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Cuspal Movement and Gap Formation in Premolars Restored with Preheated Resin Composite

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Clinical Relevance

The use of preheated resin composite to 37°C may improve adaptation and decrease interfacial gaps, but when the composite is preheated to higher temperatures, including 54°C and 68°C, this can cause tooth deformation and subsequently other clinical manifestations.

SUMMARY

Objective: The current study aimed to determine the effect of preheating resin composite to three different temperatures on the cuspal movement and gap formation at the tooth/restoration interface. Methods: Fifty extracted, sound human upper premolars were subjected to standardized MOD cavity preparations. Five groups of 10 premolars each were restored with either 1) Tetric Ceram HB, 2) a layer of Tetric Flow followed by Tetric Ceram HB, 3-5) preheated composite to 37°C, 54°C and 68°C, respectively, using a chairside preheating device (Calset thermal assist unit). Cuspal movement was calculated by measuring the intercuspal distance between the indexed cusp tips before restoration 5 minutes and 24 hours after composite curing using a stereomicroscope. The teeth were sectioned longitudinally and examined under a stereomicroscope connected to a digital camera and image analysis software to detect gap formation. Results: Group 2 showed the least cuspal movement at 5 minutes and 24 hours and the highest gap area, while Groups 4 and 5 showed the highest cuspal movement at 5 minutes and 24 hours. Group 3 had the least gap area. Conclusions: Preheating resin composite to temperatures higher than 37°C increases cuspal movement. The adaptation and gap area of preheated resin composite to 37°C and 54°C improved, but it did not change with resin composite preheated to 68°C.

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INTRODUCTION

Viscoelastic materials, such as resin composites, exhibit decreased viscosity and greater flowability with temperature increase.[1-2] This makes them easily applied and adapted to cavity walls.[3-4] Recently, preheating resin composites with suitable devices has been advocated as a method to reduce paste viscosity, improve marginal adaptation and monomer conversion and shorten curing times.[5] The temperature at which the polymerization occurs affects the conversion process and polymer properties.[6-9] Increased temperature enhances both radical and monomer mobility, resulting in higher overall conversion and reaction rate.[8,10]

The attainment of high conversion values by short exposure times, as stated by Daronch and others in 2005,[5] implies a more rapid polymerization at elevated temperatures. Such high reaction rates may result in elevated stress formation and hastens the development of the vitrification point, proving detrimental to the resin/tooth interfacial bond.[11-12] In addition, resin composites exhibit a six-to-eight times greater thermal expansion than the surrounding tooth structures;[13] polymerization contraction, along with thermal contraction, might create high interfacial stresses in preheated composites upon thermal equilibrium, which affects the marginal adaptation, integrity and seal.[14-15]

The magnitude of polymerization shrinkage stresses depends on the material's composition, stiffness and flow of the composite, rate of polymerization and restoration geometry.[16] These factors combine and interact simultaneously in complex ways, translating polymerization shrinkage into tooth stresses. Polymerization shrinkage can produce two types of problems: If the bond between the composite and tooth structure is less than the force of polymerization shrinkage, marginal failure and subsequent microleakage will occur.[17] In contrast, if the adhesive strength exceeds the contraction stress, there is no detachment, but the restoration maintains an internal tension that pulls the walls of the tooth together, reducing the intercuspal distance. The deformation of the tooth is a clinically significant outcome; in addition, it is a reasonable indicator of other polymerization shrinkage effects as interface stresses.[18] Cuspal deflection may clinically manifest as changes in occlusion points, followed by post-operative discomfort, and it may even lead to tooth fracture.[19] However, increased conversion of preheated composite may also result in enhanced restoration properties.[10]

The current study tested the effect of preheating resin composite to three different temperatures on cuspal movement and gap formation at the tooth/restoration interface of upper premolars. The null hypothesis tested was that the preheating of resin composites results in improved marginal adaptation without increasing cuspal movement.

METHODS AND MATERIALS

Selection and Standardization of Teeth

Fifty freshly extracted caries-free human upper premolars were selected. The teeth were examined visually and found to be free from hypoplastic defects or fractures. They were cleaned with a 70% ethyl alcohol solution and surface deposits were carefully removed using a hand scaler. The teeth were kept in saline at room temperature (23°C±2) until use.

In an attempt to standardize the dimensions of the maxillary premolars, the maximum bucco-palatal widths were measured using a digital caliper (Mitutoyo, Digimatic Caliper, Mitutoyo Corporation, Tokyo, Japan) with an accuracy of ± 0.02 mm. These dimensions were used to distribute the teeth into five groups of 10 teeth each, so that the mean bucco-palatal widths of each group differed by no more than 5%.

Cavity and Indentation Preparation

Large standardized MOD slot cavities were prepared in teeth using a high-speed handpiece, a carbide inverted cone bur #012 ISO 500 314 and a carbide plain fissure bur #010 ISO 500 314 with air/water spray coolant. The preparations were centered

Table 1: *Materials Used in This Study*

Material	Description	Composition	Manufacturer (Lot #)
Tetric Ceram HB	Hybrid composite Shade$A_{3.5}$	Monomer matrix: Bis-GMA, Urethane dimethacrylate decandiol dimethacrylate (19 wt%) Inorganic fillers: Barium glass, Ba-Al-fluorosilicate glass, ytterbium trifluoride, highly dispersed silicon dioxide and spheroid mixed oxide (81 wt%). The particle size ranges from 0.04 µm to 3.0 µm. Additional contents: Catalysts, stabilizers, and pigments (0.8 wt%).	Ivoclar Vivadent (G00101)
Total Etch	Etchant gel	37% phosphoric acid, thickening agents and pigments.	Ivoclar Vivadent (J09719)
Excite	One-bottle adhesive system	Phosphoric acid acrylate, 2-hydroxyethyl- methacrylate (HEMA), Bis-GMA, dimethacrylate, silicon dioxide, initiators and stabilizers and alcohol.	Ivoclar Vivadent (J00987)
Tetric Flow	Flowable composite ShadeA_3	Monomer matrix: Bis-GMA, Urethane dimethacrylate and triethylene glycol dimethacrylate Inorganic fillers: Barium glass, ytterbium triflouride, Ba-Al-fluorosilicate glass, highly dispersed silicon dioxide and spheroid mixed oxide. The total content of inorganic fillers is 68.1 wt%. The particle size ranges from 0.04 µm to 3.0 µm. Additional contents: Catalysts, stabilizers, and pigments (0.4 wt%).	Ivoclar Vivadent (G00128)

between the buccal and palatal cusps to preserve the maximum dentinal support of both cusps. The width of the cavity was 3.5 mm bucco-palatally, and the depth of the pulpal floor was 4 mm from the palatal cusp tip. The buccal and palatal walls were prepared parallel to each other to ensure consistency in cavity preparation. The digital caliper was used again to make sure that the bucco-palatal widths of all cavities were 3.5 mm, and a marked fissure bur at a distance of 4 mm from its end was used to check the depth of the cavities.

To index the cusp tips, two small sharp indentations were made on the buccal and palatal cusp tips using diamond cylindrical fissure bur #08 ISO 804 314 in a high speed handpiece with coolant. These small indentations were used as reference points for measuring the intercuspal distance. To standardize the depth of the indentations, they were checked with a marked fissure bur at a distance of 0.5 mm from its end. The teeth were examined under a stereomicroscope to assure that if cracking occurred during preparation of the indentations, the teeth that showed cracks were discarded.

Grouping of Teeth

The teeth were divided into five groups of 10 each. The materials used in the current study are presented in Table 1. In Group 1, the cavities were restored with Tetric Ceram HB at room temperature (23°C±2). In Group 2, a layer of Tetric Flow was placed as a liner on the floor, followed by Tetric Ceram HB. For Groups 1 and 2, the composite was left for three hours after taking it out of the refrigerator and before placing it in the cavity. In Groups 3, 4 and 5, Tetric Ceram HB was preheated to 37°C, 54°C and 68°C, respectively, before application.

Teeth Restoration and Cuspal Movement Measurement

A U-shaped metallic mold was specially constructed to hold the teeth in position perpendicular to the focal plane of the microscope during cuspal movement measurement as shown in Figure 1. Two small screws were projected from both sides of the mold to fix the tooth in the same place each time. In Group 1, the cavities were etched using 37% phosphoric acid for 15 seconds, then rinsed and gently air-dried. Excite Single Bond was activated, and one coat was applied with a microbrush and a light scrubbing motion to the enamel and dentin walls. It was gently air dried and cured for 20 seconds using a light-curing unit (Heliolux II, Vivadent, Schaan, Liechtenstein). The cavities were restored at room temperature with Tetric Ceram composite that was placed in two equal oblique increments and each was cured for 40 seconds. The occlusal surfaces were carved to restore normal anatomy. No matrix was used to avoid any tension on the cusps.

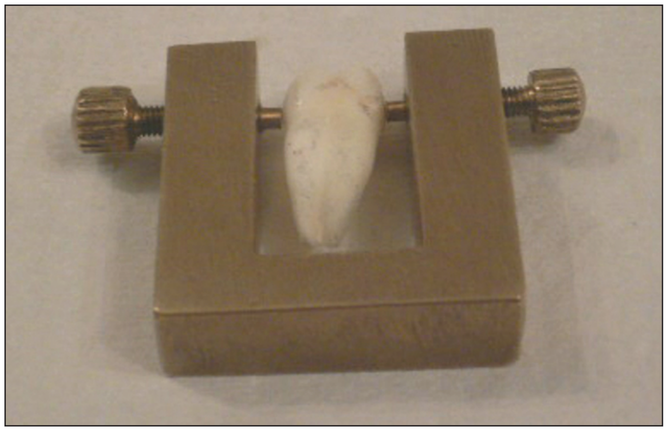

Figure 1. *Metallic mold constructed to hold teeth perpendicular to the focal plane of the microscope during cuspal movement measurement.*

The same steps were followed in Group 2, but after curing the bonding agent, a layer of flowable composite was placed as a liner on the floor and cured first. The thickness of the liner was about 1 mm, and for standardization, each tooth was weighed before and after the liner application to keep constant the weight of the liner (1 mg approximately). In Groups 3, 4 and 5, the same steps were followed as in Group 1, except that the composite was preheated before application to 37°C, 54°C and 68°C, respectively, with a chairside preheating device (Calset thermal assist unit, AdDent Inc, Danbury, CT, USA).

Warming the compule in the Calset unit took about 10 minutes. Once the desired temperature was reached, the heated compule was loaded into the syringe gun and the composite was applied in two increments into the cavity, where each increment was cured for 40 seconds. The compule was then returned to the Calset unit after application of the first increment to avoid temperature loss during curing of the first increment.

Cuspal movement was calculated at room temperature for each tooth by measuring the intercuspal distance between the indexed cusp tips using a stereomicroscope (Olympus-SZ-PT, Japan) with a 6.7x magnificatio,. Special computer software was used (Image J 1.34, NIH, USA), to draw two lines tangential to the indentations on the computer screen; the distance between the two lines was measured before tooth restoration and five minutes after applying and curing the composite as shown in Figure 2. The cuspal movement was calculated from the difference between the two measurements. The teeth were then kept in water at room temperature for 24 hours and the distance between the cusp tips was measured again. This third measurement was done to determine the degree of stress relaxation in the cusps.

Measurement of Gap Total Surface Area

After completing the cuspal movement measurements, each tooth was sectioned into two halves longitudinally

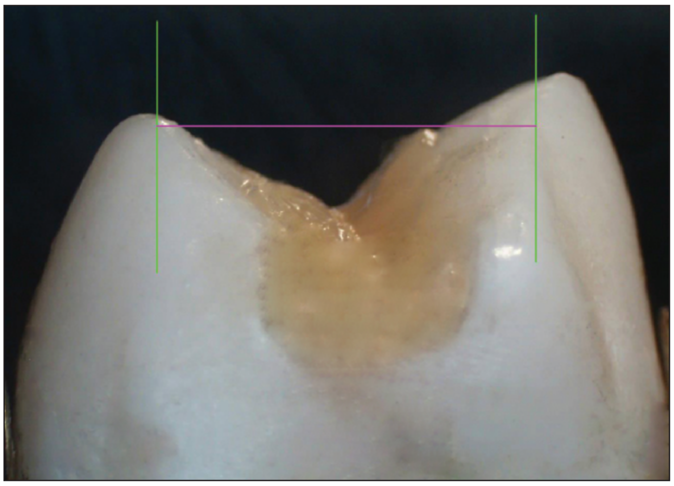

Figure 2. *Computer software was used to draw two lines tangential to the indentations on the computer screen. The distance between the two lines was measured before tooth restoration, five minutes and 24 hours after applying and curing the composite.*

in a bucco-palatal direction using an air water-cooled 7/8-inch diamond disc (Dendia Werk Gmbh, Feldkirch, Austria) rotating at a low speed of 10.000 rpm (Nouvag NM 1500 micromotor 230 v/50 Hz). The teeth were then finished with three ascending grits of Sof-Lex finishing discs (3M ESPE Dental Products, St Paul, MN, USA) using the same pressure for five seconds for each grit, successively. To remove the debris, the teeth were then swabbed with 99% absolute alcohol. The tooth halves were placed individually under a stereomicroscope (Olympus-SZ-PT, Japan) connected to a digital camera (Olympus DP10, Japan) and a computer with image analysis software (image ware, Image Jl.41 [NIH, USA]). Photomicrographs were captured for each tooth-half. An appropriate threshold that ensures selection of gaps only, excluding any other non-desired areas, was selected. The images were processed for color enhancement, brightness and contrast adjustment; they were then converted into an 8-bit gray scale image. For each photomicrograph, the gap total surface area was automatically traced and calculated and the data from the two halves were averaged for each tooth.

Statistical Analysis

One-way analysis of variance (ANOVA) was used to detect significant differences between groups in cuspal movement and gap dimension values. Duncan's post-hoc and paired *t*-tests were used for pairwise comparisons of cuspal movement results, while the Tukey's test was used to separately compare gap area values between each of the two groups.

RESULTS

Cuspal Movement

The means and standard deviations of cuspal movement at five minutes (difference between the intercuspal distance five minutes after light curing and intercuspal distance before restoration) and after 24 hours from the composite application are shown in Table 2. One-way analysis of variance showed differences between groups when ($p \leq 0.05$) at 5 minutes and 24 hours from curing. The Duncan's test showed insignificant difference between Groups 1 and 3 at 5 minutes and 24 hours. In addition, there was an insignificant difference between Groups 4 and 5, where they showed the highest cuspal movement values at 5 minutes and 24 hours from curing, while Group 2 showed the least cuspal movement at both time intervals. Table 2 also

Table 2: *Means, Standard Deviations, Amount of Relaxation (μm) and Test of Significance to Compare the Cuspal Movement Among the Different Groups*

Group	Means (SD) at 5 Minutes	Means (SD) at 24 Hours	Amount of Relaxation
Group 1	40.4 (3)[b]	27 (3.5)[b`]	13
Group 2	28 (4.9)[c]	17 (3.5)[c`]	11
Group 3	38 (3)[b]	29 (3.5)[b`]	9
Group 4	57 (3.5)[a]	48 (6)[a`]	9
Group 5	59 (4.8)[a]	46 (8.5)[a`]	13

Means with different superscript letters are statistically different according to Duncan's test at $p \leq 0.05$ *at 5 minutes and at 24 hours after curing.*

Table 3: *Paired* t*-test to Compare Between Means (μm) of the Cuspal Movement in Each Group at 5 Minutes and at 24 Hours After Curing*

Group	Means at 5 Minutes	Means at 24 Hours	*t*-value	*p*-value
Group 1	40.4	27	6.417*	.0002*
Group 2	28	17	4.044*	.0037*
Group 3	38	29	4.340*	.0024*
Group 4	57	48	2.889*	.0202*
Group 5	59	46	2.982*	.0175*

**: Significant at* $p \leq 0.05$

shows the amount of relaxation for each group that revealed no significant differences. The paired *t*-test showed significant differences between cuspal movement at 5 minutes and 24 hours for all groups as shown in Table 3.

Gap Total Surface Area

The means and standard deviations of gap total surface area for the tested groups are shown in Table 4. One-way analysis of variance showed differences between groups when $p \leq 0.05$. The high standard deviation values found in this table revealed that differences in the cavity geometry had led to large variations. It was decided to calculate the linear gap at the pulpal floor, which had the greatest gap in all samples, to factor out the geometry variable. The Tukey's test showed statistically significant difference between Groups 3 and 4 compared to Groups 1, 2 and 5. However, no statistically significant differences were found between Group 1 and Groups 2 and 5 or between Group 3 and 4.

Table 4: *Means, Standard Deviation Values and Results of the Tukey's Test for Pair Wise Comparison Between Two Groups for the Total Gap Surface Area and the Linear Pulpal Gap*

Group	Total Gap Area	Linear Puplal Gap
	Means (S.D) (μm²)	Means (S.D) (μm)
Group 1	114967 (15927)[bc]	18 (2.2)[a]
Group 2	174729 (16139)[a]	22 (3.6)[a]
Group 3	96664 (7780)[c]	11 (1.6)[b]
Group 4	156244 (36672)[ab]	13 (1.8)[b]
Group 5	156542 (21599)[a]	20.5 (1.8)[a]

Means with different superscript letters are statistically different according to the Tukey's test at $p \leq 0.05$.

DISCUSSION

Clinically, polymerization shrinkage of resin composites may be manifested as enamel fractures, cracked cusps or cuspal movements, resulting in post-operative pain and microleakage. The *in vitro* restoration of posterior teeth with a bonded composite material generates polymerization shrinkage stresses that can be recorded as tensile strains and displacement of tooth surfaces.[20]

In the current investigation, the null hypothesis should be partly rejected, as all the experimental groups showed a reduction in the intercuspal distance five minutes after curing, but not all preheated composite groups improved the marginal adaptation. This reduction suggests that adhesion at the tooth/restoration interface was established and, thus, polymerization contraction stresses have been manifested as cuspal movement. This was in agreement with Palin and others.[21] The degree of cuspal movement is known to be directly related to the amount of dental structure lost, given that the loss causes a reduction in tooth resistance[22-23] and requires an increase in the volume of composite required for the filling, thus producing greater contraction forces.[24] The significantly lower cuspal movement values of Group 2 compared to the other groups is believed to be due to the lower elastic modulus of the flowable composites, so they act like a cushion, absorbing stresses resulting from polymerization shrinkage. It can be also explained by the lower cavity volume to be restored with the hybrid composite, which has a higher elastic modulus. This came in accordance with Alomari and others.[25] The results of the current study agree with that of Rooklidge and others,[26] who found that use of a flowable composite liner reduces cuspal movement by nearly one-third. On the other hand, Group 2 showed the highest gap total surface area and linear pulpal gap, which may be attributed to the high polymerization shrinkage of flowable composite due to its low filler content.

At elevated temperatures, a more rapid photopolymerization occurs. These high reaction rates may lead to higher stress formation and faster development of the gel point, providing detrimental effects to the integrity of the resin/tooth interfacial bond.[11,27] This may explain the significant increase in total gap surface area and linear pulpal gap of Group 5 (cavities restored with resin composite preheated to 68°C) compared to Groups 3 and 4 (cavities restored with resin composite preheated to 37°C and 54°C). Furthermore, it is expected that curing composite at a very high temperature, such as 68°C, would increase the amount of thermal contraction during cooling. Group 3 showed the least gap total surface area of all the groups. This may be due to the increased flowability and decreased viscosity with higher composite temperature during curing. The increased cuspal movement in Groups 4 and 5 may have been the result of two concurrent factors. First, it is likely that there was a rapid stress buildup within the composite due to a faster rate of polymerization as a result of preheating and rapidly achieving the gel point.[12-27] Second, a higher degree of conversion value due to preheating, leading to an increase in volumetric shrinkage and elastic modulus of the material,[28] contributes to producing higher stresses. Another potential issue is the effect of thermal shrinkage of the heated composite as it cools to physiologic temperature, thus, thermal shrinkage may combine with polymerization shrinkage to increase stress at the tooth/restoration interface.[1]

The insignificant difference in cuspal movement between Group 1 and Group 3 may be attributed to the drop in composite temperature upon removal from the heater in Group 3, which may approach room temperature. This depends on the quickness of the operator, the distance between the heat source and the restored tooth and the accessibility of the tooth preparation as stated by Knight and others.[1] Daronch and others[29] reported that, within two minutes, there was a dramatic loss in composite temperature after removal from the heater, where a 50% temperature drop was noted. However, even if preheated composite cools to 30°C or 40°C, it still showed significantly less linear pulpal gap than composites cured at room temperature.

The significant decrease in cuspal movement after 24 hours of water storage can be attributed to the gradual relaxation of the internal stresses by the hygroscopic expansion of the composite,[24-25,30] thus contributing to the recovery of the initial situation. The design of the current study did not allow the author to evaluate the long-term effects. However, some studies[24,31] have shown that the total or near total recovery of the initial intercuspal distance is a slow process that may last for weeks and is never complete in medium and large-sized restorations. Table 2 also shows that the amount of relaxation is nearly the same for all groups, regardless of the amount of shrinkage that originally occurred. This observation suggests that the materials that undergo higher shrinkage will function with considerably higher residual stress (non-linear increase).

Cuspal movement measurements have been employed in the dental literature using bulk filling[24] or 1–2 mm horizontal layers across the base of the cavities.[16] These filling techniques minimized cuspal deflection by constraining the cusps, resulting in an underestimation of the deflection expected when one cusp was not constrained when resin-based composites are incrementally filled. This was avoided in the current study by applying the composite in two oblique increments. In addition, standardized cavity design was employed in previous cuspal deflection studies, but the authors failed to standardize the size of the teeth, resulting in variation of the buccal and palatal cusp dimensions after cavity preparation.[16,24,32] In the current study, the grouping of teeth was done after standardizing tooth sizes, so they differed by no more than 5%. As a result, significant differences between groups would show, if they were present.

In the current study, intercuspal distance was measured before and five minutes after tooth restoration, as the properties of light-cured composites continue to change after irradiation stops.[33] The use of a stereomicroscope for evaluation of cuspal movement induced by polymerization shrinkage of tooth-bonded composite materials has the advantage of being able to assess tooth deformation without physically contacting the tooth. Other techniques used for measuring shrinkage of this nature, such as strain gauges[34] and Linear Variable Differential Transformers (LVDTs),[21] rely on mechanical detection devices. These techniques are less sensitive in detecting cuspal strain, as detectors are in contact or are even bonded to the structure undergoing deformation.

CONCLUSIONS

Under the conditions of the current study, the following conclusions can be made:

Preheating resin composite to temperatures higher than 37°C increases cuspal movement. The adaptation and gap area of preheated resin composite to 37°C and 54°C improved; however, it did not change when resin composite was preheated to 68°C. Preheating resin composite to very high temperatures, such as 68°C, will not improve adaptation and will cause considerable tooth deformation.

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References

1. Knight JS, Fraunghn R & Norrington D (2006) Effect of temperature on the flow properties of resin composite *General Dentistry* **54(1)** 14-16.
2. Freedman G & Leinfelder K (2006) Seventh-generation adhesive systems *Dentistry Today* **21(11)** 106-111.
3. Freedman G (2003) Clinical benefits of pre-warmed composites *Private Dentistry* **8** 111-114.
4. Summitt JB, Robbins JW & Schwartz RS (2001) *Fundamentals of Operative Dentistry: A Contemporary Approach*, 2nd ed Quintessence Chicago 287.
5. Daronch M, Rueggeberg FA & de Goes MF (2005) Monomer conversion of pre-heated composite *Journal of Dental Research* **84(7)** 663-667.
6. Bajaj P, Gupta DC & Babu GN (1977) The temperature dependence of the monomer reactivity ratios in the copolymerization of styrene with vinyl methyldiacetoxysilane *European Polymer Journal* **13(4)** 623-624.
7. Bausch JR, De Lange C & Davidson CL (1981) The influence of temperature on some physical properties of dental composites *Journal of Oral Rehabilitation* **8(4)** 309-317.
8. Cook WD (1992) Thermal aspects of the kinetics of dimethacrylate photopolymerization *Polymer* **33(10)** 2152-2161.
9. Cook WD, Simon GP, Burchill PJ, Lau M & Fitch TJ (1997) Curing kinetics and thermal properties of vinyl ester resins *Journal of Applied Polymer Science* **64(4)** 769-781.
10. Lovell LG, Lu H, Elliott JE, Stansbury JW & Bowman CN (2001) The effect of cure rate on the mechanical properties of dental resins *Dental Materials* **17(6)** 504-511.
11. Uno S & Asmussen E (1991) Marginal adaptation of a restorative resin polymerized at reduced rate *Scandinavian Journal of Dental Research* **99(5)** 440-444.
12. Sakaguchi RL & Berge HX (1998) Reduced light energy density decreases post-gel contraction while maintaining degree of conversion in composites *Journal of Dentistry* **26(8)** 695-700.

13. Sidhu SK, Carrick TE & McCabe JF (2004) Temperature mediated coefficient of dimensional change of dental tooth-colored restorative materials *Dental Materials* **20(5)** 435-440.

14. Braga RR, Ballester RY & Ferracane JL (2005) Factors involved in the development of polymerization shrinkage stress in resin-composites: A systematic review *Dental Materials* **21(10)** 962-970.

15. Watts DC, Issa M, Ibrahim A, Wakiaga K, Al-Samadini M & Silikas N (2008) Edge strength of resin-composite margins *Dental Materials* **24(1)** 129-133.

16. Davidson CL, de Gee A & Feilzer AJ (1984) The competition between the composite-dentin bond strength and the polymerization contraction stress *Journal of Dental Research* **63(12)** 1396-1399.

17. Leinfelder KF, Bayne SC & Swift EJ (1999) Packable composites: Overview and technical considerations *Journal of Esthetic Dentistry* **11(5)** 234-249.

18. Carvalho RM, Pereira JC, Yoshiyama M & Pashley DH (1996) A review of polymerization contraction: The influence of stress development versus stress relief *Operative Dentistry* **21(1)** 17-24.

19. Tantbirojn D, Versluis A, Pintado MR, Delong R & Douglas WH (2004) Tooth deformation patterns in molars after composite restoration *Dental Materials* **20(6)** 535-542.

20. Meredith N & Setchell DJ (1997) *In vitro* measurement of cuspal strain and displacement in composite restored teeth *Journal of Dentistry* **25(3-4)** 331-337.

21. Palin WM, Fleming GJP, Nathwani H, Burke FJT & Randall RC (2005) *In vitro* cuspal deflection and microleakage of maxillary premolars restored with novel low-shrink dental composites *Dental Materials* **21(4)** 324-335.

22. McCullock & Smith BG (1986) *In vitro* studies of cuspal movement produced by adhesive restorative materials *British Dental Journal* **161(11)** 405-409.

23. Blaser PK, Lund MR, Cochran MA & Potter RH (1983) Effect of designs of Class II preparations on resistance of teeth to fracture *Operative Dentistry* **8(1)** 6-10.

24. Suliman AA, Boyer DB & Lakes RS (1993) Cusp movement in premolars resulting from composite polymerization shrinkage *Dental Materials* **9(1)** 6-10.

25. Alomari QD, Reinhardt JW & Boyer DB (2001) Effect of liners on cusp deflection and gap formation in composite restorations *Operative Dentistry* **26(4)** 406-411.

26. Rooklidge E, Boyer D & Bouschlicher M (1999) Cusp deformation by shrinkage of condensable composites *Journal of Dental Research* **78** Abstract #2349 p 339.

27. Daronch M, Rueggeberg FA, de Gee MF & Giudici R (2006) Polymerization kinetics of preheated composite *Journal of Dental Research* **85(1)** 38-43.

28. Feilzer AJ, de Gee AJ & Davidson CL (1993) Setting stresses in composites for two different curing modes *Dental Materials* **9(1)** 2-5.

29. Daronch M, Rueggeberg FA, Moss L & de Goes MF (2006) Clinically relevant issues related to preheating composites *Journal of Esthetic Restorative Dentistry* **18(6)** 340-350.

30. Feilzer AJ, de Gee AJ & Davidson CL (1990) Relaxation of polymerization contraction shear stress by hygroscopic expansion *Journal of Dental Research* **69(1)** 36-39.

31. Segura A & Donly KJ (1993) *In vitro* posterior composite polymerization recovery following hygroscopic expansion *Journal of Oral Rehabilitation* **20(5)** 495-499.

32. Cerutti A, Flocchini P, Madini L, Mangani F, Putignano A & Docchio F (2004) Effects of bonded composite vs amalgam on resistance to cuspal deflection for endodontically-treated premolar teeth *American Journal of Dentistry* **17(4)** 295-300.

33. Sakaguchi RL, Wiltbank BD & Shah NC (2004) Critical configuration analysis of four methods for measuring polymerization shrinkage strain of composites *Dental Materials* **20(4)** 388-396.

34. Jantarat J, Panitvisai P, Palamara JEA & Messer HH (2001) Comparison of methods for measuring cuspal deflection of teeth *Journal of Dentistry* **29(1)** 75-82.