



Cuspal Deflection and Marginal Adaptation in Premolars Restored with Low-Shrinkage Resin Composites

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Abstract

Objectives The aim of this in vitro study was to evaluate cuspal deflection and marginal adaptation in premolars restored with conventional and low-shrinkage resin composites (RCs).

Materials and Methods Fifty-six maxillary first premolars with standardized MOD cavities were randomly assigned to four groups ($n = 14$): Clearfil Majesty Posterior (CMP), Charisma Diamond (CHD), Beautifil II LS (BL), and Filtek Z550 (FZ). Cuspal deflection was measured using a digital micrometer as the linear distance between two reference points at baseline, 5 minutes, and 24 hours after restoration. Deflection values were calculated relative to the baseline. Three samples per group were evaluated using scanning electron microscopy to assess marginal adaptation.

Statistical Analysis Data were analyzed using IBM SPSS Statistics V23.0. Data distribution was evaluated using the Shapiro–Wilk test. Kruskal–Wallis and one-way ANOVA tests were used according to data distribution, followed by appropriate post hoc tests. The significance level was set at $p < 0.05$.

Results The amount of cuspal deflection at 5 minutes was greater than that observed at 24 hours in all groups. CMP, CHD, and BL showed lower cuspal deflection compared with FZ at all time intervals ($p < 0.001$). CMP exhibited the lowest cuspal deflection values, although no significant differences were found among the low-shrinkage RCs.

Conclusion Modifications in the organic matrix or material formulation of the RCs can contribute positively to the control of cuspal deflection and support improved marginal adaptation. The reduced cuspal movement produced by low-shrinkage RCs may increase the likelihood of clinical success by helping preserve restoration integrity.

Keywords

- cuspal deflection
- dental materials
- polymerization shrinkage
- low-shrinkage resin composite

Introduction

Resin composites (RC) have become an indispensable part of dentistry today due to their color compatibility with dental tissues, conservative treatment, improved mechanical properties, and their ability to bond to hard dental tissues mediated by adhesive systems.¹ However, polymerization shrinkage stresses remain a concern, compromising the clinical performance of RCs.² The formation of covalent

bonds between monomers during the polymerization process leads to a shortening of the intermolecular distance and a decrease in free volume.³ Polymerization shrinkage and subsequent stresses can have critical consequences on the tooth structure, such as enamel microcracks and bond failure, which may result in marginal leakage and secondary caries.⁴ However, the shrinkage stresses in RCs mediated by adhesion promoters interact with the cavity walls, causing linear displacement of the tooth's cuspal tips,

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thus bringing the cusps closer together. This phenomenon is biomechanically referred to as cuspal deflection.⁵ This may result in weakened adhesion at the adhesive interface, causing bacterial microleakage, postoperative sensitivity, occlusal discrepancies, and, in some cases, tooth fractures.⁶

There are two main biomechanical factors that influence the level of cuspal deflection. The first involves material-related properties, including polymerization shrinkage, marginal adaptation, and elastic modulus. The second involves clinical factors, including placement technique, use of cavity liner, restoration technique, and polymerization technique.⁷ In the literature, cusp deflections in the range of 10 to 45 µm have been observed in conventional RC restorations.²

The reduction of polymerization shrinkage in direct RCs has recently advanced considerably, giving rise to materials with enhanced properties. In this context, low-shrinkage RCs are one of the next-generation materials designed to minimize shrinkage during polymerization and improve marginal adaptation. Although Bis-GMA continues to be preferred as a base monomer in some composite formulations, higher-molecular-weight monomers are added, or the filler amount is increased to limit shrinkage during polymerization.⁸ The role of high molecular weight monomers in reducing polymerization shrinkage stems from their lower C=C bond content compared to low molecular weight monomers.^{9,10} Another method used to minimize shrinkage is to increase the proportion of filler in the RC, creating a lower resin-to-filler ratio. Since the resin matrix primarily determines the volumetric shrinkage, such RCs are expected to exhibit lower shrinkage during the polymerization process.¹¹ Studies have shown that changes in filler content affect volumetric shrinkage, and that increasing filler content minimizes volumetric shrinkage.^{12,13} However, increasing the filler-to-resin matrix ratio is known to increase viscosity and reduce flowability, which may affect the handling characteristics of RCs.¹⁴

The cuspal deflection of various formulations of conventional RCs has been extensively evaluated in the literature; however, information on the impacts of low-shrinkage RCs on cuspal deflection is limited. Therefore, the aim of this study was to evaluate the cuspal deflection and marginal adaptation in permanent maxillary premolars restored with low-polymerization shrinkage RCs at different time intervals and to compare the results with conventional RC. Two null hypotheses were tested: (1) there would be no significant difference in the amount of cuspal deflection between direct restorations made with different low-shrinkage RCs and a conventional RC and (2) the evaluation time would not influence the amount of cuspal deflection.

Materials and Methods

Sample Size Calculation

G*Power software (version 3.1.9.4, Heinrich-Heine University Düsseldorf, Germany) was used to calculate the required sample size. One-way ANOVA-type power analysis revealed an effect size of 0.50 for 56 samples, a 95% confidence interval, and an 80% power. A minimum of 14 samples per group was determined as the required sample size.

Preparation Procedure

The study was conducted in accordance with the guidelines of the Declaration of Helsinki and approved by the Erzincan Binali Yıldırım University Noninvasive Clinical Research Ethics Committee (approval no.: 2025-16/02). In this study, 56 maxillary first premolars extracted for orthodontic purposes, with similar crown dimensions and regular occlusal morphology, free of caries, cracks, or defects, were used. Following extraction, the teeth were disinfected in a 0.1% thymol solution for 24 hours and subsequently stored in distilled water until use. Variation in buccopalatal width of the premolars did not exceed 10% of the mean value. The selected teeth were fixed by placing them in cylindrical molds made of acrylic material (Imident; Imicryl, Konya, Türkiye), extending 2 mm apical to the cemento-enamel junction. The distance between the cusp tips was then measured by creating reference points on the buccal and palatal cusp tips of each tooth. The cusp surfaces were etched with 37% phosphoric acid for 30 seconds. Single Bond Universal (3M ESPE, St. Paul, Minnesota, United States) was then applied and cured with an LED device (Valo Cordless; Ultradent, South Jordan, United States). The approximately 1 mm diameter RC spheres (Filtek Z250, 3M ESPE) were placed on the cusp tips and light-cured. Moreover, for each sample, a silicone index was created using silicone impression material (Silect Set; Muller-Omicron GmbH & Co., KG, Germany). This silicone index enabled accurate initial positioning and subsequent repositioning of the digital micrometer beaks on the reference points.

In each premolar, standardized MOD cavities were prepared with a buccal-palatal width of 3 mm and a cavity depth of 4 mm measured from the cavosurface margins.² The dimensions of each cavity preparation were verified using a periodontal probe to ensure standardization. The MOD cavities were prepared without proximal boxes so as to minimize the preparation variability.¹⁵ Moreover, the buccal and the palatal walls of each cavity were also prepared parallel to each other. The cavities were prepared so that the pulpal floor and mesial and distal gingival floors were at the same level. The pulpal floors were positioned above the cemento-enamel junction in the cervical direction. All the teeth were prepared with a straight fissure carbide bur with a rounded end using a high-speed handpiece with air/water spray. To maintain the cutting efficiency of the burs, after every four preparations, a new bur was used. Any tooth with pulp exposure was excluded from the study.

Restoration Procedure

After completion of the preparations, the samples were randomly divided into four groups according to the RC materials applied. The RCs tested in the study and applied to the cavities are presented in ► **Table 1**. A universal matrix (Tofflemire, ABD) adaptation was performed on each tooth before restorations. Enamel margins were then etched using 37% orthophosphoric acid for 30 seconds using a selective etching technique. Following rinsing and drying, a universal adhesive system (Single Bond Universal, 3M ESPE) was applied to the cavity according to the manufacturer's

Table 1 Resin composites tested in the study

Material	Type	Manufacturer	Filler content (vol%/wt%)	Matrix composition	Filler composition	Lot number
Clearfil Majesty Posterior (CMP)	Low-shrinkage resin composite	Kuraray Noritake Dental Inc, Tokyo, Japan	82/92	Bis-GMA, TEGDMA, hydrophobic aromatic dimethacrylate	Surface-treated alumina micro-filler, silanated glass ceramics, silica	7L0097
Beautiful II LS (BL)	Low-shrinkage resin composite	Shofu Co, Kyoto, Japan	68/83	Bis-GMA; Bis-MPEPP, TEGDMA, UDMA	S-PRG, multifunctional aluminofluoroborosilicate, glass	122275
Charisma Diamond (CHD)	Low-shrinkage resin composite	Heraeus Kulzer, GmbH, Hanau, Germany	64/81	TCD-DI-HEA, UDMA, Bis-GMA, TEGDMA	Barium, aluminum, flour glass, and colloidal silica	K010079
Filtek Z550 (FZ)	Conventional resin composite	3M ESPE, St. Paul, MN, USA	68/82	Bis-GMA, UDMA, BIS-EMA, TEGMA, and PEGDMA	Surface-modified zirconia/silica fillers 3,000 nm (3 µm or less), nonagglomerated/non-aggregated surface-modified silica particles 20 nm	NF43825

Abbreviations: BIS-EMA, bisphenol A ethoxylated dimethacrylate; Bis-GMA, bisphenol A diglycidyl dimethacrylate; Bis-MPEPP, bisphenole A ethoxylate dimethacrylate; PEGDMA, polyethylene glycol dimethacrylate; S-PRG, surface pre-reacted glass; TCD-DI-HEA, 2-propenoic acid (octahydro-4,7-methano-1H-indene-5-diy) bis(methyleneiminocarbonyloxy-2,1-ethanediy) ester; TEGDMA, triethylene glycol dimethacrylate; UDMA, urethane dimethacrylate.

recommended application protocol and light-cured for 10 s using an LED unit (Valo Cordless, Ultradent) with an output intensity of 1,000 mW/cm². The RCs were placed into the cavities using horizontal incremental layering in 2-mm increments. Each increment was individually light-cured for 20 s according to the manufacturer's recommendations. During polymerization, the light-curing tip was positioned perpendicular to the restoration surface and maintained at a standardized distance of 1 mm. The output power was periodically monitored using a radiometer to ensure an intensity of at least 1,000 mW/cm². Finishing procedures were performed using fine-grit diamond burs, followed by polishing with rubber tips. All restorative procedures were performed by the same operator.

Cuspal Deflection Assessment

A digital micrometer (LOYKA 5202–25, Ankara, Türkiye) was utilized by the same operator to measure the separation between the reference points created on the teeth. According to the manufacturer's specifications, the digital micrometer had a measurement accuracy of 0.001 mm (1 µm). Measurements were made at three different times: before cavity preparation (T₀), 5 minutes after restoration placement (T₁), and 24 hours after restoration placement (T₂).^{16,17} At each specified measurement time, the distance between the reference points of each sample was measured three times. The average of these three measurements was recorded as the cuspal deflection value for that time. The cuspal deflection differences between T₀–T₁ and T₀–T₂ were recorded as CD₁ and CD₂. Between the 5-minute and 24-hour measurement intervals, the samples were stored in distilled water at room temperature under standardized conditions.

Scanning Electron Microscopic Analysis

After completing the cuspal deflection measurements, three randomly selected restored samples from every group were prepared for scanning electron microscopy (SEM; FEI Quanta450 FEG, United States) analysis. Each tooth selected for examination was sectioned horizontally 2 mm apical to the cervical line, removing the crown from the root. The crown was then transected buccopalatally with a diamond saw. The samples were coated with gold so that the gaps at the internal interface could be examined by SEM. Next, images were taken from vertical sections at standard magnifications (250 ×) to document the bonded internal surfaces.

Statistical Analysis

IBM SPSS Statistics version 23 (IBM Corp., Armonk, New York, United States) was employed to assess the data. The normality of data distribution was assessed using the Shapiro–Wilk test. As the CD₁ data did not meet the assumption of normal distribution, intergroup comparisons were performed using the Kruskal–Wallis test, followed by Dunn's test for multiple comparisons. The CD₂ data showed a normal distribution and were therefore analyzed using one-way analysis of variance (ANOVA). Tamhane test was applied for post hoc multiple comparisons. The significance level was set at $p < 0.05$.

Table 2 Descriptive statistics and statistical analysis results of cuspal deflection (CD₁ and CD₂) values (μm) of the resin composite groups

	Material				F	p-Value
	CMP	BL	CHD	FZ		
CD ₁	3 (2–6) ^b	5 (2–7) ^b	6 (2–10) ^b	22 (11–26) ^a	38.721	<0.001
CD ₂	2.0 ± 1.0 ^c	3.0 ± 1.0 ^b	4.0 ± 2.0 ^b	19.0 ± 5.0 ^a	52.734	<0.001

Abbreviations: BL, Beautifil II LS; CHD, Charisma Diamond; CMP, Clearfil Majesty Posterior; FZ, Filtek Z550.

Note: CD₁—Kruskal–Wallis/Dunn’s test, median (minimum–maximum). CD₂—one-way ANOVA/Tamhane test, mean ± standard deviation.

^{a,b,c}Different letters indicate a statistically significant difference between the groups ($p < 0.05$).

Results

Cuspal deflection values and results of the statistical analysis are presented in ►Table 2. An inward deflection of the cuspal tips was observed in all groups tested. However, the highest cuspal deflection values in the study were observed at CD₁ for all RC groups. Kruskal–Wallis test showed that there were statistically significant differences among the groups tested at CD₁ ($p < 0.001$). Dunn’s test demonstrated that the lowest cuspal deflection values were obtained in the CMP group, and this value was not statistically different from the BL and CHD groups ($p > 0.05$). The highest value was observed in the FZ group ($p < 0.001$).

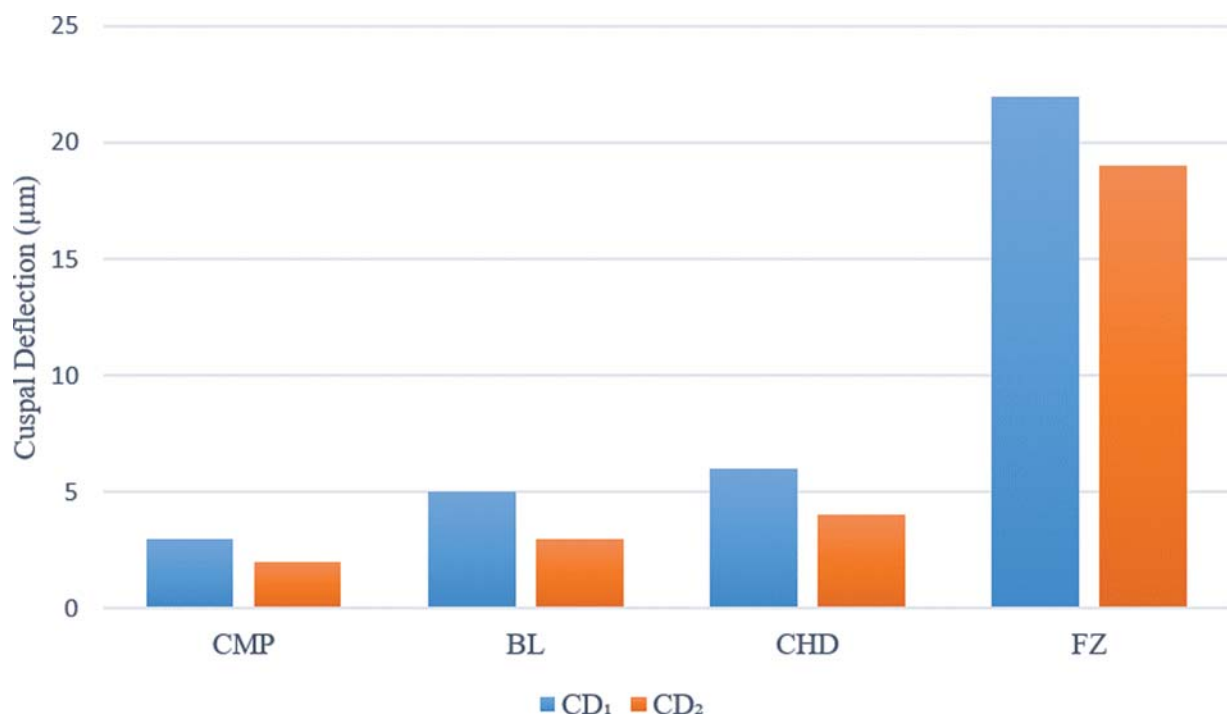
Upon examination of the CD₂ values, the lowest cuspal deflection values were observed in the CMP group ($p < 0.001$), while the highest were obtained in the FZ group ($p < 0.001$). BL and CHD groups showed no significant difference in cuspal deflection values ($p > 0.05$; ►Fig. 1).

SEM images of the RC/enamel interfaces obtained 24 hours after completion of the RC restoration are shown

in ►Fig. 2. Representative SEM images of the RC/enamel interfaces revealed material-dependent marginal adaptation. CMP demonstrated a relatively continuous and compact interface with close adaptation to enamel. BL and CHD showed a discernible and generally homogeneous adhesive interface with limited discontinuities. In contrast, FZ showed a marked interface separation extending toward the cervical region, suggesting a disruption of marginal integrity. These qualitative SEM observations appeared to support the trends observed in the cuspal deflection results.

Discussion

Cuspal deflection arises when polymerization shrinkage stresses are transmitted to the tooth. This deformation increases tensile stress and may lead to fractures and is recognized as a major factor in clinical failure.¹⁸ This study examined the impact of three types of low-shrinkage RCs on cuspal deflection in comparison with a conventional composite. This study showed that cuspal deflection was present

**Fig. 1** Comparison of cuspal deflection values measured at 5 min (CD₁) and 24 h (CD₂) in premolars restored with different resin composites. CMP, Clearfil Majesty Posterior; BL, Beautifil II LS; CHD, Charisma Diamond; FZ, Filtek Z550.

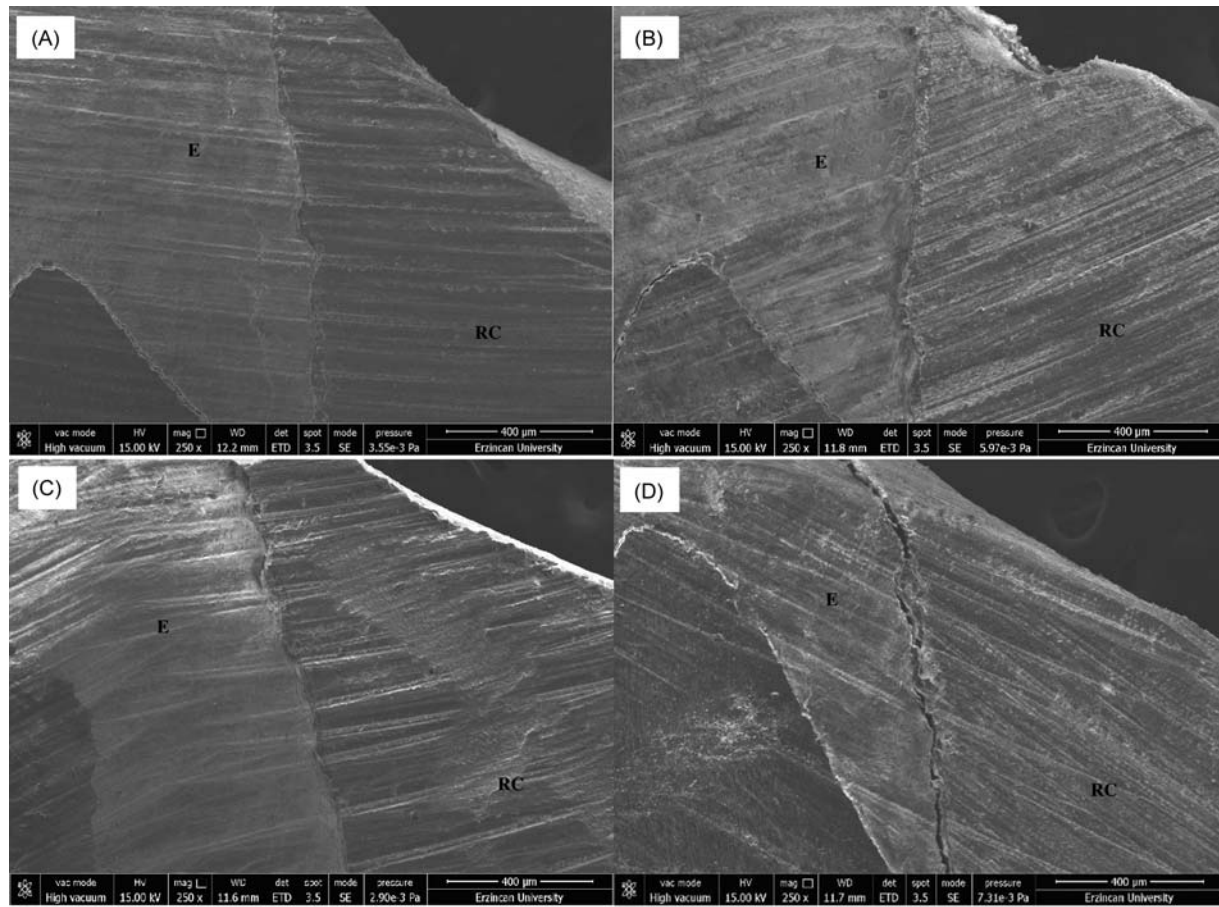


Fig. 2 Representative scanning electron microscopy images (250× magnification) of resin composite–enamel interfaces at the lateral wall of the investigated resin composite restoration. (A) Clearfil Majesty Posterior, (B) Beautifil II LS, (C) Charisma Diamond, and (D) Filtek Z550. RC, resin composite; E, enamel.

in all RC groups following restoration, with mean values, ranging from 2 to 22 µm. This result is consistent with many studies in literature.^{19,20} Studies have linked the cuspal deflection resulting from restorations to the shrinkage stresses of the organic monomer in the resin matrix.²¹ However, cuspal movement occurred in all tested RC groups, suggesting that a bonded interface was established and that polymerization shrinkage stresses were transmitted from the restoration to the tooth structure.

The first null hypothesis of the study suggested that there would be no significant difference in the amount of cuspal deflection between direct restorations made with different low-shrinkage RCs and a conventional RC. However, the results did not support this hypothesis. The highest cuspal deflection at both time intervals was observed in the FZ group, whereas the low-shrinkage RCs exhibited significantly lower values compared to FZ. Considering that polymerization shrinkage is the direct cause of cuspal deflection, the present findings suggest that RCs with low shrinkage lead to less cuspal deformation than methacrylate-based composites.²¹ The difference in lower cuspal deflection observed in low-shrinkage composites at 5 minutes and 24 hours could be attributed to the optimized resin composition, initiator components, and filler characteristics within their struc-

tures. However, the filler content of the FZ control group, which contained zirconium/silica fillers with a high elastic modulus, may have resulted in an increased amount of cuspal deflection.²²

The stress of an RC restoration applied to a tooth depends on the combined effects of factors such as composition, elastic modulus, and volumetric shrinkage.²³ The extent to which these interactions contribute to the total stress remains unclear. In the current study, the lowest cuspal deflection values measured at 5 minutes and 24 hours were obtained in the CMP group. This result confirms knowledge that high inorganic filler content causes low polymerization shrinkage. In the study, the CMP group had the highest filler ratio (82–92% v/w) among all low-shrinkage RCs. The percentage of inorganic filler content has been shown to affect the viscosity and fluidity of the material.²⁴ Higher filler loads reduce the amount of resin in composite materials. Thus, polymerization shrinkage stress is minimized, and cuspal deviation is consequently reduced,¹³ which is also compatible with the present study. Elastic modulus, another parameter affecting polymerization shrinkage in composites, is affected by the chemical formula of the monomers, the filler particle ratio, and the interaction of the components in the resin.²⁵ RCs containing high filler

content generally exhibit a higher modulus of elasticity with lower volumetric shrinkage.²⁶ However, literature suggests that composites with higher modulus of elasticity may be associated with greater cuspal deflection, which appears to contradict the findings of the present study.²⁷ Although CMP showed a high elastic modulus,²⁸ these variations were not reflected in significantly different cuspal deflection values. This result can be connected to the properties of the fillers as well as the monomer composition, filler content, and organic matrix structure, which greatly affect the physico-mechanical characteristics of the tested RBCs.²⁹

The limited cuspal deflection observed in the BL and CHD composites, despite the low filler ratio, can be attributed to the effects of the high-molecular-weight monomer components added to their structures on the polymerization process. In a systematic review examining the stresses arising from resin polymerization by Meereis et al, it was reported that modifications to the RC matrix significantly improved stress relief by minimizing polymerization stress.³⁰ Beautifil II LS, used in the research, is a giomer-based RC with low-shrinkage properties. Its structure includes S-PRG fillers, as well as Bis-GMA, TEGDMA, and Bis-MPEPP, which exhibit relatively low viscosity. According to one study, the presence of a low-viscosity monomer in the RC improves the matrix viscosity and promotes the action of free radicals, which contributes to lower polymerization stress and reduced cuspal deflection.³¹ The CHD evaluated in this study is a nanohybrid composite containing the high-molecular-weight and low-viscosity monomer TCD-DIHEA, which, according to the manufacturer, is associated with low polymerization shrinkage.³² In general, higher molecular weight monomers offer lower mobility.³³ It is suggested that, compared to a typical resin matrix, the high-molecular-weight monomer content lowers the proportion of functional groups forming double bonds during polymerization, reducing the available free volume and thus reducing polymerization shrinkage.³⁴ The greater flexibility of the urethane modulator groups results in a more uniform network formation with a delay in the rate of the shrinkage reaction. Thus, less stress formation is observed by compensating for the possible effects of polymerization shrinkage. The low elastic modulus and the low stress levels produced have a synergistic effect in reducing the amount of cuspal deflection.³⁵ The similar filler ratio and elastic modulus values of BL and CHD (9.5 GPa³⁶ and 10.5 GPa,³⁷ respectively) may have caused them to present similar cuspal deflection values. However, the present study did not directly evaluate polymerization kinetics or elastic modulus. Therefore, these explanations should be interpreted with caution and require further experimental verification.

The second null hypothesis, which stated that the evaluation time would not influence cuspal deflection, was rejected. The present study demonstrated that time significantly affected the cuspal deflection of RCs, and for each RC group, the mean change in cuspal distance at 5 minutes was higher than that measured at 24 hours. Many studies in the literature confirm this result.^{17,38} Yarmohammadi et al stated that the highest cuspal deflection occurred in the measurement taken 5 minutes after the restorations were

applied, while the distance between the cusps increased and approached the initial value in the measurements taken 24 and 48 hours later.¹⁶ Alquzweeni et al stated in their study that the inward cuspal deflection depends on the amount of reactive radical groups and double bonds remaining in the RC that continue reacting after polymerization.³⁹ The majority of the polymerization reaction occurs within the first 20 seconds following light-curing, although a slight increase persists for several minutes as unsaturated bonds react.⁴⁰ This phenomenon occurs when short covalent bonds replace the weak Van der Waals forces. Cuspal relaxation can be attributed to various mechanisms such as stress relaxation, tooth flexibility, or the development of dental restoration gaps.⁴¹ This information may explain the high cuspal deflection values observed at 5 minutes and the cuspal relaxation observed over time in the tested RCs.

The proposed in vitro research has certain limitations. The findings obtained should be evaluated carefully because experiments performed in a laboratory environment may not always accurately reflect clinical results. Another limitation is that RCs absorb moisture in the oral environment. The resulting hygroscopic expansion can mitigate the disadvantages caused by polymerization shrinkage and help reduce cuspal deflection. In addition, the present findings should be interpreted within the limitations of the experimental design and should not be directly generalized to all low-shrinkage RCs. Future investigations are required to examine the long-term effects of low-shrinkage RCs and to validate these findings in clinical settings.

Conclusion

Within the limitations of the present study, it can be concluded that low-shrinkage RCs significantly reduce cuspal deflection compared to conventional RCs and may contribute to reduced marginal gap formation. The monomer composition and the proportion and properties of the filler particles appear to have a direct impact on cuspal deflection. In clinical practice, it can be concluded that restorations made with low-shrinkage RCs, especially those with higher filler content, may help reduce cuspal deflection and preserve marginal integrity.

Conflict of Interest

None declared.

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