Cuspal deflection and marginal microleakage following the application of bulk-fill and conventional composite resins

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Research Article

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Abstract

Objectives

This study compared the cuspal **deflection** and marginal microleakage following the application of bulk-fill and conventional composite resins.

Materials and Methods

70 sound premolars with MOD preparation were randomized into 5 groups (n = 14). In three groups, the cavities were restored with Tetric Ceram N, X-tra fil, and Opus bulk-fill composite resins. In the remaining two groups, the cavities were restored with P60 conventional composite with 2 mm (incremental technique) and 4 mm (bulk-fill technique) increments. Cuspal **deflection** was measured by a digital micrometer. After aging, marginal microleakage was assessed. Data were analyzed by repeated measures one-way and two-way ANOVA, and Tukey, Bonferroni, Kruskal-Wallis, Mann-Whitney, Friedman, Wilcoxon signed rank, and t tests.

Results

Cuspal **deflection** of bulk-fill composite groups was lower than that of conventional composite applied incrementally ($P < 0.05$), but it was not significantly different among the bulk-fill composite groups ($P = 0.16$). The microleakage scores was not significantly different among the bulk-fill composites, or between the bulk-fill and conventional incremental composite group ($P > 0.05$). Microleakage at the cervical cementum margin of proximal box was significantly higher than that at the cervical and occlusal enamel margins of proximal box ($P = 0.001$).

Conclusion

the cuspal deflection in bulk-fill composite restoration was lower than that in the conventional composite in incremental technique but marginal microleakage of bulk-fill and conventional composite resin restorations were comparable.

Introduction

Application of composite resins for restoration of posterior teeth is on the rise due to higher demands of patients for tooth-colored restorations and the existing concerns regarding the health hazards of mercury in the composition of amalgam [1]. Composite resins have favorable properties such as easy application, optimal clinical service, excellent esthetics, and optimal physical properties [2]. However, polymerization shrinkage remains a major drawback of conventional composite resins [3]. Factors such as the filler content and composition, modulus of elasticity of composite resin, and its flow ability before the gel point affect the polymerization stress [4]. Polymerization shrinkage generates stress at the tooth-composite interface. Debonding occurs when the stress due to polymerization shrinkage exceeds the bond strength. Subsequently, microleakage occurs, and marginal discoloration and postoperative tooth hypersensitivity pursue [5]. In case of presence of a strong bond between the restoration and tooth structure, the outcome of interactions between the high bond strength and polymerization shrinkage stress would be cuspal flexure, enamel cracks, tooth hypersensitivity, and pain under occlusal forces, and may even lead to cusp fracture [6].

At present, the incremental application technique is practiced to minimize volumetric polymerization shrinkage and stress generation at the tooth-composite interface [7]. However, this technique has drawbacks such as debonding between the increments due to contamination, void formation, time-consuming nature due to incremental application and individual polymerization of each layer, and difficult application of composite due to conservative cavity preparation [8].

Bulk-fill composites were introduced to the market in the past decade with enhanced faster application for restoration of posterior teeth. Bulk application of composite resins in 4-5-mm thick layers accelerates the restorative procedure and decreases its technical sensitivity and the need for long-term isolation of the teeth. Also, bulk-fill application of composite minimizes the risk of void formation between the composite increments [9,10].

Different types of bulk-fill composites are available in the market such as high viscosity, low-viscosity, full-body, base, dual-cure, and light-cure types. Some bulk-fill composites can be used as the main restorative material, and are referred to as true bulk-fill composites since they have high filler content and wear resistance. However, some others are only used as base material, and should be covered with conventional composite resins [11].

Bulk-fill composites have a lower polymerization shrinkage stress than the conventional composites due to the incorporation of polymerization modulators in their resin monomer structure that delay the gel point or filler content [12–14].

Since, long-term success of restorations highly depends on minimization of cuspal flexure and marginal leakage [15]. Thus, this study aimed to compare the cuspal flexure and marginal microleakage of several commonly used high-viscosity bulk-fill composite resins and a conventional methacrylate-based composite with a high filler content. The null hypothesis was that the cuspal flexure and marginal microleakage of the tested bulk-fill and conventional composites would not be significantly different.

Materials And Methods

This in vitro, experimental study was performed on sound premolars extracted for orthodontic treatment purposes. The study was approved by the ethics committee of Shahid Beheshti University of Medical Sciences (IR.SBMU.DRC.REC.1398.097) and the patients consented to the use of their extracted teeth in this study.

After collection of the teeth, calculus and soft tissue residues were removed by a hand scaler, and the teeth were immersed in 0.5% chloramine T solution. They were rinsed and stored in distilled water at room temperature (24 ± 1°C) 1 week before the experiment. To standardize the buccopalatal width of the teeth, their buccopalatal width was measured at the height of contour using a digital micrometer with 1 µm accuracy (230–293;Mitutoyo, Kawasaki, Japan). Accordingly, the teeth were assigned to three groups of small (with a buccopalatal width of 6-6.5 mm), medium (buccopalatal width of 6.5-7 mm) and large (buccopalatal width of 7-7.5 mm). Considering the normal distribution of the teeth in terms of size, 70 teeth were randomized into 5 groups (n = 14).

Cuspal deflection measurement:

The inter-cuspal distance was measured by creating reference points on the teeth. For this purpose, the buccal and palatal cusp tips of each tooth with an approximate diameter of 2 mm were etched with 37% phosphoric acid for 30 s. After rinsing off the acid, Tetric N Bond (Ivoclar Vivadent, Schaan, Lichtenstein) adhesive agent was applied on the etched surface and cured for 10 s with a curing unit (Woodpecker, Guilin, Guangxi, China) with a light intensity of 1000 mW/cm^2. Composite cylinders (Opus bulk-fill flow, Brazil) with 1 mm width and length, and 2 mm height were made on the buccal and palatal cusp tips and cured. After 1 week of storage in distilled water at room temperature, the distance between the reference points was measured by digital micrometer and recorded as the baseline distance. To assess the reliability of the measurements, the distance between the reference points was measured at three different time-points with 1h intervals.

Large standard mesio-occluso-distal cavities were then created by a 010 fissure diamond bur (Jota, Rüthi, Switzerland) and high-speed hand-piece under water coolant. The mesial and distal boxes were extended gingivally such that the cervical margin was 1 mm above the cementoenamel junction at one side and 1 mm below the cementoenamel junction at the other side. The axial depth of the proximal boxes was 1.5 mm as measured by a periodontal probe. The occlusal extension of the cavity had 3 mm buccolingual width, and 4 mm pulpal floor depth (Fig. 1). This particular design was selected aiming to assess the marginal leakage at the occlusal enamel, proximal box enamel, and proximal box cementum margins according to a study by Zavattini et al [21]. Next, a metal matrix band was placed and the cavities were restored in five groups as follows:

Group 1: Enamel and dentin were etched with 37% phosphoric acid (Ultradent, South Jordan, UT, USA) for 15 s and rinsed with air and water spray for 20 s according to the manufacturer's instructions. Excess water was removed by absorbent paper. One layer of Tetric N Bond bonding agent (Ivoclar Vivadent AG, Schaan, Liechtenstein) was gently applied by a microbrush for 10 s, dried with air spray, and cured for 10 s. Tetric N Ceram bulk-fill composite (Ivoclar Vivadent AG, Schaan, Liechtenstein) was then applied in the mesial and distal boxes such that they were filled to the level of the pulpal floor. Composite resin in each of the proximal boxes was cured for 40 s by a curing unit (Woodpecker, Guilin, Guangxi, China) with 1000 mW/cm^2 light intensity from the occlusal surface of the cavity. This particular curing time was selected since curing in contact mode was not possible [22]. The remaining part of the cavity was then filled with composite by bulk-fill application in one increment to the occlusal cavosurface and cured. The occlusal surface of the cavity was hypothetically divided into a mesial and a distal half, and each half was cured for 20 s using the overlapping technique.

Tooth preparation in groups 2, 3 and 4 was performed similar to group 1, but the cavities were filled with A2 shade of X-tra fil (Voco GmbH, Cuxhaven, Germany) in group 2, A2 shade of Opus bulk-fill (FGM, Joinville, SC, Brazil) in group 3, and A2 shade of P60 conventional composite (3M ESPE, St. Paul, MN, USA) with the bulk-fill application technique in group 4.

In group 5, the cavities were restored with P60 composite using the incremental application technique such that a 1-mm thick composite layer was first applied on the gingival floor of the box and cured for 40 s. The remaining part of the cavity was then filled with 2-mm thick increments applied horizontally until the cavity was filled. Each increment was separately cured. Table 1 presents the characteristics of the composite resins used in this study.

Table 1
Characteristics of the composite resins used in this study

Composite resin	Type/shade	Manufacturer	Chemical composition
Filtek P60	High viscosity Packable composite resin Shade: A2	3M ESPE, St. Paul, MN USA	Inorganic fillers (61vol%) Bis-GMA, UDMA, Bis-EMA Zirconia/Silica nanofillers
X-tra fill	High viscosity Packable resin composite for bulk fill shade: A2	Voco,Cuxhaven, Germany	Filler load: 70.1%vol, 86wt% Bis-GMA,UDMA TEGDMA
Tetric N-Ceram Bulk Fill	High viscosity packable resin composite for bulk fill Shade: A2	Ivoclar Vivadent AG, Schaan Liechtenstein	Barium-aluminumsilica glass prepolymer filler (monomer glass filler, ytterbium fluoride), spherical mixed oxide 79-81wt% /60–61 Vol% Bis-GMA, UDMA, Bis-EMA
OPUS	High viscosity packable resin composite for bulk fill shade: A2	FGM Joinville, SC, Brazil	79wt% Inorganic

After filling of the cavities, the teeth were stored in distilled water at room temperature (24 ± 1°C) during the time intervals between the cuspal deflection measurements. The distance between the reference points was measured by a digital micrometer at 4 time intervals(immediately ,10 min, 24 h, and 7 days) after restoration[23](Fig. 2). The magnitude of cuspal deflection of the teeth at each time point was calculated based on the difference between the value measured at each time point and the baseline value.

Marginal microleakage assessment:

To assess the marginal microleakage, the restored teeth were stored in distilled water at 37°C for 1 month, and then were subjected to 2000 thermal cycles [24] between 5–55°C in a thermocycling machine with a dwell time of 30 s and a transfer time of 10 s. After thermocycling, the teeth were stored at 37°C for 2 weeks. The teeth were then coated with one layer of beeswax at the apex and two layers of nail varnish leaving a 1 mm margin around the tooth-restoration interface. All teeth were subsequently immersed in 1% methylene blue for 48 h [25]. The teeth were then rinsed with running water for 10 min, mesiodistally sectioned, and inspected under a stereomicroscope (Olympus SZX16, Japan) at x40 magnification.

The marginal microleakage was scored based on the extent of dye penetration as follows:

Score 0: No dye penetration at the cavity margins

Score 1: Dye penetration to one-third of the gingival wall of the cavity

Score 2: Dye penetration to over one-third of the gingival wall of the cavity

Score 3: Dye penetration to the entire gingival wall, reaching the axial wall(Fig. 3,4)

Data regarding the microleakage at the occlusal enamel margin, and the proximal box enamel and cementum margins were recorded for each tooth

Statistical analysis:

The Shapiro-Wilk test showed normal distribution of cuspal deflection data. Thus, repeated measures two-way ANOVA was used to analyze cuspal deflection at different time-points ($\alpha = 0.05$). Since the interaction effect of time and group was significant, repeated measures one-way ANOVA was applied to analyze the reduction in the mean cuspal deflection of each composite resin over time. One-way ANOVA was used to compare the mean cuspal deflection of different composite resins at each time point. Multiple comparisons were made by the Tukey's HSD and Bonferroni tests.

The Kruskal-Wallis test was used to compare the microleakage of composites at the occlusal enamel margin, and the proximal box on the enamel or cementum margins. Pairwise comparisons were made by the Mann-Whitney test. The microleakage at the occlusal enamel, and proximal box enamel and cementum margins was compared within each composite group using the Friedman test followed by pairwise comparisons with the Wilcoxon signed rank test. Level of significance was set at 0.05.

Results

Table 2 presents the mean cuspal deflection of the groups at different time points. Repeated measures two-way ANOVA with time as the within-group factor, and type of composite as the between-group factor, showed that the interaction effect of these two factors on cuspal deflectionwas statistically significant ($P < 0.05$). Thus, subgroup analysis was performed. Repeated measures ANOVA showed a reduction in cuspal flexure over time ($P = 0.001$). The maximum cuspal deflectionwas recorded immediately after polymerization while the minimum value was noted after 7 days. Pairwise comparisons of time points by the Bonferroni test showed significant difference of each time point with the previous time point ($P = 0.001$).

Table 2
Mean cuspal flexure (μm) of the groups at different time points

Group		Cuspal flexure immediately after restoration	Cuspal flexure after 10 min	Cuspal flexure after 24 h	Cuspal flexure after 1 week	*P-Value within group
P60 incremental	Mean	14.25 ± 0.96 ^{A}	14 ± 0.95 ^{A}	12.48 ± 0.79 ^{B}	4.31 ± 0.55 ^{C}	0.001
	Minimum	12	12	11	3.2	
	Maximum	15.5	15.1	13.9	5	
P60 Bulk-fill	Mean	9.47 ± 1.6 ^{A}	9.22 ± 1.71^{A}	7.18 ± 1.81 ^{B}	2.32 ± 0.67 ^{Cd}	0.001
	Minimum	7	7	5	1.6	
	Maximum	13.1	13	12.1	4	
OPUS	Mean	11.50 ± 1.07 ^{Aa}	11.23 ± 1.08 ^{Ab}	8.72 ± 0.93 ^{Bc}	2.83 ± 0.57 ^{Cd}	0.001
	Minimum	9.9	9.7	7.5	2	
	Maximum	13.2	13.1	11	4.2	
Tetric	Mean	11.70 ± 0.85 ^{Aa}	11.40 ± 0.81 ^{Ab}	8.86 ± 0.75 ^{Bc}	2.76 ± 0.49 ^{Cd}	0.001
	Minimum	10.5	10.4	8	2	
	Maximum	13	12.8	11	4	
X tra fil	Mean	12.59 ± 0.67 ^{Aa}	12.34 ± 0.70 ^{Ab}	9.14 ± 0.62 ^{Bc}	3.10 ± 0.55 ^{Cd}	0.001
	Minimum	11.2	11	8	2	
	Maximum	13.7	13.5	10.1	4	
**P – Value between groups		0.001	0.001	0.001	0.001	

*Repeated measures ANOVA, **One-way ANOVA,

***Groups with similar lowercase letters have no significant difference in pairwise comparisons with the Tukey's test.

****Groups with similar uppercase letters have no significant difference in within-group pairwise comparisons of cuspal flexure at different time points.

One-way ANOVA revealed a significant difference between different composite groups in cuspal deflection ($P = 0.001$). Pairwise comparison of composites in this respect by the Tukey's tests showed minimum cuspal deflectionin P60 composite applied by the bulk-fill technique and maximum cuspal flexure in P60 composite applied incrementally at each time point ($P = 0.001$). The cuspal deflectionof the three bulk-fill composite groups was not significantly different ($P = 0.16$). Figure 5 shows the error bar of the mean cuspal deflectionof the groups at different time points.

Pairwise comparisons of different time-points regarding cuspal deflection of different composite types, were revealed significant differences between all time-points ($P < 0.05$), except for immediately and 10 min after polymerization in all composite groups ($P > 0.05$).

Marginal microleakage:

Table 3 presents the frequency distribution of marginal microleakage scores in different composite groups. Comparison of microleakage of different composite groups at occlusal margin and gingival margin of proximal box on enamel or cementum by the non-parametric Kruskal-Wallis test revealed no significant difference at the occlusal margin ($P = 0.086$) between the composite groups and also in the gingival margin of proximal box on cementum ($P = 0.126$). However, the difference between the composite groups at the gingival margin of proximal box on enamel was significant ($P = 0.036$).

Table 3
Frequency distribution of marginal microleakage scores at the occlusal and proximal box enamel and cementum margins in different composite groups

Margin	Composite		Score 0	Score 1	Score 2	Score 3	P value*
Occlusal margin	P60 incremental	a	6	5	2	1	0.086
	P60 bulk-fill	a	2	4	4	4	
	OPUS	a	6	6	1	1	
	Tetric	a	8	4	2	1	
	X-tra fil	a	6	4	4	0	
Proximal box enamel	P60 incremental	b	3	4	4	3	0.036
	P60 bulk-fill	c	0	1	7	6	
	OPUS	b	3	4	4	3	
	Tetric	b	3	5	4	2	
	X-tra fil	b	3	6	3	2	
Proximal box cementum	P60 incremental	d	0	3	5	6	0.126
	P60 bulk-fill	d	0	0	6	8	
	OPUS	d	1	4	5	4	
	Tetric	d	2	4	3	5	
	X-tra fil	d	1	5	4	4	

*Kruskal-Wallis test, **Groups with similar letters have no significant difference in pairwise comparisons by the Mann-Whitney test.

Pairwise comparisons of microleakage at the gingival margin of proximal box on enamel between different composites by the Mann-Whitney test revealed significant differences between P60 bulk-fill with P60 incremental ($P = 0.033$), Opus ($P = 0.033$), Tetric N Bond ($P = 0.009$), and X-tra fil ($P = 0.005$). Comparison of microleakage at different margins within each composite group by the non-parametric Friedman test showed a significant difference ($P = 0.001$). Pairwise comparisons of the margins within each composite group by the Wilcoxon signed rank test revealed significant differences in all groups ($P < 0.05$), except for P60 bulk-fill ($P = 0.083$). the gingival margin of proximal box on cementum had a significantly higher microleakage score than the gingival margin of proximal box on enamel margin and occlusal margin ($P < 0.05$). the microleakage at the gingival margin of proximal box on enamel was significantly higher than that at the occlusal margin in this group ($P < 0.05$).

T-test was applied to assess the effect of incremental and bulk-fill application of composites on microleakage, which revealed no significant difference in the microleakage score between the two composite application techniques (P = 0.194).

Discussion

Cuspal deflection can cause micro-crack propagation, crazing, reduction of fracture resistance, pulpal conditions, or even cusp fracture [8,27]. The present results revealed that the cuspal deflection of restored cavities with bulk-fill composites was significantly lower than that of cavities restored with the conventional composite with the incremental application technique at all-time points. Thus, the null hypothesis of the study in this respect was rejected. This finding was in agreement with the results of previous studies on this topic [28,30–32]. Different bulk-fill composites were not significantly different regarding cuspal flexure in our study, which was in accordance with previous findings. [27,31] A systematic review [33] indicated that despite the differences in the methodology of studies (type of composite, sample size, technique of testing), bulk-fill composites show lower cuspal deflection than conventional composite resins. Lower cuspal deflection of bulk-fill composites can be attributed to the structure of their resin matrix, and filler technology [34]. Lower cuspal deflection of X-tra fil may be due to its higher filler content compared with P60 [28]. TEGDMA-rich matrix of conventional composites results in higher cross-linking and higher polymerization shrinkage [35]; while, bulk-fill composites have higher amounts of UDMA and bis-EMA oligomers and no or very small amount of TEGDMA, resulting in lower polymerization shrinkage and lower cuspal deflection [31,32]. Higher UDMA content of bulk-fill composites, which is a high molecular weight monomer with relatively low viscosity, prolongs the polymerization reactions and leads to higher stress release due to higher composite flow before reaching the gel point [28,32]. The manufacturer of Xtra-fill composite claims that stress relievers have been used in its composition, serving as chemical cushions between the filler particles, and resulting in higher elasticity and lower polymerization shrinkage and cuspal deflection [32].

In the present study, maximum cuspal deflection was immediately after restoration, which significantly decreased within 7 days. These findings confirmed the previous results in this respect [32]. Following water storage, internal stresses are gradually released due to hygroscopic expansion of composite [36]. However, the primary stress generated in the first couple of minutes after restoration causes cuspal deflection, and may lead to debonding, enamel cracks, postoperative tooth hypersensitivity, and marginal microleakage. These side effects are not reversible even after compensation of polymerization shrinkage by hygroscopic expansion of composite.

Cuspal deflection of conventional composite restorations has been reported in laboratory experiments from 15 to 45 µm [28]. Considering the limited number of previous clinical studies, a standard value for cuspal deflection that causes clinical problems or the effect of time of occurrence of these changes on development of clinical symptoms such as postoperative tooth hypersensitivity, pain or secondary caries have yet to be identified.

It has been reported that return of cuspal deflection to baseline value takes time, and may never occur in the medium-size and large cavities [36]. In the present study, the values closely approximated the baseline value after 7 days, which was in agreement with the findings of a previous study [32]. Width and depth of the cavity can affect cuspal deflection as well [30]. Thus, similar mesio-occluso-distal cavities with the same dimensions were prepared in all teeth to eliminate the effect of this confounder on the results. Also, the type of light curing unit, curing time, light intensity, type of bonding system, and the bonding protocol were the same in all teeth to eliminate the effect of these confounding factors on the results.

In this study after 2000 thermal cycles marginal microleakage of restorations were assessed by the dye penetration technique using methylene blue because a significant correlation has been reported between the results of scanning electron microscopy and dye penetration test after 30 min of immersion in methylene blue [40]. The results showed that microleakage was minimum at the occlusal enamel margin, followed by the proximal box enamel margin, which was in agreement with previous findings [37,41,42]. Histological, morphological and compositional differences between the enamel and dentin lead to different marginal adaptation and bond strength values [43].

One advantage of this study, compared with previous ones, was assessment of microleakage at both the occlusal and proximal box enamel margins, revealing that the occlusal enamel margin of restoration had significantly lower microleakage than the proximal box enamel margin. This finding can be due to higher degree of conversion of composite and adhesive at the occlusal margin due to shorter distance between the tip of the curing unit and the surface, compared with the proximal box enamel margin [41]. Moreover, enamel thickness in the occlusal area is higher than that in the proximal area. Higher number of enamel cracks in the cervical region can also contribute to higher marginal leakage in the proximal area [39].

Microleakage is influenced by the type and size of tooth, C-factor of the cavity, adhesive technique, and composite polymerization technique [44]. Since, we tried to standardize all these factors in the present study; therefore, the results obtained only reflect the effect of the composite type on microleakage. We found that irrespective of the location of margin, the difference in marginal microleakage was not significant between bulk-fill composites and the conventional composite applied incrementally, which was in line with previous findings [45–48] although the frequency of margins with no or low-grade leakage was higher in bulk-fill composites. Previous studies did not report a significant difference in marginal leakage of bulk-fill and conventional composite resins either [46–49]. Also, this study showed lower microleakage at the enamel compared with dentin margin, which was in agreement with previous findings [37], and is due to simpler process of bonding to enamel, and the challenges encountered in bonding to dentin due to the differences in the degree of mineralization and water content of enamel and dentin. In this study, maximum leakage was recorded for P60 conventional composite applied as bulk-fill in 4-mm increments. Marginal microleakage of other composite groups was not significantly different at any margin. Low marginal microleakage of bulk-fill composites can be due to their modified composition, higher curing depth, and lower polymerization shrinkage. Higher polymerization depth of bulk-fill composites is due to the type, size, and shape of filler particles and their chemical composition, resulting in their higher translucency and subsequently higher polymerization depth [28,35,43,56]. Addition of prepolymerized fillers [57] and presence of stress inhibitors [1] in the composition of bulk-fill composites further decrease the polymerization stress. Also, some of bulk-fill composites have novel photo-initiators such as Ivocerin with higher capability to generate free radicals compared with camphorquinone [55].

This study was conducted on extracted teeth then lack of pulpal blood supply changes the physical and structural properties of dentin, which can affect the cuspal flexure and microleakage of composite resins after their polymerization. Short-term follow-up was another limitation of this study since cuspal flexure and microleakage were only assessed for 7 days after restoration. Future in-vivo studies are required to assess the effect of cuspal flexure following different restorative techniques particularly with bulk-fill composites on clinical signs and symptoms to obtain more reliable results.

Conclusion

According to the limitations of this study, the cuspal deflection in bulk-fill composite restoration was lower than that in the conventional composite in incremental technique. The marginal microleakage of bulk-fill in bulk fill method was comparable with conventional composite resin restorations in incremental technique.

Declarations

Ethical disclosures

The authors declare that no experiments were performed on humans or animals for this study.

Conflicts of interest

The authors have no conflicts of interest to declare.

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Figures

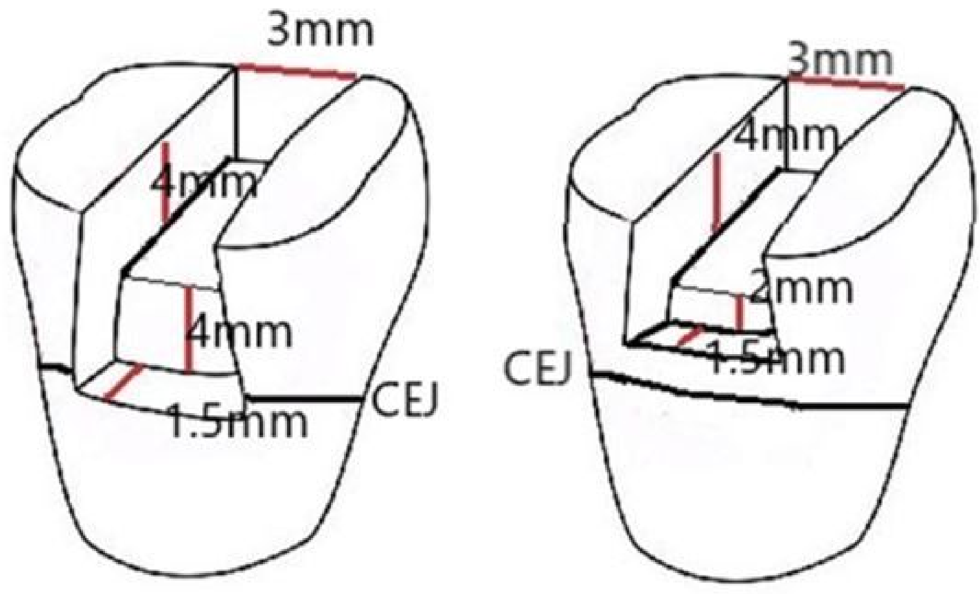

Figure 1

Showing stylized cavity design and measurements.

Figure 2

Showing adjustment and measurement of the tooth sample in the digital micrometer assembly

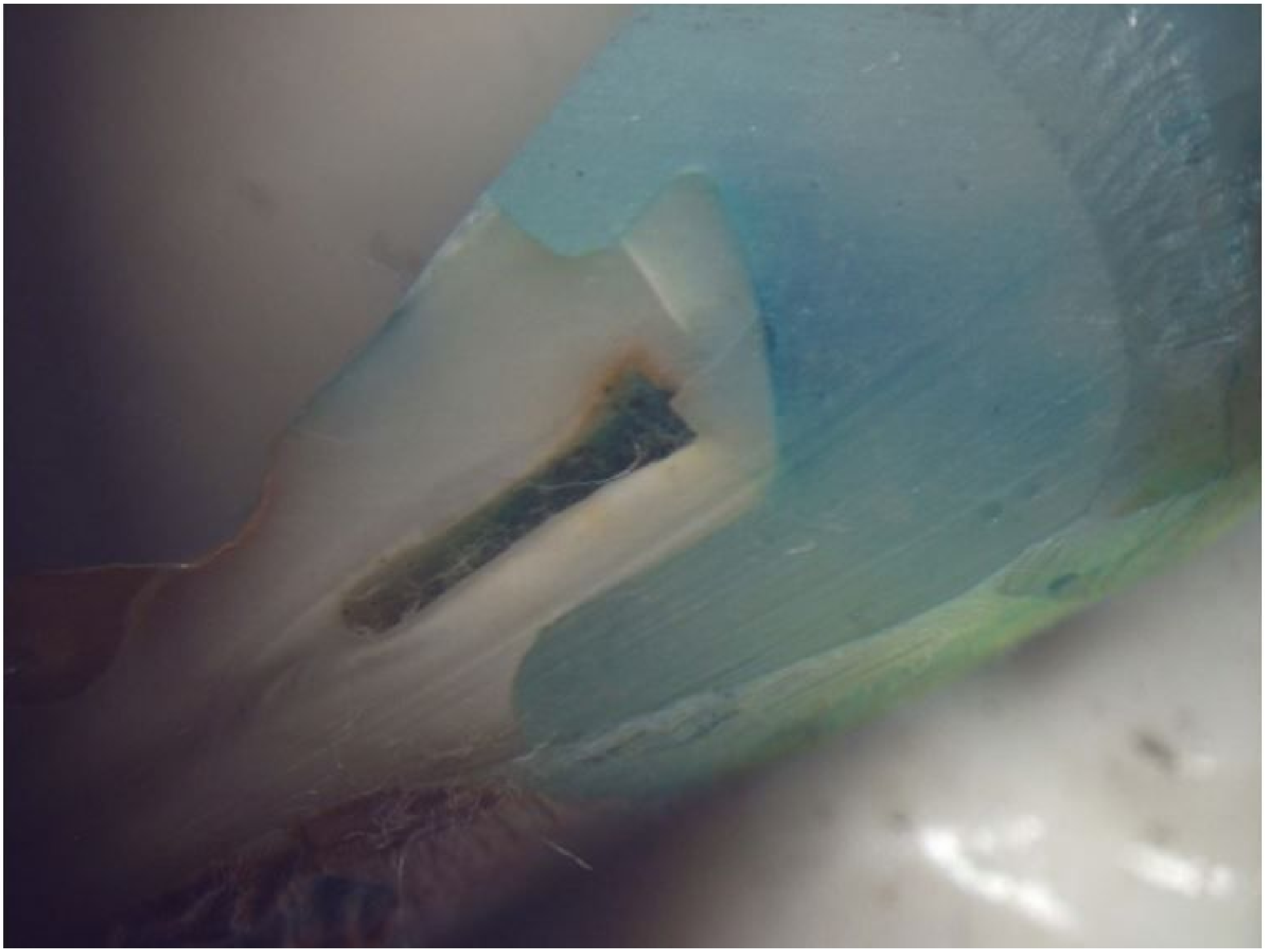

Figure 3

Score 0 microleakage

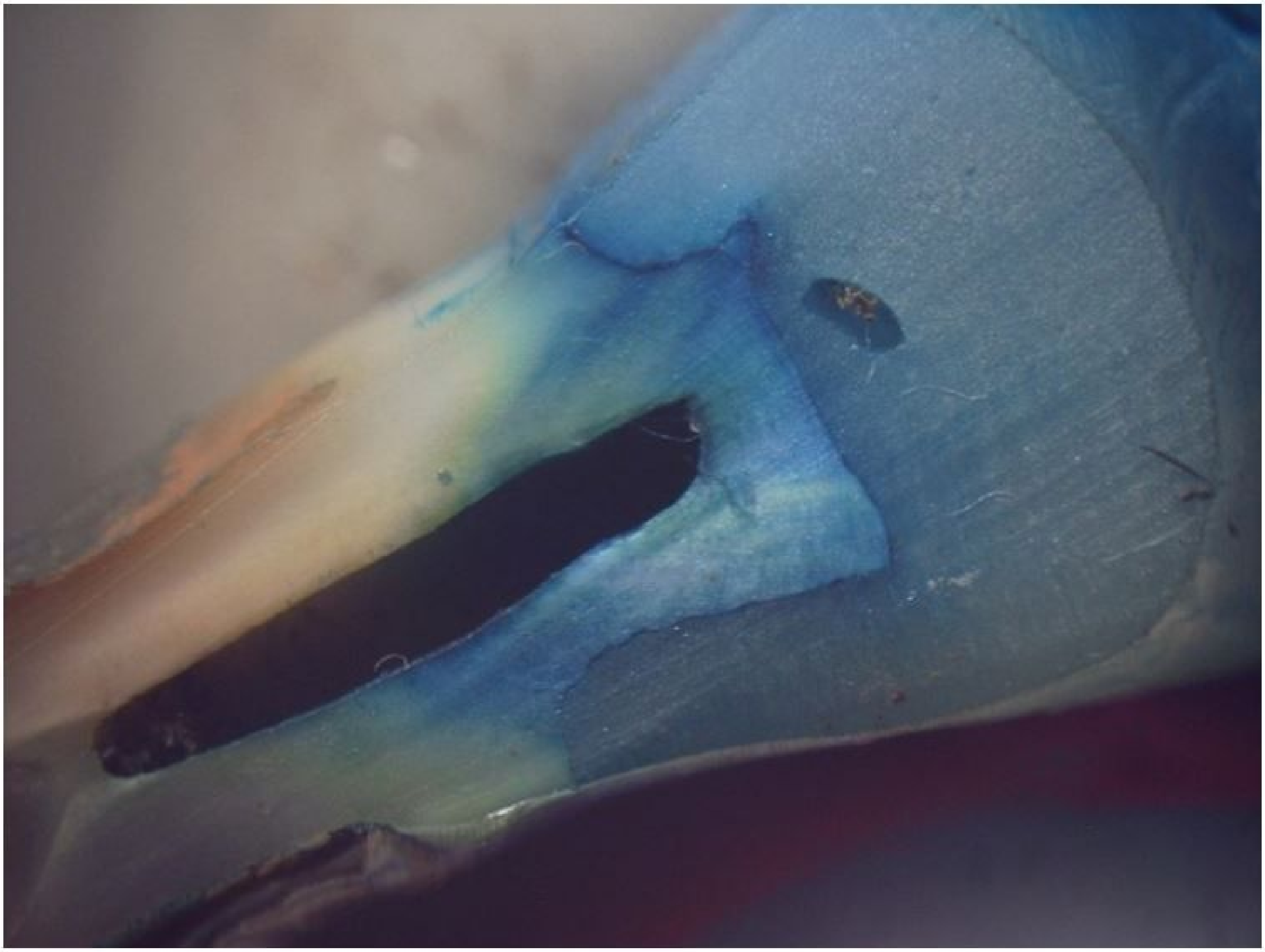

Figure 4

Score 3 microleakage

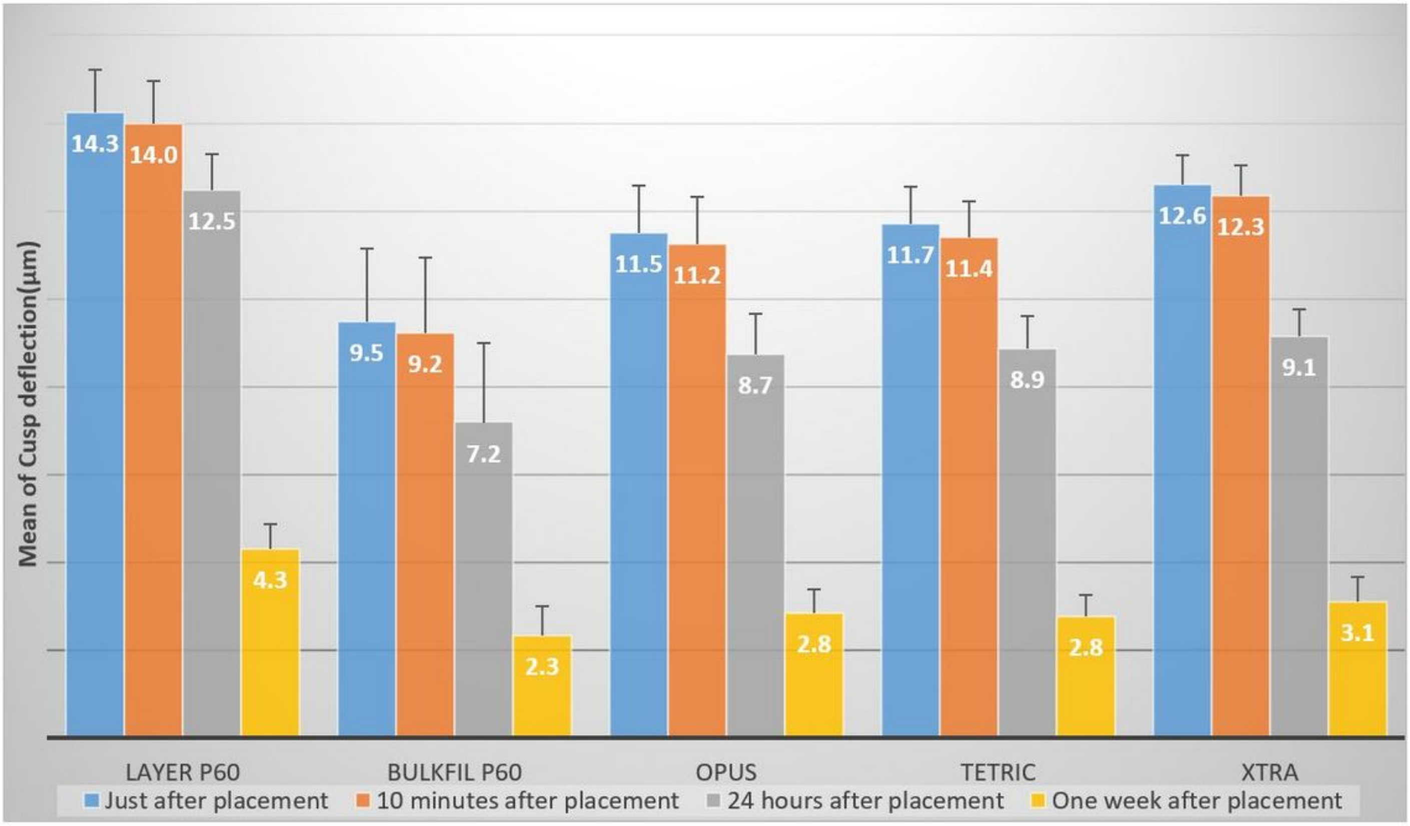

Figure 5

Error bar of the mean cuspal flexure of the groups at different time points