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Original Article

# Efficiency of bulk-fill versus conventional resin-based composite in class II restorations: A dental student perspective

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ABSTRACT

*Purpose/objectives:* The aim of the study was to evaluate the effect of two distinct light-polymerization protocols, used by dental students, on the placement time and polymerization efficiency of bulk-fill (BF) and conventional (CRC) resin-based composites (RBCs).
*Methods:* Thirty dental students participated in this study. Each student was asked to complete four Class II RBC restorations using two different types of RBCs (BF and CRC) paired with two distinct light-polymerization protocols: one using 1200 $mW/cm^2$ irradiance (P1200) and one using 800 $mW/cm^2$ irradiance (P800). Manufacturer instructions for curing times relative to these irradiance levels were adhered to. The restorations were retrieved, sectioned and Vickers microhardness (VMH) was measured at specific reading points. The placement time was recorded for each procedure. Multivariate analysis of variance and Bonferroni post hoc test were used for data analysis.
*Results:* Bulk-fill RBCs were associated with significantly shortened placement times ($P < 0.001$). VMH values of CRC-P800 were significantly higher compared to all other groups ($P < 0.02$). Across all groups tested, the VMH values at the deepest reading points exceeded those at the occlusal surfaces by over 80 %.
*Conclusions:* The use of BF RBCs with a P1200 light-polymerization protocol reduced students' procedural times while maintaining effective polymerization of the restorations.

## 1. Introduction

Resin-based composites (RBCs) are widely accepted for various restorations, with ongoing improvements in their physical, mechanical, and handling properties (Rizzante et al., 2019; Pereira et al., 2018). Despite their advantages, light-cured RBCs face challenges such as polymerization shrinkage and longer procedure times due to the incremental placement technique, necessary for ensuring adequate light penetration and efficient polymerization (Kaisarly and Gezawi, 2016; Scolavino et al., 2016). To address these issues, bulk-fill (BF) materials, which can be cured in bulk up to 4–5 mm thick, have been developed (Chesterman et al., 2017; Silva et al., 2023).

The production of BF materials involves various modifications to monomers and fillers, improving light penetration and reducing polymerization shrinkage (Corral-Núnez et al., 2015; Abed et al., 2015). However, concerns remain regarding the impact of these modifications on microhardness and depth of cure (Marovic et al., 2013). Microhardness is a key indicator of a material's resistance to deformation and provides insights into wear, polish retention, and the abrasive effects on opposing teeth (Cidreira Boaro et al., 2019). Longitudinal microhardness testing can assess the depth of cure, which is deemed adequate if surface values reach 80 % or higher (Rizzante et al., 2019). Insufficient depth of cure can negatively impact mechanical properties and increase the release of uncured monomers (De Souza et al., 2015).

Light-polymerization techniques significantly affect the physical and mechanical properties of RBC restorations (Catelan et al., 2015). Factors such as light irradiance, exposure duration, and the positioning of the light-curing tip influence the polymerization process (Awad et al.,

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2017). The principle of reciprocity, or "exposure reciprocity law," proposes a reciprocal relationship between irradiance levels and exposure time for effective curing (Sadeghyar et al., 2020). Although this principle is clinically appealing for achieving adequate curing with higher irradiance in shorter times, it does not apply universally due to variables like photoinitiator type and material viscosity (AlShaafi, 2017; Sadeghyar et al., 2020). Limited reciprocity applies to both conventional resin composites (CRCs) and BF materials, as higher irradiance cannot fully compensate for insufficient exposure time, leading to inadequate depth of cure and polymerization (Daugherty et al., 2018).

Many dental schools worldwide continue to favor incremental placement techniques in students' clinical training (Sidhu et al., 2021). Although studies show that BF RBC materials perform comparably to CRCs placed incrementally, educators still hesitate to teach BF techniques, due to uncertainties related to the students' handling of the material (Saati et al., 2022; Sengupta et al., 2023; Silva et al., 2023; Tirapelli, 2022). Understanding whether potential gaps in students' knowledge and technique affect BF restoration outcomes is crucial for informed curriculum decisions.

This study aims to evaluate the effect of two distinct light-polymerization protocols used by dental students on the placement time and polymerization efficiency of BF and CRC RBCs, following manufacturer instructions for curing times relative to irradiance levels. The null hypothesis posits that these factors will not significantly influence polymerization efficiency or placement time.

## 2. Material and methods

### 2.1. Study design

This study, approved by the Research and Ethics committee at Dar Al Uloom University (DAU) under reference number COD/IRB/2020/13, involved thirty preclinical dental students from the College of Dentistry at DAU. Each student provided informed consent to participate in the study. All participants had attended a "Light Curing Techniques" lecture and had at least three months of preclinical training on two-surface RBC restorations.

Each student performed four RBC restorations using two types of RBC (BF and CRC) and two light-polymerization protocols: 1200 mW/cm$^2$ (P1200) and 800 mW/cm$^2$ (P800). Both RBCs were high viscosity with mechanical properties suitable for clinical use (Rizzante et al., 2019). A light shade (A2) was used to ensure adequate light penetration, in addition to being one of the most regularly used shades. Both RBCs, produced by the same manufacturer, shared a common composition except for the components that allow bulk curing in BF materials. Details of the RBCs are summarized in Table 1.

Standardized mesial slot cavities were prepared in mandibular first molar Ivorine teeth (Frasaco, Germany) by a single operator. The dimensions (5.0 mm occlusogingivally, 3.5 mm buccolingually, and 2.0 mm in axial depth) were confirmed with a micrometer to 0.01 mm accuracy, ensuring no undercuts were present. The prepared teeth were positioned between adjacent teeth in a Dentiform arch secured in a phantom head to simulate posterior restorations, in which restricted access could compromise the delivered irradiance values. A circumferential metal Tofflemire matrix band was applied and secured with a wooden wedge. The slot preparations were lightly coated with glycerin to facilitate the retrieval of the restoration after polymerization. Excess glycerin was wiped off using a micro-brush to ensure that the glycerin film would not interfere with the RBC placement.

Students placed the RBC restorations in increments for CRC groups and in bulk for BF groups, following manufacturer recommendations. A three-sided polymerization technique was instructed: curing from the occlusal surface, followed by curing from the buccal and lingual surfaces after removing the matrix band and wedge. Two light-emitting diode (LED) units were used: Bluephase (Ivoclar Vivadent AG) with a wavelength spectrum of 385–515 nm at 1,200 mW/cm$^2$ ± 10 %, and Bluephase Style M8 (Ivoclar Vivadent AG) with a wavelength spectrum of 430–490 nm at 800 mW/cm$^2$ ± 10 %. Curing times followed manufacturer recommendations (Table 1). The light irradiance was checked with a radiometer (Bluephase Meter II Radiometer – Ivoclar Vivadent AG) before each use.

All restorations were placed in a single session, with students instructed not to discuss the experiment until completion. Supervision ensured adherence to the study protocols.

### 2.2. Microhardness testing

After polymerization, restorations were carefully removed using an excavator. The preparation's configuration and glycerin lubrication facilitated removal. Specimens were stored at 37 °C for 24 h in distilled water, then embedded in epoxy resin and sectioned mesiodistally with a water-cooled diamond disc (Isomet; Buehler, USA).

Vickers microhardness (VMH) was measured at predefined locations along the cut surface of the restorations in vertical and horizontal planes (Fig. 1). In the vertical plane, VMH measurements were taken at 0.2 mm from the matrix band, through the center, and 0.2 mm from the axial face. Horizontal measurements were taken at 1 mm intervals, starting 0.1 mm below the occlusal surface to 0.1 mm above the gingival floor.

**Table 1**
Resin-based composite materials used in the study and grouping.

| **Composite Material Brand Name (Shade)** ***Lot Number*** | **Resin composition** | **Fillers** | **Manufacturer** | **Study Groups Codes** | **Application method (Per manufacturers' recommendations)** |
|---|---|---|---|---|---|
| Filtek-One BF Restorative (A2) *0009712946–70201404871* | AUDMA, UDMA, AFM, and 1,12-dodecane-DMA | Si, Zir, YbF3 (76.5 % by wt) | 3 M ESPE St. Paul, MN, USA | BF-P1200 | Bulk placement<br>Bulk and 3-sided polymerization with 1200 mW/cm$^2$ light for 10 sec/cycle |
| | | | | BF-P800 | Bulk placement<br>Bulk and 3-sided polymerization with 800 mW/cm$^2$ light for 20 sec/cycle |
| Filtek Z350 XT (A2B) *9,503,963* | BIS-GMA, UDMA, TEGDMA, BIS-EMA and PEGDMA | Si, Zir (72.5 % by wt) | 3 M ESPE St. Paul, MN, USA | CRC-P1200 | Incremental placement<br>and 3-sided polymerization with 1200 mW/cm$^2$ light for 20 sec/cycle |
| | | | | CRC-P800 | Incremental placement<br>and 3-sided polymerization with 800 mW/cm$^2$ light for 40 sec/cycle |

***Footnote:*** AUDMA: aromatic urethane dimethacrylate; UDMA: urethane dimethacrylate; AFM: addition fragmentation monomers, 1,12-dodecane-DMA: 1,12-dodecane-dimethacrylate; BIS-GMA: bisphenol A-glycidyl methacrylate; TEGDMA: triethylene glycol dimethacrylate; BIS-EMA: ethoxylated bisphenol-A dimethacrylate; PEGDMA: polyethylene glycol dimethacrylate; BF: Bulk Fill, CRC: Conventional resin-based composite, P1200: 1200 mW/cm$^2$ light curing protocol, and P800: 800 mW/cm$^2$ light curing protocol.

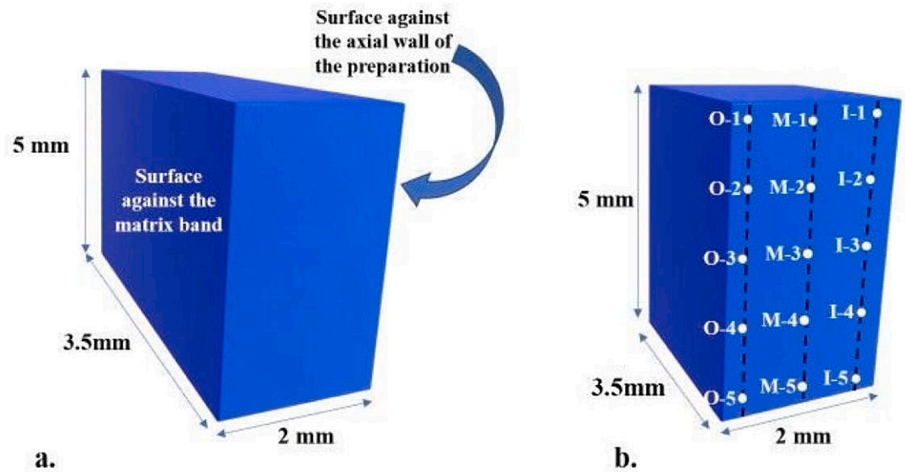


**Fig. 1. Diagram of the extracted restoration and VMH Testing Reading Points.** a: Dimensions of the extracted restoration: 5 mm in height, 3.5 mm in bucco-lingual width, 2 mm in depth; b: Cut restoration surface through the middle in a mesiodistal direction showing VMH reading points, where the "O", "M" and "I" letters represent the following: "O": the outer surface reading plane –adjacent to the metal band, M: the middle reading plane and "I": the inner reading plane – adjacent to the tooth surface. Numbe1, 2,3, 4 and 5 along the reading planes represent the following: "1″: 0.1 mm from the occlusal surface, "2": 1 mm gingival to point "1", "3": middle of the restoration occlusogingivally, "4": 1 mm gingival to point 3, "5" 0.1 mm occlusal to the gingival surface.

Fifteen VMH measurements were obtained per specimen.

A 100 g load was applied for 30 s per measurement. VMH values (kg/mm$^2$) were calculated using VMH = (1.8544 × P)/D$^2$, where P is the load in kg and D is the average diagonal distance (mm) of the indentation. A bottom-to-top VMH ratio was calculated to evaluate cure depth, with 80 % considered acceptable.

### 2.3. Placement time

Placement time was recorded using a digital stopwatch (Lynch et al., 2010). The time recorded excluded matrix and wedge placement, which was performed by the instructor, and included only the time consumed by the students for packing and light curing the RBC restorations.

### 2.4. Statistical analysis

Data homogeneity was checked using Levene's test. Multivariate analysis of variance and Bonferroni post-hoc tests were conducted for data analysis (SPSS 22, IBM Corp., USA). The sample size and significance level ($\alpha = 0.05$) provided adequate power (ß-1 = 95) to detect small effect size differences between groups.

## 3. Results

The statistical analysis identified significant differences in VMH as a function of the type of resin-based composite (RBC) ($F = 911$, $P < 0.001$), the light-polymerization mode ($F = 11.7$, $P < 0.001$), and their interactions ($F = 567$, $P < 0.001$). The highest VMH readings were recorded in the CRC-P800 group, followed by CRC-P1200, BF-P1200, and BF-P800 groups. VMH values were highest at the outer plane (closest to the matrix band) compared to the middle and inner planes (closest to the axial wall of the prepared tooth) ($F = 2786$, $P < 0.001$). Additionally, a significant reduction in VMH was noted from the top to the bottom of the restorations ($F = 120$, $P < 0.001$). Nevertheless, VMH values at the deepest points in all groups remained above 80 % of those at the occlusal surface. Regarding the vertical plane, VMH decreased significantly from the outer wall to the middle and inner planes ($F = 2786$, $P < 0.001$) (Table 2).

No significant differences were observed among the 30 students participating in the study ($P > 0.05$). However, there was a significant difference in the time taken by students in each group to complete the restorations ($P < 0.001$). The CRC-P800 group took the longest time, while the BF-P1200 group took the least (Table 3).

## 4. Discussion

Dental schools worldwide are integrating the teaching of posterior RBC restorations into their curricula but remain hesitant to introduce BF materials and techniques into undergraduate training (AlQahtani et al., 2015; Kanzow et al., 2023; Lynch et al., 2014; Wilson and Mjör, 2000). Our findings can help educators make informed decisions about incorporating BF materials into dental students' clinical training and shed light on their polymerization efficiency when placed by the hands of dental students.

The VMH readings of the CRC material tested in this study were generally higher than those of the BF materials. That finding is consistent with other studies, which found that no BF materials exhibited VMH readings as high as those of conventional RBCs (Alshali et al., 2015, Rizzante et al., 2019). We also observed the same result when the BF was polymerized with higher radiance power. This finding suggests that the lower microhardness of BF is predominantly a material-specific property rather than being dependent on the polymerization protocol.

Radiant exposure time is crucial for the proper polymerization of RBCs to ensure that they exhibit adequate physical and mechanical properties. The radiant exposure can be calculated as the product of the irradiance and the time of irradiation (Rencz et al., 2012). Aguiar et al. (2005) reported that the extended exposure time could increase the irradiant energy available for the carbon double bond conversion, even without changes in the light power output. On the other hand, other studies have shown that shortening the curing time can negatively affect material properties, particularly if insufficient levels of light permeate more deeply (Aravamudhan et al., 2006; da Silva et al., 2008). According to the law of reciprocity, shortening the exposure duration can be compensated for by raising the irradiance level. We verified this concept, which holds true to some limit; the VMH readings that we attained were generally higher when the RBC materials were polymerized using P1200, despite the shorter curing times. This finding is consistent with the results of Alkhudhairy (2017), who demonstrated that higher curing light irradiance had a positive influence on microhardness compared with lower curing light irradiance.

Another factor to consider for polymerization efficiency is the reduction in light irradiance as the distance from the light-curing tip to the surface of the restoration increases. The effectiveness of the polymerization and the irradiant exposure are directly proportional

**Table 2**
Mean and standard deviation (SD) of Vickers Microhardness (VMH) test readings of the bulk fill (BF) and conventional (CRC) resin-based composite (RBC) restorations at the different vertical and horizontal reading points.

| RBC | Light Polymerization Protocol | Vertical Plane | VMH Mean (SD) | Horizontal Plane at reading points level | VMH Mean (SD) |
|---|---|---|---|---|---|
| BF | P1200 | Inner | 51.41 (5.347) | 1 | 63.81 (7.489) |
| | | Middle | 59.88 (3.995) | 2 | 62.51 (7.378) |
| | | Outer | 67.75 (4.913) | 3 | 59.83 (6.956) |
| | | | | 4 | 57.10 (7.613) |
| | | | | 5 | 55.14 (8.374) |
| | P800 | Inner | 47.91 (4.669) | 1 | 59.33 (5.700) |
| | | Middle | 56.31 (5.159) | 2 | 57.27 (5.528) |
| | | Outer | 61.11 (3.983) | 3 | 55.07 (6.792) |
| | | | | 4 | 53.47 (7.105) |
| | | | | 5 | 50.41 (7.104) |
| CRC | P1200 | Inner | 52.32 (4.421) | 1 | 59.69 (8.882) |
| | | Middle | 62.36 (4.374) | 2 | 64.11 (6.173) |
| | | Outer | 67.45 (3.598) | 3 | 61.99 (5.988) |
| | | | | 4 | 59.72 (7.269) |
| | | | | 5 | 58.03 (7.605) |
| | P800 | Inner | 55.63 (6.380) | 1 | 62.43 (5.022) |
| | | Middle | 65.35 (7.173) | 2 | 75.07 (3.912) |
| | | Outer | 71.44 (6.219) | 3 | 74.97 (4.198) |
| | | | | 4 | 72.87 (3.767) |
| | | | | 5 | 71.87 (3.702) |

***Footnote:*** BF: Bulk Fill, CRC: Conventional resin-based composite, P1200: 1200 mW/cm$^2$ light polymerization protocol, and P800: 800 mW/cm$^2$ light polymerization protocol.
Significant differences were found between RBC types ($p < 0.02$), light polymerization protocols ($p < 0.001$), interaction between RBC types and light intensity ($p = 0.001$). Significant differences were found in horizontal and vertical locations ($p < 0.001$).
Across all groups tested, the VMH values at the deepest reading points exceeded those at the occlusal surfaces by 80%.

(Gonçalves et al., 2010); these factors can be affected by variables such as the exposure time, the light power output, and the distance between the guide tip of the light curing unit and the resinous material surface (Aguiar et al., 2005; Chesterman et al., 2017; Hasanain et al. 2022; Prati et al., 1999). In our study, the students were instructed to polymerize the material from the buccal and lingual surfaces for an additional cycle after the removal of the band. Doing so helped to bring the light source closer to the external surfaces of the resin composite, which in turn explained the higher VMH values recorded at the external wall (closest to the matrix band) in the vertical axis and in the most occlusal reading points in the horizontal axis.

Measuring the exact distance between the light-curing tip and the surface of the restoration with each student application was not a focus of our study. Even though some differences in the technique were observed between individual students, no statistically significant difference was found between their restorations VMH values; that finding may be related to the academic clinical setup. Furthermore, our statistical analysis revealed that all the dental students were able to place the selected RBCs using two light sources and two placement techniques without compromising the restorations' microhardness properties. This finding is consistent with the results of Al-Zain and Al-Osaimi (2021) who reported that, regardless of the light curing technique used by students or the instruction methods they received, the mean radiant exposure was between 11.5 and 13.7 J/cm$^2$. That exposure is much higher than the required minimum value of 6 J/cm$^2$ (Price et al., 2010).

**Table 3**
Time taken by students to complete the restorations.

| Groups | Time in minutes | | Repeated measures ANOVA *P*-value |
|---|---|---|---|
| | Mean (SD) | 95 % Confidence Interval | |
| BF-P1200 | 2.79 (0.68) | 2.54, 3.05 | <0.001* |
| BF-P800 | 3.35 (0.93) | 3.00, 3.70 | |
| CRC-P1200 | 4.58 (1.17) | 4.14, 5.02 | |
| CRC-P800 | 6.18 (1.33) | 5.69, 6.68 | |

***Footnote:*** BF: Bulk Fill, CRC: Conventional resin-based composite P1200: 1200 mW/cm$^2$ light curing protocol, and P800: 800 mW/cm$^2$ light curing protocol.
* Significantly different at $p < 0.05$.

The curing efficiency or depth of cure has been measured by calculating the ratio of bottom to top surface hardness values, and a ratio of 80 % has been used as a minimum clinically acceptable value (Bouschlicher et al., 2004). This threshold in turn corresponds to the maximum depth at which an RBC should be safely placed (Kelić et al., 2016). We found that the microhardness ratios of both BF and CRC materials combined with the two light polymerization protocols that were tested in the hands of students attained this minimum value (Lima et al., 2018; Marovic et al., 2013; Pereira et al., 2018). This finding suggests that BF RBCs can perform as well with students as with experienced dentists in terms of microhardness.

The shortest recorded time was achieved for the BF-P1200 protocol (2.79 min); the longest time was recorded for the CRC-P800 protocol (6.18 min). That outcome is consistent with the findings of Vianna-de-Pinho et al. (2017) and Leinonen et al. (2023). We accordingly rejected our proposed null hypothesis—the two different light-polymerization protocols did, in fact, have a significant effect on the polymerization efficiency and the placement time of BF and CRC restorations. However, we noted that the depth of cure was sufficient in all cases.

Limitations of the pre-clinical study include some limitations related to mimicking clinical conditions as the distance or the angle between the light cure tip and the surface of the restorations were not assessed. Recording these data for each student and correlating them with the polymerization outcome could be the subject of future work. Additionally, the internal fit and the presence of voids are additional factors crucial to the overall success of restorations (Al-Zain et al., 2023). However, making such assessments was beyond the scope of this study. Moreover, using Fourier Transform Infrared (FTIR) spectroscopy tests, which required more resources, would have provided more insights into the polymerization behavior of the resin, and complemented the results obtained by the Vickers microhardness test.

## 5. Conclusions

Within the limitations of this study, one can conclude that dental students can safely place BF and conventional RBC restorations using the different irradiance protocols tested without compromising polymerization efficiency beyond clinically accepted levels.

## Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT to improve language and readability. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

## Ethical statement

This study was conducted after obtaining approval by the Research and Ethics committee at Dar Al Uloom University (DAU) under the reference number COD/IRB/2020/13. A total of thirty preclinical dental students at the College of Dentistry – DAU, were recruited for volunteer participation after signing an informed consent to their participation in the study.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## References

Abed, Y.A., Sabry, H., Alrobeigy, N.A., 2015. Degree of conversion and surface hardness of bulk-fill composite versus incremental-fill composite. Tanta Dental J. 98, 71–80.
Aguiar, F.H.B., Lazzari, C.R., Lima, D.A.N.L., Ambrosano, G.M.B., Lovadino, J.R., 2005. Effect of light curing tip distance and resin shade on microhardness of a hybrid resin composite. Braz. Oral Res. 19, 302–306.
Alkhudhairy, F.I., 2017. The effect of curing intensity on mechanical properties of different bulk-fill composite resins. Clin. Cosmet. Investig. Dent. 9, 1–6.
AlQahtani, M., Michaud, P., Sullivan, B., Labrie, D., AlShaafi, M., Price, R., 2015. Effect of high irradiance on depth of cure of a conventional and a bulk fill resin-based composite. Oper. Dent. 40, 662–672.
AlShaafi, M.M., 2017. Factors affecting polymerization of resin-based composites: A literature review. Saudi Dent J 29, 48–58.
Alshali, R.Z., Salim, N.A., Satterthwaite, J.D., Silikas, N., 2015. Post-irradiation hardness development, chemical softening, and thermal stability of bulk-fill and conventional resin-composites. J. Dent. 43, 209–218.
Al-Zain, A.O., Al-Osaimi, T.M., 2021. Effectiveness of using an instructional video in teaching light-curing technique. Adv. Med. Educ. Pract. 29, 289–302.
Al-Zain, A.O., Baeesa, L., Jassoma, E., Alghilan, M.A., Hariri, M., Ismail, E.H., Münchow, E.A., 2023. Assessment of internal porosities for different placement techniques of bulk-fill resin-based composites: a micro-computed tomography study. Clin. Oral Invest. 27, 7489–7499.
Aravamudhan, K., Floyd, C.J.E., Rakowski, D., Flaim, G., Dickens, S.H., Eichmiller, F.C., Fan, P.L., 2006. Light-emitting diode curing light irradiance and polymerization of resin-based composite. J. Am. Dent. Assoc. 137, 213–223.
Awad, M.M., Salem, W.S., Almuhaizaa, M., Aljeaidi, Z., 2017. Contemporary teaching of direct posterior composite restorations in Saudi dental schools. Saudi J. Dental Res. 8, 42–51.
Bouschlicher, M.R., Rueggeberg, F.A., Wilson, B.M., 2004. Correlation of bottom-to-top surface microhardness and conversion ratios for a variety of resin composite compositions. Oper. Dent. 29, 698–704.
Catelan, A., de Araújo, L.S.N., da Silveira, B.C.M., Kawano, Y., Ambrosano, G.M.B., Marchi, G.M., Aguiar, F.H.B., 2015. Impact of the distance of light curing on the degree of conversion and microhardness of a composite resin. Acta Odontol. Scand. 73, 298–301.
Chesterman, J., Jowett, A., Gallacher, A., Nixon, P., 2017. Bulk-fill resin-based composite restorative materials: a review. Br. Dent. J. 222, 337–344.
Cidreira Boaro, L.C., Pereira Lopes, D., de Souza, A.S.C., Lie Nakano, E., Ayala Perez, M. D., Pfeifer, C.S., Gonçalves, F., 2019. Clinical performance and chemical-physical properties of bulk fill composites resin -a systematic review and meta-analysis. Dent. Mater. 35, e249–e264.
Corral-Núnez, C., Vildósola-Grez, P., Bersezio-Miranda, C., Alves-Dos Campos, E., Fernández Godoy, E., 2015. State of the art of bulk-fill resin-based composites: a review. Revista Facultad De Odontología Universidad De Antioquia 27, 177–196.
da Silva, E.M., Poskus, L.T., Guimarães, J.G.A., 2008. Influence of light-polymerization modes on the degree of conversion and mechanical properties of resin composites: a comparative analysis between a hybrid and a nanofilled composite. Oper. Dent. 33, 287–293.
Daugherty, M.M., Lien, W., Mansell, M.R., Risk, D.L., Savett, D.A., Vandewalle, K.S., 2018. Effect of high-intensity curing lights on the polymerization of bulk-fill composites. Dent. Mater. 34, 1531–1541.
De Souza, G., Braga, R.R., Cesar, P.F., Lopes, G.C., 2015. Correlation between clinical performance and degree of conversion of resin cements: a literature review. J. Appl. Oral Sci. 23, 358–368.
Gonçalves, F., Kawano, Y., Braga, R.R., 2010. Contraction stress related to composite inorganic content. Dent. Mater. 26, 704–709.
Hasanain, F.A., Nassar, H.M., Ajaj, R.A., 2022. Effect of light curing distance on microhardness profiles of bulk-fill resin composites. Polymers (Basel) 14, 528.
Kaisarly, D., Gezawi, M.E., 2016. Polymerization shrinkage assessment of dental resin composites: a literature review. Odontology 104, 257–270.
Kanzow, P., Lechte, C., Wiegand, A., Wilson, N.H.F., Lynch, C.D., Blum, I.R., 2023. Teaching of posterior composites for the restoration of permanent teeth in undergraduate dental training programmes: Systematic review and meta-analysis. J. Dent. 135, 104589.
Kelić, K., Matić, S., Marović, D., Klarić, E., Tarle, Z., 2016. Microhardness of bulk-fill composite materials. Acta Clin. Croat. 55, 607–614.
Leinonen, K.M., Leinonen, J., Bolstad, N.L., Tanner, T., Al-Haroni, M., Johnsen, J.-A.-K., 2023. Procedure time and filling quality for bulk-fill base and conventional incremental composite techniques-A randomised controlled in vitro trial. J. Dent. 138, 104725.
Lima, R.B.W., Troconis, C.C.M., Moreno, M.B.P., Murillo-Gómez, F., De Goes, M.F., 2018. Depth of cure of bulk fill resin composites: A systematic review. J. Esthet. Restor. Dent. 30, 492–501.
Lynch, C.D., Frazier, K.B., McConnell, R.J., Blum, I.R., Wilson, N.H.F., 2010. State-of-the-art techniques in operative dentistry: contemporary teaching of posterior composites in UK and Irish dental schools. Br. Dent. J. 209, 129–136.
Lynch, C.D., Opdam, N.J., Hickel, R., Brunton, P.A., Gurgan, S., Kakaboura, A., Shearer, A.C., Vanherle, G., Wilson, N.H.F., 2014. Academy of Operative Dentistry European Section, 2014. Guidance on posterior resin composites: Academy of Operative Dentistry - European Section. J. Dent. 42, 377–383.
Marovic, D., Panduric, V., Tarle, Z., Ristic, M., Sariri, K., Demoli, N., Klaric, E., Jankovic, B., Prskalo, K., 2013. Degree of conversion and microhardness of dental composite resin materials. J. Mol. Struct. 1044, 299–302.
Pereira, R., Giorgi, M.C.C., Lins, R.B.E., Theobaldo, J.D., Lima, D.A.N.L., Marchi, G.M., Aguiar, F.H.B., 2018. Physical and photoelastic properties of bulk-fill and conventional composites. Clin. Cosmet. Investig. Dent. 10, 287–296.
Prati, C., Chersoni, S., Montebugnoli, L., Montanari, G., 1999. Effect of air, dentin and resin-based composite thickness on light intensity reduction. Am. J. Dent. 12, 231–234.
Price, R.B., Felix, C.M., Whalen, J.M., 2010. Factors affecting the energy delivered to simulated class I and class v preparations. J. Can. Dent. Assoc. 76, a94.
Rencz, A., Hickel, R., Ilie, N., 2012. Curing efficiency of modern LED units. Clin. Oral Invest. 16, 173–179.
Rizzante, F.A.P., Duque, J.A., Duarte, M.A.H., Mondelli, R.F.L., Mendonça, G., Ishikiriama, S.K., 2019. Polymerization shrinkage, microhardness and depth of cure of bulk fill resin composites. Dent. Mater. J. 38, 403–410.
Saati, K., Khansari, S., Mahdisiar, F., Valizadeh, S., 2022. Evaluation of microhardness of two bulk-fill composite resins compared to a conventional composite resin on surface and in different depths. J. Dent. (Shiraz) 23, 58–64.
Sadeghyar, A., Watts, D.C., Schedle, A., 2020. Limited reciprocity in curing efficiency of bulk-fill resin-composites. Dent. Mater. 36, 997–1008.
Scolavino, S., Paolone, G., Orsini, G., Devoto, W., Putignano, A., 2016. The Simultaneous Modeling Technique: closing gaps in posteriors. Int. J. Esthet. Dent. 11, 58–81.
Sengupta, A., Naka, O., Mehta, S.B., Banerji, S., 2023. The clinical performance of bulk-fill versus the incremental layered application of direct resin composite restorations: a systematic review. Evid. Based Dent. 24, 143.
Sidhu, P., Sultan, O.S., Math, S.Y., Malik, N.A., Wilson, N.H.F., Lynch, C.D., Blum, I.R., Daood, U., 2021. Current and future trends in the teaching of direct posterior resin composites in Malaysian dental schools: a cross-sectional study. J. Dent. 110, 103683.
Silva, G., Marto, C.M., Amaro, I., Coelho, A., Sousa, J., Ferreira, M.M., Francisco, I., Vale, F., Oliveiros, B., Carrilho, E., Paula, A.B., 2023. Bulk-fill resins versus conventional resins: an umbrella review. Polymers (basel) 15, 2613.
Tirapelli, C., 2022. Is the clinical performance of incremental and bulk-fill resin composite different? Evid. Based Dent. 23, 84.
Vianna-de-Pinho, M.G., Rego, G.F., Vidal, M.L., Alonso, R.C.B., Schneider, L.F.J., Cavalcante, L.M., 2017. Clinical time required and internal adaptation in cavities restored with bulk-fill composites. J. Contemp. Dent. Pract. 18, 1107–1111.
Wilson, N.H., Mjör, I.A., 2000. The teaching of Class I and Class II direct composite restorations in European dental schools. J. Dent. 28, 15–21.