with methacrylate resin. It seems that the polymerization degree and rate, the elastic modulus acquired during polymerization, and the volumetric changes are important contributing factors in contraction stress development.[28] Regarding the polymerization rate, although the cycloaliphatic oxirane sites of silorane have high reactivity and shrink less during polymerization, the extent to which the reactions will achieve better polymerization and higher cross-linking density compared with free-radical polymerization is not yet clear.[29] Additionally, the change in the composite viscoelastic behavior that occurs during polymerization makes polymerization stress development quite a complex event.[2] Therefore, any analysis of shrinkage stresses should consider the restorative material properties and all other contributing factors.

CONCLUSIONS

Incremental cuspal deflections of both materials over the tested intervals were almost comparable. However, after five minutes of curing, the silorane-based resin composite surpassed the methacrylate-based resin composite in controlling the cumulative cuspal deflection.

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Conflict of Interest Declaration

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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