

CRACK INITIATION AND PROPAGATION IN A POST-AND-CORE RESTORED MAXILLARY FIRST PREMOLAR: A 2D ANALYSIS

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Abstract. *The primary purpose of a post in post-and-core restoration systems is to retain the core in an endodontically treated tooth that has lost its coronal structure extensively. The aim of the present study is to compare the crack initiation and propagation conditions in an endodontically treated maxillary first premolar tooth restored by post-and-core system with one and two posts. The study is done using the finite element method employing the strategy named mesh fragmentation technique. The results show that a tooth restored with a single post can withstand higher loads before the first fracture occurs. In the case of the two-post system a catastrophic fracture occurred on the vestibular root of the tooth at a relatively low load of 365 N even when no adhesive bond failure was permitted on the material interfaces. The results suggest that the use of multiple posts for tooth restoration can lead to root weakening.*

Keywords: *Post-and-core restoration. Interface finite elements. Multiple posts. Tooth fracture. Adhesive bond failure.*

1. INTRODUCTION

The goal of endodontics and restorative dentistry is to retain the natural teeth with maximal function and pleasing aesthetics (Rosenstiel, Land, and Fujimoto, 1995). Endodontic treatment determines the loss of dental tissue with the consequent weakening of the tooth, and tooth fractures are common causes of tooth loss after endodontic treatment (Faria *et al.*, 2011; Ferrari, 2008). The clinical longevity of endodontically treated posterior teeth is significantly improved with coronal coverage, and a post-and-core restoration system is often necessary to retain the prosthetic crown. However, the preparation of a post space may significantly weaken the root, and affect the integrity of the tooth. An artificial post adhesively cemented into the root canal transmitting the masticatory loads from the coronal structure directly to dentin is another factor that can increase the chances of root fracture. Common complications leading to fractures in the restored teeth are flaws or cracks induced in dentin, and failure of adhesive bonds between the restorative components. Nevertheless, the posts are indicated for premolars to provide retention and resistance for the core material, and corono-radicular stabilization (Milewsky and Chojnacka-Brozek, 2016; McComb, 2008; Robbins, 1990).

With the improvement of restorative materials, placing multiple posts for core retention is seldom needed, however, two-post restorative systems are still found in clinical practice (Kaufmann, 2007). Little is known about the biomechanical effect that the placement of a second post might have on the tooth, and the aim of the present study is to compare crack initiation and propagation conditions in an endodontically treated maxillary first premolar restored by post-and-core system with one and two posts.

The study is done using finite element method (FEM) employing the mesh fragmentation technique proposed by Sánchez *et al.* (2014), Manzoli *et al.* (2012, 2013, 2016), and Rodrigues *et al.* (2016). This technique is based on insertion of special finite elements between the regular elements of an original mesh. The original mesh is reassembled in such a manner that the regular elements are first transformed into independent elements by duplicating the shared nodes, and then a very small reduction is imposed on each element, creating narrow spaces between the elements. After that, the gap between the two neighbouring modified elements is filled by a pair of three-node triangular finite elements with high aspect ratio. Manzoli *et al.* (2012) refer to these degenerated elements as “interface solid elements” (ISE) or, for the sake of simplicity, “interface elements” (IE).

Two constitutive damage models are adopted to represent the behaviour of the materials involved in the proposed technique. For the conventional IE of the fragmented mesh, a tension damage model is used. For the IE used between two different materials (IE used as a contact element), two combined damage models are applied: J2 and a tension damage model. A detailed formulation of the ISE and the damage models can be found in Manzoli *et al.* (2012), and Manzoli *et al.* (2016).

In order to spare computational resources and obtain guidelines for testing of the complete models, two-dimensional (2D) models of the restored tooth were used in this study.

1.1. Constitutive damage model

The damage models are formulated in terms of two scalar damage variables, $d \in [0,1]$ and $d^J \in [0,1]$, and two appropriated damage criterions, for the J2 and a tension damage models, respectively. In this way, as shown in Eq. (1), during the analysis the current stress tensor for each IE is calculated as:

$$\sigma = \begin{cases} \frac{(1-d^J)\bar{S} + \bar{\sigma}_V}{\bar{\sigma}} & \text{if } \bar{\sigma}_{nn} \leq 0 \\ [(1-d^J)\bar{S} + \bar{\sigma}_V](1-d) & \text{if } \bar{\sigma}_{nn} < 0 \end{cases} \quad (1)$$

where $\bar{\sigma}$ is the effective stress tensor, \bar{S} and $\bar{\sigma}_V$ are the deviatoric and the volumetric components of the effective stress tensor and $\bar{\sigma}_{nn}$ is the component of tension stress normal to the base of the finite element with high aspect ratio. Note that for the conventional IE of the fragmented mesh only the tension damage model can be used, assuming that $d^J = 0$. The damage variable, d , is applied only in tension condition, ensuring the non-overlapping in compression. More details about the formulation can be found in Manzoli *et. al* (2012) and Fedotova *et. al* (2017).

2. MATERIALS AND METHODS

Geometrical models of the maxillary first premolar used for the present study were adapted from a previously constructed healthy tooth model (Munari, 2016), which was based on computed tomography images. The geometry of a healthy tooth with two roots was modified in CAD software Rhinoceros 5 (Robert McNeel & Associates, Seattle, USA) to include two types of post-and-core restoration systems: a system with one post (1PS), and a system with two posts (2PS). In case of 1PS, a 15 mm long tapered glass fibre post with the coronal diameter of 1.25 mm, and the apical diameter of 0.92 mm was placed into the palatal root of the tooth so that the post would descend 2/3 of the root canal. A 0.1 mm thin layer of cement was modelled around the post. A complete ceramic crown substituted the enamel of the healthy tooth model, and a composite resin core restoration partially replaced the dentin. The vestibular canal entrance was filled with gutta-percha, the periodontal ligament (PDL) was preserved, and the supporting bone was modelled without differentiation between cortical and trabecular bone. In the 2PS instead of gutta-percha, a 12 mm long post (coronal diameter 1.25 mm, apical diameter 0.97 mm) was placed, so that it would take 1/2 of the length of the vestibular root canal. Vertical cross-sections of each model were then used as a 2D simplification of the problem (Fig. (1a) and (1b)).

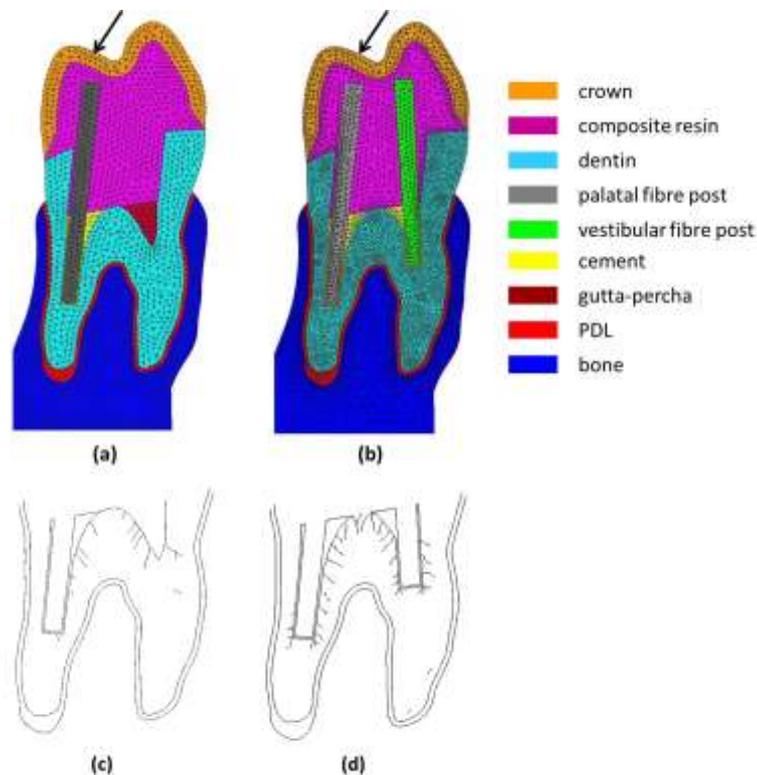


Figure 1.(a) 2D model with one-post-and-core restoration and the applied load indicated by an arrow; (b) 2D model with two-posts-and-core restoration and the applied load indicated by an arrow; (c)flaws induced in dentin (short lines around root canals) in 1PS; (d) flaws induced in dentin (short lines around root canals) in 2PS

After pre-processing of the models in GID (CIMNE, Barcelona, Spain) software, interface elements were introduced into the meshes through the mesh fragmentation technique. Also small cracks were introduced into the models in order to simulate the pre-existing flaws in dentin; Fig. (1c) and (1d) show the localization of these cracks. Then a custom-made script was used to run the finite element analysis in Matlab (The MathWorks, Natick, USA) environment. Two cases were tested for each model: a case when no adhesive bond failure was permitted between the materials and another where adhesive bond failure was possible on the dentin/cement, cement/post, core/dentin, and cement/core interfaces. One additional case was tested for the 2PS: when the adhesive bond failure was possible only on dentin/cement interface. The models were tested with a simulation of the occlusal forces: an oblique load up to 1000 N was gradually applied on the palatal surface of the crown, as shown on Fig. (1a) and (1b). GID software was used for post-processing of the results. The analysis was performed for crack formation and propagation loads.

Table (1) summarizes the material properties used in this study in accordance with Mattos *et al.* (2012), Chung *et al.* (2004), Lanza *et al.* (2005), Saskalauskaite *et al.* (2008), de Jager *et al.* (2004), Friedman *et al.* (1977), Kinney *et al.* (1999), Pietrzak *et al.* (2002), Baker *et al.* (2010), Reilly *et al.* (1974), Misch *et al.* (1999), van Staden *et al.* (2006), and Ferrari *et al.* (2010). In addition to the data presented in Tab. (1), the values of ultimate tensile strength (UTS) for the cement/dentin and core/dentin interfaces are 16 and 18 MPa, respectively, in accordance with Phrukkanon, Burrow and Tyas (1999) and the data provided by core resin manufacturer.

Table 1. Material properties used in the model

Material	Elastic modulus (GPa)	Poisson's ratio
Composite resin core	10.49	0.30
Glass fibre post	40	0.34
Resin cement	5.5	0.24
Gutta-percha	0.14	0.40
Dentin	18.45	0.29
Ceramic crown	82.3	0.22
Periodontal ligament (PDL)	0.31 e-04	0.45
Cortical bone	11.17	0.45
Composite resin/Dentin interface	4.4	0.24

3. RESULTS

In case of 1PS, the initiation of cracks was observed at the load of 500 N when no bond failure was permitted and at 350 N when the adhesive bond failure was possible. In both cases, the cracks did not propagate significantly, and a catastrophic failure of the tooth did not occur even when the maximal load value was reached.

The following figures show the results of the numerical testing for crack formation in the 2PS model. The load reached is shown for each case. Poorly visible cracks are highlighted on the figures.

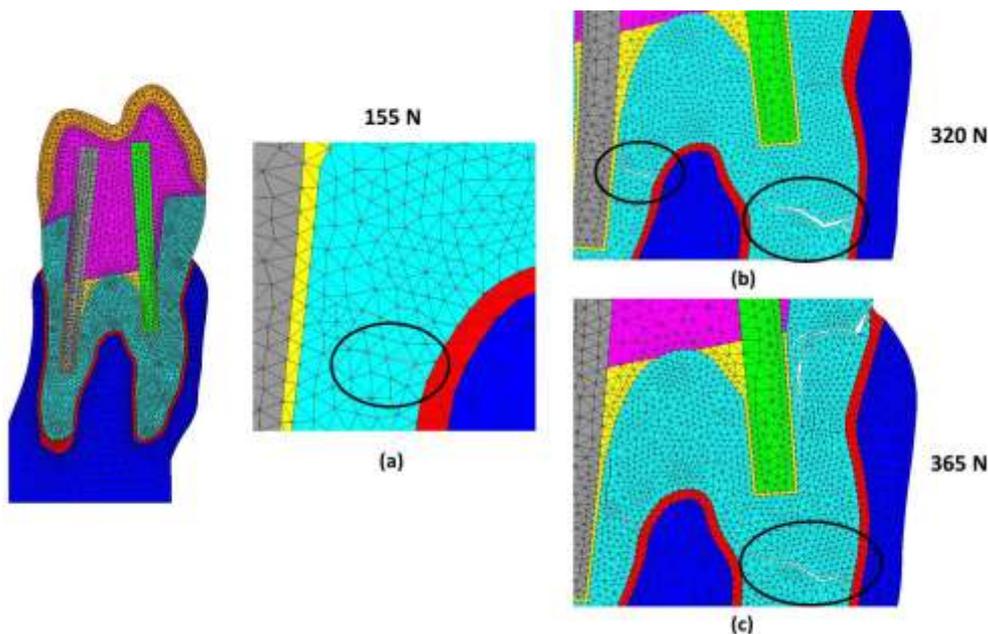


Figure 2. Crack initiation and propagation in 2PS model when no adhesive bond failure is permitted on the interfaces. (a) crack initiation; (b) crack propagation; (c) tooth failure

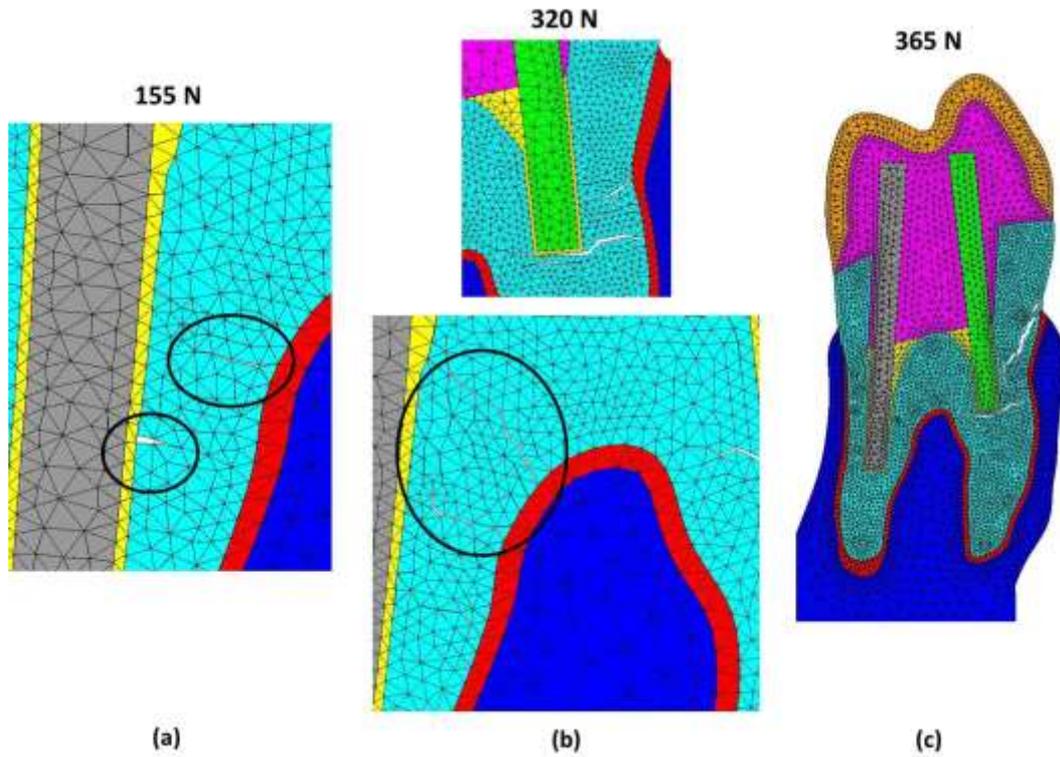


Figure 3. Crack initiation and propagation in 2PS model when the adhesive bond failure is possible on the dentin/cement interface. (a) crack initiation; (b) crack propagation; (c) tooth failure

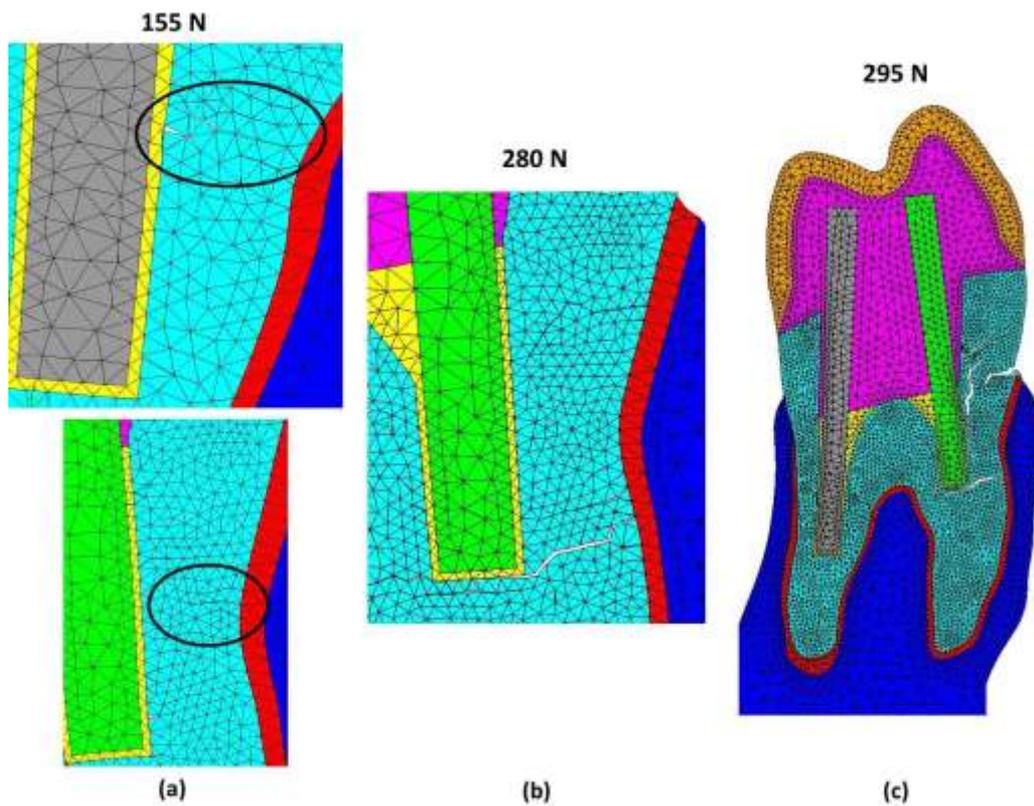


Figure 4. Crack initiation and propagation in 2PS model when the adhesive bond failure is possible on the dentin/cement, cement/post, core dentin, and cement/core interface. (a) crack initiation; (b) crack propagation; (c) tooth failure

4. DISCUSSION

Endodontic treatment is a common procedure, and post placement is required to retain the restorative core when there is insufficient remaining coronal structure. Fracture of the post-and-core restored teeth is a significant problem in dentistry, as the preparation of post space jeopardizes the integrity of the remaining dentin. Sometimes multiple posts are indicated for restoration of posterior teeth; however, some authors argue that with the modernization of the restorative materials, placement of multiple posts is no longer beneficial for the longevity of the restored tooth (Kaufmann, 2008).

The results of this study indeed demonstrate that the tooth restored with 2PS is subjected to fractures at the loads much lower than the tooth restored with 1PS. A horizontal/oblique fracture of dentin at the cervical level on the vestibular side of the 2PS restored tooth occurred at the load of 365 N in cases without adhesive bond failure or with the bond failure only on dentin/cement interface, whereas the tooth with bond failures on multiple interfaces fractured catastrophically at the load of 295 N. The initial fractures in 2PS appeared when the load reached 155 N, regardless the bond failure type. The importance of good adhesion between cement and dentin has been previously demonstrated (de Santis et al., 2000), as the cement bulk is expected to preserve the dentin from dangerous stress accumulation. This mechanism is apparent for 1PS, when the model with no adhesive bond failure resisted the fracture until the load of 500 N was reached, and the model with bond failure on multiple interfaces demonstrated the crack initiation when the load reached 350 N (note that these loads are higher than previously demonstrated by Fedotova *et al.* (2017), as the UTS values adopted in the present work are higher). In case of 2PS, however, the placement of the second post appears to play a more important role in the tooth fracture than the adhesive bond failure. A rapid tooth failure in case of 2PS is most likely attributed to the increased number of flaws induced in dentin.

Despite the formation of the cracks also in the palatal root, the tooth failure in case of 2PS occurs on the vestibular side. This is in agreement with the data for a healthy tooth demonstrated by Munari (2016) – author has shown that when oblique loads are applied on the tooth, the higher stress concentrations appear at the cervical region and in the alveolar bone insertion.

5. CONCLUSIONS

Little information is available on the biomechanical effects of multiple post placement in post-and-core restoration systems. The findings of the present study suggest that two-post restored tooth is significantly weakened and fractures at lower loads if compared to one-post-and-core restored, therefore the necessity of multiple post placement in posterior tooth restoration shall be carefully revised.

6. REFERENCES

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