Original Article

Influence of cavity preparations and restorative procedures on stress distribution by finite element method

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The influence of the preparation and restoration of cavities by using composite resin on the stress distribution of the upper central incisor was evaluated through a three-dimensional finite element method. Nine models were constructed. Model 1 was prepared with the enamel, coronary and radicular dentin, pulp and cortical and cancellous bones. In models 2 to 5, the dentin and enamel were removed to simulate interproximal and endodontic access cavity preparations and. In models 6 to 9, the preparations were restored with composite resin. All models were subjected to a 100-N static load with an inclination of 45° at a distance of 2.0 mm from the incisal edge of the palatal surface of the tooth. Compared to healthy teeth, the conservative interproximal cavity preparation resulted in an 80% increase in the maximum von Mises stress concentration, and in the endodontic access cavity, the stress concentration increased to 99%. In the extensive interproximal cavity preparations, the maximum stress concentration increase to 134% compared to that of healthy teeth and in the endodontic access cavity, the stress concentration increased to 173%. The stress concentration in the endodontic access alone increased to 116% compared to that of a healthy tooth. The values of stress concentration for extensive interproximal and two interproximal cavities, increased to 118% and 127%, respectively. It was concluded that the reduction in the dental structure led to an increase in the stress concentration. The biomechanical conditions for cavity restoration with composite resin have been established.

Key words: Cavity preparations, finite element method, stresses

INTRODUCTION

Dental surgeons frequently encounter difficulties in their practice accompanied by doubts regarding the most appropriate therapeutic course to follow. A controversial matter and subject of considerable doubt is the treatment of teeth that have undergone extensive structural loss due to decay lesions and cavity formation.[1,2] It should be taken into consideration that the loss of structural integrity induces changes in biomechanical properties and influences the capacity to assimilate and distribute the occlusal loads along the structures involved in functional and parafunctional activities.[3]

Literature reports such as those of Reeh, Douglas and Messer[4] state that the endodontic treatment reduces the resistance of the dental element by only 5%, while the cavity preparation results in a decrease of 20%; the mesiodistal occlusal cavity (MDO) reduces the resistance of the same group of teeth by 63%. Therefore, the professionals should select an appropriate technique that minimizes the wear on the healthy dental structure and also induces minimum stress on the remaining structure; thus, such a technique will decrease the fracture risk and permit carrying out restorations with a long-term high clinical success index. Thus, on selecting from the techniques and materials available in the market, it should be considered that none of these materials can replace the efficiency of the dental tissue while reestablishing the intimate and balanced relationship among the biological, mechanical, functional and aesthetic parameters.

Several methodologies have been employed for investigating teeth and restorations subjected to the action of loads, among which the finite element method is the technique of choice.[5,6] This method is one of the most informative concerning the analysis of one-, two- and three-dimensional structures subjected to diverse external actions.[7–12] The efficiency of this method is demonstrated by the good agreement of results obtained by numerical analysis based on several clinical and experimental observations and conclusions.

Considering that the loss of dental structural integrity induced by decay, cavity preparation, and endodontic access alters the biomechanical properties and influences the capacity of assimilation and distribution of occlusal loads, the purpose of this study was to determine the influence of cavity preparations and restorative procedures on the stress distribution of the upper incisor through the three-dimensional finite element method.

MATERIALS AND METHODS

In this study, the finite element method was employed with software ANSYS, version 5.7. The geometric three-dimensional models were obtained by using the anatomy of the right upper central incisor as presented by Wheeler.[13]

Nine finite elements models were developed. In model 1, a healthy tooth was defined as a healthy, decay-free tooth. This model was prepared using enamel, coronary and radicular dentin, pulp and cortical and cancellous bones. In models 2, 3, 4 and 5, dentin and enamel were removed from the teeth in model 1 to simulate the interproximal cavity preparation and endodontic access. The teeth in models 6, 7, 8 and 9 were restored with composite resin.

Stress distribution analysis was carried out in the following cases:

1. Healthy tooth control - Model 1 [Figure 1]
2. Tooth with two conservative and extensive interproximal cavity preparations - Model 2 [Figure 2]
3. Tooth with endodontic access preparation [Figure 3]
4. Tooth with extensive interproximal cavity preparation and endodontic access - Model 4
5. Tooth with two conservative and extensive interproximal cavity preparations and endodontic access - Model 5
6. Restoration of model 2 with composite resin - Model 6
7. Restoration of model 3 with composite resin - Model 7
8. Restoration of model 4 with composite resin - Model 8
9. Restoration of model 5 with composite resin - Model 9

A large number of structures were used for analysis considering the conditions closely related to real life. After the preparation of the models, the materials (dental structures and/or restorative materials) of

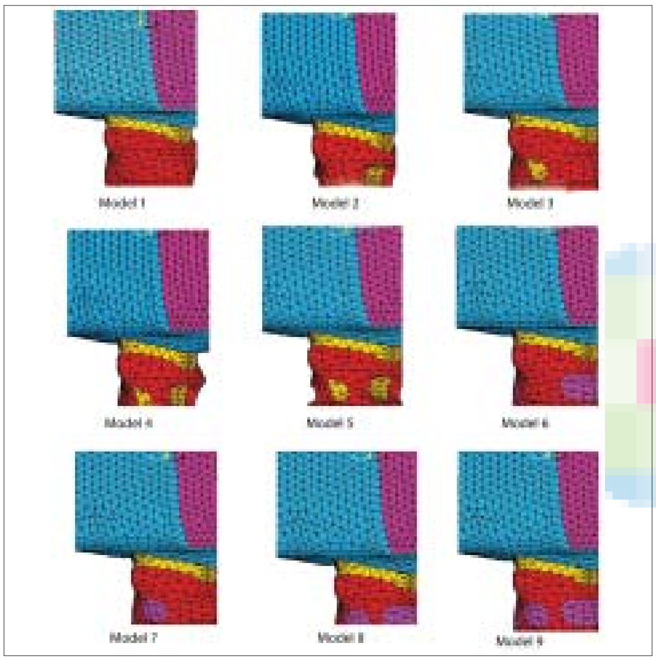

Figure 1: Simplified three-dimensional geometry. Models 1, 2, 3, 4, 5, 6, 7, 8 and 9

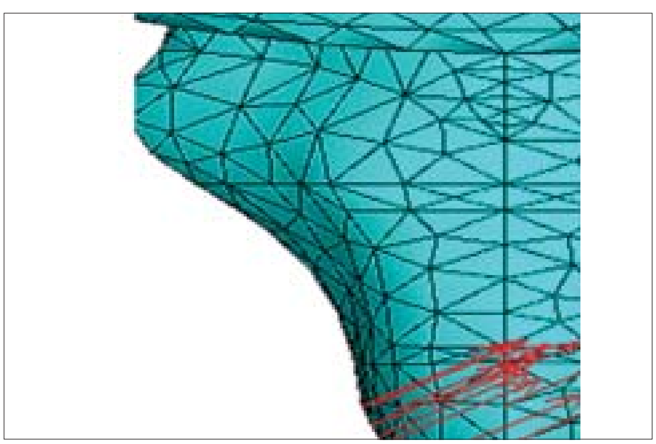

Figure 2: External surface mesh of the studied models and applied load at the cross section

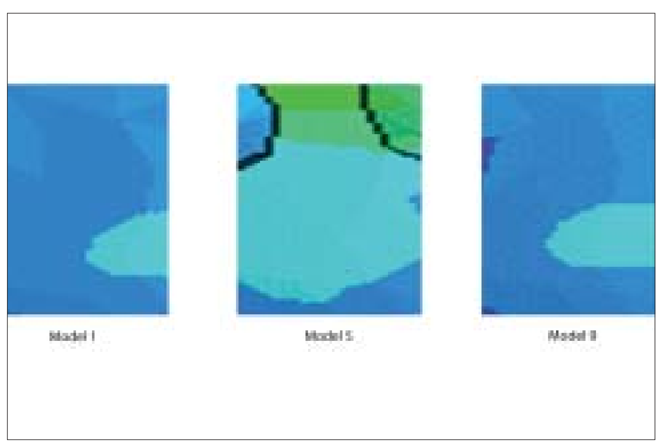

Figure 3: Graphical representation of the distribution of von Mises stresses developed on the dental structure compared those on the designed models

each volume of the models and their mechanical properties (Poisson's ratio and Young's modulus) were determined as shown in Table 1.

The materials were considered homogeneous and isotropic, presenting a linear elastic behavior. Structure discretization was carried out by the generation of a network of finite elements formed by a set of subspaces called 'elements'. Tetrahedral elements with 10 nodes called 'SOLID 92' were used. Table 2 presents the number of elements, nodes, and degrees of freedom of the models.

The models were subjected to a static load of 100 N with an inclination of 45° at a distance of 2.0 mm from the incisal edge of the palatal tooth surface. To prevent displacement, the geometric models were immobilized by mounting the nodes on the upper portion of the cortical bone as well as the cortical bone nodes facing contiguous teeth, thus leaving the models free in the vestibule-lingual direction.

RESULTS AND DISCUSSION

The stress distribution pattern (von Mises) of the models studied enabled us to conclude that the preparation of cavities and restorative procedures present three significant areas of stress concentration associated with the healthy tooth: the areas of conservative interproximal cavity preparation, extensive interproximal cavity preparation, and endodontic access cavity. A summary of the maximal stress of Von Mises is presented in Table 3.

Concerning the conservative interproximal cavity preparation area, relative to the healthy tooth (8.3 MPa), the von Mises stress concentration increased to 80% in model 2 (14.9 MPa), while it increased to 99% in model 5 (16.5 MPa). Therefore, the endodontic access through this area exacerbates the stress concentration in this area.

In contrast, in the extensive interproximal cavity preparation area, the healthy tooth demonstrated a maximal von Mises stress concentration of 10.7 MPa, which was significantly difference as compared to those in models 2, 4 and 5. The maximal von Mises stress in models 2 (25.0 MPa) and 4 (29.3 MPa) demonstrated an increase of 134% and 174%, while model 5 (27.8 MPa) demonstrated a 160% increase as compared to the healthy tooth.

With regard to the endodontic access cavity preparation area, the healthy tooth demonstrated the maximal von Mises stress concentration of 11.3 MPa. Models 3, 4 and 5 showed a significant increase in the stress concentration (maximal von Mises stress values, 24.4 MPa, 24.6 MPa and 25.7 MPa, respectively) compared to the healthy tooth. However, no significant variation was observed between them, indicating that the different interproximal cavity preparations do not affect the stress concentration in this area. The models restored with composite resin (models 6, 7, 8 and 9) exhibited a decrease in the stress in these areas in the order of ca. 28%; this shows the importance of the restorative procedure for the functional reestablishment of the tooth. It is worth indicating that the tooth / restoration interface was considered ideal in this study, that is, the tooth / restoration interface showed perfect adhesion, which is difficult to achieve in clinical practice.

The main objective of restorative dentistry is to reestablish the biomechanical, functional and aesthetic principles of natural dentition through restorations that can withstand the masticatory load and the thermal variations that they are subjected to along with a long life for the dental element.

The application of a load onto a dental element can result in important structural modifications that may,

Table 1: Material properties

Material	Young's modulus (GPa)	Poisson's ratio
Enamel	41	0.30
Dentin	18.6	0.31
Pulp	0.002	0.45
Cortical bone	13.7	0.30
Spongy bone	1.37	0.30
Resin composite	22.2	0.30

Table 2: Number of elements, nodes and degrees of freedom of the geometric models studied

Models	1	2	3	4	5	6	7	8	9
Nodes	9012	8955	8916	8886	8859	9011	9012	9012	9012
Elements	47628	47170	46806	46570	46348	47622	47629	47629	47629
Degrees of freedom	26779	26608	26491	26401	26320	26776	26779	26779	26779

Table 3: The von Mises maximal stress concentration (MPa) in different regions of the three-dimensional models

Models		1	2	3	4	5	6	7	8	9
Conservative	σvM	8,3	14,9	9,7	9,7	16,5	9,0	8,9	8,7	9,3
Extensive	σvM	10,7	25,0	11,5	29,3	27,8	12,4	10,9	12,8	12,7
Acess	σvM	11,3	13,5	24,4	24,6	25,7	11,8	8,6	8,8	8,9

in some cases, alter its morphology. The substitution of the dental structure by restorative materials, such as composite resins, leads to a considerable change in the biomechanical properties of the tooth. Consequently, it is important to understand these alterations. This study shows that the removal of healthy dental structure in cavity preparation alters the stress distribution pattern and renders the dental element more susceptible to fracture. The load assimilation capacity of teeth is improved after restoration.

In 1989, Reeh, Douglas and Messer[4] demonstrated that endodontic procedures such as preparation of endodontic access cavity, instrumentation, and filling affect only 5% of the relative rigidity of the tooth. The occlusal cavity preparation affects the relative rigidity of the tooth by 20%. The largest rigidity loss has been reported for the removal of the integrity of the marginal edge; MDO cavity preparation caused an average loss of 63% in tooth resistance. Magne and Douglas[14] observed an alteration in the biomechanical behavior compared to the anterior dentition. The endodontic procedures on the anterior dentition affected the resistance of the dental structure more significantly, while class III cavity preparations are less harmful to the dental structure. In our study, the extensive interproximal cavity preparation presented the maximum stress concentration, followed by the endodontic access and the conservative interproximal cavity.

CONCLUSIONS

- Considering the results obtained with the methodology used in this study, following conclusions can be drawn:
- Among the cavity preparation procedures, the maximum stress concentrations are associated with extensive interproximal preparations.
- A second cavity preparation implied alterations in the stress distribution induced by the first preparation as distinct areas of the dental element exhibit higher or lower stress concentrations.
- Restoration with composite resin improved the load assimilation capacity of the dental element, indicating the importance of the restorative treatment.

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