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Evaluation of early resin luting cement damage induced by voids around a circular fiber post in a root canal treated premolar by integrating micro-CT, finite element analysis and fatigue testing

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ABSTRACT

Objective. This study utilizes micro-CT image combined with finite element (FE) analysis and *in vitro* fatigue testing to investigate the mechanical behavior associating with early resin luting cement damage induced by voids around a circular fiber post in a root canal treated premolar.

Methods. Six similar mandibular first premolars with root canal treatment were scanned with high resolution micro-CT before and after fatigue testing. Micro-CT images of all teeth were processed to identify various materials (dentin, luting cement and void) to evaluate the volume/position of the void in each reconstructed tooth root canal model. Six corresponding mesh models from CT images were generated to perform FE simulations under receiving oblique concentrated loads (200 N) to evaluate the luting cement layer mechanical behavior. All teeth were subjected to the fatigue test with 240,000 load cycles simulating chewing for one year to compare results with those in FE simulations.

Results. The result showed that most voids occurred adjacent to the apical third of the fiber post. Voids induced the fiber post to pull out, creating a stress concentration at the void boundary. Fatigue life in the experimental testing was found decreased with the stress value/micro-motion increasing in FE analysis.

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Significance. This study establishes that micro-CT, FE simulation and fatigue testing can be integrated to understand the early de-bonding mechanism at the luting cement layer in a root canal treated premolar, suggesting that attention must be paid to resin luting cement dissolving/debonding easier when voids occur in the apical and peri-apical areas of fiber posts.

1. Introduction

Fiber posts have been used to restore endodontically treated teeth with insufficient coronal tooth structure to retain a core for the definitive restoration [1,2]. Clinical studies have demonstrated high success rates without the occurrence of root fractures owing to fiber posts that have a similar elastic modulus to that of dentin reducing stress transmission to the root. Possible root fractures are thus avoided [1,3–6]. However, the most frequent cause of failure in teeth reconstructed with fiber posts involve post debonding, which can occur at the post-cement (resin luting material) interface and/or between the cement and root dentin [7–9].

As a consequence of the cement application technique and polymerization shrinkage, a number of gaps, voids are observed within the luting material interface [10–13]. The formation of voids within the resin bulk could be incorporated, inducing stress concentration which induces micro leakage and increases the post tendency to debond [1,11]. A study using micro-CT and finite element (FE) submodeling techniques indicated that attention must be paid to resin luting material initial failure/debonding when large voids might be generated with stress concentration during the luting procedures [4]. Although clinical studies have reported that debonding resulting from insufficient bond strength is the most common cause of failure for fiber post restorations [1,14,15]. However, a direct relationship between the post region with certain amounts of voids inside or around the resin cements inducing push out bonding strength was not observed [1]. Information on the micro-mechanical mechanisms related to voids within the resin luting material (cement) associated with stress concentration at the adhesive layer is therefore required to understand and decrease the risk for endodontically treated teeth.

Visual control or using conventional methods (SEM, X-ray) to detect voids within the cement is not possible [16,17]. High-resolution micro-computed tomography (micro-CT) has been found to be a non-destructive, rapid, and powerful tool to evaluate the resin matrix. CT image allows for examination of the adhesive layer structure, mechanical properties and voids detection, reconstruction and volumetric evaluation around post materials [1,18–23].

This study utilizes micro-CT image processing with finite element (FE) analysis and *in-vitro* fatigue testing to investigate the mechanical behavior of a root canal treated premolar associated with voids stress behavior at the luting material (cement) layer to understand the early luting cement damage distribution.

2. Materials and methods

2.1. *Endodontically treated premolar preparation & micro-CT analysis*

Six freshly extracted intact mandibular first premolars with single root of similar sizes and shapes were selected using root length and crown dimensions after measuring the buccolingual and mesiodistal widths at the cemento-enamel junction (CEJ) in millimeters. A maximum deviation of 20% from the mean was allowed. The artificial periodontal ligament (PDL) of each premolar was replicated with approximately 0.2 mm thickness around the tooth from 1.0 mm below the CEJ to the root using silicon (Gingifast Elastic, Zhermack SpA, Badia Polesine, Italy) and embedded into an epoxy resin block.

Tooth canals were prepared to apical size 30 (F3) with ProTaper nickel titanium rotary instruments (Dentsply-Maillefer, Ballaigues, Switzerland) and obturated with thermoplasticized, injectable gutta-percha (Gutta percha points #30, DENTSPLY International Inc., New York, USA) in about 5 mm lengths with a resin sealer (AH-26, DeTrey, Zurich, Switzerland) using the vertical condensation technique. A self-etching bonding agent with a dual-cured composite resin material (Dentsply Core-X flow, DENTSPLY Caulk, Milford, DE, USA) was placed into the post space using an intraoral tip, with the post then inserted and the luting material light-cured for 40 s. The post-space depth preparation was 13 mm from the CEJ and the fiber post with 1.35 mm (X-Post Radix Fiber Post No. 1, Dentsply Maillefer, Ballaigues, Switzerland) was inserted into the root canal due to the average canal width of all samples above the root tip was 1.35 mm. The fiber post was kept in position using a polymerization lamp with the luting material polymerized for 60 s.

Coronal tooth structure design was standardized between samples. The ferrule was designed 2 mm in height and 1 mm in width. The height of the core (Dentsply Core-X flow, DENTSPLY Caulk, Milford, DE, USA) is 2 mm. Custom made 6 mm height crown with Co–Cr alloy and 2 mm height composite core (Core-x-flow, Dentsply Maillefer, Ballaigues, Switzerland) were then luted using RelyX U200 cement (3M ESPE, Seefeld, Germany) on each tooth.

All teeth were scanned with high resolution micro-CT scanner (Skyscan 1272, Aartselaar, Belgium) with a voxel dimension of 9 μm, 111 μA, 90 kV (Cu. 0.11 mm filter), a 0.4° rotation step, a 0.282158 reconstruction duration per slice (seconds) and total reconstruction time (723 slices sample No. 5) in 204 s. All micro-CT image files were processed to identify the contours of different materials (crown, dentin, luting material and void) and those contours were extracted and converted

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