ORIGINAL RESEARCH

Effect of Type of Resin Composite Material on Porosity, Interfacial Gaps and Microhardness of Small Class I Restorations

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Abstract

Aim: This study aimed to compare the best restorative approach for the conservative class I cavity by comparing flowable and nanohybrid composites versus the placement technique regarding surface microhardness, porosity, and presence of interface gaps.

Materials and methods: Forty human molars were divided into four groups ($n = 10$). Standardized class I cavities were prepared and restored using one of the following materials: Group I – Flowable composite placed by incremental technique; group II – Flowable composite placed in one increment; group III – Nanohybrid composite placed by incremental technique; and group IV – Nano-hybrid composite placed in one increment. After finishing and polishing, specimens were sectioned into two halves. One section was chosen randomly for the Vickers microhardness (HV) evaluation and the other section was used for the assessment of porosities and interfacial adaptation (IA).

Results: The surface microhardness range was 28.5–76.2 ($p < 0.05$), mean pulpal microhardness range was 27.6–74.4 ($p < 0.05$). Flowable composites had lower HV than conventional counterparts. The mean pulpal HV of all materials exceeded 80% of occlusal HV. Restorative approaches did not statistically differ in porosities. However, IA percentages were higher in flowable materials compared to nanocomposites.

Conclusion: Flowable resin composite materials have lower microhardness than Nanohybrid composites. In small class I cavities, the number of porosities was similar between the different placement techniques and the interfacial gaps were highest in the flowable composites.

Clinical significance: The use of nanohybrid resin composite to restore class I cavities will result in better hardness and less interfacial gaps compared to flowable composites.

Keywords: Class I cavities, Flowable composite, Interfacial gaps, Microhardness, Nanohybrid composites.

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Introduction

Adhesive dentistry has changed the principles and practice of operative dentistry. In treating occlusal carious lesions, dentists need only to remove the decayed tooth substance.[1] This may result in an occlusal opening of fissures that have a small dimension and local extension into dentin.[2]

After preparation, dentists can restore the irregularly shaped small cavities using a variety of materials and techniques. Due to their lower viscosity, flowable resin composites have been recommended as the material of choice for restoring small, narrow cavities.[3–5] On the other hand, and due to their lower filler content, flowable resin composites have inferior physical properties and might not withstand the occlusal forces as a normal hybrid resin composite will.[6] A hybrid resin composite can produce posterior restorations with excellent longevity, but polymerization shrinkage stresses and incomplete adaptation to the walls of the cavity may limit their performance.[7]

Although several studies indicated that the incremental placement of resin composite restorations can improve bond strength, recently there is an increased usage of bulk-filling restorative resin materials since it reduces the time required to fill a cavity in comparison with the traditional incremental filling technique.[8–12] This thicker increment became possible due to the increased translucency of the bulk-fill composites which allow greater light transmission.[12,13] In addition, the manufacturers have used stress-relief monomers and more reactive photo-initiators which resulted in decreased polymerization shrinkage stresses.[14,15]

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When the stresses of polymerization shrinkage of resin composite exceed the strength of the bond between the adhesive and the tooth structures, gap formation at the bonding interface will result. Gap formation can contribute to postoperative sensitivity, development of secondary caries, and pulpal inflammation, which can cause restoration failure.[16] Cavities with a high configuration factor (c-factor: ratio of bonded to non-bonded resin surfaces) are at a greater risk for gap formation because polymerization stresses may be increased.[9,14,17] Furthermore, the type of resin composite used and the restorative technique might affect the adaptation of the restorative material to cavity walls. There are contradictory results in the literature regarding the effect of the restorative technique on marginal adaptation. For example, better marginal adaptation has been found when using restorative bulk-fill composite compared to flowable bulk-fill composite.[18] While no significant differences in marginal adaptation were found between incremental and bulk placement techniques within a given product per location.[19]

Another study showed better internal adaptation in class I cavities when using the incremental placement of composite restorations compared to bulk placement.[20] Furthermore, voids and defects within the body of the resin composite can form because of mechanical air entrapment during the placement of the restoration.[21] The presence of porosities has been found to depend on the thickness of the composite material, the placement technique, and operator skills.[22]

Since both gap formation and internal defects will adversely affect the mechanical properties of the composite and the longevity of the restoration. Therefore, Proper handling of dental adhesives and resin composites should ideally lead to restoration with a perfect seal and free of porosities and voids.[23]

Because it has less viscosity, the flowable resin composites will adapt better to the walls of the cavity but on the other hand, it has a higher polymerization shrinkage, and this might lead to debonding of the restoration from the cavity walls. Also, bulk fill composites are placed in one increment, and this might be more difficult to get adapted to the cavity walls. Therefore, we wanted to compare the bulk fill technique to the traditional incremental placement technique regarding porosity and marginal adaptation in small class I cavities.

Therefore, the aim of this study is to investigate the effect of the restorative material (flowable versus nanohybrid resin composite) and the restoration technique (incremental versus bulk-fill placement) on porosities, interfacial gap formation and micro-hardness of class I resin composite restoration. Materials from the same company were selected for this purpose, namely: conventional flowable composite (Filtek™ Z350 XT Flowable; 3M ESPE), Bulk-fill flowable base composite (Filtek™ bulk fill flowable restorative; 3M ESPE), conventional nanohybrid composite (Filtek™ Z350 XT universal restorative; 3M ESPE) and bulk-fill composite (Filtek™ bulk fill posterior restorative; 3M ESPE).

Materials and Methods

Study Design and Ethical Aspects

This work was supported by a research grant from Kuwait University Research Administration, project no. DR 01/16 and used the facility of Kuwait University General Facility Project SRUL 01/14. The study and the materials that have been used are listed in Table 1. The sample size of this study was based on earlier related published studies and based on the mean differences and standard deviations assumptions; the total sample size was estimated at 40 cavities (10 per group) at α = 0.05 and power of 85% (G* Power Statistical power software v. 3.1.9.7).[24]

Forty extracted noncarious human molar teeth were used for this study. The teeth included in the study were extracted for periodontal or prosthetic reasons. The patients who attend Kuwait University Dental Clinics sign a consent form for the treatment plan before they receive any treatment. The teeth had no fractures, no cracks, no wear, and have completed roots. The teeth were cleaned with pumice and stored in 5% thymol within three months after extraction. All teeth were mounted in acrylic blocks to ease manipulation. The teeth used in the study were of similar size and were randomly assigned to the groups.

Table 1: Groups with materials, batch numbers and number of layers used in this study

Group	*Restorative materials*	*LOT numbers*	*Number of layers*
I	Filtek ™ Z350XT flowable restorative	N728318	2
II	Filtek ™ bulk fill flowable	N693135	1
III	Filtek ™ Z350 universal restorative	N564536	2
IV	Filtek ™ bulk fill posterior restorative	N660727	1

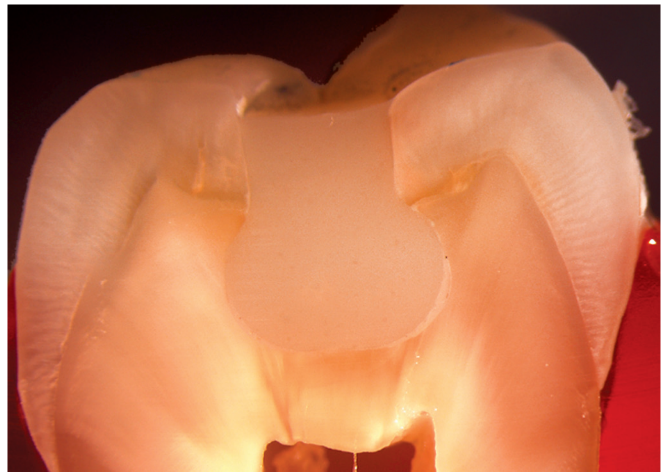

Fig. 1: Image showing a cross section of a restored cavity

Cavity Preparation

Class I cavities were prepared in 40 permanent molar teeth using carbide round burs size 8 (diameter 2.3). The burs were used on a high-speed handpiece and with watercooling. One bur was used per group. The depth of the cavities was 4 mm measured from the deepest part of the cavity to the cavosurface margin using a periodontal probe. To simulate an excavation process in dentine at the bottom of the cylindrical cavity, an extension was prepared using the same bur on a slow-speed friction-grip handpiece.

The bur was placed at the bottom of the cavity and used against the ascending cavity wall to simulate an excavation process. The shaft of the bur acted during this procedure as a stopgap against further extension of the cavity. An example of a restored cavity is shown in Figure 1.[24]

Adhesive Protocol

The adhesive protocol was the same for all teeth. The cavities were cleaned with air-water spray and then the enamel part of the cavity was acid etched with 35% phosphoric acid for 15 seconds, washed, and dried. Subsequently, the adhesive (Single Bond Universal™; 3M ESPE) was applied according to the manufacturing instructions and cured using Elipar S10 LED curing light (3M ESPE) for 20 seconds.

Restorative Protocol

Teeth were randomly divided into four groups 10 teeth each, depending on restorative material and protocol:

Group I: Cavities were restored using conventional flowable resin composite (Filtek™ Z350 XT Flowable; 3M ESPE) in the two-layer application. Each layer was cured for 20 seconds according to the manufacturing instructions.

Group II: Cavities were restored using bulk-fill flowable base composite (Filtek™ bulk fill flowable restorative; 3M ESPE) as one layer and cured for 20 seconds according to the manufacturing instructions.

Group III: Cavities were restored with nanocomposite (Filtek™ Z350 XT universal restorative; 3M ESPE) in two layers and each layer was cured for 20 seconds according to the manufacturing instructions.

Group IV: Cavities were restored with bulk-fill composite (Filtek™ bulk fill posterior restorative; 3M ESPE) as one layer and cured for 20 seconds according to the manufacturing instructions.

Immediately after each restoration, finishing and polishing were performed using carbide finishing burs and rubber points (green and yellow), respectively.

Sectioning

After finishing and polishing specimens were placed in distilled water at 37°C for 24 hours. Specimens were not subjected to thermocycling or cyclic load, so the effect of the restorative material alone can be assessed.

The embedded specimens were then sectioned longitudinally from a predetermined location in the buccolingual direction into two halves using Accutom 10 cut-off machine (Struers ApS, Pederstrupvej 84, 2750 Ballerup, Denmark) with a silicon carbide cut-off wheel (10S15, Struers ApS, Denmark) with 150 mm (6″) diameter and 0.5 mm thickness.

One section was chosen randomly for the microhardness evaluation and the other section was used for porosities and interfacial gaps assessment.

Microhardness

For microhardness evaluation, the samples were polished with silicon carbide sandpapers 600 and 1000 grits respectively. Then they were cleaned with the diamond suspension of 6 µm and 3 µm particle size and finally they were cleaned with colloidal silica polishing suspension of 0.05 µm particle size. Vickers microhardness (HV) testing was done with a force of 200 gm using Microhardness Tester (400 DAT, micro-Vickers measurement, INNOVATEST Europe BV Borgharenweg 140, 6222 AA Maastricht, the Netherlands). The measuring indenter, the Vickers pyramid, was pressed to the resin composite of each section 0.5 mm from the occlusal surface and at 0.5 mm from the pulpal side of the cavity. For each specimen, HV of the lower surface was compared with the upper surface value and the 80% ratio was considered as the cut-off point. The pictures were evaluated using a microscope at 10× for each specimen, the average of three indentations at each depth was used in the statistical analysis.

Porosities and Interfacial Gaps

For porosities and interfacial gap formation, pictures of the sections were taken with a digital camera (Leica DC 200, Leica Microsystems, Wetzlar GmbH, Ernst-Leitz Strasse, D-35578 Wetzlar, Germany) attached to a stereomicroscope (Leica MZ-6, Leica Microsystems, Wetzlar GmbH, Ernst-Leitz-Strasse, D-35578 Wetzlar, Germany). The pictures were taken at two magnifications: ×20 and ×100. At magnifications of × 20 the sections were inspected for porosities and interfacial gaps:

Internal voids (porosity) scores

Score 0 = voids or porosities absent

Score 1 = voids or porosities present

Interfacial gaps scores

Score 0 = gaps are absent

Score 1 = gaps present

Then at magnification of ×100, the size of the porosities and/or the length interfacial gaps were measured in micrometers with an accuracy of 0.001 mm.

Statistical Analysis

The data were analyzed statistically with SPSS software, version 23.0 (SPSS Inc., Chicago, Illinois, USA). The differences in microhardness between the top and bottom surfaces within each material were compared using paired *t*-tests. Multivariate analysis was used to examine the differences between groups in occlusal and pulpal microhardness, a diameter of the largest void, and the length of the interfacial gap.

Furthermore, the Chi-square test was used to determine the difference between groups in the number of porosities and a number of gaps.

Results

The mean occlusal microhardness ranged from 32.8 for group II to 73.9 for group III, as shown in Table 2. Multivariate analysis showed a statistical difference between the groups ($p < 0.001$). The Tukey HSD *post-hoc* test showed that all groups were statistically different. The ranking of the mean occlusal microhardness from lowest to highest was: Bulk-fill flowable resin composite, conventional flowable resin composite, bulk-fill resin composite, and conventional Nano-fill resin composite.

The mean of pulpal microhardness ranges from 27.7 for group II to 70.7 for group III. The difference between the groups was the same as for the occlusal microhardness. The paired *t*-test showed a statistically significant difference between the occlusal and the pulpal microhardness ($p < 0.05$) but the ratio between the two was higher than 80% for all groups. Table 3 shows the number of porosities present in each group. The Chi-square test showed no statistically significant difference between the groups ($p > 0.05$). Also shown in the table is the mean diameter of the largest porosity in each group. There was no statistically significant difference between the groups ($p > 0.05$).

The mean length of the gaps for each group ranged from 2.3 mm for group I to 4.3 mm for group II as presented in Table 4. Multivariate analysis showed a statistical difference between the groups ($p < 0.05$). The Tukey HSD *post-hoc* test showed that group II was different than the other groups.

Discussion

This study was carried out to investigate the influence of different restorative resin composite materials on microhardness, porosities, and gap formation while restoring minimal class I cavities. The null hypothesis was that there is no difference between flowable resin composite material, bulk flowable resin composite,

Table 2: Means and standard deviations of Vickers hardness at the occlusal and pupal sides per group

Groups	*Occlusal microhardness*	*Pulpal microhardness*	*Pulpal/occlusal ratio*
I	46.5 ± 2.5 A a	44.9 ± 3.7 A a	96.6
II	32.8 ± 2.5 B b	27.7 ± 1.3 B b	84.5
III	73.9 ± 5.8 C c	70.7 ± 4.7 C c	95.7
IV	57.0 ± 4.4 D d	54.0 ± 4.1 D d	

*Different upper case letters represent statistical difference in rows; Different lower case letters indicate statistical difference in columns

Table 3: Number of voids present in each group and the mean diameter of the largest void

Group	*Number of voids*				*Diameter of the largest void*
	0	1	2	3	
I	2	3	2	3	0.25 ± 0.29 a
II	4	3	3	0	0.27 ± 8.6 a
III	1	5	4	0	0.27 ± 0.26 a
IV	2	2	6	0	0.30 ± 0.25 a

*Different lower case letters indicate statistical difference in columns

Table 4: Number of samples with interfacial gaps and the gap length in mm

Group	*Count*	*Gap length (mm)*
I	10/10 a	2.4 a
II	9/10 a	4.3 b
III	10/10 a	2.4 a
IV	10/10 a	2.7 a

*Different lower case letters indicate statistical difference in columns

nanocomposite, and bulk fill resin composite material in their microhardness, porosities, and gap formation while used to restore small class I cavities. The results showed that there was a difference between the materials in their microhardness both at the occlusal and pulpal sides of the cavity and there was a difference also between materials in the interfacial gap length. On the other hand, there was no difference between the materials in the number of porosities.

Microhardness for all Bulk fill resin composites was less than conventional resin composites. Similar results have been reported in the literature.[25,26] Furthermore, the bottom-to-top ratio was above 80% for all the studied materials. Also, similar results have been found in the literature but the reported ratios in the literature are less than our results.[25,26] The reason for this is the fact that studies measure microhardness by preparing the samples in metal molds. In this study we were trying to mimic a clinical-situations, therefore we did measure the hardness after curing the resin composite inside a class I cavity. Also in this study, we used 20-second curing time as recommended by the manufacturer. It has been found that increasing the curing time will affect the mean hardness and the depth of cure of bulk fill resin composite materials.[25,26]

Flowable bulk-fill composites had lower microhardness than conventional flowable and also lower than bulk-fill resin composite material. Similar results have been reported in the literature.[15] Bulk-fill flowable also showed more interfacial gap formation compared to conventional flowable resin composite. This can be attributed to the fact that bulk-fill flowable has more shrinkage than conventional flowable.[27]

The number of samples with interfacial gaps and the length of gaps found in this study were relatively high. The reason for this can be the shape of the cavities (high c-factor) used and also the 4 mm depth. Both of these factors have been found to contribute to adhesive de-bonding.[17,28] Furthermore, the length of the interfacial gap was higher for bulk-fill materials compared to conventional materials. Similar results have been found in the literature.[18] This can be explained by the fact that bulk-fill composites have higher polymerization shrinkage than conventional resin composites.[12] On the other hand, others have found bulk-fill resin composite materials to have lower volumetric post gel shrinkage and lower stresses compared to conventional resin composite materials.[15] Benetti et al. demonstrated that polymerization contraction and gap formation of bulk-fill resin composite is viscosity dependent.[29] They found out that some high-viscosity bulk-fill resin composites have similar gap formation to that of conventional resin composites. Heating high-viscosity bulk-fill resin composite materials has been recommended prior to placement to improve adaptation.[10]

Variations in the results between studies can be attributed to differences in the restorative materials, adhesive systems, type of cavity, curing time, and method used in these studies in addition to the way the gap formation and internal adaptation have been looked at. In trying to limit variations, we used in this study all the materials from one company.

There was no difference between conventional flowable and conventional resin composite material in the interfacial gap formation. Although flowable resin composite has higher polymerization shrinkage at the same time it has lower modulus of elasticity and a lower flexural strength which might compensate for the higher polymerization shrinkage.[30]

This study used only one example of each material and one cavity size. Therefore, the results of this study apply to the materials and cavity design used. Different materials and different cavity designs and sizes are needed to confirm the results of the current study.

Conclusion

With these limitations in consideration, it can be concluded that bulkfill resin composites showed lower HV than their conventional equivalents. Bulk fill flowable composites presented longer interfacial gaps compared to other type of resin composites in small class I cavities. Studies of different materials and different cavity configurations and sizes are needed to confirm the results of this study.

Author Contributions

All authors have contributed to conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation and writing; funding acquisition, Qasem Alomari, Qoot Alkhubaizi & Mohammad Y. Sabti. All authors have read and agreed to the published version of the manuscript.

References

1. Akpata ES, Alomari QD, AlShammery AR. Dental caries in principles and practice of operative dentistry: A modern approach. United Kingdom: Quintessence Publishing, 2013. pp. 1–27.
2. Opdam NJ, Roeters JJ, de Boer T, et al. Voids and porosities in class I micro preparations filled with various resin composites. Oper Dent 2003;28(1):9–14. PMID: 12540112.

3. Jager S, Balthazard R, Dahoun A, et al. Filler content, surface microhardness, and rheological properties of various flowable resin composites. Oper Dent 2016;41(6):655–665. DOI: 10.2341/16-031-L.
4. Peters MC, McLean ME. Minimally invasive operative care I. Minimal intervention and concepts for minimally invasive cavity preparations. J Adhes Dent 2001 Spring;3(1):7–16. PMID: 11317386.
5. Peters MC, McLean ME. Minimally invasive operative care. II. Contemporary techniques and materials: An overview. J Adhes Dent 2001;3(1):17–31. PMID: 11317381.
6. Baroudi K, Rodrigues JC. Flowable resin composites: A systematic review and clinical considerations. J Clin Diagn Res 2015;9(6): ZE18–ZE24. DOI: 10.7860/JCDR/2015/12294.6129.
7. Rho YJ, Namgung C, Jin BH, et al. Longevity of direct restorations in stress-bearing posterior cavities: A retrospective study. Oper Dent 2013; 38(6):572–582. DOI: 10.2341/12-432-C.
8. Loguercio AD, Reis A, Schroeder M, et al. Polymerization shrinkage: Effects of boundary conditions and filling technique of resin composite restorations. J Dent 2004;32(6):459–470. DOI: 10.1016/j.jdent.2004.02.010.
9. Nikolaenko SA, Lohbauer U, Roggendorf M, et al. Influence of c-factor and layering technique on microtensile bond strength to dentin. Dent Mater 2004;20(6):579–585. DOI: 10.1016/j.dental.2003.08.001.
10. Chesterman J, Jowett A, Gallacher A, et al. Bulk-fill resin-based composite restorative materials: A review. Br Dent J 2017;222(5): 337–344. DOI: 10.1038/sj.bdj.2017.214.
11. Fronza BM, Rueggeberg FA, Braga RR, et al. Monomer conversion, microhardness, internal marginal adaptation, and shrinkage stress of bulk-fill resin composites. Dent Mater 2015;31(12):1542–1551. DOI: 10.1016/j.dental.2015.10.001.
12. Fronza BM, Ayres A, Pacheco RR, et al. Characterization of inorganic filler content, mechanical properties, and light transmission of bulk-fill resin composites. Oper Dent 2017;42(4):445–455. DOI: 10.2341/16-024-L.
13. Shibasaki S, Takamizawa T, Nojiri K, et al. Polymerization behavior and mechanical properties of high-viscosity bulk fill and low shrinkage resin composites. Oper Dent 2017;42(6):E177–E187. DOI: 10.2341/16-385-L.
14. Braga S, Oliveira L, Rodrigues RB, et al. The effects of cavity preparation and composite resin on bond strength and stress distribution using the microtensile bond test. Oper Dent 2017;43(1):81–89. DOI: 10.2341/16-338-L.
15. Rosatto CM, Bicalho AA, Veríssimo C, et al. Mechanical properties, shrinkage stress, cuspal strain and fracture resistance of molars restored with bulk-fill composites and incremental filling technique. J Dent 2015;43(12):1519–1528. DOI: 10.1016/j.jdent.2015.09.007.
16. Dennison JB, Sarrett DC. Prediction and diagnosis of clinical outcomes affecting restoration margins. J Oral Rehabil 2012;39(4):301–318. DOI: 10.1111/j.1365-2842.2011.02267.x.
17. Han SH, Sadr A, Tagami J, et al. Internal adaptation of resin composites at two configurations: Influence of polymerization shrinkage and stress. Dent Mater 2016;32(9):1085–1094. DOI: 10.1016/j.dental.2016.06.005.
18. Jung JH, Park SH. Comparison of polymerization shrinkage, physical properties, and marginal adaptation of flowable and restorative bulk fill resin-based composites. Oper Dent 2017;42(4):375–386. DOI: 10.2341/16-254-L.
19. Furness A, Tadros MY, Looney SW, et al. Effect of bulk/incremental fill on internal gap formation of bulk-fill composites. J Dent 2014;42(4):439–449. DOI: 10.1016/j.jdent.2014.01.005.
20. Bakhsh TA, Sadr A, Shimada Y, et al. Concurrent evaluation of composite internal adaptation and bond strength in a class-I cavity. J Dent 2013;41(1):60–70. DOI: 10.1016/j.jdent.2012.10.003.
21. Nazari A, Sadr A, Shimada Y, et al. 3D assessment of void and gap formation in flowable resin composites using optical coherence tomography. J Adhes Dent 2013;15(3):237–243. DOI: 10.3290/j.jad.a28623.
22. Samet N, Kwon KR, Good P, et al. Voids and interlayer gaps in class 1 posterior composite restorations: A comparison between a microlayer and a 2-layer technique. Quintessence Int 2006;37(10):803–809. PMID: 17078279.
23. Vichi A, Margvelashvili M, Goracci C, et al. Bonding and sealing ability of a new self-adhering flowable composite resin in class I restorations. Clin Oral Investig 2013;17(6):1497–1506. DOI: 10.1007/s00784-012-0846-6.
24. Opdam NJ, Roeters JJ, Peters TC, et al. Cavity wall adaptation and voids in adhesive Class I resin composite restorations. Den Mater 1996;12(4):230–235. DOI: 10.1016/s0109-5641(96)80028-5.
25. AlQahtani MQ, Michaud PL, Sullivan B, et al. Effect of high irradiance on depth of cure of a conventional and a bulk fill resin-based composite. Oper Dent 2015;40(6):662–672. DOI: 10.2341/14-244-L.
26. Zorzin J, Maier E, Harre S, et al. Bulk-fill resin composites: Polymerization properties and extended light curing. Dent Mater 2015;31(3):293–301. DOI: 10.1016/j.dental.2014.12.010.
27. Jang JH, Park SH, Hwang IN. Polymerization shrinkage and depth of cure of bulk-fill resin composites and highly filled flowable resin. Oper Dent 2015;40(2):172–180. DOI: 10.2341/13-307-L.
28. Van Ende A, De Munck J, Van Landuyt K, et al. Effect of bulk-filling on the bonding efficacy in occlusal Class I cavities. J Adhes Dent 2016; 18(2):119–124. DOI: 10.3290/j.jad.a35905.
29. Benetti AR, Peutzfeldt A, Lussi A, et al. Resin composites: Modulus of elasticity andmarginal quality. J Dent 2014;42(9):1185–1192. DOI: 10.1016/j.jdent.2014.07.004.
30. Tsujimoto A, Barkmeier WW, Takamizawa T, et al. Depth of cure, flexural properties and volumetric shrinkage of low and high viscosity bulk-fill giomers and resin composites. Dent Mater 2017;36(2): 205–213. DOI: 10.4012/dmj.2016-131.