Comparative Evaluation of Stress Distribution of a New Restorative Material : A Finite-Element Analysis Study

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Abstract

Aim: To investigate the distribution and stress pattern in mandibular molar teeth restored with different restorative materials under 600N load by 3D Finite Element Analysis

Materials and Methods: Using Finite Element Analysis, Stress generated in Class II MOD lesion using different restorative materials were studied.

Results: Software performs a series of calculations and mathematical equations and yields the simulation result. The models was restored with three different restorative material which was subjected to a force of 600 N load. Von-Mises Stress were analyzed and compared in different materials. From the results of the study , it can be concluded that Amalgomer CR performed best followed by Zirconomer and GIC (Fuji IX).

Conclusion : Restoration of Class II MOD lesions with materials of higher modulus of elasticity will enable better stress distribution.

Keywords : Finite Element Analysis, Mandibular First Molar , Mesial-occlusal-distal cavity, Von-Mises Stress analysis.

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Introduction

In dentistry, an advance digital imaging technology has opened up new alternative possibilities as compare to ethical concerns limit laboratory studies on living subjects . The computational simulation method takes a more important position in both clinical and restorative applications in the dental industry . Usage of virtual models offers an alternative method of investigation, and costs can also be reduced for in vivo and in vitro experiments. The concept of Finite Element Analysis (FEA) originated during 1940's with advances in aeronautical engineering. Finite element analysis has slowly but steadily found wide spread popularity in the fields of medicine and dentistry. Especially in dentistry; where this tool of research methodology is being used to understand the behaviour of various materials. FEA has become a solution to the task of predicting failure due to unknown stresses by showing problem areas in a material and allowing designers to see all of the theoretical stresses within.[6] There are generally two types of analysis that are used in industry: 2-D modeling, and 3-D modeling .[5] The stress distribution in 3-D models of restorative tooth structure complex is best studied by Finite Element Analysis which helps in the understanding of biomechanic of tooth and restorative materials. The purpose of this FEA study was to obtained 3D models of mandibular first molar with MOD Class II cavity prepared and restored with different materials. The effect of load on the stress distributions were also analyzed for three restorative materials GIC(Fuji IX) , Cention N and Zirconomer Cement.

Materials & Methods

Modeling of a Normal Molar Tooth

The first step in finite element analysis is modeling. The value 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 0.5mm.

Theses section were obtained in Digital Imaging and Communication of Medicine (DICOM) format and the data were fed into the computer. Using the software Materialise Interactive Medical Image Control System (MIMICS), these cross-sections were converted in to 3-D model. The MIMICS is an interactive tool for the visualization and segmentation of CT images, as well as MRI images and 3D rendering of the objects. Thus a virtual model of the mandibular first 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 (Figure 1).

Preparation of Virtual Cavity

The cavity was excavated in the computer model. A class II MOD cavity measuring 1.5 mm initial depth, 5 mm Buccolingual at occlusion, 2 mm pulpal depth, Axial wall 0.5 mm to 0.8 mm into dentin, Cervical margin on mesial cavity 1 mm below CEJ and Cervical margin on distal cavity 1 mm below CEJ was prepared. After cavity preparation, the cavity was restored in the computer model according to the mechanical properties of the tooth and restorative materials. The mechanical properties of the tooth and restorative materials are given in Table 1. The cavity was restored with three different restorative materials and these were accredit to three groups :

* Group I – Restored with GIC Fuji IX
* Group II – Restored with Zirconomer
* Group III –Restored with Cention N

Loading Conditions

A load of 450N 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 cusps (Figure 2-a,b).
Restorations should be strong enough to resist the
intra-oral forces; in fact, as a result of bite forces,
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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
GIC (Fuji IX)	4000	0.3
Zirconomer	794	0.37
Cention N	11200	0.34

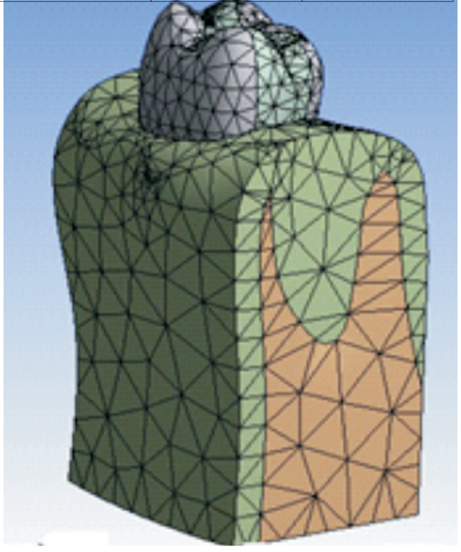


Figure 1:Model after Meshing

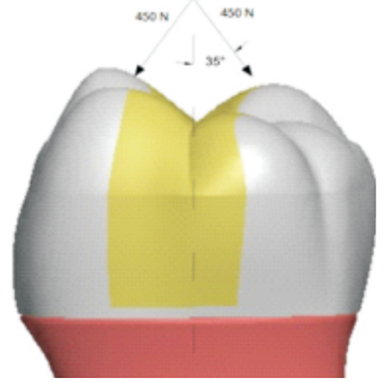
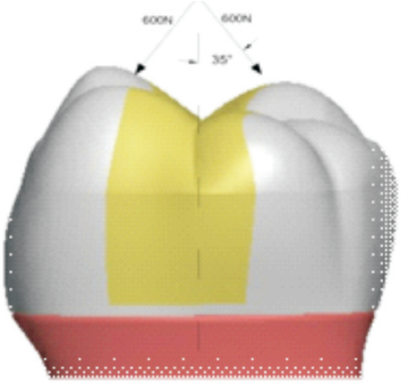


Figure 2 (a,b)- 3D Model and Load Application



Results

The principal stresses in each of the models were studied. The results are presented in terms of the Von-Mises Stress values.(Figure 3,4 &5). The highest Von-Mises Stress value was recorded in GIC (Fuji IX) ; the lowest Von-Mises stress value was recorded in Cention N.

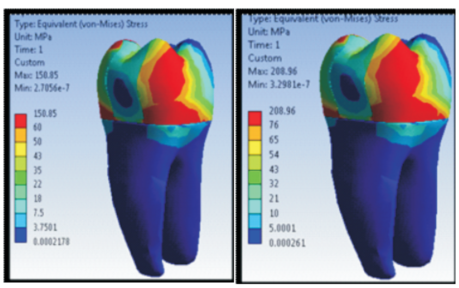
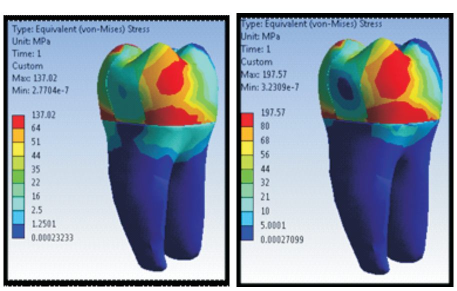


Figure 3: Von-Mises Stress distribution on restoration when tooth restored with GIC (Fuji IX) at (a) 450 N & (b) 600 N Load was applied.



450 N Load 600 N Load

Figure 4: Von-Mises Stress distribution on restoration when tooth restored with Cention N at (a) 450 N and (b) 600 N Load was applied.

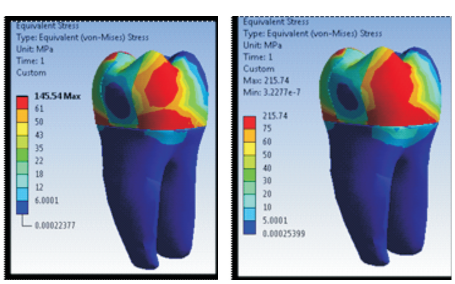


Figure 5: Von- Mises Stress distribution on restoration when tooth restored with Zirconomer at (a) 450 N and (b) 600 N Load was applied.

Discussion

In the oral cavity , the tooth and the restoration are mainly subjected by different type of stresses i.e mechanical stresses which generaly generated during functional and masticatory activities. Therefore, it is important to understand the pattern of stress distribution so as to improve the longevity of the restorations.[6]

The scope of this study was to evaluate the mechanical behavior of various restorative materials known to be used in MOD Class II Cavities under different loading characteristics. The possible changes in the tooth structure because of occlusal restoration, the utilized restorative material and their consequences were studied in detail.

In this study, 3D-FEA was used, which produces more accurate results compared to 2D-FEA modeling. 3D-FEA is preferred to obtain an visual practical analysis with detailed tooth anatomy and computational process. The tooth modeled for this analysis was a mandibular first molar . The study discovered that the experimental models restored with different materials showed high resultant stress concentration at the distal region . Hence , this area is most likely the potential failure site of the restoration from analytical point of view . The study used two different type of 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[7] . The loading procedure of 600 N load in this study was in according to formerly conducted studies by Nakamura et al [8] at an angle of 35^0 with respect to the long axis of the tooth and perpendicular to the buccal and lingual cusp .

Using finite element analysis the stress distribution at different loads on Class II MOD cavities restored with different restorative materials were evaluated .The results were displayed as color measurement bar in which each color represent 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 maximum stress generation was seen in GIC (Fuji IX) (150.85 MPa) at 450 N load and (215.54 MPa) at 600 N load followed by Zirconomer (145.54 MPa) at 450 N and (208.96 MPa) at 600 N load and Cention N (138.02 MPa) at 450 N and (198.57 MPa) at 600 N loads.

However the stress generation in Cention N was less than other restorative materials, this behaviour of Cention N and also other materials can be explained based on Young's modulus elasticity and Poisson's ratio .Materials having higher modulus of elasticity exhibit the less stress concentration.

As the formation of non-carious lesions/ cavities are an inevitable part of various etiological factors, their possible negative effects should be foreseen and necessary precautions should be taken. From the mechanical point of view, restoration of these defects is important and the best clinical approach would be to apply restorative materials,which have large Young's moduli.

Conclusion

Within the limitation of FEA , different computerized model may be increasingly used in biomechanical application of dentistry. It is a computerized in vitro study in which clinical condition may not be absolutely virtual. Stress analysis is usually conducted under static loading, and the mechanical properties of materials are set as isotropic and linearly elastic, although it is not so in reality. So, the results may only be recognized qualitatively. Szwedowski et al [11] compared FEA with real models and found that the model accorded well with strain gauge measurements. Keeping in mind these limitations, further FEA research should be supplemented with clinical evaluation. The study concluded that the materials of higher modulus of elasticity will enable better stress concentration.

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