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Original Research Report

Three-Dimensional Finite Element Analysis of the Stress Distribution Pattern in a Mandibular First Molar Tooth Restored with Three Different Restorative Materials

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Abstract

The purpose of this finite element analysis (FEA) is to evaluate and compare the stress distributions at the permanent molars and restorative materials according to the material used. ***Materials and Methods:*** 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 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.

INTRODUCTION

The principal goal of dentistry is to preserve and improve the quality of life of the dental patients. This goal can be achieve by preventing diseases, improving masticatory efficiency, relieving pain, improving appearance and enhancing speech. As many of these objectives require the replacement or modification of the existing tooth structure, the main challenges for centuries have been the development and selection of biocompatible materials that can withstand the unique conditions of the oral environment [1].

In recent years, dentistry has witnessed introduction and subsequent withdrawal of numerous unsatisfactory products and techniques from the market. The failure of various product and techniques is mainly because of unique conditions of oral environment. These failures have made the researchers investigate the relationship between laboratory research and clinical performance of the techniques and materials. So, all the laboratory research or in-vitro studies should be done keeping the oral environment in mind [1, 9].

The field of biomedical research raises specific problems due to the fact that today's research may prove to be extremely expensive and ethically questionable when performed on live subjects. To limit the costs and risks involved in live experiments, virtual models and simulation approaches have become unavoidable [2]. Classical methods of mathematical stress analysis are extremely limited in their scope and are inappropriate 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]. It is a numerical technique for obtaining approximate solution to a wide variety of engineering problems where the variables are related by means of algebraic, differential and integral equations [4].

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 lad on the stress distributions were also analyzed for three restorative materials GIC (Fuji IX), Zirconomer and Amalgomer CR cement.

MATERIALS AND METHODS

The study was performed using a three-dimensional (3D) FEA. A 3-D cross-sectional model that consisted of 34253 nodes and 17851 elements representing the mandibular right first molar was constructed, using an FEA Software (ANSYS version 14.0).

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 Amalgomer CR

Loading Conditions

A load of 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).
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
Amalgomer CR	13300	0.34

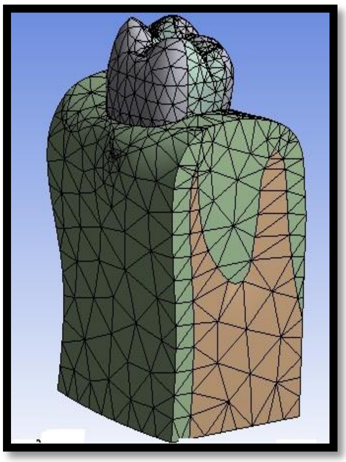

Fig-1: Model after meshing

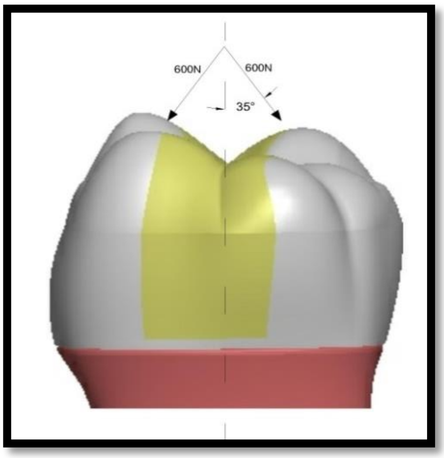

Fig-2: 3-D model and load application

RESULTS

The principal stresses in each of the models were studied. The results are presented in terms of the Von-Mises Stress values (Table-2 and Figure-3). The highest Von-Mises Stress value (176.34 MPa) was recorded in GIC (Fuji IX); the lowest Von-Mises stress value (137.02 MPa) was recorded in Amalgomer CR.

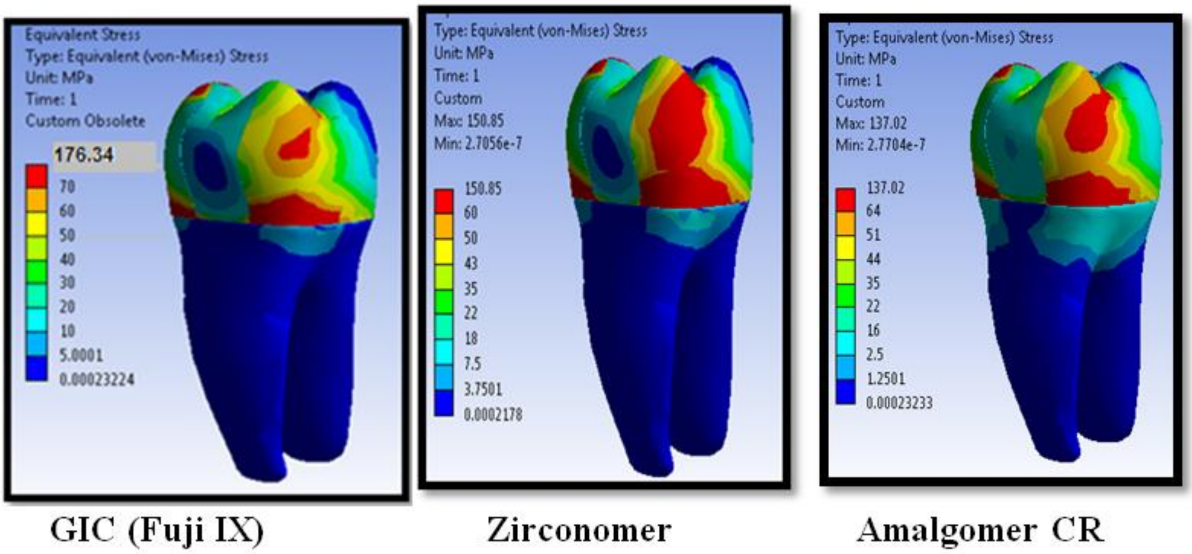

Fig-3: Stress distribution pattern

Table-2: Stress distribution patterns when load was applied

Loads	GIC(Fuji IX) stress distribution in MPa	Zirconomer Stress distribution in MPa	Amalgomer CR Stress distribution in MPa
600 N	**176.34 MPa**	**150.85 MPa**	**137.02 MPa**

DISCUSSION

In the oral cavity, the tooth and the restoration are mainly subjected to different types of stresses, mechanical stress is one of them which generate during functional and masticatory activities. Thus, it is important to understand the pattern of stress distribution so as to enhance the longevity of the restorations [5].

The Finite Element Analysis has been used extensively in dental biomechanics research. The method is powerful and adaptable in that it can present detailed information on Strains, Stresses and displacements within complex structures such as teeth [6]. It is a new design concept which has the ability to accurately obtain the stress pattern throughout the structure under consideration, even if the structure is nonhomogeneous [10].

In the present study, the stress distribution analysis on mandibular first molar tooth and Class II MOD restored with different restorative materials were evaluated, using FEA. Thus, the study aims to simulate the conditions by subjecting the computer models to a maximum bite force of 600 N at angle of 35^0 with respect to the long axis of the tooth and perpendicular to the Buccal and lingual cusps.

A load of 600 N was employed in this study to simulate the maximum bite force. The loading protocol of 600 N load in this study was according to previously conducted studies by Imanishi *et al.,* [7] and 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.

Results were displayed as color measurement bar in which each color corresponded to a range of stress values. Different shades of color indicate the amount of stress generated with dark red indicating maximum stress and dark blue indicating minimum stress.

The maximum stress generation was seen in GIC (Fuji IX) cement (176.34 MPa) followed by Zirconomer Cement (150.85 MPa) and Amalgomer CR (137.02 MPa).

However, the stress generation in GIC (Fuji IX) was higher as comparison to other restorative materials. This behaviour of GIC and also other materials can be explained based on Young's modulus of elasticity. Materials having higher modulus of elasticity exhibit the less stress concentration.

CONCLUSION

- Numerical simulations provide a biomechanical explanation for stress distribution in restored teeth. Within the limitations of the study, it was concluded that the stresses are higher in GIC (Fuji IX).
- When the tooth restored with Amalgomer CR the less stress distribution was performed.

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