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# Effect of Composite Insertion Technique on Cuspal Deflection Using an *In Vitro* Simulation Model

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### Clinical Relevance

All insertion techniques using composite materials caused measurable cusp deflection during polymerization, with little difference between different incremental techniques. The silorane-based composite produced significantly less cuspal movement.

## SUMMARY

**Objective: The objective of this study was to investigate, by simulation, the effect of conventional composite resin insertion techniques on cuspal deflection using bonded typodont artificial teeth. The deflection produced by a new low-shrinkage composite was also determined.**

**Materials and Methods: Sixty standardized MOD preparations on ivorine maxillary premolars were prepared: group A at 4 mm depth and group B at 6 mm depth. Each group was further subdivided according to composite insertion technique (n=6), as follows: 1) bulk insertion, 2) horizontal increments, 3) tangential increments, and 4) a modified tangential technique. Preparations were microetched, acid-cleaned, and bonded with adhesive resin to provide micromechanical attachment before restoration with a conventional composite (Spectrum TPH[3], Dentsply). Two additional subgroups at 4 mm and 6 mm depth (n=6) were restored in bulk using low-shrinkage composite (Filtek LS, 3M/ESPE). All groups received the same total photo-polymerization time. Cuspal deflection was measured during the restorative procedure using two Linear Variable Differential Transformers attached to a data acquisition system.**

**Results: The average cuspal deflections for group A were 1) 40.17 ± 1.18 μm, 2) 25.80 ± 4.98 μm, 3) 28.27 ± 5.12 μm, and 4) 27.33 ± 2.42 μm. The deflections in group B were 1) 38.82 ± 3.64 μm, 2) 50.39 ± 9.17 μm, 3) 55.62 ± 8.16 μm,**

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DOI: 10.2341/11-086-L

**and 4) 49.61 ± 8.01 μm. Cuspal flexure for the low-shrinkage composite was 11.14 ± 1.67 μm (group A: 4 mm depth) and 16.53 ± 2.79 μm (group B: 6 mm depth).**

**Conclusions**: **All insertion techniques using conventional composite caused cuspal deformation. In general, deeper preparations showed increased cuspal deflection—except in the case of bulk insertion, which was likely affected by decreased depth of cure. Cuspal movement using low-shrinkage composite was significantly reduced.**

## INTRODUCTION

In spite of the increased use of resin composite materials in various procedures in dentistry, bulk contraction or polymerization shrinkage remains a major contributor to the clinical drawbacks associated with these materials.[1,2]

Polymerization stresses generated by polymerization shrinkage may compromise the bond integrity,[3] leading to concerns such as microleakage, postoperative sensitivity, and ultimately secondary caries.[1–8] If the composite-tooth bond remains intact, stresses transferred to tooth structure may result in cuspal flexure, enamel fracture, or fractured cusps.[4,7,9–13]

All methacrylate-based composite materials undergo polymerization shrinkage upon curing, with a reported range of 2–5%.[4] Optimizing particle sizes, maximizing filler content, and minimizing the concentration of 'diluent' monomers in the resin formulation are steps taken by the manufacturers to reduce the degree of polymerization shrinkage.[2]

In addition, material development by incorporation of ring-opening monomers has resulted in formulation of a new class of silorane composites with significantly lower volumetric shrinkage (less than 1%).[2] However, conventional composites are still widely used in practice, and polymerization shrinkage remains a clinical concern.

Incremental insertion techniques are recommended to reduce the undesirable effects of polymerization shrinkage by maximizing the ratio of unbonded to bonded surfaces (C-factor).[12] The unbonded surface purportedly allows for unhindered "flow" of composite monomers and permits stress relief along this surface. Incremental insertion techniques can also reduce the effects of polymerization shrinkage by reducing the bulk of composite cured with each layer, and it is generally recognized that the overall size and cavity configuration influence the resulting shrinkage stress and the degree of cuspal deflection.[12–16] Many different incremental insertion techniques are recommended; however, the evidence used to define the most appropriate technique is inconclusive, and many questions remain. Research to measure the degree of cuspal deflection with different materials and/or techniques *in vitro* has inherent limitations. The use of extracted teeth can be problematic as a result of their size, shape, and biological differences.[16] In addition, the modulus of elasticity varies between teeth, which can affect the degree of flexure and the interpretation of results. The use of artificial materials, such as aluminum blocks, has been suggested[16] to avoid these biological problems; however, the specimens used do not provide morphological similarity to teeth.

The aims of this study were to use an *in vitro* simulation model 1) to determine the effect on cuspal deflection of different incremental insertion techniques and 2) to determine the effect of a new proprietary low-shrinkage resin composite on cuspal deflection.

## MATERIALS AND METHODS

### Specimen Preparation

Sixty stylized, MOD preparations were prepared in maxillary second bicuspid ivorine teeth (Kilgore International, Coldwater, MI, USA). Cavities were prepared using a uniform cavity design with standardized measurements and were facilitated by a single operator. The width of the prepared cavities was two-thirds of the intercuspal distance (4 mm) at two variable cavity depths, 4 mm and 6 mm. The cavity depth was gauged from the tip of the buccal cusp to the pulpal floor. Buccal and lingual walls were prepared parallel without occlusal convergence. The stylized, slot MOD preparation, prepared without proximal boxes, was utilized in order to minimize preparation variation. The depth of 4 mm provided an intermediate overall MOD depth instead of the combination of a shallower occlusal portion with deeper proximal boxes. The 6mm depth preparations were included to simulate endodontically treated teeth that are deeper because of the necessity for occlusal access into the pulp.

All cavity preparations were air-abraded using 50-μm aluminum-oxide powder for 60 seconds to create cavity wall microroughness in order to simulate a bonded restoration. To ensure an adequate strength of micromechanical attachment between the composite and ivorine teeth, a pilot study using standard microtensile testing was carried out. A group of

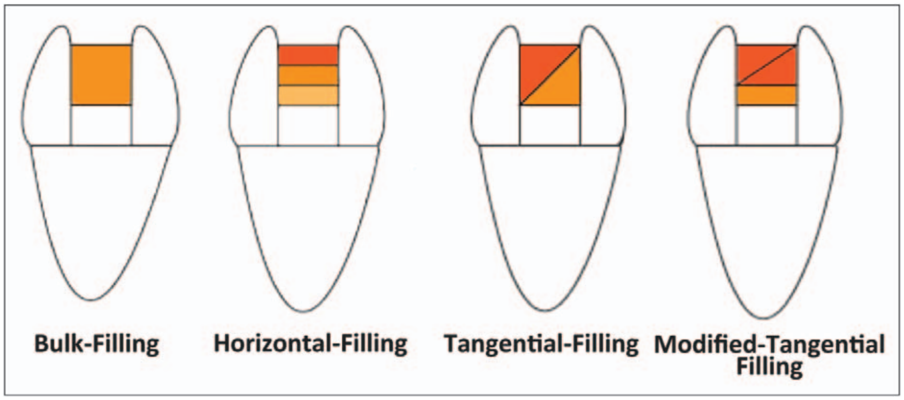


Figure 1. *Schematic diagram illustrating the different composite placement techniques.*

ivorine teeth were sectioned, air-abraded, and bonded to both methacrylate and silorane-based resin composite using identical bonding agents and procedures as for the cuspal deflection study described below. Standard microtensile serial sectioning and bond strength testing (Bisco, Schaumburg, IL, USA) were performed. Means were calculated and were considered adequate to ensure attachment of restorations to the cavity walls.

Prepared teeth were divided into two main groups of 30 specimens each: group A (4 mm depth) and group B (6 mm depth). Each group was further subdivided into five subgroups (n=6) according to the composite and the insertion technique used. Four subgroups were all restored using a conventional hybrid composite, Spectrum TPH[3] (Dentsply, Caulk, Milford, DE,USA), and were categorized according to their insertion technique, as follows: 1) bulk insertion, 2) horizontal increments, 3) tangential increments, and 4) a modified tangential technique (Figure 1). The fifth subgroup of both groups was restored using a proprietary low-shrinkage (silorane-based) composite (Filtek LS, 3M ESPE, St Paul, MN, USA) inserted in bulk.

Bonding for all subgroups restored with Spectrum TPH[3] was carried out using Scotchbond Multi-Purpose Adhesive (3M ESPE), omitting the dentin primer step. The low-shrinkage composite restorations were bonded using the corresponding silorane adhesive, following the manufacturer's recommendations. Restorations were inserted and photo-polymerized using a Demetron LC halogen light curing unit (Sybron Dental Specialist, Orange, CA, USA) with an intensity of 400 mW/cm$^2$. All subgroups received the same total curing time of 80 seconds, as defined in Table 1, and in all cases the light cure was directed from the occlusal surface. Light source was held as close as possible to the occlusal surface, avoiding any contact with the tooth to eliminate any effect on the Linear Variable Differential Transformers (LDTVs).

## Cuspal Deflection Measurements

Cuspal deflection was measured continuously throughout the restorative placement procedure using two LVDTs (AX/1/S, Omega, Stamford, CT, USA) with a sensitivity of 2/2.03 mV/V. These were attached to an Instron machine DAX V7.0 data acquisition system at room temperature and mount-

Table 1: *Photo-Polymerization Scheme Followed for the Different Subgroups*

| Cavity Depth | Bulk Insertion | Horizontal Increments | Tangential Increments | Modified Tangential Increments |
|---|---|---|---|---|
| Group A (4 mm) | 80 seconds | 1 mm + 1.5 mm + 1.5 mm | Two equal increments | 1 mm + two equal increments |
| | | 20 × 20 × 40 = 80 s | 40 × 40 = 80 s | 20 × 30 × 30 = 80 s |
| Group B (6 mm) | 80 seconds | 2 mm + 2 mm + 2 mm | 2 × 2 mm increments | 2 mm + two equal increments |
| | | 20 × 20 × 40 = 80 s | 40 × 40 = 80 s | 20 × 30 × 30 = 80 s |

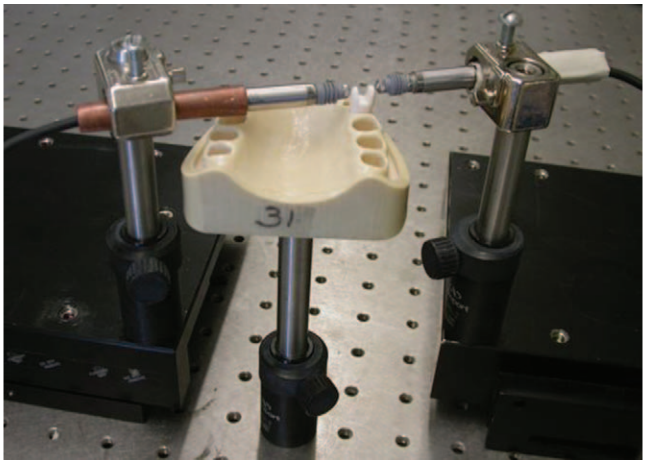

Figure 2. *LVDTs touching the buccal and lingual cusps (the mechanism allowed LVDTs to be constantly in contact with the tooth).*

ed on a stabilized table. The LVDTs were placed such that they touched the buccal and lingual surfaces of the mounted ivorine tooth throughout the test (Figures 2 and 3). Cuspal deflection was recorded from the start of the restorative procedure until the deflection became a continuous plateau. The combined extent of buccal and lingual cuspal deflection was calculated and statistically analyzed using univariate analysis of variance with post hoc Tukey's test ($p$<0.05). If detachment from the bonded interface was identified from an abnormal pattern of deflection, the sample was rejected.

## RESULTS

In a pilot study, used to assess the strength of the composite to ivorine attachment, the mean microtensile bond strengths of conventional hybrid and low-shrinkage composite materials to air-abraded ivorine "tooth" surfaces were 27.56 and 28.33 MPa, respectively, ensuring adequate attachment with which to measure cuspal deflection.

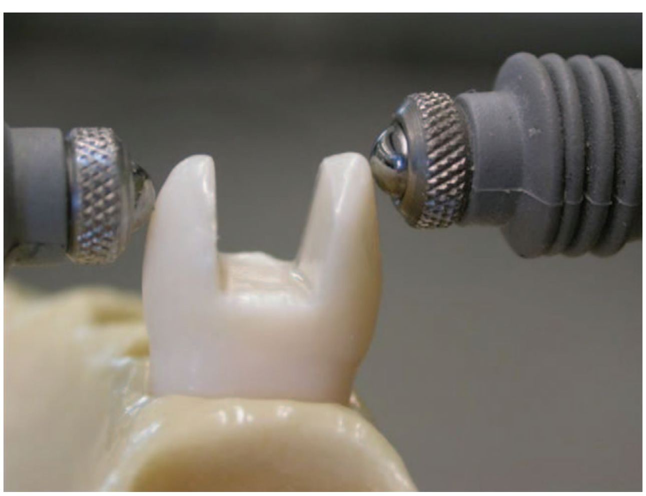

Figure 3. *LVDTs connected to data acquisition system, in which the entire setup was assembled on a stabilized table to minimize noise.*

Table 2: *Means ± Standard Deviations of Combined Buccal and Lingual Cuspal Deflection of all Subgroups Restored with Conventional Composite*[a]

| Insertion Technique | Group A (4 mm Depth) | Group B (6 mm Depth) |
|---|---|---|
| Bulk placement | 40.17 ± 1.18 Aa | 38.82 ± 3.64 Aa |
| Horizontal increments | 25.80 ± 4.98 Bb | 50.39 ± 9.17 Cb |
| Tangential increments | 28.27 ± 5.12 Bb | 55.62 ± 8.16 Cb |
| Modified tangential increments | 27.33 ± 2.42 Bb | 49.61 ± 8.01 Cb |

[a] *Means followed by different on-line small capital letters in the same row and lowercase letters in the same column are significantly different at* $p < 0.05$.

All insertion techniques using conventional composite caused measurable cuspal movement. Table 2 shows the results for the combined palatal and lingual cusp deflection of all experimental groups restored with conventional composite. Table 3 provides the results for the combined palatal and lingual cusp deflection for those groups restored in bulk using proprietary low-shrinkage material. Group B (6 mm deep) generally revealed higher cusp flexure when compared to group A (4 mm deep); however, bulk insertion at both 4 mm and 6 mm produced essentially similar cusp movement (Figure 4). At 4 mm depth, bulk placement produced greater cusp flexure than with any of the incremental insertion techniques. All incremental techniques used in 6 mm depth preparations were significantly higher than those for 4 mm depth. Overall, there

Table 3: *Means ± Standard Deviations of Combined Buccal and Lingual Cuspal Deflection of Subgroups Restored with Low-Shrinkage Composite*[a]

| Insertion Technique | Group A (4 mm Depth) | Group B (6 mm Depth) |
|---|---|---|
| Bulk-placement | 11.14 ± 1.67 A | 16.53 ± 2.79 B |

[a] *Means followed by different on-line small capital letters are significantly different at* $p < 0.05$.

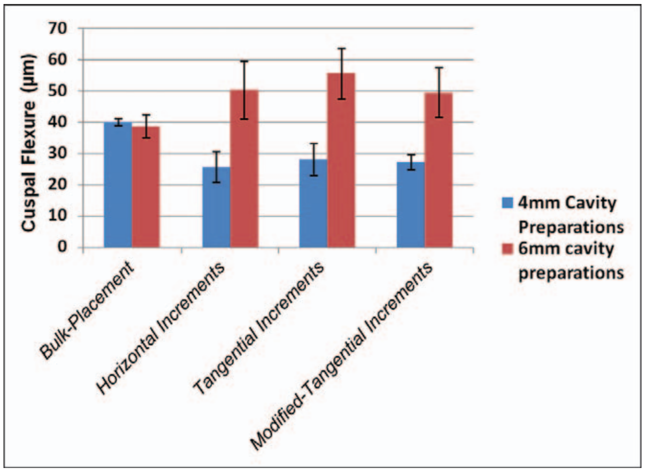


Figure 4. *Bar chart representing means and standard deviations (SDs) of combined buccal and lingual cuspal deflection of all subgroups restored with conventional composite.*

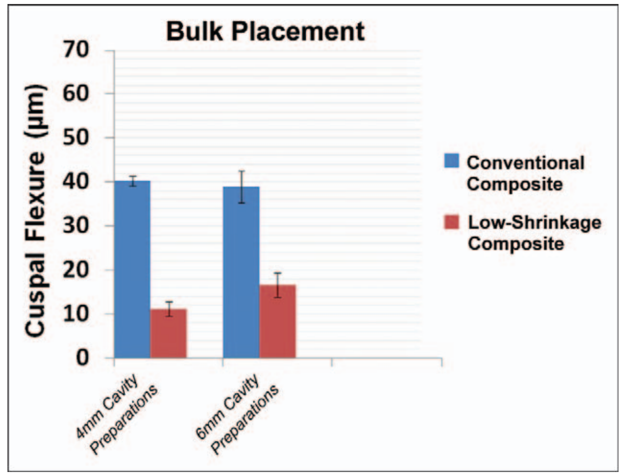


Figure 5. *Bar chart comparing means and standard deviations (SDs) of combined buccal and lingual cuspal deflection of subgroups restored with conventional and low-shrinkage composites placed only using bulk technique.*

were no statistically significant differences among the different incremental placement techniques at each preparation depth (Table 2).

Figure 5 illustrates the difference in cuspal flexure between conventional hybrid composite and low-shrinkage material when bulk placement was used. The low-shrinkage material demonstrated the lowest cuspal flexure of all experimental groups.

## DISCUSSION

It was possible to simulate the cuspal flexure resulting from intracoronal composite restorative procedures by using a micromechanical approach to achieve composite attachment to artificial ivorine plastic teeth.

All insertion techniques using composite resin produced measurable cuspal movement, which could be accurately and continuously recorded during the photo-polymerization process using LVDTs and a data acquisition system on a stable platform. An LVDT is a type of electrical transformer used for measuring linear displacement, and two LVDTs were placed such that they were touching the outer and upper buccal and lingual surfaces of the tooth. The stability of the setting was essential since any slight motion was easily detected by the data acquisition setting. Micromechanical attachment of composite to ivorine polymer was provided through use of air-abrasion. Preliminary microtensile bond strength measurements using this method showed that appropriate bond strengths could be obtained, as indicated by the results recorded in the pilot study. Detachment of composite from the internal preparation walls of the ivorine tooth during polymerization occurred only on two occasions and was obvious as an abrupt halt in movement on the continuous plot recording. Such samples were not included in the results. This experimental simulation system was therefore successful in mimicking the microscopic cusp deformation caused by polymerization shrinkage of composite, without the inherent difficulties involved in the use of extracted teeth. Natural teeth come in many different anatomical shapes and sizes, cannot be standardized, and are difficult to procure. Even a standardized cavity preparation on natural teeth would result in differing cavity wall thicknesses from tooth to tooth, which would affect the resulting cusp movement. The subsequent high standard deviations achieved with natural teeth often preclude determination of significant differences between materials or techniques.

That the use of artificial ivorine teeth was an effective method of simulating cusp movements in natural teeth is shown by the comparable range of cusp movements recorded in the published literature. According to a review by Versluis and others,[8] the overall reported range for studies using natural teeth was 16–45 µm, and the results of these authors' finite element analysis resulted in intercuspal changes of between 25.5 and 45.5 µm for MOD restorations of different sizes. Smaller deflections (15–23 µm) have been reported[11] for natural teeth when smaller dimension cavities were utilized. Use of an experimental silorane low-shrinkage composite in natural bicuspids resulted in a cuspal deflection of 6 µm using a slightly smaller preparation size and a greater (8) number of increments than were used in the current study. [4] These comparisons provide some validation of the ivorine model used.

Ivorine teeth do not, however, replicate the combined properties of dentin and enamel inherent in natural tooth structure; therefore, the use of artificial replacements cannot provide absolute values of expected intraoral cuspal movement, nor do they permit subsequent assessment of marginal microleakage in the restored teeth. The simulation does allow comparison of different restorative materials, preparation sizes, and/or insertion techniques by providing a standardized tooth model. Such comparisons are more clinically realistic than the use of metal or plastic blocks as a result of the anatomical similarity to real teeth.[16]

All insertion techniques using conventional composite caused measurable cusp movement, and, in general, deeper preparations showed significantly higher cuspal deflection. The use of incremental insertion reduced the overall amount of flexure over bulk insertion at standard cavity depth (4 mm); however, there were no significant differences among the different incremental insertion techniques used. It is generally recognized that incremental insertion techniques can reduce the negative effects of polymerization shrinkage by reducing the bulk of composite cured with each layer. Increasing the ratio of unbonded to bonded surfaces has also been suggested to reduce the curing shrinkage by allowing unhindered "flow" in the unbonded surface layer. In this study differences between horizontal and tangential incremental techniques were not apparent, refuting the increased efficacy of tangential increments.

Deeper preparations were clearly more vulnerable to cuspal movement, which almost doubled between 4 mm and 6 mm depths of preparation, despite the use of increments. This is in general agreement with the mathematical theory discussed by Hood,[17] who stated that doubling the cavity depth increases the deflection by a factor of eight, hence the significantly greater risk of fracture for endodontically treated posterior teeth, which may have a cavity depth many times greater than a vital tooth as a result of the access opening. Parenthetically, in this study, the amount of cuspal flexure observed with bulk filling was essentially the same for the 6 mm cavity depth as it was for the 4 mm depth. It is hypothesized that this effect was due to light attenuation preventing the deepest layers of the restoration from full polymerization, which was carried out from the occlusal surface. In essence it is possible that the polymerization light was curing the composite to full cure only for the first 4 mm of depth, thus negating any major differences between 4 mm and 6 mm depths. In contrast, the use of increments allowed full access of each increment to the light, and full cure was effected, resulting in the development of greater contraction shrinkage over the full depth of the cavity preparation. The effect on cusp movement was therefore more significant.

The development of novel low-shrinkage, resin-based composites offers a potential reduction in polymerization shrinkage stresses generated at the tooth/restoration interface compared with current conventional methacrylate composites. The proprietary low-shrinkage silorane material used in this study showed significantly lower cuspal flexure, in accordance with the manufacturer's claim. A reduction in cuspal deflection, as well as a decrease in restoration microleakage, for a similar experimental silorane material has also been reported.[4] With lower polymerization shrinkage, increased marginal integrity,[2] and decreased microleakage,[4] silorane composites may provide potential for decreased marginal staining, decreased postoperative sensitivity, and greater restoration longevity. However, caution is advised with respect to attributing greater clinical success on the basis of lower shrinkage alone. A recent study[18] indicated that low volumetric shrinkage does not necessarily correspond to low polymerization stress development, particularly if the material has a high flexural modulus. Many factors determine restoration success and longevity; therefore, true outcome data will be dependent on appropriate clinical trials.

Shrinkage during curing of resin composite restorative materials can cause significant problems in adhesive dentistry, such as debonding of the restoration-tooth interface, microleakage, marginal staining, and postoperative sensitivity. The use of incremental insertion is recognized as one method of reducing these negative effects. This study confirms the advisability of incremental insertion but was unable to demonstrate the superiority of one particular incremental technique. The amplified negative effect of increased cavity depth was apparent despite the use of incremental insertion. Furthermore, the potential for a proprietary silorane composite material to significantly reduce cusp deflection during polymerization was demonstrated.

## CONCLUSIONS

Under the conditions of this study:

- All insertion techniques using conventional composite caused measurable cusp movement.

- In general, deeper preparations showed significantly higher cusp deflection.
- There were no significant differences in cusp deformation among different incremental insertion techniques.

Cusp flexure using low-shrinkage composite was significantly lower than that caused by use of conventional composite.

*(Accepted 3 October 2011)*

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