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Biomechanical Stress Analysis of Mandibular First Permanent Molar Restored with Different Restorative Materials : A 3-Dimensional Finite Element Analysis.

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Abstract

Normal mastication with its varying magnitude and direction generates extensive intransigent stresses in teeth and their supporting tissues. The structure of the human tooth and its supporting tissues is a multifarious assemblage of materials of various mechanical properties. Finite element method (FEA), a modern technique of numerical stress analysis has great advantage of being applicable to solids of irregular geometry and heterogeneous material properties. It is therefore ideally suited for the examination of the structural behaviour of teeth. Three- dimensional Finite Element Analysis was used to compare Stress distribution generated in Class II MOD lesion using different restorative materials. Results: Software performs a series of calculations and mathematical equations and yields the simulation result. The models was restored with different restorative material which was subjected to a force of 450 N and 600 N loads. Mechanical Properties were analyzed and compared in different materials. From the results of the study, it can be concluded that ClearFil AP-X performed best followed by other restorative materials.. **Conclusion:** Restoration of Class II MOD lesions with materials of higher modulus of elasticity will enable better stress distribution.

Keywords: Finite Element Analysis, MOD Class II Cavities, Mandibular First Molar, Von-Mises stress, Compressive Stress, Tensile Stress.

Introduction

The achievement of dental treatments depends not only on physical , chemical, biological and pathophysiological principles but also on the adequate and precise knowledge of the mechanical properties of dental tissues and materials.[1] In the oral cavity, restorations go through stress from masticatory forces producing different reactions that lead to deformation, which can eventually compromise their durability over time.[2] This is limited if the strength of restorative materials is close to the strength of the tooth structure. Therefore, biomechanical principles have an important part in the clinical success of restorative materials. Configuration and allocation of forces, caused by teeth and surrounding tissues, directly affect the prognosis of restorative treatment .

Recently, Finite Element Method (FEM) was used to assess the durability of different restorative materials under chewing forces in a swift and reasonable way. Classical methods of mathematical stress analysis are extremely limited in their scope and are inappropriate for dental structures that are an irregular structural form with complex loading. However, the Finite Element Method, a modern technique of numerical stress analysis, has great advantage of being applicable to solids of irregular geometry and heterogeneous material properties. It is therefore ideally suited for the examination of the structural behaviour of teeth.[3,4,5,6,15]

The main goal of this study was to analyzing stress distribution in teeth restored with different restorative materials .

Materials and Methods: Finite Element Method

The study was performed using a three-dimensional Finite Element Analysis, using an intact normal extracted human mandibular first molar.

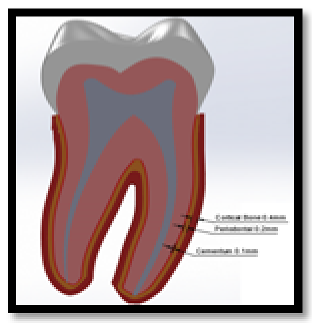
Modeling of a normal lower mandibular tooth

The first step in finite element analysis is modeling .The quality of the analysis results depends on the accuracy of the model. The tooth was subjected to a CT (computerized tomography) scan and the cross section of the tooth was obtained at an equal interval of 0.5 mm. (Figure 1).These sections were obtained in DICOM format and the data was fed to the computer. [DICOM (Digital Imaging and Communication of medicine) is a neutral image format basically for medical imaging purposes like CT, MRI (magnetic resonance imaging etc.]

Using the software MIMICS, these cross sections were converted into a three-dimensional model. [Materialise's Interactive Medical Image Control System (MIMICS) is an interactive tool for the visualization and segmentation of CT images, as well as MRI images and 3D rendering of objects.] Thus a virtual model of the First mandibular molar was obtained.

Meshing

The creation of the Finite Element Model was divided in to several finite element. The element chosen for the study was tetrahedral, which is a 4-nodal element. NASTRAN was used to create the Finite Element Model. (Figure 2).



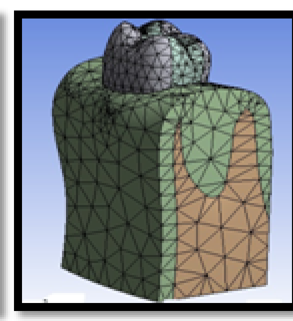


Figure 1: Cross-Section of a Tooth   Figure 2: Model after meshing

Dimensions of the virtual cavity

With a computer-aided design (CAD) modeling program, the appropriate class II MOD cavity was designed in all the models. After the cavity preparation, all the models were restored with different restorative materials (Figure3).

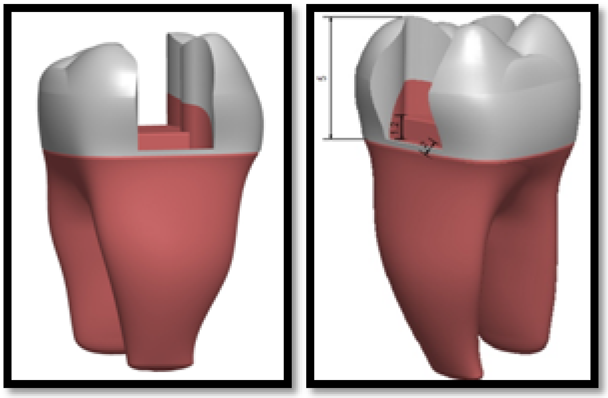


Figure 3: Solid virtual model of Class II MOD cavity

Materials Properties

The mechanical properties of the tooth and restorative materials are given in Table 1.

Loading Conditions

A load of 450 N and 600 N was applied to the tooth at an angle of 35^0 with respect to the long axis of the tooth and perpendicular to the buccal and lingual cusp .

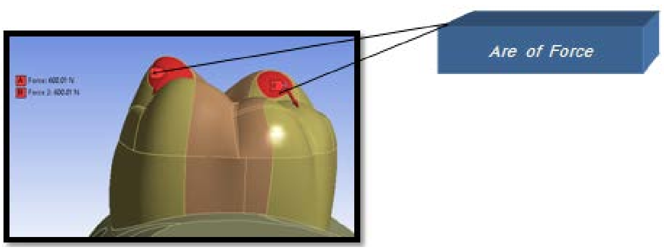


Figure 4: Load area applied

Table 1. Materials properties used in the study

Materials	Young's Modules (MPa)	Poisson's Ration
Enamel	72700	0.30
Dentin	18600	0.31
Pulp	02	0.45
Periodontium	50	0.45
ClearFil AP-X	17580	0.36
GIC(FUJI IX)	4000	0.3
Filtex Z350-XT	11300	0.30
Cention N	11200	0.34

Restoration of the Lesion

The cavity was restored with four different restorative materials and these were accredit to four groups :

Group I – Intact Tooth

Group II – Restored with ClearFil AP-X Composite Resin (Kuraray)

Group III –Restored with GIC Fuji IX GP (GC)

Group IV- Restored with Filtex Z350-XT (3M)

Group V- Restored with Cention N (Ivoclar Vivadent).

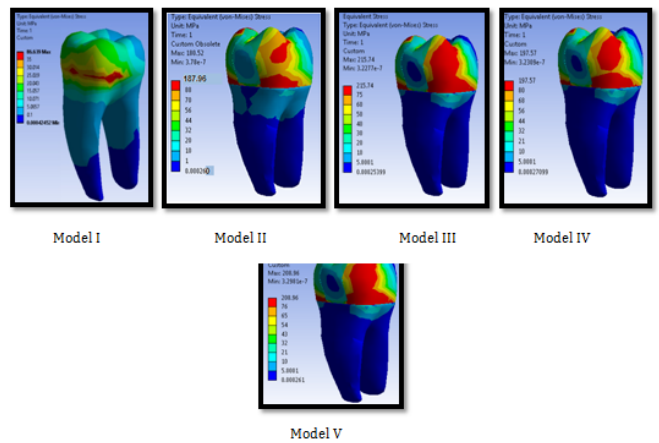


Figure 5: The distribution of Von –Mises Stress according to groups.

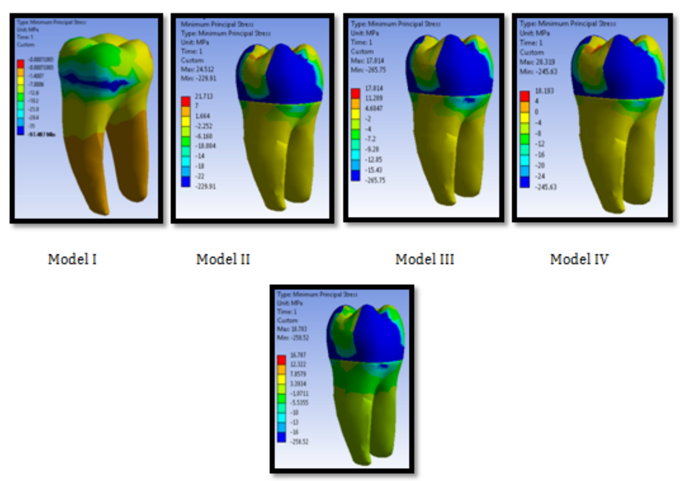


Figure 6: The distribution of Compressive Stress according to groups

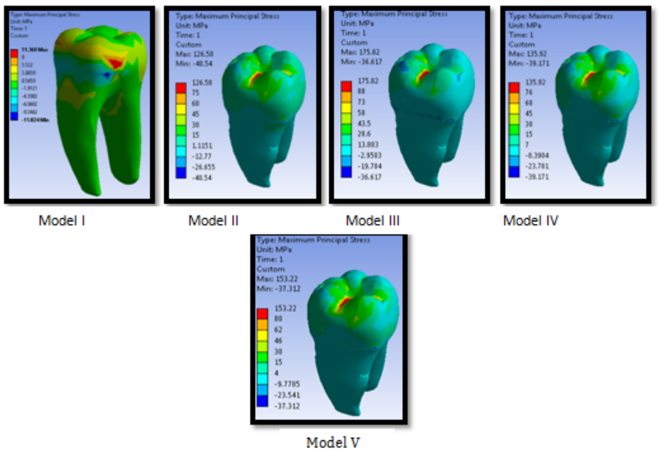


Figure 7: The distribution of Tensile Stress according to groups

Results

Finite Element Methods

The principal stresses in each of the models were studied. The results are presented in terms of the Von Misses stress, Compressive stress and Tensile stress values .(Graph1-Graph 3).

Graph 1: Comparison of Maximum Von-Mises Stress on Restoration

Graph 2: Comparison of Compressive Stress on Restoration

Graph 3: Comparison of Tensile Stress on Restoration

Discussion

The success of dental treatment depends not only on, biological, physical, chemical and pathophysiological principles but also on the acceptable and decisive knowledge of the mechanical properties of dental tissues and materials.[52] The structure of the human tooth and its supporting tissues is a complex assemblage of materials of varied. mechanical properties. **(Shrirekha et al 2010)**[2] Stress analysis of dental structures has been a topic of interest in recent years with the objective of determination of stresses in the tooth and it's supporting structures and improvement of the mechanical strength of these structures. **(Shetty 2013)**[4].

For the evaluation of the stress measurement and analysis, various methods are applicable, such as the strain gauge method, the loading test, and the photoelastic method. These techniques being homologous, two dimensional are difficult to reproduce at times. A valid index of stress distribution at the root structure becomes difficult to create based solely on experimental and clinical observation **(Memon et al 2016)**[42]. To resolve unworkable engineering problems, an innovative theoretic method is used named Finite element analysis (FEA).

Finite elements method allows knowing the stress distribution in complex structures. The effectiveness depends on the study closeness to the real clinical model. The structure of the human tooth and its supporting tissues is a complex assemblage of materials of varied mechanical properties. **(Shrirekha et al 2010)**[7] Stress analysis of dental structures has been a topic of interest in recent years with the objective of determination of stresses in the tooth and it's supporting structures and improvement of the mechanical strength of these structures. **(Shetty 2013)**[8] .

In this study different loads like 450 N and 600 N which is in accordance with literature reference for the range of normal bite force that varies between 300 N to 600 N by **Bakee M et al 2018**[9] . The loading protocol of 600 N load in this study was according to previously conducted studies by **Imanishi *et al.***[10] and **Nakamura *et al***[11] at an angle of 35^0 with respect to the long axis of the tooth and perpendicular to the buccal and lingual cusp . This was similar to force application in the study conducted with different restorative materials on permanent mandibular molar tooth by **Kathleen D'Souza et al 2017**[12].

In the present study , the stresses distribution at different loads on Intact molar tooth and Class II MOD cavity restored with different restorative materials were evaluated , using the finite element analysis .

When an Intact tooth was subjected to different loads, the maximum Von – Mises Stress and Tensile Stress were generated in the Mesio- Buccal Groove and Cervical region of Crown where the Compressive stress was located on the Mesio- Lingual cusp and Cervical region of the Crown.

The reason for higher stresses in enamel than dentin was probably due to the difference in their Young's Modulus of elasticity or to the fact that the applied force was concentrated on the enamel at the occlusal contact areas. Maximum Young's modulus of elasticity of enamel **(72700 MPa)** is much higher than that of the dentine **(18600 MPa)**. This is the reason why tooth region where enamel concentration is more more stress distribution is shown than areas where bulk dentin is present. The peak of the stress on the left and on the right side of tooth structure also depends on more rigid area that is in enamel. **(Ausiello P, 2011)**[46]

Results were displayed as color measurement bar in which each color corresponded to a range of stress values . Different shades of color indicated the amount of stress generated with **Red** indicating maximum stress and **Blue** indicating minimum stress.

The highest stress generation was seen in GIC (Fuji IX), However, the stress generation in ClearFil AP-X was less than that of intact tooth. This behavior of ClearFil AP-X and also other materials can be explained based on Young's modulus of elasticity and Poisson's Ratio. Materials having higher modulus of elasticity exhibit the less stress concentration.

Conclusion

After analyzing the results and the comparison of the theoretical and experimental methods, we can conclude that both share the following items:

In Finite Element Method the material with high Young's Modulus of elasticity exhibits less stress distribution in teeth and restorations.

In Experimental test there was a significant difference among the tested materials in all the testing parameters.

Hence, it can be concluded that the Nano-Composites (ClearFil AP-X) can be used as a posterior restorative material in load-bearing areas. Further in vivo studies are mandatory to prove its performance.

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