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ORIGINAL ARTICLE

Micro-computed tomography analysis of gap and void formation in different prefabricated fiber post cementation materials and techniques

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KEYWORDS

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Abstract *Objective:* The study was built around the objective of determining the variances in the gap and void formation around cemented prefabricated fiber posts with two different cementation materials and techniques with micro-computed tomography (μCT).

Methods: Standardized acrylic resin roots (N = 40) with prefabricated fiber posts (RelyX™ Fiber Post 3D) were split into four sets (n = 10) based on many types of cementation materials and techniques. In the first group, resin cement (RelyX™ Unicem) was inserted to the canals via root canal tips. In the second group, the same cement was injected, and a microbrush was used to distribute the cement inside the canal. In the third group, dual polymerizing resin cement (Multi-Core® Flow) was injected into the canals by using root canal tips. In the fourth group, the same cement was injected, and a microbrush was used to distribute the cement inside the canal. The gap and void formation in the cement and the root canals was evaluated with μCT. IBM SPSS Statistics was used to perform the statistical evaluation, then the Kolmogorov-Smirnov test of nor-

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mality and Kruskal-Wallis H test to compare these variables with respect to the all groups significant difference (a = 0.05).

Results: The study outlined no difference of significance when evaluating the gap and void formation within the experimental groups ($P > 0.05$).

Conclusion: There was a certain amount of void and gap formation inside all of the tested specimens. However, no significant variances were found.

1. Introduction

A good number of endodontic-treated teeth present with extensive destruction due to carious lesions, endodontic treatment procedures, and previous restorations which make the remaining tooth structure often unable to support the final restoration. However, the post and core restoration can be useful in providing appropriate retention and support for final restorative activity (Torbjorner and Fransson, 2004). Furthermore, different prosthetic techniques and materials have been suggested for post and core restorations. Prefabricated fiber posts are the current trend for restoring endodontically treated teeth due to their convenience and cosmetic and mechanical properties – such that they are comparable to those of dentin (Dietschi et al., 2007, 2008). This is considered to be a clinical advantage (Schmitter et al., 2006; Faria-e-Silva et al., 2009). Some studies have related the flexibility of fiber posts to the homogeneous stress distribution along the apical third of the root, which results in a smaller frequency of root fracture (Abduljawad et al., 2016).

Deformity is caused by polymerization shrinkage, and in the event that the cement used has a thicker layer, it may lead to polymerization stress (Grandini et al., 2005). The cement deformity may result in voids and gaps formation, which may compromise the post retention within the root canal (Grandini et al., 2005). The void formation happens when air entraps within the cement itself, while the gap occurs when the air entraps between the cement and the internal canal wall. Moreover, a thick layer of cement can lead to a higher incidence of void formation, which in turn leads to an increase in the tendency for debonding. This is the main issue that leads to fiber posts failing. On the other hand, void formation could be decreased with a uniform and thin layer (Grandini et al., 2005; Barfeie et al., 2015). Prospective and retrospective clinical studies have outlined that post displacement fiber can occur when thicker cement layers are used (Ferrari et al., 2000; Figueiredo et al., 2015). In addition, voids may cause periodontal inflammation via lateral canals (Fredriksson et al., 1998).

Micro-computed tomography (μCT) can be applied in an in vitro assessment to examine the gaps and voids inside the canal by using a three-dimensional (3D) view (Kenneth and Louis, 2010). Another technique that can be used is to section the specimens, which is considered to be a disadvantage due to specimen destruction when compared to the μCT technique (Vichi et al., 2002; Uzun et al., 2016). This is the reason that the main objective of the study at hand is to examine the variation in the gap and void formation around cemented prefabricated fiber posts with two different cementation materials and techniques with μCT. The study tested the hypotheses that cementation materials and techniques would lead to different void and gap area formations between resin cement, root and post interface.

2. Materials and methods

This in vitro study was designed to use standardized acrylic roots (B22X Series #21; Nissin Dental, Kyoto, Japan) ($N = 40$). The roots were split into four sets randomly as per the many cementation materials and techniques, including self-adhesive resin cement (RelyX™ Unicem 2 Self-Adhesive Resin Cement; 3M, Maplewood, MN, USA) and dual polymerizing resin cement (MultiCore® Flow; Ivoclar Vivadent, Schaan, Liechtenstein) with red size prefabricated fiber posts (RelyX™ Fiber Post 3D; 3M, Maplewood, MN, USA). The injection technique was used with and without a microbrush, as studies proved that the thicker the cement the more the voids and gaps, using microbrush in the canals was to distribute and thinning the layer of cement. Specimens divided into two groups according to materials (FR, FM) and each is split into two subsets as per techniques (I, B):

- FRI group: 10 roots, resin cement (RelyX™ Unicem 2 Self-Adhesive Resin Cement; 3M) by injecting the material inside the canal by using a root canal tip, followed by cementation of the post.
- FRB group: 10 roots, resin cement (RelyX™ Unicem 2 Self-Adhesive Resin Cement; 3M) by injecting the material inside the canal by using a root canal tip and a microbrush to distribute the cement inside the canal, followed by cementation of the post.
- FMI group: 10 roots, dual curing resin cement (MultiCore® Flow; Ivoclar Vivadent) by injecting the material inside the canal by using a root canal tip, followed by cementation of the post.
- FMB group: 10 roots, dual curing resin cement (MultiCore® Flow; Ivoclar Vivadent) by injecting the material inside the canal by using a root canal tip and microbrush to distribute the cement inside the canal, followed by cementation of the post.

A standardized post space was created for every single specimen (12 mm) by using a standard size (Peeso Reamer #3; Dentsply Maillefer, Ballaigues, Switzerland) based on the size of the fiber post (red), then with (ParaPost drill, red; 3M, Maplewood, MN, USA) corresponding of the fiber post. Each specimen was numbered and scanned via μCT (SkyScan 1172 machine; Belgium) with the following parameters: source voltage 90 kV, source current 112 μA, image pixel size 13.73 μm,

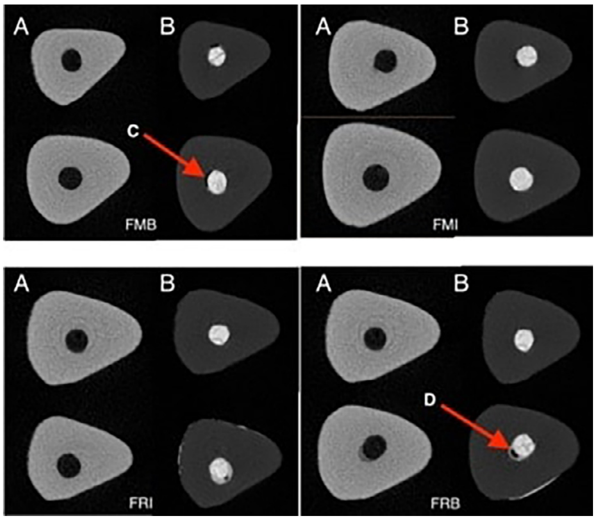

Fig. 1 Representative µCT radiograph. Pre-scan of the post space (A), post-scan of the fiber post with the cementation material (B), gap (C), void (D). Two specimens for each group. FRB: cemented fiber post with RelyX resin cement injected with the use of microbrush, FRI: cemented fiber post with RelyX resin cement only injected, FMI: cemented fiber post with Multicore resin cement only injected, FMB: cemented fiber post with Multicore resin cement injected with the use of microbrush.

Al + Cu filter, TIFF image format, exposure 2900 ms, rotation step 0.700 deg, frame averaging 3, random movement 10, and rotation 360 degree. The TIFF format raw images were reconstructed with NRecon version 1.6.4.8 SkyScan 2011 software with the following settings: smoothing 6, smoothing kernel 2 (Gaussian), ring artifact correction 5, beam hardening correction 10%, and BMP file type for results. CTAN version 1.11.10.0+ (64-bit) SkyScan 2003-11 software was employed to measure the void and gap volumes in cubic millimeters.

For the FMB and FRB groups, the brushing technique was used after injecting the cementation material; the brush was inserted along the post space, moved in a round motion, and pulled out. For the FR groups, the posts were cleaned and disinfected with alcohol and dried with air that had no oil or water. Then, they were rinsed and air dried. The root canal was cleaned with a solution made up of three percent sodium hypochlorite (NaOCl), rinsed with water, subsequent to which it was dried with paper points completely before the process of cementation (Absorbent Points; Dentsply Maillefer, Ballaigues, Switzerland). For the FM groups, a dentin bonding agent was used to condition the root canal (ExciTE F DSC; Ivoclar Vivadent, Schaan, Liechtenstein), and the extra cement found itself displaced after the post was inserted. To ensure complete polymerization to the cement, a curing light (Elipar™ S10 LED Curing Light; 3M ESPE, St. Paul, MN, USA) was used on each specimen for 40 s. Subsequent to this, the curing unit's glass head was placed in the orifice of the roots. The manufacturer instructions were used when handling the material. When splitting the work flow for preparing the specimens, each procedure for each specimen was assigned to one of the authors. We agreed upon the steps themselves, and typed them up for the assigned person to follow. IBM SPSS Statistics for Windows version 22.0 was the main ingredient behind the statistical evaluation. The mean, median, standard deviation and range for numerical (measurable) variables (void and gap) were calculated for the study. We used the Kolmogorov-Smirnov test of normality to check whether or not our measurable variable data (numerical variables) was normally distributed. Then, non-parametric Mann-Whitney *U* test was put in place to equate these variables with respect to the materials, Multicore (M) and RelyX (R), techniques, injecting in the canal space and brushing (B) and only injecting in canal space (I). In addition, non-parametric Kruskal-Wallis H test was used to evaluate these variables with respect to the four different groups (FMB, FMI, FRB, and FRI).

3. Results

There was no significant effect on the void and gap parameters ($p > 0.05$) in any of the groups (Fig. 1).

The voids and gaps seen on the µCT images in terms of the many resin cements and their demarcations within the post regions can be studied in Table 1. As per Mann-Whitney U results, the void formation had no real statistical difference

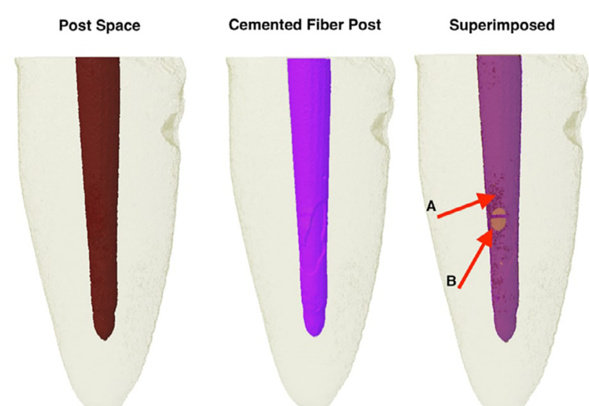

Fig. 2 Representative image of a 3-dimensional model. Void (A), Gap (B).

Table 1 Comparison between the two different materials with respect to the void and gap formation.

	Materials		P-value[a]
	M (n = 20) Mean ± SD	R (n = 20) Mean ± SD	
Void (mm^3)	0.005701 ± 0.014936	0.00971 ± 0.021911	0.065
Gap (mm^3)	0.5303705 ± 0.63056754	0.427508 ± 0.34623079	0.646

[a] By Mann-Whitney *U* test. SD: standard deviation, M: Multicore material, R: RelyX material.

Table 2 Comparison between the two different techniques with respect to the void and gap formation.

	Techniques		P-value[a]
	B (n = 20) Mean ± SD	I (n = 20) Mean ± SD	
Void (mm^3)	0.0107695 ± 0.02575836	0.0046415 ± 0.00532769	0.635
Gap (mm^3)	0.5337615 ± 0.51147	0.424117 ± 0.505105	0.234

[a] By Mann-Whitney *U* test. SD: standard deviation, B: injecting the resin cement with the use of microbrush, I: only injecting the resin material

Table 3 Comparison of the four different groups with respect to the void and gap formation.

	Groups				P-value[a]
	FMB (n = 10) Mean ± SD	FMI (n = 10) Mean ± SD	FRI (n = 10) Mean ± SD	FRB (n = 10) Mean ± SD	
Void (mm^3)	0.008918 ± 0.0207065	0.002484 ± 0.00438297	0.006799 ± 0.00551071	0.012621 ± 0.03105366	0.121
Gap (mm^3)	0.59093 ± 0.68021082	0.469811 ± 0.6071027	0.378423 ± 0.40668969	0.476593 ± 0.28691543	0.633

[a] By Kruskal-Wallis test. SD: standard deviation, FRB: cemented fiber post with RelyX resin cement injected with the use of microbrush, FRI: cemented fiber post with RelyX resin cement only injected, FMI: cemented fiber post with Multicore resin cement only injected, FMB: cemented fiber post with Multicore resin cement injected with the use of microbrush.

within tested" cemented materials ($p > 0.05$). The voids and gaps were observed at the apical third going toward the coronal third, and every root canal that was filled, alongside the toot post cementation, was examined overall (Fig. 2).

The void and gap formation by using different techniques along with their dissemination in the post regions can be studied in Table 2. "The Mann-Whitney U results show that no significant variance was found in" the void and gap formation by using different resin techniques within the cement techniques under observation ($p > 0.05$).

The void and gap formation in all the groups is presented in Table 3, and no noticeable variance was observed within the groups in terms of the void and gap formation ($p < 0.05$). The values for structural discontinuities are stated as a whole and not distinguished in terms of size and/or location.

4. Discussion

The study worked by standardizing the post space prior to the fiber post cementation. Nevertheless, the hypothesis that this study put forth did not come to fruition. This is because no significant variance was observed when studying the many cementation materials and techniques. Void and gap formation was not affected by the cement types and techniques that were used.

The use of micro brush as one technique is to try to distribute the cement layer inside the canal space as equal thickness as if there are air bubbles or any air entraps in the cement material, also, trying to reduce the thickness of the cement material as the literature stated that more thickness of cement will cause more voids and gaps (Grandini et al., 2005).

The presence of voids and gaps could potentially cause areas that can impact interface degradation and decrease the longevity of the fiber post (Watzke et al., 2009; Gomes et al., 2014). The voids and gaps formation, which represent areas that are weak in terms of the material, have a lower likelihood of appearing by utilization of a uniform and thin cement layer (Grandini et al., 2005). As described by studies in different disciplines in which different cementation materials and techniques were tested, there is a link between the presence of voids and gaps and leakage in the context of the cemented fiber post on the interfacial surfaces (Beyer-Olsen et al., 1983; Alkahtani et al., 2013).

Different methods were used to evaluate the voids and gaps with regard to leakage; however, the presence of voids and gaps was evaluated with 2-dimensional images. Overall, some of these studies have proven that there is a positive correlation shared by voids and gaps and leakage (Moll et al., 2004; Venturi, 2006; Ishikiriama et al., 2007; Bansal and Tewari, 2008; Souza et al., 2012). Based on these studies, we can conclude that the leakage will be greater with the presence of voids and gaps.

We can put forth that the voids became a part of the cementation during the process of mixing or through the technique used to apply the cement in the root canal. Mixing the paste components when they are not complete can result in voids within the root canal (Choet al., 2011). This, in some way, explained a dependence on the photoactivation of the cementation materials (Kim et al., 2009). The root dentin is filled with numerous accessory canals that will combine with the presence of voids and gaps and increase the chance of re-infection from the accessory canals (D'Alpino et al., 2015). Ideally, the area in the middle of the dentin and post surface should not have any gaps and voids in order to produce a homogeneous one-unit structure (Mjör et al., 2001).

Our study's results show that the highest mean value of void formation (0.012%) was noticed in FRB group while the lowest value (0.002%) was presented in the FMI group. In Caceres et al. (2018) study, the range of void formation was 0.69–2.66% among the different groups. It can be noticed that the mean values of void formation in our results are much lesser than the void formation values in Caceres study. Furthermore, this might be referred to the accuracy of cementation techniques among all tested groups following the manufacturer instructions, which might cause no significant difference in the void and gap formation between the groups.

When performing an analysis with μCT instead of conventional techniques, like scanning electron microscopy or optical microscopy, the accuracy of the measurements will be improved. In a previous study, μCT was used to measure the formation of voids in endodontically-treated teeth, rebuilt through various types of fiber posts in use. The luting cement volume and oval posts displayed bigger surrounding cement thicknesses than circular posts, leading to more failure (Tay and Pashley, 2007). One μCT analysis examined images of voids in the root canals. The examination outlined that setting aside the shape of the post or the cemented material, the void formation was greater in the coronal part than in other root canal parts (Tay and Pashley, 2007). One of the techniques used in a previous study was an injection technique with specific syringes for applying the cementation material. This helped with a reduction of the voids located in the cementation material and the gaps that were found near the fiber post, and the walls of the root canal (Rengo et al., 2014). In one previous study, the cementation materials were applied with elongation tips, which reduced the void formation when compared to application with a Lentulo spiral, irrespective of the type of fiber post being put in place (Kim et al., 2010).

One tool that provides a precise 3D view without killing the specimens is μCT (Svizero et al., 2013; Uzun et al., 2016; Sampaio et al., 2017; Caceres et al., 2018). The technology is fairly new and works with X-rays to help isolate the cross sections of an objection with pixels within the mm range. The μCT analyses that we have conducted prove that this is a useful tool to investigate different parameters, and it will detect any failures in any of the dimensions. The methodology employed by this study is similar to previous work on the subject (Caceres et al., 2018).

Future studies should examine methods through which voids and gaps can be reduced by focusing on the perfecting the time that the fiber post is being cemented into the canal.

The limitations of this study can include that this study was conducted in-vitro while in-vivo investigations may represent more clinical relevancy. Two cements and two techniques were used while it would be recommended to include additional cement materials other than resin cements, different cementation techniques as reline technique and different post type as metal post, zirconia post and cast post and core.

5. Conclusion

The study has concluded that a certain level of void and gap formation was inside all of the tested specimens. This result should be considered keeping in mind the limitations of the study. However, no difference of any significance was identified in the context of the gap and void formation in terms of the cementation materials and techniques used. Furthermore, the brushing technique did not seem to be effective for eliminating the void and gap formation around the cemented fiber posts.

Ethical statement

The work described in this article did not involve experiments on humans or animals. Therefore, it did not require an ethical approval related to our institutions.

Conflict of interest

None of the authors that were a part of the study in any capacity have any shape, size or form of conflict of interest to declare.

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