Core build-up designs
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CHAPTER 3

The Influence of Fatigue Loading on the Performance of Adhesive and Non-adhesive Luting Cements for Cast Post and Core Restorations in Premolars

3.1 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 into three investigations. The first part concerned cast post and core restorations cemented with an adhesive and a non-adhesive cement (this Chapter). 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 (Chapter 5) 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 first part.

Materials and Methods. The adhesive cement used was Panavia 21 TC, chemical-cured resin composite cement and the non-adhesive cement was PhosphaCem/C, a zinc-oxy-phosphate cement. The coronal sections of single rooted human premolars were removed at the level of the proximal cemento-enamel junction (CEJ). After endodontic treatment a cast post (length 6 mm) and core (height 5 mm) was prepared for each tooth and cemented into the root canal with either Panavia 21 TC (n = 8) or PhosphaCem/C (n = 8). Half of the specimens from each cement group were exposed to fatigue loading in buccal-lingual direction (10⁶ load cycles of 40 N), almost perpendicular to the axial axis (85°), while the other half was used as control. Three parallel transverse root sections were cut from each specimen and used for evaluation of the influence of fatigue loading. For each section the cement integrity was studied by SEM and the retention strength of the cemented post section was determined with a push-out test.

Results. Fatigue loading did not cause separation of the post and cores from the roots or affect the push-out strength and SEM scores. However, for the SEM evaluation, as well as for the push-out test, Panavia 21 TC proved to be significantly better than PhosphaCem/C (P < 0.01).

Conclusion. Under the conditions of this study, fatiguing of cemented cast post and core restorations was not decisive as a single test to evaluate the quality of the cements.
3.2 Introduction

Conventional use of non-adhesive luting cements such as zinc-oxy-phosphates has relied upon frictional forces for the retention of posts. The degree of friction depended on the accuracy of fit of the post and on the surface roughness of both the post and the root canal. These non-adhesive luting cements were intended primarily to fill up the space between post and tooth tissue. This concept had to be revised with the introduction of adhesive resin-composite luting cements, as adhesion contributes substantially to retention [1-3].

Clinical studies have shown that many post and core restorations fail over a period of years [4-6]. Apart from traumatic injuries that can occur at any moment, cyclic mechanical loading during physiological function is considered as an important factor for failures over the long-term [7,8]. Cyclic loads during mastication can lead to fatigue of the cements resulting in disintegration of the cements and/or failure of the cement-substrate interface. If leakage occurs at the same time dissolution of the cement may further degrade the mechanical properties of the cement layer [9], finally resulting in loosening of the post and core build-up. In this respect, adhesive resin based composite cements may perform better over the long term than non-adhesive zinc-oxy-phosphate cements for post and core restorations on endodontically treated premolars, especially when the post length is limited [10] and/or an adequate ferrule is absent [11-13]. Also, the endodontic seal of an adhesive cement may be better than that of a non-adhesive cement.

In particular the anatomy of premolars may frequently be incompatible with the application of long endodontic posts. There may be exterior radicular grooves, running from the cemento-enamel junction to the apical area [14]; converged shape of the root canal(s); a buccal root which is vulnerable to perforation [15]; and variants in the root canal system anatomy (1,2,3 rooted and different levels of furcation entrances) [16]. Moreover, for its sealing quality the apical root canal filling has to be preserved as much as possible [17]. When partially removed for an endodontic post, a remaining apical fill of at least 5-6 mm should be preferred [18-20]. In view of that, the post length may frequently be limited, which would plead for shorter posts.

In many studies, these types of restorations are evaluated by determining the retentive strength of the post and core restoration with the cemented final crown on top of it. However, the forces generated to cause fracture are frequently superior to those developed in the clinical setting. Therefore, evaluating a restorative material after repeated (fatigue) loading of a post and core restoration is considered more relevant to the clinical reality [4-6] than its reaction to a single application of force to the point of rupture. For this reason, fatigue tests were introduced for evaluating post and cores. Fatigue failure is defined as the breaking or fracturing of a material.
Fatigue loading of cast post and core restorations

caused by cyclic or repeated applied loads below the yield limit, usually noticed initially as minute cracks followed by tearing and rupture, termed brittle failure or fracture [21].

The aim of this study was to evaluate the influence of fatigue loading on the quality of the cement layer between a cast post with restricted length and the root canal wall, for adhesive and non-adhesive cement by means of SEM observation and the push-out test. It was hypothesized that cast posts placed with adhesive cements resist fatigue loading better than cast posts placed with non-adhesive cements.

3.3 Materials and methods

Preparation of the tooth

Sixteen freshly extracted caries free human single rooted premolars were used for this study and divided into two groups each with 8 teeth. Before and throughout the investigation, the teeth were stored in water at 37 °C. The coronal portion of each premolar was separated from the root at the proximal cemento-enamel junction (CEJ), using a low-speed water-cooled saw of grit 230-270 (Buehler Ltd.). The sectioned teeth were then endodontically instrumented to within 1 mm from the apex with endodontic files (Dentsply/Maillefer), while regularly irrigating with 2% sodium hypochlorite. Then the root canals were dried with paper points and filled with gutta-percha points (Demedis) and the epoxy-based root canal sealer AH26 (Dentsply/Maillefer) using the lateral condensation technique. The periodontal ligament was simulated, by coating the root surface with a thin layer (approximately 0.3 mm) of silicone (TSE 399, General Electric). Finally the teeth with the artificial periodontal ligament were embedded in acrylic resin inside a standard copper tube, leaving 2 mm of the root above the acrylic. During setting of the resin, the specimens were kept in a moist environment to avoid dehydration of the dental tissue.

Cast post and core procedure

Gutta-percha was removed from the root canal with a low-speed Gates Glidden drill (# 3) to a depth of 6 mm as measured from the shoulder, in most cases leaving 4-6 mm of gutta-percha filling in the apical part. A post space was made to the same depth with a low-speed calibrated drill (code yellow, 1.3 mm) provided by the manufacturer of the Tenax endodontic post system (Coltène Whaledent). The corresponding burnout post (code yellow, TE-EP 13) displayed an adequate fit in the apical part of the root canal. In the more spacious medial and coronal part of the root canal, where the diameter of the calibrated drill was not always sufficient, the post was adjusted with Duralay (Dental Mfg.).
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A standard matrix was placed around the premolar and filled with Duralay to form a core build-up pattern. After setting, the core build-up was prepared with high-speed, coarse diamond burs under profuse water spray (type FG 142 G. 014, Horico). The height of the core was adjusted to 5.0 ± 0.2 mm and the axial surfaces were in conformity with the shape of the tooth. When completed, the post and core pattern was removed and used to cast a permanent post and core in a non-precious Phantom metal (Degussa).

Cementation procedure

The 16 prepared teeth and their corresponding cast post and core were randomly assigned to one of the two groups. In the first group Panavia 21 TC (Kuraray) was used as luting cement and in the second group PhosphaCem/C (Vivadent). All post and cores were cleaned with ethanol and dried. For each tooth the root canal and dentin shoulder were cleaned with pumice and rinsed with water. After removing the water in the root canal with absorbent paper points the tooth was air-dried. Mixed PhosphaCem/C was applied to the shoulder and injected into the root canal with a Lentulo Paste Carrier (Dentsply/Maillefer) before seating the posts [22]. For Panavia 21 TC the tooth was air-dried but not dehydrated. The root canal and shoulder were first conditioned for 60 seconds with ED Primer (Kuraray), applied with a micro-brush and paper point. Excess was blown away and in the apical part removed with absorbent paper points. Then the entrance of the root canal and post and core were coated with a surplus of mixed Panavia 21 TC and the post was seated into the root canal. Excess cement was removed with a brush and the cement margin covered with Oxyguard (Kuraray). During setting of the materials the post and core was kept under occlusal finger pressure for three minutes. To standardize the pressure as much as possible this was always done by the same operator. Excess luting agent was removed with a probe.

Fatigue loading procedure

In each cement group, half of the specimens (n = 4) was exposed to a fatigue load for one million cycles [7] in water at 37 °C in the ACTA twelve-station fatigue machine (ACTA) (Figure 3.1). The other half was used as control and was stored in water at 37 °C for the same period of time as the duration of the fatigue experiment (277 hours). The specimens were fixed in an acrylic block, placed in the fatigue machine and loaded in buccal-lingual direction on the axial-occlusal corner of the core with the load direction almost perpendicular to the post axis (85°). The placement of a crown with a ferrule in the set-up was deliberately omitted to exclude any external strengthening influence on the post and core. This configuration was believed to be the most severe with regard to the resistance of the restored tooth and appeared suitable for
specifically evaluating the fatigue behavior of the cement layer between post and intra-radicular dentin [11-13]. Each second the load alternated between 8 N (0.8 s) and 40 N (0.2 s). The small displacements, which occur during loading, due to the elasticity of the silicon layer between the tooth and embedding material, do not affect the adjusted maximum load, as the loading stylus returns to its upward position only if the maximum load has been fully reached. These low values, meeting the core at an unfavorable angle (85°), were chosen to simulate a masticatory load, within the range of physiological masticatory forces, in which a small horizontal component is present [23-27].

The fatigue tester used is based on a pneumatic system (Figure 3.1) containing twelve units, which makes it possible to test multiple specimens simultaneously. Electronic valves and control circuitry are used to generate forces. Cycling of the load is effected by continuously switching the feed pressure of the cylinders between two values. The loads are set with two membrane-type pressure regulators for each unit. While the regulators are adjusted, load cells are used to monitor the forces. A rubber membrane seals off the piston in the cylinder, to prevent the friction associated with regular sliding pistons, so to avoid variations in the magnitudes of the forces.

Fig. 3.1 Left: The twelve-station ACTA fatigue tester. Right: Schematic representation of one of the twelve stations (for more explanation see Materials and methods section).
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As the pistons cannot lift the rods, none of the forces can be set to less than 1.8 Newton, which is the total weight of a rod, a load cell and a piston. The cylinders are connected by a relatively thin (3 mm) hose, which leads to a slightly damped switching of the pressure (the time constant is approximately 40 ms); this working mechanism and the fact that the rods cannot be lifted eliminates any impact phenomena. More details can be found at www.dentalmaterials.nl.

**Specimen evaluation by Scanning Electron Microscopy**

Starting just apical from the level of the proximal CEJ, three consecutive, parallel, transverse 1.5 mm thick sections were cut (Figure 3.2) using a low-speed water-cooled saw. Impressions of the coronal surfaces of the three sections (coronal, medial and apical) were made using an elastomeric impression material (Impregum F, 3M-ESPE). The boxed impressions were poured in epoxy resin Araldite D (Vantico) and placed for 5 minutes in a sealed jar under 500 mm Hg pressure to remove air bubbles. After setting, the epoxy models were separated from the impressions. The specimens were mounted on 10 mm aluminum mounting stubs (Balzers) and gold sputter-coated (S150BE, Edwards), then examined in a Scanning Electron Microscope (XL20, Philips) and photographed at a magnification of approximately 50x.

![Diagram](image)

**Fig 3.2** Left: Schematic representation of a premolar root with post and 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. Right: Cross-sectional view.

The specimens were scored for irregularities like cracks and air-bubbles in the cement layer and insufficient adaptation of the cement to post or dentin. If no irregularities were found, a score of zero was assigned. A score of one was assigned when irregularities occupied 1/12th or
les (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. An example of a score can be found in Figure 5.2 on page 85. SEM photographs of sections of a cast post are illustrated in Figure 3.3.

![SEM micrographs of coronal cross-sections of cast posts.](image)

**Fig 3.3** SEM micrographs of coronal cross-sections of cast posts. The specimen at the left cemented with Panavia 21 shows fewer air bubbles and better adaptation to the post and intra-radicular dentin than specimen at the right cemented with PhosphaCem/C.

**Push-out test**

After making the impressions for the SEM examination, the push-out strength of the post-cement-root system in the cross-sectional disks was determined in a universal Instron testing machine (High Wycombe). Each cross-section was positioned with the coronal plane downwards and the central post segment centered over two parallel steel supports aligned in the testing device (Figure 3.4).

![Schematic representation of the push-out test.](image)

**Fig 3.4** Schematic representation of the push-out test. Each disk (1.5 mm) was positioned with the coronal plane downwards. The pushing steel rod was only in contact with the central post segment (crosshead speed of 0.5 mm/min).

A steel rod, only in contact with the central post segment was pressed downwards with a crosshead speed of 0.5 mm/min. To calculate the bond strength the load required to push out the
post segment was divided by the surface formed by the perimeter and thickness (1.5 mm): Bond strength (MPa) = Push out force (N) / Perimeter (mm) x specimen thickness (mm). The perimeter was measured with a map-measuring device (ANWB) on the SEM photographs. No distinction was made between loss of retention between post and cement layer or between intra-radicular dentin and cement layer.

**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). Effects with a $P$-value not exceeding .05 were considered significant. Whenever an interaction or 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-results and the push-out test results were the dependent variables. Test condition (fatigue loading or control) and type of cement (PhosphaCem/C or Panavia 21 TC) were treated as between subjects factor, while section location (apical, medial or coronal) was entered as a within subjects factor.

### 3.4 Results

Fatigue loading did not cause separation of the build-ups from the roots in any of the specimens. The scores after SEM examination for irregularities like cracks and air-bubbles in the cement layer and insufficient adaptation of the cement to post or dentin, together with the results for the push-out strengths are compiled in Table 3.1. In Table 3.2 the results from Table 3.1 with regard to fatigued and non-fatigued (control) specimens are pooled. The results from the MANOVA are summarized in Table 3.3. These show that the main effects condition (fatigue or non-fatigue) and location (apical, medial or coronal) were not significant. The cement main effect was the only one to be multivariately significant ($P < 0.001$). Univariately it is significant for the push-out strength ($F = 15.729, P = 0.002$) as well as for the SEM scores ($F = 88.571, P < 0.001$).
Fatigue loading of cast post and core restorations

Table 3.1 Means and standard deviations (in brackets) per cement for SEM evaluation of irregularities and push-out strengths for coronal, medial and apical sections from control specimens and fatigued specimens. 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.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Cement</th>
<th>Apical section</th>
<th>Medial section</th>
<th>Coronal section</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Control</td>
<td>Fatigue</td>
<td>Control</td>
</tr>
<tr>
<td>SEM evaluation (scores 0-12)</td>
<td>Panavia 21</td>
<td>4.5 (1.3)</td>
<td>6.0 (1.2)</td>
<td>3.0 (1.8)</td>
</tr>
<tr>
<td></td>
<td>PhosphaCem/C</td>
<td>11.0 (1.4)</td>
<td>10.8 (1.9)</td>
<td>9.0 (2.2)</td>
</tr>
<tr>
<td>Push-out Strength (MPa)</td>
<td>Panavia 21</td>
<td>5.5 (3.1)</td>
<td>6.2 (3.6)</td>
<td>6.0 (1.9)</td>
</tr>
<tr>
<td></td>
<td>PhosphaCem/C</td>
<td>4.1 (0.3)</td>
<td>3.0 (1.7)</td>
<td>2.7 (0.9)</td>
</tr>
</tbody>
</table>

Table 3.2 Data from table 3.1 pooled for control specimens and fatigued specimens.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Cement</th>
<th>Apical section</th>
<th>Medial section</th>
<th>Coronal section</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Control</td>
<td>Fatigue</td>
<td>Control</td>
</tr>
<tr>
<td>SEM evaluation (Ranking 1-12)</td>
<td>Panavia 21</td>
<td>5.2 (1.2)</td>
<td>3.1 (2.2)</td>
<td>3.0 (1.3)</td>
</tr>
<tr>
<td></td>
<td>PhosphaCem/C</td>
<td>10.9 (1.6)</td>
<td>9.4 (3.0)</td>
<td>9.4 (2.2)</td>
</tr>
<tr>
<td>Push-out Strength (MPa)</td>
<td>Panavia 21</td>
<td>5.8 (3.3)</td>
<td>6.1 (2.2)</td>
<td>6.0 (1.0)</td>
</tr>
<tr>
<td></td>
<td>PhosphaCem/C</td>
<td>3.5 (1.0)</td>
<td>3.5 (1.6)</td>
<td>3.6 (1.4)</td>
</tr>
</tbody>
</table>

Table 3.3 Multivariate tests for the dependent variables push-out strength and SEM scores, jointly for PhosphaCem/C and Panavia 21, which show only significant differences between the cements (F ratios are exact statistics for Wilks). Condition denotes fatigue or non-fatigue and location denotes apical, medial or coronal.

<table>
<thead>
<tr>
<th>Effect</th>
<th>F</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Subject</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Condition</td>
<td>0.450</td>
<td>0.649</td>
</tr>
<tr>
<td>Cement</td>
<td>42.232</td>
<td>0.000</td>
</tr>
<tr>
<td>Condition * Cement</td>
<td>0.008</td>
<td>0.992</td>
</tr>
<tr>
<td>Location</td>
<td>2.247</td>
<td>0.144</td>
</tr>
<tr>
<td>Location * Condition</td>
<td>0.346</td>
<td>0.840</td>
</tr>
<tr>
<td>Location * Cement</td>
<td>0.136</td>
<td>0.965</td>
</tr>
<tr>
<td>Location * Condition * Cement</td>
<td>0.502</td>
<td>0.735</td>
</tr>
<tr>
<td>Within Subject</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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3.5 Discussion

As with many in vitro studies it is difficult to extrapolate the results directly to the clinical situation, as it is hardly possible to simulate the complex of clinical conditions all at the same time in one in vitro test. The present study simulated, where possible, the clinical situation for cast post and core restorations by the application of a "periodontal ligament" and the action of mastication by fatigue loading [7] in water at 37 °C. The applied load of 40 N was derived from an average of forces that occur clinically for premolars under an angle of 85° with the axial axis. However the height and direction of the load were constant, which is not the case with chewing forces in the clinical situation, where extremely high forces can occur by impact of hard substances in food as well as with parafunctional loads [7,9,23-27].

Standardization of the test specimens is another aspect, which needs careful attention. In the selection of the teeth, only single rooted premolars were selected, but differences in the anatomical perimeter of the teeth could not be avoided.

A limitation of the test set-up is the scoring method of irregularities in the cement layer from the SEM pictures. The different findings, summarized as irregularities, represent different causes, e.g. a void is caused by the application method, while a crack or insufficient adaptation may be caused by shrinkage stresses within the luting agent or fatigue loading. Consequently a general irregularity score does not only represent the influence of fatigue loading. The problem with scoring the mentioned irregularities is that it is not possible to examine the same specimen before and after fatigue loading. Therefore it had to be assumed that, the amount of irregularities as result from the application method and shrinkage stresses, were roughly the same in both the fatigued and non-fatigued specimens. Consequently an increase of the amount of irregularities in the fatigued specimens had to be considered being caused by fatigue loading.

With the present in vitro model we were not able to demonstrate that for cast post and core restorations fatigue loading would affect a non-adhesive cement significantly more than an adhesive resin composite cement; therefore the hypothesis was rejected. The results showed that both cements resisted fatigue loading after one million load cycles. Push-out strengths were not different between cyclically loaded and unloaded sections and SEM inspection did not show an increase in irregularities like cracks in the cement layer or loss of adaptation of the cement to post or dentin. These results were somewhat unexpected as the build-ups were loaded with a force of 40 N under a most unfavorable direction, nearly perpendicular to the axis of the post. Moreover the load was applied directly on the build-up, without the support of a crown with a ferrule preparation [11-13]. In addition the post-to-core length ratio for the cast posts cemented with zinc phosphate cement was at the limit required for non-adhesive cements to offer
acceptable retention [10]. Under these circumstances an effect of fatiguing might be expected in the coronal sections, which were right below the interface between root and build-up. However, because of the exact fit of the cast post, supported by a relatively large surface of the wide oval shape of the perimeter in this part of the root, the stresses were homogeneously distributed and may have stayed well below the mechanical limits of the cements. It has been reported that the situation will be different when prefabricated metal posts are used, as their smaller radius can result into higher local stresses and may exceed the mechanical limits of the phosphate cement [28].

Although none of the cores were separated from the roots after load cycling, unapparent small defects may still have formed at the interface, which could induce leakage. Leakage may then continue all the way down to the root canal filling along the post following the cracks, which were found in all sections. As one million load cycles is estimated to represent a functional life of 5 years [7], the period of time of only 12 days for running this test was too short to reveal possible effects of disintegration of the cement by leakage, which is a long-term process. Apparently this fatigue test is not decisive for evaluating the quality of cemented cast posts for clinical service. Many of the failures observed after years of service [4–6] may well be the result of a disintegrated cement from the combination of loading and long-term leakage [29]. Follow-up studies with the test set-up where the specimens are immersed in a dye solution could provide information about the leakage pattern [30], where leakage starts and how it progresses inside the root canal after load cycling.

Besides the significant difference between the push-out strength of PhosphaCem/C and Panavia 21 TC, these cements also differed in the SEM evaluation of the number of irregularities like air-bubbles in the cement layer between post and intra-radicular dentin and insufficient adaptation of the cement to post or dentin. Although the application method of Panavia 21 TC increased the risk of air entrapment, the SEM results (Table 3.1) and Figure 3.3 show that the use of a Lentulo paste carrier does not guarantee a better adaptation of the cement.

Summarizing, the hypothesis that cast posts placed with adhesive cements resist fatigue loading better than cast posts placed with non-adhesive cements was rejected. However, it should be kept in mind that the experiment is an accelerated test to simulate long-term effects of cyclic mechanical loading during physiological function; the duration of the test was too short to include long-term leakage effects on cement stability. In view of the higher push-out strength and lower scores for irregularities in the cement layer, resin composite luting cements such as Panavia 21 TC are in favor for the cementation of cast posts and cores. Yet the application technique should be improved to diminish incorporation of voids and to ease handling. This may be obtained when the cement is injected into the root canal with a needle syringe [31]. Besides
the importance of the cement type, strict compliance to the recommended procedures [32], an adequate ferrule and the preservation of tooth structure are the key factors in promoting resistance to failure [33-37].

3.6 Conclusions

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

- Under the conditions of this study, fatiguing of cemented cast post and core restorations was not decisive as a single test to evaluate the quality of the cements.
- In this test set-up cast post and cores performed significantly better when cemented with Panavia 21 TC than with PhosphaCem/C.

3.7 References

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