

Biomechanical properties of mandibular first molar with truss and conventional access cavities: A finite element analysis

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ABSTRACT

Aim: The aim of this study was to compare the biomechanical strength properties of the mandibular first molar with truss and conventional endodontic access cavities using the finite element method.

Methods: Two finite element analysis (FEA) models of a mandibular first molar were designed and constructed with truss endodontic cavity (TREC) and Conventional endodontic cavity (CEC). Each model was subjected to three different force loads directed at the occlusal surface. The stress distribution patterns and the maximum von Mises (VM) stresses were calculated and compared. FEM software ANSYS was used for evaluation.

Results: The peak VM stress on both models was at the site of the force load. The occlusal stresses were spread in an approximate actinomorphic pattern from where the force was loaded, and the stress was much higher when the force load was close to the access cavity margin. The peak root VM stresses on the root-filled teeth occurred at the apex and were significantly higher than that on the intact tooth, which appeared on the pericervical dentin. The area of pericervical dentin experiencing high VM stress increased as the cavity size increased and became concentrated in the area between the filling materials and the dentin.

Conclusion: Under all loading conditions, the TREC model showed low-stress concentration compared to the CEC model. With enlargement of the access cavity, the stress on the pericervical dentin increased significantly.

Keywords: Endodontic cavity, finite element analysis, minimally invasive, stress

INTRODUCTION

A predictable treatment outcome and successful long-term retention of the root canal-treated teeth are the primary goals of modern endodontics.^[1] However, the longevity of endodontically treated teeth (ETT) depends on various factors. Of these, structural factors and microbial infections are of major concern.

Among the permanent teeth, the mandibular first molar erupts as early as 6 years of age.

Hence, it is most prone to caries and very often requires endodontic treatment.^[2,3] The first step in endodontic treatment is access cavity preparation. Gaining access to the root canal space is one of the most important aspects of endodontic treatment as it influences the ultimate prognosis.^[3,4] This is usually achieved by a conventional endodontic cavity (CEC) preparation which uncovers the complete roof of the pulp chamber.

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Currently, the crucial role played by the remaining dentin structure for maximizing the longevity of ETT has come to the fore.^[5] The basic focus now is to retain more of the coronal and radicular tooth structure without compromising on the endodontic treatment procedures. This has given rise to the concept of minimally invasive endodontics.^[6] Truss endodontic cavity (TREC) preparation is an orifice-directed access preparation. It is a recent approach that aims to preserve most of the tooth structure. Several methods may be employed to analyze stress in dental structures such as strain gauges, holography, and finite element analysis (FEA). FEA is a computerized method for predicting the behavior of products that are subjected to a variety of physical stresses and vibrations, as well as fatigue and motion. It converts real objects into many finite elements in the form of small cubes.^[7] It is a useful tool to investigate complex systems and has been widely applied to endodontic stress analyses. Knowledge of the stress distribution is important for understanding fatigue development.^[7,8]

So far, there are not many FEA studies comparing the effects of CEC and TREC on fracture resistance of ETT. Therefore, the aim of this study was to compare the weakening effects of CEC and TREC designs in the mandibular first molar using FEA.

MATERIALS AND METHODS

In the present study, the molar tooth under investigation was scanned using a computed tomography (CT) scan and the three-dimensional (3D) slice data which was 0.1 mm apart was converted into a 3D image using DICOM software. The DICOM data were fed into the 3D Slicer to convert the slice data into a 3D model using filters in the 3D Slicer software. The bone geometry was exported as a STereoLithography (STL) format which is a computer-aided design neutral format commonly used for 3D printing. The geometry in STL format was read into the Blender software which converts the raw data in STL format into smooth geometry which was then exported to FEM Software. The smooth geometry from the Blender was then exported to FEM software ANSYS where the FEA was carried out on the tooth geometry. Commercially available FEA tool ANSYS was used for this study. It has the ability to analyze a wide range of problems from a simple linear, static analysis to a complex nonlinear, and transient dynamic analysis. In this study, 3D tetrahedral elements were used to generate the tooth finite element model. Von Mises (VM) equivalent stresses in enamel, dentin, gutta-percha, and composite resin were determined.

Description of the model

In the present analysis, the physical model of the entire tooth was considered. The filters were used in such a manner to get

the mineral material of the tooth structure. Three different material properties were assigned to the tooth structure for dentin, enamel, and pulp for the intact tooth. The filler material used for obturation was gutta-percha. The material properties of the structures are defined in Table 1. To simplify the development of the FEA model, the following assumptions with material properties were considered in the analysis.

- The cement material between the gutta-percha and dentin was simplified due to the negligible thickness of the cement material and the cement was considered to be part of dentin
- The cementum covering the surface of the root was also simplified to be dentin material
- Flowable and hybrid composite resin was used for the access filling
- The root was considered to be rigid while applying the boundary conditions since the effect of load on the dentin and enamel was only considered for analysis [Table 1]
- Three different loading conditions were considered for analysis.

Cavity design

Incorporating the structure of enamel and dentin, the model of the tooth was designed. Two 3D models were generated: the TREC model and the CEC model. A traditional access opening in the CEC model was designed so that the entire roof of the pulp chamber was removed, and a direct access was achieved from the access opening to the coronal part of the canal. The truss access cavity was designed to prepare two separate cavities to negotiate the mesial and distal canals preserving the central part of the roof of the pulp chamber. The outline was determined with a line drawn from the center of the root canal furcation level landmarks through the central canal orifice in the region of the floor of the pulp chamber and this was extended onto the occlusal surface.

Loading processes

The loading processes were as follows:

Table 1: Material properties

Material	Elastic modulus (E: GPa)	Poisson ratio (μ)
Enamel	84.1	0.33
Dentin	18.6	0.31
Pulp	0.002	0.45
Cortical bone	13.7	0.3
Cancellous bone	1.37	0.3
Periodontal ligament	0.0689	0.45
Gutta-percha	0.00069	0.45
Composite resin	12	0.3
Flowable composite resin	5.1	0.27
Cement layer	6	0.3

A vertical occlusal force was applied on the models at a constant intensity of 250 N at the central groove area to simulate a normal centric occlusion.^[9]

A total force of 800 N was applied to five different points as the pressure load to the occlusal surface to simulate the maximum mastication force.^[10]

A total force of 225 N was applied to the buccal plane of the buccal cusp at 45° to the longitudinal axis of the tooth, at 2 points, to mimic lateral mandibular excursions.^[11]

RESULTS

Under the different force loads, the distributions of VM stress on the TREC model were much lower than in the CEC model [Graph 1]. Under the vertical force of 250N, the peak VM stress in both models occurred at the central groove. For the TREC model, the peak stress was 44 MPa while that of CEC was higher (51 MPa). Under vertical load of 800 N, the peak VM stresses on the TREC and CEC models were 207 MPa and 222 MPa, respectively. For the lateral load of 225N, the TREC model had the least VM stress (66MPa) while CEC had higher VM stress (74 MPa).

DISCUSSION

Extensive caries and access cavity preparation are two of the major contributors for increasing fracture of ETT. The amount of dentin lost varies according to the design employed for access cavity preparation. Cuspal deflection which normally occurs under occlusal stresses is further increased once an access is prepared. CEC designs have been reported to increase the fracture susceptibility of ETT.^[12] Since the focus is on complete deroofting of the pulp chamber and obtaining straight-line access to the root canals, these designs sacrifice more strategic dentin present in the pericervical region. Whenever the access preparation extends to involve a greater

portion of the occlusal surface, there is a proportional rise in the stresses accumulating at the neck of the tooth. This has been suggested by recent *in vitro* and FEA-based studies.^[13]

TREC preserves both the marginal ridges and a portion of the roof of the pulp chamber which provides a continuous chain of strength. It is believed that strategically important dentin is retained.^[14]

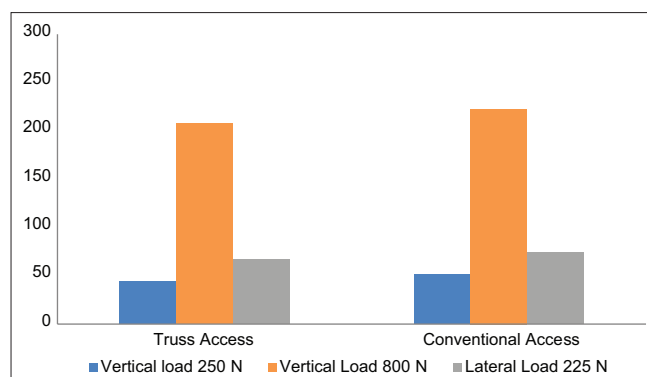
The present study was performed on mandibular first molar as it poses a high risk for fracture after root canal therapy. The probable reasons are that among all posterior teeth this tooth frequently requires endodontic treatment and its wide occlusal surface bears very high biting stresses.

FEA was the methodology employed to create standardized conditions. A major advantage with this method is that since it is virtual the tooth can be stressed multiple times without causing damage and the areas where stress concentrates can be clearly delineated.^[12] For purpose of standardization, the models were created in such a way that while maintaining similar morphology for both samples only the size of the access cavity and access restoration were varied.

Various forces were applied to study how stress distribution occurred with reference to the area where the force was applied [Figure 1]. To simulate maximum intercuspation, a vertical force of 250 N was applied on the central groove area.^[5,9] It was observed that the maximum stresses were concentrated at the cavity margins closest to the point where the force was applied. From there, they spread in a radially symmetrical manner.

VM is a theoretical measure of stress in FEA used to estimate fracture. The VM stress was lower in the TREC model compared to that of the CEC model.^[12]

To simulate the maximum masticatory force, 800 N force was applied to both models at five different locations, simulating a real chewing scenario.^[10] The peak VM stress in the TREC model was concentrated on the mesial marginal



Graph 1: Comparison of Peak Von-mises stress for both the models and loading conditions

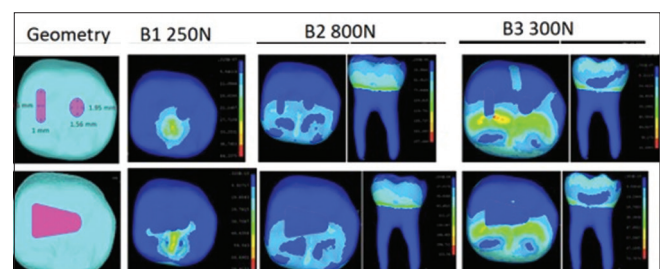


Figure 1: Comparison of stress contours for both models at different loads

ridge for both models. However, in the TREC model, it was lower (207.65 MPa) while the CEC model had considerably higher stress (222.54 MPa). Since the stress on the mesial marginal ridge steadily increased as the cavity size increased from the TREC to the CEC, maintaining the mesial marginal ridge is critical for improving fracture strength following root canal therapy.^[15]

A force of 225 N was applied on the buccal plane of the buccal cusp at 45° for mimicking lateral excursive movements. This is because, during excursive movements, lower loads can induce greater stresses when compared to vertical loading increasing fracture susceptibility of teeth.^[11] In this case, also the TREC model exhibited the least stress. According to our study results, TREC showed lower stress values than CEC at all load levels. This is similar to the findings of an FEA study reported by Allen *et al.*^[16] Our results are also in accordance with a previous *in vitro* study which concluded that truss access preparation improved the fracture resistance of ETT.^[13] The authors attributed this to the retention of strategic internal architecture at the center of the roof of the pulp chamber connecting the buccal and lingual surfaces of the tooth. The preservation of this portion of the pulp chamber roof also aims to distribute the occlusal forces before they reach the floor of the pulp chamber.^[7] The truss access also has the advantage of conserving both marginal ridges along with conservation of the cervical dentin which is vital for the longevity and optimal function of teeth. A previous study has reported the loss of marginal ridge integrity accounts for a 46% decrease in the strength of teeth.^[13]

An *in vitro* study done by Zhang *et al.* has shown that teeth with truss access showed a restorable type of tooth fractures while those with conventional access showed catastrophic tooth fractures.^[10]

In contrast, Corsentino *et al.* reported that there was no difference in the resistance to fracture between truss and traditional access preparations. This disagreement could be due to the difference in methodology as their study was *in vitro* and lacked standardization of the size of the truss access.^[13]

According to the occlusal stress nephrogram, the range of the VM stress that diffused from the composite resin was smaller than the stress that diffused from the enamel. Although enamel is more rigid than composite, it can withstand greater stress. This may be because the enamel has a higher elastic modulus and can withstand elastic deformation better than composite resin.^[5]

Analyzing cross sections of the cemento-enamel junction revealed that the VM stress increased as the access cavity size increased. Since composite resin has a lower elastic modulus than dentin, the stress on the dentin will increase to sustain the resin under greater distortion. As a result, when the access cavity filled with composite resin is wider, the tension on the dentin is greater.^[17]

In the root-filled models, the VM stress on the roots was much higher than the stress on the roots in the intact tooth model. This may be because the interior of the tooth is packed with gutta-percha/sealer/composite resin and adhesive that have different physical properties than dentin.^[5] When the occlusal surface of a tooth is loaded with a constant force, the stress mostly concentrates on the pericervical and apical dentin.^[7] In this study, structural loss of the tooth due to access preparation without actual canal shaping also produced an area of concentrated stress at the apex. These findings suggest that changes in tooth structure during access preparation can also influence stress distribution irrespective of whether or not the endodontic treatment is completed.^[18]

Although the results of our study support truss access, there are certain practical difficulties with this kind of design. The truss access compromises the instrumentation and debridement of the root canal.^[19,20] It has been reported that there are deviations of the original canal anatomy in mandibular molars during canal shaping following conservative access preparation.^[21]

FEA studies also exhibit certain limitations. FEA models are ideal and consider perfect conditions with uniform properties of the constituents. Access preparations designed in the digital environment do not simulate intraoral conditions such as pH-, temperature-, and fatigue-induced failure due to dynamic loading. Thus, FEA provides only a general insight into the biomechanical properties and fracture risk assessment of molar teeth with different access cavity designs.^[12,22]

Further FEM studies are necessary after incorporating occlusal fingerprint analysis to determine the relation between numerical values and actual clinical consequence.^[12] This should also be supported by future *in vivo* studies.

CONCLUSION

Under all loading conditions, the TREC model showed low-stress concentration compared to the CEC model. Since the TREC model preserves more coronal tooth structure and also the pericervical dentin, fracture resistance provided

by this design may be superior. For the CEC model, as the volume of the cavity increased, the stresses in the cervical region were more concentrated.

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Conflicts of interest

There are no conflicts of interest.

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