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Finite element analysis of devitalized teeth

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Abstract

Elimination of a large part of dental tissues during root canal treatment affects the mechanical behavior of devitalized teeth. The present study addresses how much dentin removal affects changes in mechanical behaviors of the intact tooth and tooth with root canal treatment. In order to estimate the tooth weakening, we performed ан experimental assessment of critical force and numerical Finite Element Method (FEM) analysis with the intention to analyze stresses distributions. The results showed that root canal treatment had significant influence on stress distributions. By analysis of retrieved results, it is concluded that this study is an efficient framework which could be applied in a number of different cases, so that practitioners could analyze and prepare the treatment with more certainty.

Keywords: Devitalized teeth, Finite Element Method

1. Introduction

It is well known that every tooth restoration leads to loosing of mechanical performances, thus causing the unexpected failure. As there is a large number of studies, there are many factors influencing tooth fracture resistance. Elimination of a large part of dental tissue at some point in endodontic treatment is needed, which surely affects the mechanical behavior of these teeth. So far, investigators mostly used destructive methods which are based on experimental loading until fracture point. However, destructive methods cannot provide important data about stress distribution on tooth structures. As a solution, recently, Finite Element Method (FEM), which gives the biomechanical analysis, is applied. FEM shows high-stress concentration points and structure-stress distribution in dental tissues, as well as in the dental restorations used in the treatment. First FEM analyses were based on basic tooth models (Asmussen and Peutzfeldt 2008) or models of average teeth proportions (Ren et al., 2010). However, since the accuracy of FEM analysis depends on accurate input information, the most reliable data are received from the real teeth CT scans further used to generate the FEM model (Soares et al., 2008). Furthermore, although this is rarely practiced, the best FEM studies include experimental verification of the obtained results (Soares et al., 2008). Thus, the scanned teeth are subjected to the in vitro experiment, with the same setting as those in FEM analysis. The aim of this study is to apply numerical FEM analysis and experimental validation of the intact tooth and tooth with root canal treatment with two surface cavity.

2. Materials and methods

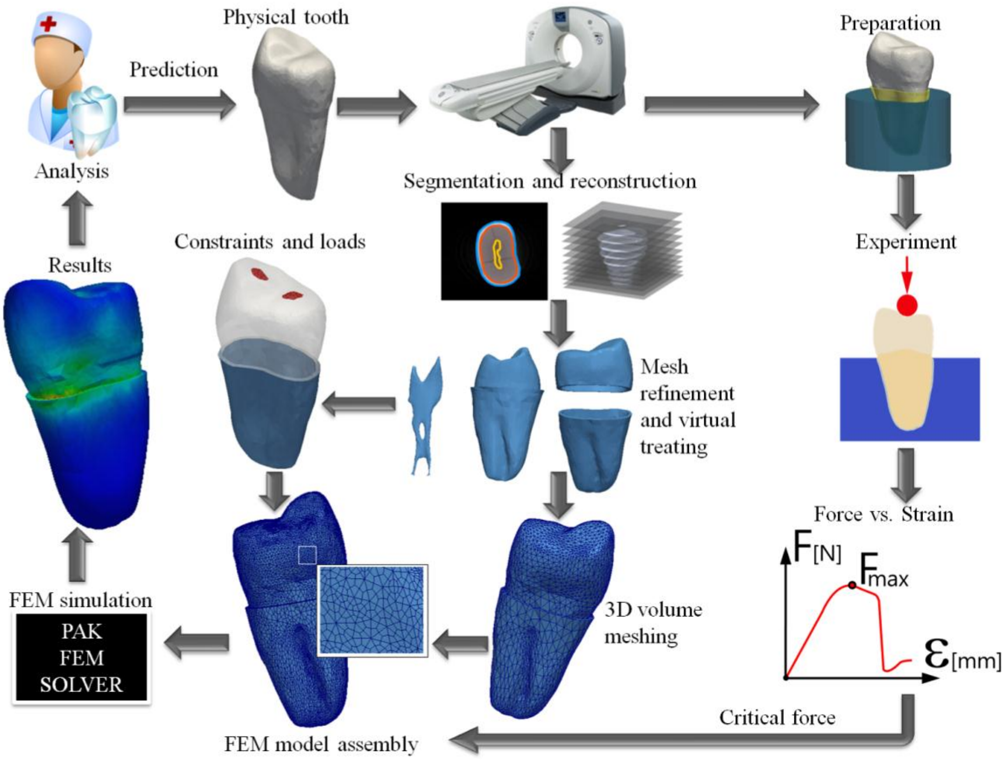


Fig. 1. Schematic overview.

Two intact upper second premolars were used in this study (Approved by the Ethics Committee of the School of Dentistry, University of Belgrade). X-rays of the teeth were made to confirm the similarity of the morphology. One tooth underwent an in vitro root canal procedure and the other remained intact. A mesio-occlusal (MO) Class II preparation was performed with root canal enlargement. The canal was filled with cold gutta-percha. The tooth was restored with composite resin. Both teeth were scanned on CT (Siemens Somatom Sensation 16). After imaging acquisition, the fracture test was performed on these teeth. The compression test was completed on the computerized measuring system for material testing ZWICK ROELL Z 100 Zwick GmbH & Co. KG. Compressive loading was applied with the use of a steel bar with a round tip, placed in the center of the tooth, with the test speed 5 mm/min. The precision of force measuring was 1N, and the precision of the compressive strain was more than 0,001 mm. The process of teeth segmentation and generation, and generation of a surface mesh from CT dicom data were performed in Mimics 10.01 (Materialise, Leuven, Belgium). In order to prepare the mesh for performing FEA, refinement and assembly of every part of the models were done in Gemagic Studio 10 (Geomagic GmbH, Stuttgart, Germany). In model 1 (intact tooth), four separate parts were modeled: enamel, dentin, pulp chamber, periodontal ligament (Fig. 2).

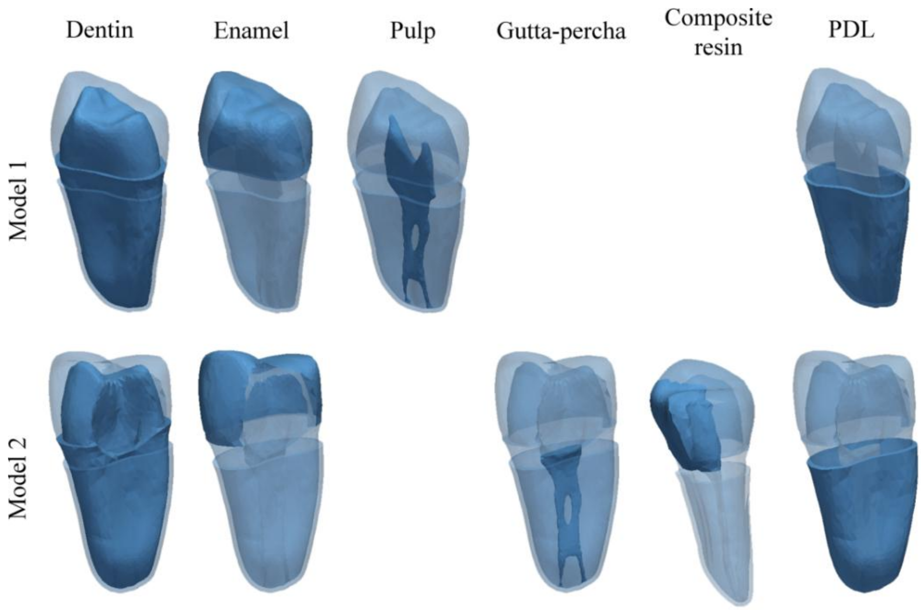


Fig. 2. Geometry of two generated FEM models.

A 250-μm-thick shell surrounding the root, represents a periodontal ligament (PDL). The bone surrounding the tooth was not modeled but the external nodes on the PDL were strangulated. Model 2 was generated from the scans of the treated tooth and included cavity preparation MO Class II and root canal enlargement. The cavity preparation was restored with composite resin and the root canals were filled with gutta-percha. For every part of tooth saved as separate STL file, a 3D volume meshing was carried out using TetGen software (Hang Si, WIAS, Berlin, Germany). After that, four-nodal tetrahedral elements (TET4) were divided into hexahedral and appropriate material properties were assigned in accordance with Table 1.

Material	*Young Modulus [Mpa] (Ref.)*	*Poison ratio (Ref.)*
Pulp	6.8(Shen et al., 2009)	0.45(Shen et al., 2009)
Dentin	$18.6*10^3$(Magne 2010)	0.31(Magne 2010)
Enamel	$84.10*10^3$(Magne 2010)	0.3(Magne 2010)
PDL	0.68(Ruse 2008)	0.45(Magne 2010)
Composite resin	$16.6*10^3$(Soares et al., 2008)	0.24(Soares et al., 2008)
Gutta-pecha	70(Ruse 2008)	0.40(Magne 2010)

Table 1. Mechanical properties of dental structures and restorative materials.

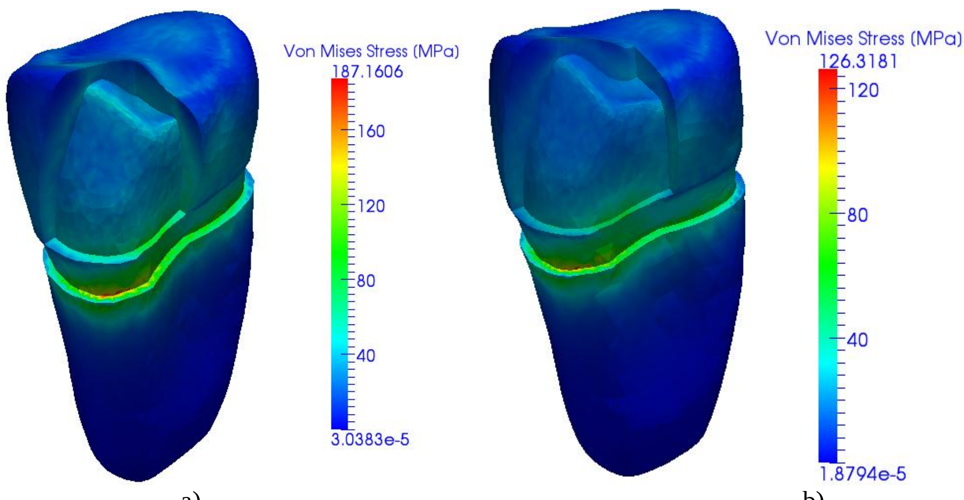
To compare stress distribution between the 2 teeth models, an experimentally determined critical breaking force gained for the treated tooth (model 2) was applied to both models. Furthermore, model 1 was also loaded with the critical breaking force obtained for the intact tooth (model 1). The load was applied on the buccal and lingual cups simultaneously to get the resulting force parallel to the tooth axial axis. Regarding to boundary conditions, displacements of nodes on the outer surface of the PDL were constrained in all three directions. FEA analysis was performed by using inhouse PAK software (Filipovic 2008; Kojic et al., 2008). For all three cases, performed analyses were static linear and all materials were assumed to be homogenous, isotropic and linear. The number of nodes, elements and applied forces for each of generated model are shown in Table 2.

Tooth model	Number of nodes	Number of elements	Applied force [N]
1	141907	124768	1025,710
2	136299	119492	710

Table 2 Number of nodes, elements and applied forces for two generated models.

3. Results

Experiment showed that the critical force for the intact tooth (model 1) was 1025 N at a compressive strain of 0.9 mm; and for the treated tooth (model 2), the critical force was 710 N at a compressive strain of 1.02 mm. Also, both teeth were fractured in the buccal cervical region. Following the conditions of the experiment, two models in the FEA simulation were loaded axially with a force of 710N in order to make comparison of changes in stress distribution. The intact tooth was also loaded with 1025N in order to better understand process of experimentally fractured teeth.



a) b)

Fig. 3. Von Mises tresses of Model 1; a) under force of 1025 N and b) 710N.

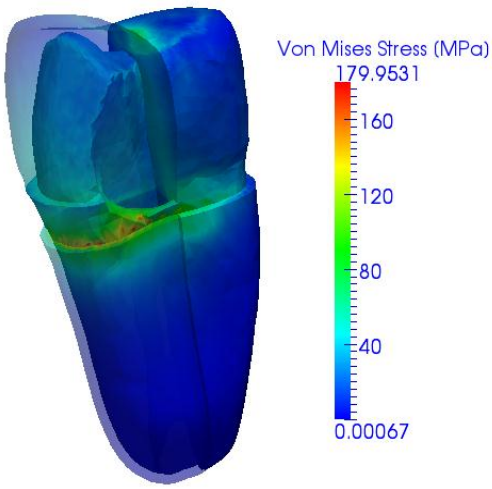


Fig. 4. Von Mises tresses of Model 2 under force of 710N.

Figures 3 and 4 depict the stress distribution of each model, which concurs with experiment's results. The largest values of the von Misses stress equivalents indicate locations with the highest risk of fracture. The riskiest location in both samples is along the cervical line. The intact model (Model 1) (Fig. 3) showed high stress concentration in the pulp chamber walls, especially the occlusal surfaces and pulp floor, but the highest stress was along the buccal cervical line. Model 2 (tooth restored with composite resin) (Fig. 4) also showed high stress in the buccal cervical region, as well as in the pulp chamber walls, but also in the internal part of the composite resin and gingival junction of the filling and dentin.

4. Discussion

In this study we presented a robust framework for numerical FEM analysis and experimental study of the influence of dental restoration and root canal treatment (root canal enlargement) on tooth fracture resistance (Fig. 1.). The FEA models were generated based on two real teeth CT data. Experimentally estimated loads were applied on an intact tooth (model 1) and on the mechanically weakest tooth (model 2). We performed numerical FEM analysis with credible input information, in order to receive clear insight into the influence of the geometry of each tooth part on stress distribution. Taking this into account, potential inaccuracies which could arise from the use of simplified models in FEA and experimentally unconfirmed results were avoided.

5. Conclusions

According to our results, endodontically treated teeth with two-surface cavity are less resistant to high occlusal load as a result of the altered stress distribution. The principal aim of this study was to propose a framework which could be applied in a number of different cases, so that practitioners could analyze and prepare the treatment withmore certainty. In order to avoid limits of stress analysis, our future research will be directed to incorporating fatigue and fracture theory which could give us more information about complex process of tooth weakening.

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Извод

Анализа девитализованих зуба методом коначних елемената

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Резиме

Уклањање одређене количине дентина приликом ендодонтске терапије утиче на механичке особине девитализованих зуба. Циљ ове студије је био да се одреди у којој мери одстрањивање дентина током процеса девитализације утиче на дистрибуцију сила и у којој мери је, са биомеханичког аспекта, девитализован зуб ослабљен. Како бисмо проценили слабљење зуба, експериментално је одређена критична сила и извршена нумеричка симулација применом методе коначних елемената (МКЕ) у циљу одређивања дистрибуције напона. Резултати су показали да ширење канала има значајан утицај на расподеле напона и да је зуб значајно механички ослабљен након девитализације. Анализом добијених резултата, закључено је да приказана студија представља поуздан алат који, уколико се примени на различитим случајевима, може бити од изузетног значаја у анализи и процени потенцијалног ризика за лом зуба.

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