Stress analysis of different restorations on maxillary central incisor with small defects

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Abstract: To investigate the influence of different restorations on maxillary central incisor. Four models were established by computer. Each three dimensional finite element model contained a defected maxillary central incisor, and a corresponding restoration. Clinical load was simulated. Von Mises and Maximum Principal stress were chosen. The stress peak value and stress distribution on residual dentin were investigated with different models. The stress peak value and distribution in the model with resin filling were close to the sound tooth. The stress distribution changed significantly and the stress peak value increased with both crown restoration and post & crown restoration. With small tooth damage, even after root canal therapy, resin can be used as final restoration. Crown, especially post, may not be necessary.
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Keywords: Maxillary central incisor; post and core; crown; finite element analysis

1. Introduction

Many teeth with defects can be preserved with the development of root canal therapy(RCT)[1-2]. There is still no general standard[3-4] in the literature about how to restore maxillary central incisor teeth post RCT. Currently commonly accepted restoration is post and crown. With crown preparation, excessive tooth structure reduction could increase the possibility of tooth fracture. Whether to grind a large amount of tooth structure for post or crown restoration becomes a consideration, especially those teeth with small damage. In this study, four computer based models were established. Each of the three dimensional finite element[5] model contained a damaged maxillary central incisor, and a corresponding restoration. Stress peak value and stress distribution on residual dentin with three different restorative methods were analyzed to provide theoretical support for clinical practice.

2. Material and Methods

Selected a maxillary central incisor using spiral CT scanning technology to establish three-dimensional finite element models. Took vertical section of long axis of tooth, thickness of the section was 0.625mm, a total of 37 two-dimensional tomography images were taken(Figure 1), saved with DICOM format. Read CT data files, extracted the tooth structure contour line and used Imageware software for edge smoothing and modification. Then used ANSYS software(with IGS format) build a entity model with different anatomical structures of the teeth. According to the existing models in Imageware software which showed actual tooth size, manipulated our models into restorative models, then used ANSYS software establish restoration entity models(Figure 2).

Model design was shown at table 1. The model1 was natural tooth, the rest were endodontic treated teeth (ETT). The model 2 (Figure 3) had a 2.5mm opening access at lingual fossa, root canal was obturated with gutta-percha, and opening access was sealed with 3M composite. Model 3 had the same treatment as model 2, with a aurum alloy porcelain fused to metal (PFM) crown as final restoration. Model4had the same treatment as model 2, and had both post & crown(fiber glass post and a aurum alloy PFM crown) as final restoration(Figure 4).

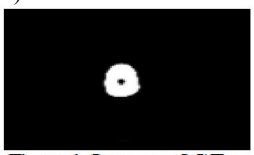

Figure1 Image of CT

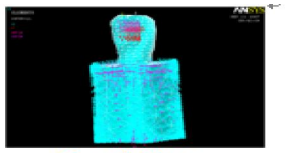

Figure2 Three dimensional finite element model of maxillary central incisor with restoration

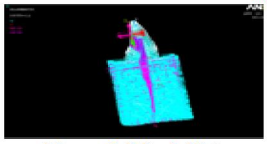

Figure3 Model2

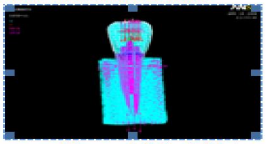

Figure4 Model4

Table 1. Effect of different restoration design models

Models	Numbers	Node number	Unit number
Normal tooth	Model 1	115854	83852
ETT resin filling	Model 2	126005	92436
ETT crown restoration	Model 3	376548	281330
ETT post & crown restoration	Model 4	367167	275948

Restoration design was followed Prosthodontics[6] standard: did 1mm labial shoulder, 0.5mm lingual chamfer. Used parallel post, with the size of 1/3 of the tooth at cervical area and left 4mm gutta-percha at root apex. The aurum alloy PFM crown was created by normal standard, and core was created accordingly. The thickness of crown cement was 0.05mm, the thickness of post cement was 0.1mm. Alveolar bone was 2mm around and 2mm below the cemento-enamel junction, and the periodontal ligament was 0.2mm in thickness.

Table 2. The mechanics parameter of the material

Materials	Modulus of Elastic (GPa)	Poisson's ratio
dentin	18.6	0.31
enamel	84.1	0.33
pulp	0.002	0.45
proper alveolar bone	13.7	0.30
periodontal membrane	0.0689	0.45
aurum alloy	101	0.33
porcelain	69	0.28
gutta-percha	0.00069	0.45
core composite resin	8.3	0.28
glass fiber post	45	0.32
composite luting cement	2.8	0.33
composite resin	13.0	0.30

The finite element models for material assignment, mechanics parameter of the experiments material[3,7-8] were showed at table 2. Grid division adopted a tetrahedral Solid92 unit, mechanical boundary condition of load, a simulated clinical normal occlusion was calculated. A arbitrary static force of 118N was applied at 45° angel to the tooth longitudinal axis at the palatal surface of the crown (Figure 2). In the models, we assumed that all materials were continuous, homogeneous, isotropic linear elasticity, the stress of material deformation as small, boundary restriction was peripheral alveolar bone[9]. Von Mises and Maximum Principal stress were chosen. The stress peak value and stress distribution on residual dentin were investigated with different models.

3. Results

Distribution of Von Mises and Maximum Principal stress on dentin was shown at Figure 5-7.

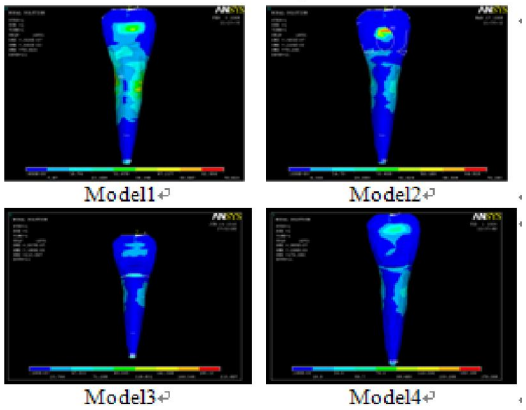

Figure 5. Von Mises distribution on dentin lingual surface in different models

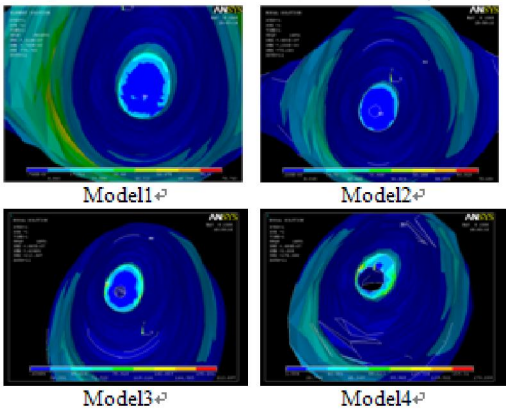

Figure 6. Von Mises distribution on apex of root in different models

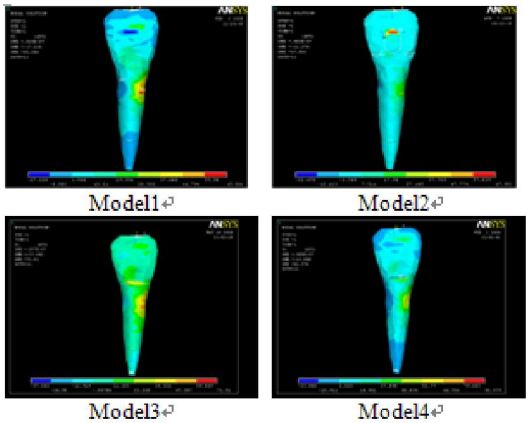

Figure 7. Maximum Principal stress distribution on dentin lingual surface in different models

Stress peak value of Von Mises and Maximum Principal stress on dentin was shown at Table 3.

Table 3. Stress peak value on dentin of different restoration design (unit: MPa)

Models	Von Mises	Maximum Principal stress
model1	70.826	65.086
model2	75.283	67.903
model3	213.897	71.51
model4	179.099	92.579

4. Discussions

To compare of Von Mises and Maximum Principal stress distribution on dentine, it can be found that model1 showed homogeneous stress and stress field was at cervical one third of the tooth. Model 2 showed slight different stress distribution. Von Mises and Maximum stress showed maximum stress at the junction of the filling material and the dentin, so clinical choice of a filling material should have similar Modulus of Elastic of dentin. The model 3 and 4 both showed maximum stress at the lingual cervical margin and root apex, significantly different from the natural tooth. This matched scholar Zarone F scholar's research[10]. Apical stress field may be created by the change of tooth anatomy from crown preparation. This apical stress may cause root fracture. Therefore, neither filling nor restoration recreated the same stress distribution as natural tooth. Crown or post & crown may cause unwanted result.

Comparison of the peak value of Von Mises and Maximum principal stress was shown at table 4.

Table 4. Stress peak value on dentin of crown and post & crown restoration (unit: MPa)

Restoration method	Von Mises	(Reduced rate)	Maximum principal stress	(Increased rate)
Crown restoration (Model 3)	213.897		71.51	
Post & crown restoration (Model 4)	179.099	(16.27%)	92.579	(29.46%)

Note: Reduced rate = (peak value of crown restoration-peak value of post & crown restoration) / peak value of crown restoration x 100%

Increased rate = (peak value of post & crown restoration-peak value of crown restoration) / peak value of crown restoration x 100% Von Mises expresses general stress condition of a material, the stress concentration area is the spot where tooth fracture happens more than other spots. The model4, with glass fiber post, stress peak value of von Mises in dentin was 16.27% less than it was in model3, post & crown showed certain clinical significance than crown only. On the other hand, compared with the model3, maximum principal stress in model4 was increased by 29.46%, and maximum principal stress had bigger influence on tooth. Reducing maximum principal stress can significantly prevent tooth fracture. So from the standpoint of maximum principal stress, crown was preferred than post & crown. Above showed, further analysis is necessary to determine which restorative method is better.

Which is the optimal restorative method selection of maxillary central incisor with small damage after RCT? Many factors may result in root fracture[11-13]. For a long time, the majority of dentists believed that post RCT tooth fracture easily. Recently, dentists believe that anterior tooth with RCT were roughly as strong as vital tooth. The quantity of residual dentin directly related to tooth fracture. Crown preparation significantly weakened the RCT tooth. There is no conclusion that a crown can prevent tooth fracture[14]. This study indicated that if a post RCT tooth presented enough tooth structure, and had intact marginal ridge, a resin filling (with similar elastic modulus as dentin) should be the option of treatment, crown was not necessary. crown preparation weakened tooth structure. Full crown restored teeth showed higher fracture rate than those teeth without crowns. If a post is always necessary when we crown a tooth? Old belief was that post can reinforce a post RCT tooth, the reality is post results in further tooth reduction, and changes stress distribution, therefore increases root fracture. Scholar Sahafi A [15] believed that crown was a better treatment than post & crown. Our study indicated that, use a post or not depends.

5. Conclusion

Within the limitations of the study, the following conclusions can be drawn:

With small tooth damage, even after root canal therapy, resin(with similar elastic modulus as dentin) can be used as final restoration. Crown, especially post, may not be necessary. Considering the complexity of the tooth and the surrounding structures, also the difference in vivo and in vitro, more studies should be conducted to support clinical practice.

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