Original Article

Evaluation of microleakage in class-II bulk-fill composite restorations

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Abstract *Background/purpose:* Despite the clinical appeal of restoring deep class II cavities in single increment using bulk-fill resin composite, sealing of bulk-filled composite restorations is a concern. This study evaluated interfacial adaptation of bulk-fill composite restoration to axial wall and gingival floor of class II cavities using cross-polarization optical coherence tomography (CP-OCT).
Materials and methods: Box-shaped class II cavities were prepared in extracted molars and divided into three groups ($n = 7$) according to adhesive used; Clearfil SE Bond 2 (SE2), Tetric-N Bond Self-Etch (TSE) or Tetric-N Bond Universal (TNU). All adhesives were applied in self-etch mode and according to manufacturers' recommendation. Then, preparations were bulk-filled with Filtek Bulk Fill Posterior Restorative resin composite and immersed in a contrast agent. Tomographic images of axial wall and gingival floor of each restoration were obtained by CP-OCT (IVS-300, Santec) with a central wavelength of 1330 nm and were imported to an image analysis software to quantify microleakage.
Results: Mann–Whitney U test showed statistically significant difference in microleakage percentage between the groups at both axial wall and gingival floor ($p < 0.05$). SE2 group had the

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lowest percentage of microleakage ($p < 0.05$), as only few cross-sections showed areas of reflections from contrast agent penetrating into axial wall (8.23 ± 6.8) and gingival floor (7.07 ± 4.1), followed by TNU group (18.13 ± 12.9 axially and 30.61 ± 11.9 gingivally). Microleakage was frequently observed at the axial wall and gingival floor of TSE group, showing the highest percentages of 25.50 ± 12.5 and 36.97 ± 10.2, respectively ($p < 0.05$).

Conclusion: All tested groups exhibited different extent of interfacial microleakage, however, two-step self-etch adhesive yielded superior adaptation in comparison to one-step self-etch adhesive and universal adhesive.

Introduction

Since their emergence in 1960s, composite resins have undergone great development. Recently, a new generation of resin-based composite, known as monoincremental or bulk-fill composite resin, has become commercially available. Using this composite, the number of increments required to fill a cavity is reduced. Contrary to the 2 mm increments in layering technique, bulk-fill resin composite can be placed in an increment up to 4 or 5 mm. This approach simplifies the application procedure and decreases chair time, especially in case of deep class II cavities.[1]

Incremental layering has been widely adopted as a standard technique for placement of resin composite.[2] The placement of composite resin in increments assures adequate light cure penetration and hence, adequate polymerization, improved physical properties and enhanced marginal adaptation.[2] Also, layering technique decreases shrinkage inherent to composite resin by reducing the volume of cured composite as well as C-factor. Such polymerization shrinkage generates internal stresses within the restoration leading to marginal discrepancies, cuspal deflection and interfacial debonding.[3] In bulk-fill resin composite, formulation modification including the addition of reactive photoinitiator and improvement in translucency is claimed to allow resin to cure well in depth.[4] However, concerns about degree of conversion, polymerization shrinkage and depth of cure along with their effects on marginal and internal adaptation of bulk-fill composite are still present.[1,5,6]

On the other hand, previous studies have suggested that polymerization shrinkage at the adhesive interface is not influenced by filling technique per se and that sealing performance of the adhesive has a more prominent influence.[7,8] Quality of adhesion, physicochemical properties of the adhesive and its strategy of interaction with enamel and dentine are indeed critical and definite factors for successful long-term clinical outcomes.[9,10]

Marginal integrity has been conventionally evaluated by tracing penetrating dyes under high magnification. Recently, optical coherence tomography (OCT) has been introduced and employed for effective interfacial gap quantification.[10—14] A distinctive feature of OCT imaging is that it allows real-time, high-resolution subsurface detection of dental structures and biomaterials based on depth-resolved refractive properties.[10—17]

This study evaluated adaptation of bulk-fill resin composite to gingival floor and axial wall of class-II cavities bonded with different types of adhesives using cross-polarization optical coherence tomography (CP-OCT). The tested null hypothesis was that there was no difference in the axial or gingival marginal adaptation between tested groups.

Materials and methods

Specimen preparation

Fig. 1 summarizes the methodology of this study. Twenty-one extracted caries-free human molar teeth were selected and used according to the obtained ethical approval from King Abdulaziz University's research ethics committee. All procedures performed in this study were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration. The roots were sectioned up to the furcation area and cusps were slightly reduced to a flat surface. Standard box-shaped cavities that measure 4 mm occluso-gingivally, 2 mm bucco-lingually and 1.5 mm mesio-distally were prepared on the distal surface of each tooth. Then, teeth were mounted on typodont model and tofflemire retainers with matrix band and interdental wedge were used to secure each tooth. The teeth were then randomly assigned into three experimental groups according to the type of adhesive ($n = 7$). In SE2 group, Clearfil SE Bond 2 (Kuraray Noritake Dental, Tokyo, Japan) was used, while Tetric N-Bond Self-Etch (Ivoclar/Vivadent, Schaan, Liechtenstein) was used in TSE group. Tetric N-Bond Universal (Ivoclar/Vivadent) was utilized in TNU group in self-etch mode. An LED light curing unit (Elipar S10; 1200 mW/cm^2 output power intensity, 3M ESPE, St. Paul, MN, USA) was used to cure the adhesives. All groups were then filled with one increment of Filtek Bulk Fill Posterior Restorative resin composite (3M ESPE) and cured with the same light cure. The composition of used materials and method of application are described in Table 1.

Contrast agent infiltration

After restoration, specimens were stored in distilled water for 24 h. Then, specimens were immersed in ammoniacal
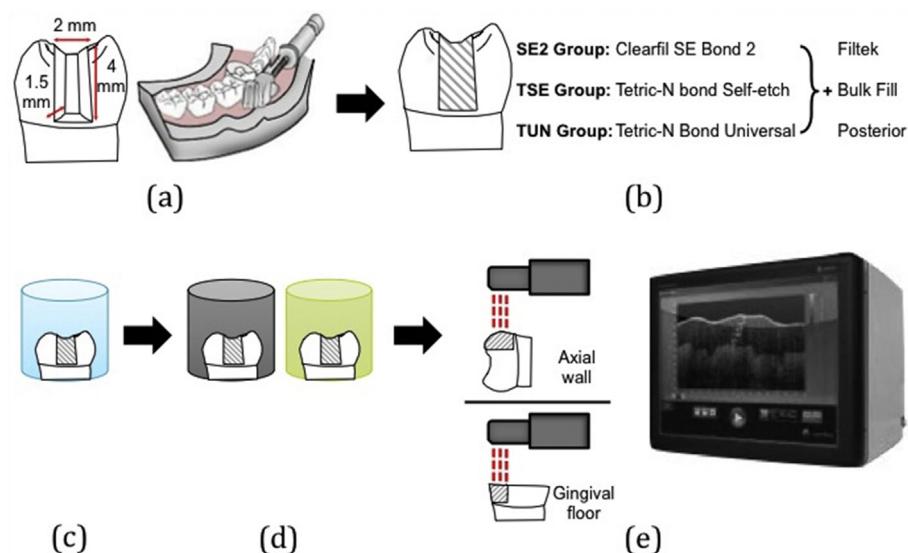
Figure 1   Schematic diagram of study methodology. (a) Cavity preparation and matrix placement. (b) Restoration and specimens grouping according to the applied adhesive (c) Water storage for 24 h. (d) Silver nitrate infiltration. (e) CP-OCT imaging of axial wall and gingival floor.

silver nitrate solution prepared as described by Bakhsh et al. and stored in dark environment.[18] After 24 h, specimens were removed from the solution, rinsed by distilled water and immersed in a photo-developing solution for 8 h.

CP-OCT system

The CP-OCT system (IVS-300, Santec, Komaki, Japan) used in this study incorporates a hand-held probe which power is within safety limits defined by the American National Standard Institute. The spectral bandwidth of the laser is centered at 1330 nm at a sweep rate of 30 kHz. The resolution in air is ~12 μm axially and 30 μm laterally. The sensitivity of this CP-OCT is around 95 dB, while its imaging depth is around 3 mm.

OCT imaging and image analysis

After infiltration with the contrast agent, specimens were scanned in 2D using CP-OCT system to evaluate interfacial adaptation. Each specimen was positioned horizontally on micrometer stage and the OCT probe was set at a fixed distance over the proximal tooth surface, with the scanning beam projected at 90° with respect to the axial surface of the specimens. Then, serial tomographic scans of the axial wall in x and y direction (B-scans) were obtained at 500 μm intervals for each restoration.

To evaluate the adaptation to the gingival floor, each specimen was subjected to occlusal reduction leaving 1.5 mm of composite restoration. This is attributed to limitation of OCT light penetration in depth. Also, the refractive index of composite resin limits the amount of penetrating light and signal collected from deep structures.[19] Five consecutive B-scans of the gingival floor were obtained by OCT scanning at 500 μm intervals.

To quantify microleakage along the axial wall and gingival floor in different groups, percentage value of interfacial microleakage was adopted as a parameter. Briefly, raw data were imported to image analysis software and a macro-file reconstructing B-scan into a 2D grayscale image was used. Then, the region of interest (axial wall or gingival floor) was selected and cropped. A binarization process was applied to the selection to determine the target pixels with brightness higher than surrounding pixels. In the obtained binary image, the bright pixels were transformed into dark pixels on a white background. The percentage ratio of total dark pixels length divided by the wall length was calculated to measure microleakage percentage.[11,13]

Statistical analysis

Statistical analysis of the results was performed using a statistical software package (SPSS-2 for windows: SPSS, USA). The values obtained from B-scans of each wall were averaged and a single value per wall was included in the statistical analysis. As the distribution of data was not normal, non-parametric tests were performed. Kruskal—Wallis test was used to determine whether there was any difference between materials, and Mann—Whitney U test was used for pairwise comparisons between each two materials with significance level defined as $p < 0.05$.

Result

Optical analysis of the OCT cross-sections showed high signal intensity in a form of bright pixels along the interface of some specimens caused by strong reflection from diffused silver particles, which was detected as dark pixels in

Table 1 Composition of materials used in this study with application protocol.

Material [Manufacturer]	Composition	Application protocol
Clearfil SE Bond 2 [Kuraray Noritake Dental]	**Primer:** • MDP • Water • HEMA • Hydrophilic dimethacrylate • CQ • N, N-Diethanol p-toluidine pH = 2 **Bond:** • Bis-GMA • HEMA • MDP • Hydrophobic dimethacrylate • Colloidal silica • CQ • Initiators • Accelerators • N, N-Diethanol p-toluidine pH: 2	Application of primer for 20 s, drying with mild air flow, application of bond and even distribution with flow, light curing for 10 s.
Tetric-N Bond Universal [Ivoclar/Vivadent]	• Bis-GMA • HEMA • MDP • MCAP • D3MA • Ethanol • Methacrylated phosphoric acid ester • CQ • 2-dimethylaminoethyl methacrylate pH: 2.5	Active application on the enamel and dentin surfaces for at least 20 s. Air-drying, curing for 10 s.
Tetric-N Bond Self-Etch [Ivoclar/Vivadent]	• Bis-acrylamide derivative • Bis-GMA • Amino acid-acrylamide • Hydroxyl alkyl methacrylamide • Diphenylphosphine oxide • Nano silica fillers • Water • Initiators • Stabilizers pH: 1.5	Active application on the enamel and dentin surfaces for at least 30 s, air-drying with a strong stream of air, light irradiation for 10 s.
Filtek Bulk Fill Posterior Restorative [3M ESPE]	• AUDMA • UDMA • DDDMA • Fillers (Silica fillers, zirconia fillers, zirconia/silica cluster fillers, ytterbium trifluoride fillers)	Application as one increment. Light cure: occlusal 10 s, buccal 10 s, lingual 10 s

Abbreviation: MDP: 10-methacryloyloxydecyl dihydrogen phosphate, HEMA: hydroxyethyl methacrylate, CQ: camphorquinone, Bis-GMA: bisphenol-A diglycidylmethacrylate, MCAP: methacrylated carboxylic acid polymer, D3MA: 1,10-decanediol dimethacrylate, AUDMA: aromatic urethane dimethacrylate, UDMA: urethane dimethacrylate, DDDMA: 1, 12-dodecanediol dimethacrylate.
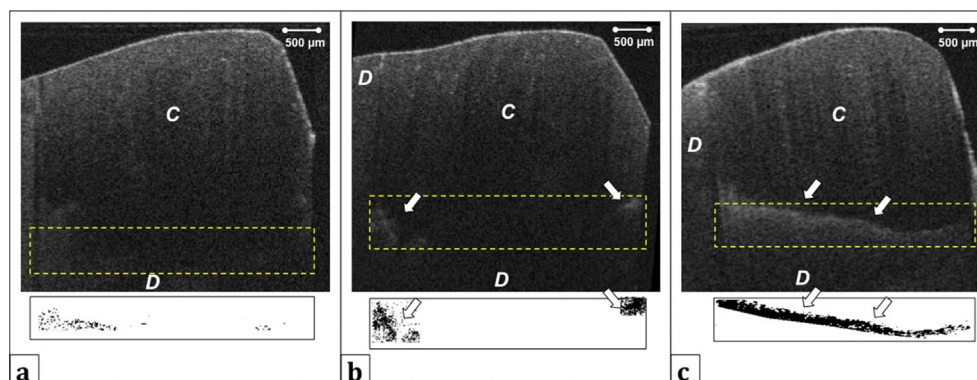
Figure 2 Representative optical coherence tomography (OCT) images and binary images of the axial wall obtained from all groups (a) The axial wall (dotted box) of this cross-section from SE2 group demonstrated no increase in signal intensity with no bright cluster formations, indicating good interfacial sealing. Applying the binarization process to the cropped axial wall in the same cross-section did not detect any target pixels. Scattered pixels in the corresponding binary image (solid line box) indicate absence of penetrating silver nitrate particles in this cross-section. (b) B-scan of a selected interface from TNU specimen showing some areas of silver nitrate uptake at the axial wall appearing as bright scatters in CP-OCT image and black pixels in the binary image (arrows), which indicate interfacial microleakage. (c) The axial wall in this B-scan of the TSE specimen is showing diffuse clusters of bright pixels extending throughout the wall, indicating loss of seal as correlated with target pixels in binarized image of the cropped interface (solid line box). C: Composite; D: Dentin.
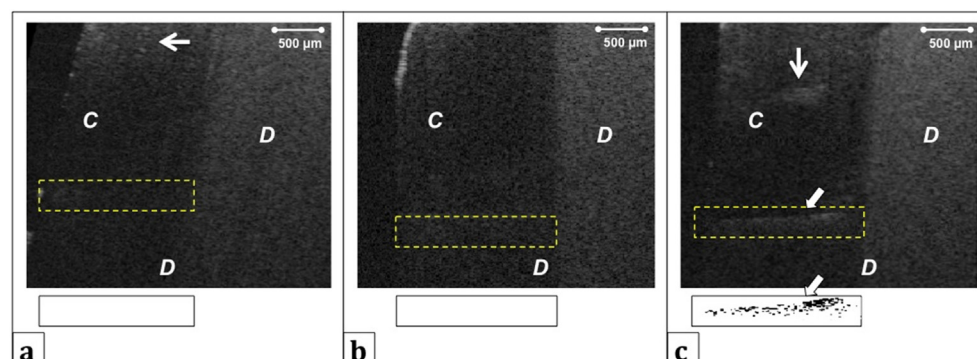
Figure 3 Cross sectional optical coherence tomography (OCT) images of the gingival floor for selected specimens with corresponding binary images of the interface (solid line boxes). (a) Cross-sectional B-scan of a SE2 specimen showing sealed gingival floor with binary image devoid of dark pixels representing microleakage. Entrapped voids in composite could be observed in this OCT image as pointed by the bold arrow. (b) Interfacial area from TNU specimen without high signal intensity at gingival floor or marked target pixels during the binarization process. (c) OCT image of TSE specimen with high reflection from silver particles detected at the interface. Blank arrows point toward the same location in OCT image and cropped interfacial area after applying binarization process to mark the target pixels. Bold arrow points at defect introduced into composite. C: Composite; D: Dentin.

the binary image and referred to as interfacial microleakage. Other specimens showed scarce or no increased brightness at axial wall or gingival floor, indicating good interfacial seal. Representatives B-scan images obtained by CP-OCT of each group with binary images of the cropped adhesive interface are presented in Figs. 2 and 3.

By analyzing the obtained data, a statistically significant difference in the microleakage percentage was found between the groups at both axial wall and gingival floor ($p < 0.05$). The lowest microleakage percentage was observed in axial wall (8.23 ± 6.8) and gingival floor (7.07 ± 4.1) of SE2 group ($p < 0.05$). For TNU group, a significantly increased microleakage was observed at both axial wall (18.13 ± 12.9) and gingival floor (30.61 ± 11.9). The microleakage percentages at axial wall and gingival floor of TSE were 25.50 ± 12.5 and 36.97 ± 10.2, respectively, which were the highest compared to other tested groups ($p < 0.05$). The average microleakage percentage values for all groups with their standard deviations are presented in Table 2.

Discussion

In this study, microleakage at the adhesive interface of bulk-filled composite restorations was evaluated using OCT.

Table 2 Microleakage percentage and standard deviation of each group (mean ± SD).

Groups	Gingival floor	Axial wall
SE2	7.07 ± 4.1[a]	8.23 ± 6.8[a]
TNU	30.61 ± 11.9[b]	18.13 ± 12.9[b]
TSE	36.97 ± 10.2[c]	25.50 ± 12.5[c]

Different superscript letters indicate statistical significance within each column.

Bulk-fill resin composite is increasingly accepted among dentists in restoring deep class-II cavities. Beside the ease of use and timesaving properties, restorative materials should achieve good marginal and internal sealing to prevent pulpal irritation with occlusal forces, marginal discoloration, microleakage and secondary caries.[10]

OCT showed its potential as a useful tool for nondestructive assessment of the adaptive behavior of dental restorations.[10,19] This study utilized a cross-polarization type OCT, which is a functional modification of SS-OCT that has been implemented in visualization of dental biofilms, enamel demineralization and remineralization.[16,17] Unlike SS-OCT, CP-OCT detects backscattered signals that are perpendicular to linearly polarized signals and omits the specular reflections.[17] Therefore, silver nitrate was used as a contrast agent to enhance the visualization of interfacial gap under CP-OCT. The optical appearance of gap under CP-OCT in the form of bright white clusters of pixels results from light reflection caused by interaction between the incident light and silver particles diffused into the gap, rather than specular reflections as in SS-OCT.[20]

These bright clusters of diffused silver showed different extent in CP-OCT gray-scale images depending on location and type of adhesive used. Along with interfacial microleakage, voids or air bubbles of different sizes within the composite restoration were clearly observed in some cross-sections and may formed due to entrapment of air during composite insertion or may have been introduced into the material during manufacturing (Fig. 3a and c).[21]

The obtained results of TSE group showed great gap extent compared with other groups, which resulted in silver nitrate penetration into the gingival and axial walls in most of cross-sections. In some areas, diffuse bright band of white pixels extended throughout the interface, indicating complete loss of seal (Fig. 2c).

CP-OCT images of TNU, however, showed variable signal intensities at the bonded interface. In axial wall, some cross-sections showed areas with high signal intensity at the interface. However, gingival floor showed more areas with strong reflection in the form of bright pixels, while other areas showed low signal intensities.

On the other hand, most of the specimens in SE2 group showed little or no detectable reflection from the interface with no abrupt change in the signal intensities at either wall. The binary images showed scattered pixels or no target dark pixels, which is an indication of no loss of interfacial seal of the bonded dentin−resin complex (Figs. 2a and 3a, b).

Among self-etch adhesive systems, Clearfil SE Bond 2 used in SE2 group is considered as "gold standard" bonding agent with optimized hybrid layer formation and good sealing of both demineralized tooth substrate and resin composite.[22] In addition, 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP) monomer interacts with calcium in hydroxyapatite forming a hydrolytically stable bond.[9] Tetric N-Bond Universal also contains 10-MDP. However, TNU group showed more interfacial gap at both walls in comparison to SE2 group. This might be attributed to the fact that this adhesive is classified as ultra-mild adhesive with a few hundreds of nanometers interaction depth with dentin.[23] Such nano-interaction might be affected by polymerization stresses, especially in the absence of stress-breaking nanofiller particles in the adhesive composition.

On the other hand, Tetric N-Bond Self-Etch used in TSE group is water-based HEMA-free adhesive. The phase separation in the absence of HEMA might have attributed to the lower sealing performance of this group.[24] Also, the hydrophilicity of HEMA is known to enhance wetting of dentin and enables sufficient resin monomer penetration into dental substrate.[22] Another explanation is ascribed to that fact that TSE adhesive contains 20%−30% water as solvent. Despite its significance for adequate ionization of the adhesive's acidic monomers, increased water content lowers the monomers concentration, hindering effective monomer infiltration into dentin.[25] Moreover, water has low vapor pressure and thus, complete removal from the adhesive interface might be difficult. Entrapped water is associated with formation of porous hybrid layer that is more prone to degradation.[24] Furthermore, residuals of uncured solvents at the adhesive surface may hamper complete copolymerization with overlying composite.

Noteworthy, none of the groups completely eliminated interfacial discrepancies. Gap formation might be influenced by other factors, such as the placement of the cavity margins in dentin, to which bonding is still difficult. Other factors related to cavity configuration, composite placement and curing techniques, dimensional changes and stress development during polymerization of resin composite should be considered. Polymerization contraction stresses have potential to induce gap formation if the initial bond between adhesive and tooth structure is insufficient to withstand the stresses.[3] A previous study reported significantly higher volumetric change in high viscosity bulk-fill resin composites than that in conventional composites.[6] Additionally, other study demonstrated that Filtek Bulk Fill had less depth of cure than other bulk-fill composites examined.[26] Apart from sealing performance of adhesive, their findings coincide with our results on light activated bulk-fill composites.

Based on the result of this study, the proposed null hypothesis was rejected. Careful selection of the adhesive system should be considered when restoring proximal cavities using bulk-fill resin composite to reduce the risk of microleakage and its subsequent sequela. Future studies taking into considerations mechanical and thermal aging are recommended.

Declaration of competing interest

No competing financial interests exist.

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