Evaluation of Composite Adaptation to Pulpal Chamber Floor Using Optical Coherence Tomography

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Evaluation of noninvasive adjustment of composite post-endodontic restorations using optical coherence tomography

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Abstract

Introduction: A coronal seal is fundamental for a positive outcome to endodontic therapy. In this *in vitro* study, we evaluated the adaptation of composite resins in post-endodontic restorations using optical coherence tomography (OCT). Our null hypothesis was that there would be no difference in marginal adaptation to the pulp chamber floor between resin composites of different viscosities.

Methods: Thirty intact upper molars, extracted for periodontal reasons, were selected, endodontically treated, and filled with gutta-percha. The excess gutta-percha was entirely removed from the pulp chamber floor and teeth were randomly divided into three groups (n=10) according to the material used for the restoration: Group A: 0.5 mm horizontal layer of flowable composite followed by nanohybrid composite; Group B: bulk layering of bulk-fill flowable composite; and Group C: oblique layering of nanohybrid composite. The degree of adaptation to the cavity floor was assessed using OCT and images were analyzed with the software program ImageJ to assess the marginal gap between the composite and pulp chamber floor. Collected data were statistically analyzed using ANOVA testing and statistical significance was set at $p<0.05$.

Results: Flowable composites showed significantly better adaptation than traditional packable nanohybrid composites ($p<0.05$). All significant differences were found between groups A and B.

Conclusion: Within the limitations of an *in vitro* study, we can recommend using a thin layer of flowable composite in post-endodontic restorations. Further studies are necessary to confirm these results.

Introduction

Several studies have demonstrated the importance of an effective coronal restoration in successful endodontic treatment [1,2]. Bacteria are primary etiological factors of apical periodontitis. Exposure of the gutta-percha to saliva and/or other oral fluids allows the migration of bacteria to the dental apex in a short period of time [3–5]. Therefore, the prognosis of endodontic therapy could be influenced by contamination of the root canal system through marginal or internal gaps of the coronal restoration [6]. Therefore, an effective coronal seal has a great impact on the long-term success of endodontic therapy [7].

Currently, post-endodontic restorations are mainly performed with adhesive techniques. However, gap formation and marginal microleakage due to adhesive bond failure is still one of the most reported problems, which could be due to various factors: composite shrinkage stress, mechanical properties of restorative materials, C-Factor [8,9], the composite layering technique, and the irradiation technique [10,11].

The use of flowable composites in high C-Factor cavities has been suggested because it ensures better marginal integrity [12,13] and reduces enamel fractures [13]. It also improves the fit between adhesive systems and composite materials, creating fewer voids [14,15] and thus decreasing microleakage. Moreover, previous studies have reported a reduction of shrinkage stress through the interposition of an intermediate layer of flowable composite, due to its superior internal flow and adaptation, which partially compensate for shrinkage stress, creating an elastic layer between the substrate and the restorative material [16–19].

Bulk-fill flowable composites were recently introduced, and they seem to show less shrinkage stress. For example, Moorty et al. [20] found that minor contraction stress exerted by bulk-fill flowable composites translates into a lower cuspal deflection compared to that of traditional composites placed via the oblique layering technique.

In the present *in vitro* study, we evaluated the adaptation abilities of several resin-based composite materials to the pulpal chamber floor. The null hypothesis was that adaptation would not be influenced by the viscosity of the material.

Materials and methods

Thirty intact human maxillary molars without caries, restorations, or root canal treatment that had been extracted for periodontal reasons were selected for this study. All teeth were first cleaned to remove debris and then stored in distilled water at room temperature. Then conventional pulp chamber access cavities were prepared in each tooth with a cylindrical diamond bur (#880-104-023, Komet, Lemgo, Germany), and the canal system was shaped using mechanical Path Files (#1-#2-#3) and X2 ProTaper Next (Dentsply Maillefer, Baillagues, Switzerland) to the working length.

During endodontic instrumentation, samples were irrigated with a solution of 5% NaOCl (5 Niclor; Ogna, Muggiò, Italy) and 10% EDTA (Tubuliclin, Ogna) using a 2 mL syringe with an endodontic needle. Before endodontic sealing, all canals were dried with medium paper points (Mynol; Curaden Healthcare, Saronno, Milan, Italy) and sealed through vertical condensation with endodontic cement (Pulp Canal Sealer EWT; Kerr, Sybron, Romulus, MI, USA) and medium gutta-percha cones using the DownPack (Hu-Friedy, Chicago, IL, USA) and the Obtura III (Analytic Technologies, Redmond, WA, USA) system. A cotton pellet was placed over the pulp chamber floor and a provisional restoration was placed to seal the access cavity (Cavit, 3M ESPE, Saint Paul, MN, USA).

After 7 days of storage in distilled water at 37°C, the provisional restoration was removed and the access cavity was cleaned of gutta percha and cement debris using sandblasting. Then a one-step self-etching adhesive system (iBond, Hereus-Kulzer, Hanau, Germany), enriched with 20% zirconia powder, was placed on the entire cavity following the manufacturer's instructions: application in one layer of the bonding resin, soft brushing for 20 s, soft air-blowing for 10 s, and polymerization using an LED lamp (Two Wave, Hereus-Kulzer) for 20 s at 1400 mW/cm2.

Samples were randomly assigned to three groups (n=10 each) according to the restorative material selected for the restoration: G1) horizontal layer of 0.5 mm of flowable composite (Venus Diamond Flow, Hereus-Kulzer) followed by anatomical stratification with traditional nano-filled composite (Clearfil Majesty ES-2, Kuraray), shade CL; G2) single layer of flowable bulk composite (Venus Bulk fill, Hereus-Kulzer); and G3) anatomical stratification with nano-filled composite (Clearfil Majesty ES-2), shade CL.

All samples were sectioned perpendicularly to the long axis, using a diamond saw in a cutting machine (Micromet, Remet, Bologna, Italy) 1 mm above the chamber floor, and the obtained horizontal surface was polished with gradually decreasing abrasive paper.

The adaptation of each restorative material to the pulp chamber floor was analyzed using a spectral domain OCT (Spectralis, Heidelberg Engineering, Heidelberg, Germany). Before performing the analyses, samples were stabilized on a silicone support at 1.5 cm from the lens of the OCT. The occlusal surface of each sample was exposed to the OCT light beam at an angle of 90°. All samples were analyzed with a technique that combines multimodal OCT images (wavelength 870 nm) with infrared images, employing a specific lens for ocular examinations (Anterior Segment Lens, Heidelberg Engineering, Heidelberg, Germany). The obtained images were acquired in high-speed and enhanced depth imaging (EDI) modes by selecting the settings for iridocorneal angle images (ART set to 60 frames, 15° × 5°, 20 sections every 139 μm). Every obtained image was analyzed using ImageJ software (ver. 1.42q). A custom computer code was developed as a plugin for ImageJ based on a previously reported binarization process [10,21,22] to facilitate the image analysis procedure and distinguish pixel clusters with higher brightness indicating gaps or unsealed interfaces at the cavity floor. The total interfacial gap of the cavity floor was calculated as:

$$\frac{\sum \text{gap length at all cross-sections}}{\sum \text{cavity floor length at all cross-sections}}\Bigg) \times 100$$

(Gap

Collected data were statistically analyzed using a one-way ANOVA test and the Bonferroni post-hoc test to evaluate differences in adaptation quality among groups. The significance level was set at 5% ($P < 0.05$). All statistical analyses were performed using STATA 11.0 (STATA Corp., TX, USA).

Figure 1. OCT scanning image of the pulpal floor chamber–composite interface once acquired in high speed and EDI modes.

Results

The mean interfacial gap values (expressed as a percentage and standard deviation) of composites on the pulp chamber floor are given in Table 1 and presented as a bar graph in Figure 1. ANOVA showed statistically significant differences between the groups. In particular, Group C had a significantly higher number of interfacial gaps within the dentin substrate than Groups A and B.

Table 1. Mean and standard deviations of pulp chamber floor gaps for the groups, expressed as percentage ratios. The superscript letters indicate statistically significant differences ($p<0.05$).[please be consistent with p vs. P]

Figure 1. Composite gap values, expressed as percentage ratios, tested on the pulp chamber.

Discussion

For successful adhesive restorations in endodontically treated teeth, it is important to obtain good dentin bonding to pulpal floor dentin as the latter always remains in any non-vital tooth that requires restoration. To date, several studies have examined the bond strength of composite restorations to pulpal floor dentin (23–25), but few studies have focused on interfacial gaps. The results obtained in the present study showed that high-viscosity composites adapted more poorly to the pulp chamber floor than flowable composites, either traditional or bulk-fill. Therefore, the null hypothesis was rejected.

Interfacial gap detection has been widely studied and several methods have been proposed for determining marginal or interfacial adhesive defects. One commonly used method entails highlighting microleakage using an organic dye or silver nitrate as a tracer [26], generally used to investigate the quality of adhesives on the basis of the marginal gaps [27] or interfacial gaps formed at the tooth–restoration interface [28]. The disadvantages of microleakage analysis are that it is an invasive semi-quantitative analysis and it shows only a limited representation of three-dimensional geometry [29]. Marginal analysis is another method employed to investigate interfacial gaps because it enables monitoring and multiple measurements of marginal integrity with the use of replicas [16,30], but it cannot cover the entire adhesive area of restorations and does not allow nondestructive internal evaluation of interfaces. Radiography can also be employed, providing clinical information about marginal discrepancies or gaps in composite restorations with adhesive luting, but it frequently results in false-positive or false-negative readings [31]. Micro-computed tomography allows a detailed display of interfacial discrepancies detectable by X-ray. However, it requires long measurement times and over-drying of specimens during scanning can cause deformation, resulting in false positives [32]. In addition, it can only be used *in vitro* due to the long-term high levels of radiation. Recently, several authors have achieved excellent results with OCT, a noninvasive imaging technique that obtains cross-sectional images of biological tissues [29,33]. The technique can reliably detect and quantify the marginal gap between restorative composite and dental tissues [22]. It also allows noninvasive evaluation of the samples. For these reasons, OCT was employed in the present study to evaluate the presence of interfacial gaps between the composite and pulp chamber floor. In this case, the light through the interface between two media undergoes partial reflection and refraction according to the refractive index of the media crossed. The refractive index of air, which is supposed to fill the gaps, is equal to n = 1.0, the enamel is n = 1.6, the dentin is n = 1.5, and the composite resins are rather variable depending on the characteristics of the material, especially its transparency [34]. For this reason, in the present study, high-transparency composite resins were selected to increase the visibility of the interfaces between composite and dental tissue. The OCT can analyze to a depth of about 2–3 mm [35,36], so it was necessary to cut samples after the post-endodontic restoration to clearly visualize the cavity floor interface. Furthermore, better-quality images are obtained with OCT when the light beam is perpendicular to the interface. We selected upper molars without pulpal calcifications to standardize the conformation of the cavity floor, which is usually irregular [22], as much as possible.

An effective coronal seal is extremely important to avoid contamination of the root canal system by bacterial organisms. Several *in vitro* studies [37–39] have shown that root canal filling materials do not provide an effective coronal seal against infiltration even when the canal system is correctly obturated with gutta percha. The absence of interfacial gaps between the restoration and root canal filling materials is essential and determines the long-term success of endodontic therapy [40]. Consequently, to obtain successful adhesive restorations of non-vital molars, it is important to obtain good resin composite adaptation to the pulpal floor dentin, as the latter always remains in any non-vital molar that requires post-endodontic restoration. Furthermore, the gap at the interface between the restorative material and dental tissue or within the restorative material itself increases the likelihood of the formation and propagation of cracks [41].

Several studies have shown that the use of flowable composites significantly reduces microleakage and internal voids in the restoration [31,32,42]. These materials have a lower percentage by weight and by volume of filler compared to a composite with the traditional formulation, providing a lower degree of viscosity. Thus, flowable composites are easier to apply, especially in deep cavities, adapt better to the cavity walls, and have greater elasticity and a lower degree of shrinkage during polymerization [43]. Moreover, Ariyoshi et al. [44] reported that resin coating using a combination of a self-etching primer system and flowable resin composite enhanced the microtensile bond strengths of indirect composite cores to pulpal floor dentin. These characteristics help to explain the results obtained in the present study. As previously stated, flowable composites, either traditional or bulk, allow better adaptation to the cavity, leading to significantly fewer interfacial gaps than nano-filled composites. Furthermore, another important characteristic is less shrinkage stress generated during photo polymerization [45]. Their high elasticity compensates for internal stress, reducing the risk of marginal gaps at the adhesive interface.

Conclusions

Flowable composites are strongly recommended to perform at least the first horizontal layer of post-endodontic restorations, to obtain a continuous and hermetic seal between root dentin and the restorative material. OCT has many potential clinical applications in dentistry and allows the detection of morphological changes in hard dental tissues with accuracy and reliability compared to validated diagnostic instruments such as the confocal microscope [22]. Further studies, both *in vitro* and *in vivo*, are necessary to confirm our results.

REFERENCES

[1] Ray HA, Trope M. Periapical status of endodontically treated teeth in relation to the technical quality of the root filling and the coronal restoration. Int Endod J 1995;28:12–8.

[2] Iqbal MK, Johansson AA, Akeel RF, et al. A retrospective analysis of factors associated with the periapical status of restored, endodontically treated teeth. Int J Prosthodont 2003;16(1):31–8.

[3] Saunders WP, Saunders EM. Coronal leakage as a cause of failure in root canal therapy: a review. Endod Dent Traumatol 1994;10:105–8.

[4] Alves J, Walton R, Drake D. Coronal leakage: endotoxin penetration from mixed bacterial communities through obturated, post-prepared root canals. J Endod 1998;24:587–91.

[5] Sly MM, Moore BK, Platt JA, Brown CE. Push-out bond strength of a new endodontic obturation system (Resilon/Epiphany). J Endod. 2007 Feb;33(2):160–2.

[6] Imura N, Pinheiro ET, Gomes BP, Zaia AA, Ferraz CC, Souza-Filho FJ. The outcome of endodontic treatment: a retrospective study of 2000 cases performed by a specialist. J Endod. 2007 Nov;33(11):1278–82.

[7] Schwartz RS. Adhesive dentistry and endodontics. Part 2: bonding in the root canal system-the promise and the problems: a review. J Endod. 2006 Dec;32(12):1125–34.

[8] Feilzer AJ, De Gee AJ, Davidson CL. Setting stress in composite resin in relation to configuration of the restoration. J Dent Res. 1987 Nov;66(11):1636–9.

[9] Davidson CL. Resisting the curing contraction with adhesive composites. J Prosthet Dent. 1986 Apr;55(4):446–7.

[10] Giachetti L, Scaminaci Russo D, Bambi C, Grandini R. A review of polymerization shrinkage stress: current techniques for posterior direct resin restorations. J Contemp Dent Pract. 2006 Sep 1;7(4):79–88

[11] Alomari Q, Ajlouni R, Omar R. Managing the polymerization shrinkage of resin composite restorations: a review. SADJ. 2007 Feb;62(1):12, 14, 16 passim

[12] Chuang SF, Jin YT, Lin TS, Chang CH, García-Godoy F. Effects of lining materials on microleakage and internal voids of Class II resin-based composite restorations. Am J Dent. 2003 Apr;16(2):84–90.

[13] Haak R, Wicht MJ, Noack MJ. Marginal and internal adaptation of extended class I restorations lined with flowable composites. J Dent. 2003 May;31(4):231–9.

[14] Yahagi C, Takagaki T, Sadr A, Ikeda M, Nikaido T, Tagami J. Effect of lining with a flowable composite on internal adaptation of direct composite restorations using all-in-one adhesive systems. Dent Mater J. 2012;31(3):481–8.

[15] Walshaw PR, McComb D. Microleakage in Class 2 resin composites with low-modulus intermediate materials. J Dent Res 1998; 77(Spec Issue):131 Abstract 204.

[16] Kemp-Scholte CM, Davidson CL. Complete marginal seal of Class V resin composite restorations effected by increased flexibility. J Dent Res 1990; 69(6):1240–3.

[17] De Gee AJ, Feilzer AJ, Davidson CL. True linear polymerization shrinkage of unfilled resins and composites determined with a linometer.Dent Mater 1993; 9(1):11–4.

[18] Aggarwal V, Singla M, Yadav S, Yadav H. Effect of flowable composite liner and glass ionomer liner on class II gingival marginal adaptation of direct composite restorations with different bonding strategies. J Dent. 2014 May;42(5):619–25. doi: 10.1016/j.jdent.2014.02.016. Epub 2014 Mar 11

[19] Oliveira LC, Duarte S Jr, Araujo CA, Abrahão A. Effect of low-elastic modulus liner and base as stress-absorbing layer in composite resin restorations. Dent Mater. 2010 Mar;26(3):e159–69.

[20] Moorthy A, Hogg CH, Dowling AH, Grufferty BF, Benetti AR, Fleming GJ. Cuspal deflection and microleakage in premolar teeth restored with bulk-fill flowable resin-based composite base materials. J Dent. 2012 Jun;40(6):500–5.

[21] Payne JH 4th. The marginal seal of class II restorations: flowable composite resin compared to injectable glass ionomer. J Clin Pediatr Dent 1999; 23(2):123–30.

[22] Bakhsh TA, Sadr A, Shimada Y, Tagami J, Sumi Y. Noninvasive quantification of resin-dentin interfacial gaps using optical coherence tomography: validation against confocal microscopy. Dent Mater. 2011 Sep;27(9):915–25.

[23] Akagawa H, Nikaido T, Tanaka T, Burrow MF, Tagami J. Shear bond strengths to coronal and pulp chamber floor dentin. Am J Dent 2002; 15: 383-388.8-11

[24] Akagawa H, Nikaido T, Burrow MF, Tagami J. Influence of cavity configuration on the adhesion of two resin-based composites to pulpal floor dentin. Am J Dent 2005; 18: 233–236

[25] Ariyoshi M, Nikaido T, Foxton RM, Tagami J. Influence of filling technique and curing mode on the bond strengths of composite cores to pulpal floor dentin. Dent Mater J. 2010 Oct;29(5):562–9

[26] Haak R, Wicht MJ, Hellmich M, Noack MJ. Detection of marginal defects of composite restorations with conventional and digital radiographs. Eur J Oral Sci 2002;110:282–6.

[27] Sun J, Fang R, Lin N, Eidelman N, Lin-Gibson S. Nondestructive quantification of leakage at the tooth–composite interface and its correlation with material performance parameters. Biomaterials 2009;30:4457–62.

[28] De Santis R, Mollica F, Prisco D, Rengo S, Ambrosio L, Nicolais L. A 3D analysis of mechanically stressed dentin–adhesive-composite interfaces using X-ray micro-CT. Biomaterials 2005;26:257–70.

[29] Turki A. Bakhsha,b, Alireza Sadrb,?, Yasushi Shimadaa, Junji Tagamia, Yasunori Sumic. Noninvasive quantification of resin-dentin interfacial gaps using optical coherence tomography: validation
against confocal microscopy. Dent Mater. 2011 Sep;27(9):915–25.

[30] De Gee AJ, Feilzer AJ, Davidson CL. True linear polymerization shrinkage of unfilled resins and composites determined with a linometer.Dent Mater 1993; 9(1):11–4.

[31] Ferdianakis K. Microleakage reduction from newer esthetic restorative materials in permanent molars. J Clin Pediatr Dent 1998; 22(3):221–9.

[32] Malmstrom H, Schlueter M, Roach T, Moss ME. Effect of thickness of flowable resins on marginal leakage in class II composite restorations. Oper Dent 2002; 27(4):373–80.

[33] Huang, D.; Swanson, E.A.; Lin, C.P.; Schuman, J.S.; Stinson, W.G.; Chang, W.; Hee, M.R.; Flotte, T.; Gregory, K.; Puliafito, C.A.; Fujimoto, J.G. Optical coherence tomography. Science 1991, 254, 1178–1181.

[34] Meng Z, Yao XS, Yao H, Liang Y, Liu T, Li Y, Wang G, Lan S. Measurement of the refractive index of human teeth by optical coherence tomography. J Biomed Opt. 2009 May-Jun;14(3):034010.

[35] Feldchtein F, Gelikonov V, Iksanov R, Gelikonov G, Kuranov R, Sergeev A, et al. *In vivo* OCT imaging of hard and soft tissue of the oral cavity. Opt Express 1998;3:239–50.

[36] Shimada Y, Sadr A, Burrow MF, Tagami J, Ozawa N, Sumi Y. Validation of swept-source optical coherence tomography (SS-OCT) for the diagnosis of occlusal caries. J Dent 2010;38:655–65.

[37] Torabinejad M, Ung B, Kettering J. *In vitro* bacterial penetrationof coronally unsealed endodontically treated teeth. J Endod 1990; 16:566–569.

[38] Magura ME, Kafrawy AH, Brown CE, Newton CW. Human saliva coronal microleakage in obturated root canals: An *in vitro* study. J Endod 1991;17:324–331.

[39] Chailertvanitkul P, Saunders WP, MacKenzie D. Coronal leakage of obturated root canals after long-term storage using a polymicrobial marker. J Endod 1997;24:610–613.

[40] Iqbal MK1, Johansson AA, Akeel RF, Bergenholtz A, Omar R. A retrospective analysis of factors associated with the periapical status of restored, endodontically treated teeth. Int J Prosthodont. 2003 Jan-Feb;16(1):31–8.

[41] James L. Drummond, Degradation, fatigue and failure of resin dental composite materials, J Dent Res. Aug 2008; 87(8): 710–719.

[42] Walshaw PR, McComb D. Microleakage in Class 2 resin composites with low-modulus intermediate materials. J Dent Res 1998; 77(Spec Issue):131 Abstract 204.

[43] Payne JH 4th. The marginal seal of class II restorations: flowable composite resin compared to injectable glass ionomer. J Clin Pediatr Dent 1999; 23(2):123–30.

[44] Ariyoshi M, Nikaido T, Foxton RM, Tagami J. Microtensile bond strengths of composite cores to pulpal floor dentin with resin coating. Dent Mater J 2008; 27: 400–407.

[45] Ilie N, Stark K. Curing behaviour of high-viscosity bulk-fill composites. J Dent. 2014 Aug;42(8):977–85.