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CHAPTER 5

The Influence of Fatigue Loading on the Quality of Cement Layer and Retention Strength of Carbon Fiber Post-Resin Composite Core Restorations

5.1 Abstract

Objective. Clinical studies show a failure incidence after years of service of endodontically treated premolars when restored with post-core crowns, especially those with short posts or deficient ferrules. The reason for this can be a deterioration of the luting cement around the post by fatigue from functional loading. Because the anatomy of premolars may frequently be incompatible with the application of long endodontic posts the aim of this study was to evaluate the influence of fatigue loading on the quality of the cement layer between posts with restricted length and the root canal wall in single rooted premolars. The study was divided in three investigations. The first part concerned cast post and core restorations cemented with an adhesive and a non-adhesive cement (Chapter 3). In the second part (Chapter 4) post and core systems with varying post and core stiffness cemented with an adhesive cement were considered and in the third part (this Chapter) various luting agents for cementation of quartz-coated carbon fiber posts were evaluated with core build-up resin composite. This Chapter was confined to the third part.

Materials and Methods. Two adhesive resin composite cements, the chemical-cured Panavia 21 (group 1) and the dual-cured RelyX-ARC (group 2), and one resin-modified glass-ionomer cement, the chemical-cured RelyX (group 3) were selected for this study. Post and core restorations were made on single-rooted human premolars from which the coronal sections were removed at the level of the proximal cemento-enamel junction (CEJ). Following endodontic treatment a post and core restoration with 6 mm post length was prepared for each tooth. The posts were directly cemented in the root canal, and after applying a dual-cured adhesive (Clearfil Photo Bond) built up with a light-cured core build-up composite (Clearfil Photo Core). For each group (n = 8) half of the specimens was exposed to fatigue loading in buccal-lingual direction (10^6 load cycles) almost perpendicular to the axial axis (85°), while the other half was used as control. Three parallel, transverse, root sections of 1.5 mm thickness were cut from each specimen at the apical, medial and coronal location. These sections were examined by Scanning Electron Microscopy (SEM) to evaluate the integrity of the cement layer, while the retention strength of the cemented post sections was determined with the push-out test.

Results. Fatigue loading did not cause separation of the build-ups from the roots. The multivariate results of MANOVA showed that the condition main effect (fatigue or control) was just not significant (P = 0.059); the two other main effects, type of cement and section location were significant (P = 0.001 and P = 0.008). For both the push-out strength and SEM evaluation of cement layer integrity the results significantly improved from RelyX to RelyX ARC to Panavia 21 and also from apical to coronal.

Conclusion. For endodontic Quartz coated carbon fiber posts that are used to support an adhesively bonded resin composite core, adhesive resin composite cements should be advised.

5.2 Introduction

Short posts with a flexibility comparable to that of dentin used with new adhesive techniques may provide sufficient strength for an adhesively bonded resin composite core build-up and preserve satisfactory sealing of the apical root canal filling. Besides properties like compressive and tensile strength of the luting agent, the amount of shrinkage during setting, and the adhesive characteristics to bond to both the post and the root canal wall can be decisive for clinical success.

As discussed in previous Chapters the handling of resin composite cements is complicated in the root canal, as the anaerobic environment and primers may accelerate the setting of these cements. In addition high setting shrinkage stresses, due to an unfavorable C-factor [1,2] in the root canal, can lead to loss of marginal integrity, being different for various types of cements. Probably chemical-cured resin composite cements will perform better than the more abruptly setting light-initiated dual-cured resin composite cements [3]. Resin-modified glass-ionomer cements have better handling characteristics, due to their slower setting time and less complicated application procedure. However, the mechanical properties and adhesive strength of these cements will in general be different from resin composite cements [4].

The aim of this study was to evaluate the influence of fatigue loading on the quality of the cement layer between Quartz coated carbon fiber posts and the root canal wall for three types of luting cements, a chemical and dual-cured resin composite cement, and a resin-modified glass-ionomer cement.

5.3 Materials and Methods

Preparation of tooth

For this study twenty-four freshly extracted, caries free, human, single-rooted premolars were used and prepared as described in Chapter 3. The 24 prepared teeth were randomly assigned to one of the three groups (n = 8). During all experimental procedures throughout the investigation, the teeth were kept moist or stored in distilled water at 37 °C.

Post and core procedure

Two adhesive resin composite cements, the chemical-cured Panavia 21 (Kuraray) and the dual-cured RelyX-ARC (3M-ESPE), and one resin-modified glass-ionomer cement, the chemical-cured RelyX (3M-ESPE) were selected for this study. Post and core restorations were made on single-rooted premolars. The posts used were the two-stage parallel-sided (a diameter of 1.2 mm apical and medial and 1.8 mm coronal) Aestheti-Plus Quartz coated Carbon fiber posts (RTD), and the core build-up material was the light-cured resin composite Clearfil Photo Core (Kuraray). The posts, the root canal and dentin shoulder were cleaned and conditioned as described in chapter 4. A survey of the successive steps in the preparation of the post and core restorations for each group is given in Table 5.1.

Table 5.1 Steps in Post and Core Build-Up Preparation for the three Groups used in this Study. [a] In the US marketed as Single Bond, [b] CC, LC, and DC denote chemical-cured, light-cured, and dual-cured respectively.

Step	Group 1	Group 2	Group 3
Dentin etching	Dentin shoulder: 32% phosphoric acid	Root canal and dentin shoulder: 32% phosphoric acid	Dentin shoulder: 32% phosphoric acid
Primer or adhesive	Root canal: ED Primer	Root canal: Scotchbond 1 adhesive [a] (LC) [b]	n.a.
Cement	Entrance root canal and post: Panavia 21 (CC) [b]	Entrance root canal and post: RelyX-ARC (DC) [b]	Root canal: RelyX (CC) [b]
Adhesive	Dentin shoulder and post exterior root canal: Clearfil Photo Bond (DC) [b]		
Core build-up resin composite	Clearfil Photo-Core (LC) [b]		

In Group 1 the dentin shoulder was etched for 30 seconds with 32% phosphoric acid (Bisco) and thoroughly rinsed with water. After removing the water in the root canal with absorbent paper points the tooth was air-dried, but not dehydrated. Self-etching ED Primer (Kuraray) was applied to the root canal dentin with a micro brush (Demedis). The dentin was conditioned for 60 seconds, the excess primer was blown away and the primer in the root canal was removed with absorbent paper points. Then the entrance of the root canal and the post were coated with a surplus of mixed Panavia 21 TC (Kuraray) and the post was seated into the root canal. Excess cement was removed with a brush and the post was kept under occlusal finger pressure for 3 minutes. The core build-up procedure was identical to the core build-ups with prefabricated posts in chapter 4.

In group 2 both the root canal and dentin shoulder were etched for 30 seconds with 32% phosphoric acid followed by rinsing with water and drying as described for group 1. Two layers of Scotchbond 1 (in the US marketed as Single Bond) adhesive (3M-ESPE) were applied to the root canal dentin with a micro-brush. After removing the excess with absorbent paper points, the bonding was light-cured for 20 seconds. Then the entrance of the root canal and the post were coated with a surplus of mixed RelyX-ARC (3M-ESPE) and the post was seated into the root canal. Excess of cement was removed with a brush and during light curing of the cement for 20 seconds the post was held in place. The steps in the preparation of the core build-up were identical to group 1.

In group 3 the dentin shoulder was etched for 30 seconds with 32% phosphoric acid followed by rinsing with water and drying as described for group1. RelyX (3M-ESPE) was mixed and injected into the root canal with a Lentulo Paste Carrier (Dentsply/Maillefer), and then the post was seated into the root canal. Excess cement was removed with a brush and the post was kept under occlusal finger pressure for 3 minutes. The steps in the preparation of the core build-up were identical to groups 1 and 2.

Fatigue loading procedure, SEM, Push-out test

The procedures for fatigue loading and quality evaluation of the cement layer by SEM and push-out strength were identical to those as described in Chapter 3. For all groups half of the specimens (n = 4) was exposed to a fatigue loading and the other half (n = 4) was used as control (non fatigue). Post and core design of the quartz coated carbon fiber post and resin core build-up, and specimen locations, are illustrated in Figure 5.1. The scoring method for SEM of irregularities in the specimen and SEM photographs of specimen with the different type of luting agent are shown Fig 5.2.

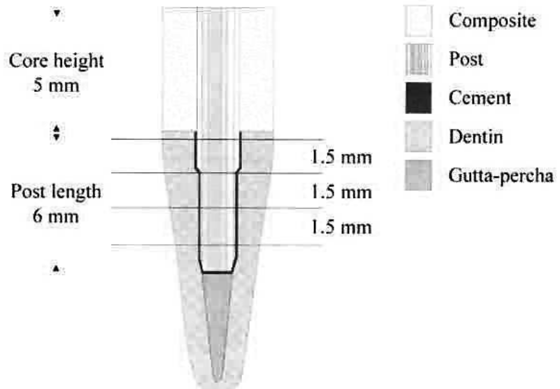

Fig 5.1 Schematic representation of a premolar root with quartz coated carbon fiber post and resin composite core build-up, and the levels (horizontal lines) where the root was cut to obtain 1.5 mm thick coronal, medial and apical cross-sections.

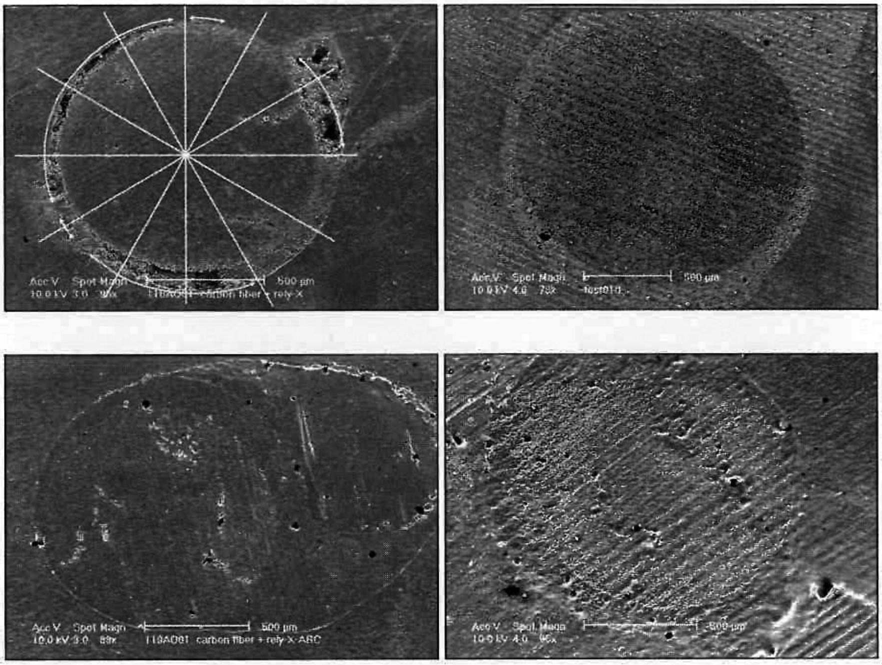

Fig 5.2 SEM micrograph of apical cross-section of a fatigued quartz coated carbon fiber post cemented with RelyX (upper left) showing cracks, voids and insufficient adaptation to the post and intra-radicular dentin. The five arrows around the circumference illustrate how irregularities were scored. As the total length of the summed arrows occupied 9/12th of the cement circumference the score was 9 for this specimen. In the other SEM micrographs better results of non-fatigued coronal cross-sections for Panavia (upper right), RelyX ARC (lower left), and RelyX (lower right).

Statistical Analysis

The obtained data were statistically analyzed by a multiple analysis of variance (MANOVA), with the aid of the GLM subprogram of the SPSS package (Windows version 11.00, SPSS Inc, Chicago IL, USA). Effects with a P-value not exceeding 0.05 were considered significant. Whenever an interaction of main effect was significant on a multivariate level it was univariately examined next. Whenever called for effects were further explored by means of simple effects and pairwise comparisons. In this analysis the SEM evaluation scores and push-out strengths were the dependent variables. Test condition (fatigue loading or control) and type of cement (Panavia 21, RelyX-ARC or RelyX) were treated as a between subjects factor, while section location (apical, medial or coronal) was entered as a within subjects factor.

5.4 Results

Fatigue loading did not cause separation of the post and core restorations from the roots in any of the specimens and at the multivariate level was just not different from the (non-fatigued) control ($F = 3.365$, $P = 0.059$). The multivariate results of the two other main effects, type of cement (Panavia 21, RelyX-ARC, and RelyX) and section location (apical, medial and apical) were significant ($F = 5.756$, $P = 0.001$ and $F = 5.252$, $P = 0.008$ respectively). The SEM evaluation scores and push-out strengths results are compiled in Table 5.2.

Table 5.2 Means (Standard Deviations) per cement of push-out strengths and SEM evaluation of irregularities for the three sections for control and fatigued samples. If no irregularities were found a SEM evaluation score of zero was assigned. A score of one was assigned when irregularities occupied 1/12th or less (8.3% or less) of the cement circumference. The highest score level of 12 indicates irregularities occupying 91.7 to 100% of the cement circumference.

		Apical section		Medial section		Coronal section	
Measurement	**Type of cement**	**Non Fatigue**	**Fatigue**	**Non Fatigue**	**Fatigue**	**Non Fatigue**	**Fatigue**
SEM score	Panavia 21	3.5 (0.6)	5.5 (2.9)	1.8 (1.5)	4.5 (2.1)	1.5 (0.6)	2.5 (1.0)
(Ranking 0-12)	Rely X-ARC	4.5 (2.4)	6.0 (3.7)	3.0 (1.6)	6.3 (1.0)	3.5 (1.9)	5.0 (4.1)
	Rely X	6.3 (1.7)	9.3 (3.8)	6.5 (3.1)	9.3 (3.0)	6.3 (2.8)	7.8 (2.1)
Push-out strength	Panavia 21	5.5 (2.3)	4.9 (0.8)	6.1 (0.9)	5.5 (1.7)	6.4 (2.3)	6.3 (2.2)
(MPa)	Rely X-ARC	2.1 (1.2)	2.1 (0.5)	6.4 (0.9)	3.4 (1.5)	6.6 (2.6)	3.9 (2.5)
	Rely X	3.2 (1.0)	3.6 (1.9)	4.2 (2.1)	4.5 (2.3)	2.4 (1.1)	2.7 (0.9)

Univariately the cement effect was significant for push-out strength ($F = 6.601$, $P = 0.007$) as well as for SEM ($F = 9.578$, $P = 0.001$). For both the push-out strength and SEM the results improved from RelyX to RelyX-ARC to Panavia 21; for push-out strength the difference between Panavia 21 and RelyX was the only one to be significant ($P = 0.002$). SEM showed significant differences between RelyX and Panavia 21 ($P < 0.001$) and between RelyX and RelyX-ARC ($P = 0.014$).

The location effect was also significant for SEM ($F = 4.288$, $P = 0.027$) and push-out strength

($F = 6.601$, $P = 0.009$). For push-out strength and SEM the results improved from the apical to the coronal location; for push-out strength there was a significant difference between the apical and the medial location ($P = 0.001$) and between the apical and the coronal location ($P = 0.005$). For SEM significant differences were found between the coronal and the apical location ($P = 0.022$) and between the coronal and the medial location ($P = 0.043$). SEM scores and push-out strength with the conditions (non fatigue and fatigue) pooled are presented in Table 5.3.

Table 5. 3 Means and standard deviations (in brackets) for SEM scores and Push-out strength per type of cement and per level (apical, medial and coronal) with the conditions (non-fatigue and fatigue) pooled. Differences between pooled data within the sections are significant for SEM scores (P = 0.027) and for Push-out strength (P = 0.009).

Measurement	Cement	Apical section	Medial section	Coronal section
SEM evaluation (Ranking 1-12)	Panavia 21	4.5 (2.2)	3.1(2.2)	2.0 (0.9)
	RelyX-ARC	5.3 (3.0)	4.6 (2.1)	4.3 (3.1)
	RelyX	7.8 (3.2)	7.9 (3.2)	7.0 (2.4)
Push-out Strength (MPa)	Panavia 21	5.2 (1.6)	5.8 (1.3)	6.4 (2.1)
	RelyX-ARC	2.1 (0.9)	4.9 (2.0)	5.3 (2.8)
	RelyX	3.4 (1.4)	4.3 (2.0)	2.6 (1.0)

5.5 Discussion

With the present *in vitro* model we were not able to demonstrate that fatigue loading would play a significant role in clinical failures and this was somewhat unexpected as the build-ups were loaded under unfavorable conditions. Under these circumstances an effect of fatiguing could have been expected in the coronal sections, which were right below the interface between root and build-up. An explanation for survival could be the relatively large peripheral surface and the accurate fit of the carbon fiber post, contributing to a homogeneous distribution of stresses keeping them well below the mechanical limits of the cement. Similar results were reported previously for well-fitting cast metal posts [5]. One may speculate that an adequate fit in the coronal part of the root canal is of paramount importance to minimize clinical failures.

Although there was no statistical difference between the fatigue and control group, the difference was close to significance ($F = 3.365$, $P = .059$), while the standard deviations for the fatigue group were higher than the control group (Table 5.2). This may indicate that unnoticed cracks had developed, which in the clinical situation could lead to leakage and on the long-term to disintegration of the cements. As described in previous chapters, this test set-up could not reveal disintegration by the effect of leakage. Many of the failures observed after years of service [6-8] may well be the result of a disintegrated cement from the combination of loading and long-term leakage [9]. To evaluate the quality of the post and core build-up systems for clinical service, follow-up studies with the test set-up where the samples are immersed in a dye solution could provide information about the leakage pattern [10], where leakage starts and how it progresses inside the root canal after load cycling.

With regard to push-out strength, the two resin composite cements Panavia 21 and RelyX-ARC performed significantly better than the resin-modified glass-ionomer cement RelyX (Table 5.2 and 5.3). This agrees with previous reports that the bond strength of resin composites is higher than that of resin-modified glass-ionomers [11]. However, for all three cements the large variability of the push-out strength showed that the root canal remains a difficult area to operate in. Bouillaguet et al. [12], who investigated the microtensile bond strength of luting cements to intra-radicular dentin when used as luting agent for endodontic posts, also reported these high variances.

An explanation could be that the integrity of all three resin cements is also influenced by the C-factor [1,2]. For the root canal the C-factor reaches values as high as 200 [12], which results in very high contraction stresses during setting. This can also create voids and, if the bond strength to either the post or intra-radicular dentin is exceeded, loss of integrity can occur. In the apical part the situation is worst, as no cement is available to flow to the area of stress. The possibility of flow is also more restricted for the abruptly setting light-curing resin cements as compared to the slower setting chemical-curing cements [3], which could create more defects in the light-curing resin cement layer and weaken the adhesive strength. This seems to be supported by both the SEM evaluation scores and the push-out strength, which became worse from Panavia 21 (chemical-cured) to RelyX-ARC (chemical and light-cured).

As explained in previous chapters for the two resin-composite cements a Lentulo Paste Carrier was not used. For the resin-modified glass-ionomer cement where the Lentulo Paste Carrier could be used, flaws and voids should have been diminished, but the SEM scores of RelyX showed that this technique did not guarantee a better integrity of the cement layer. It is clear that the presence of flaws, voids, and other defects and the worsening of the integrity from coronal to apical, as shown by the SEM results (Table 5.2) are also caused by the well-recognized problem of adequately delivering the cement at the apical level. Needle tubes to inject the resin composite cements into the root canal [13] may improve the results, but flaw and void formation as a result of the high C-factor will probably remain.

The outcome of this study, in which all luting agents survived fatigue loading when used to cement quartz coated fiber posts, is promising for the clinical situation. However, as the root canal remains a problematic area for adhesive cements, the general practitioner has to keep in mind that an adequate ferrule [14,15] and the preservation of tooth structure [16-18] are of major importance and key factors in promoting resistance to failure.

5.6 Conclusions

Within the limitations of the test set-up used in this study, it can be concluded that:

- Regardless the choice of adhesive cement, quartz coated carbon fiber posts of 6 mm and composite core build-ups can resist one million load cycles.
- With respect to cement layer integrity and retention strength resin composite cements perform better than resin-modified glass-ionomer cements.

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