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THREE-DIMENSIONAL FINITE ELEMENT ANALYSIS OF CLASS 2 INLAY ON MANDIBULAR MOLAR USING VARIOUS MATERIALS

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Abstract

Aim: To study the stress distribution in Class 2 Inlay of various materials on Mandibular Molar.
Background: Inlays are fabricated using different materials like gold, porcelain or a cast metal alloy. Difference in the modulus of elasticity of the material and tooth structure would lead to generation of stresses leading to failure of the restoration or loss of tooth structure.
Finite Element Analysis (FEA) is a mathematical tool for stress analysis in a structure. Von Mises stress being the combination of normal and shear stresses which occur in all directions. This stress has to be given diligent importance while considering the type and material of restoration to achieve long-term success.
Methodology: In our study, stress analysis was performed on the mandibular first molar using a stress analysis software (ANSYS). A computer model of mandibular first molar was generated along with generation of an inlay volume using a FEA software preprocessor. The models with the class 2 inlays of different materials were subjected to 350N and 800N load simulating normal masticatory force and bruxism respectively. Maximum and minimum stresses were calculated for each model separately.
Results: Von Mises stress distribution for different materials for normal masticatory forces and bruxism were studied and evaluated.
Conclusion: The study revealed the maximum and minimum stresses imposed over the tooth and the restoration and provides insight into the areas which are more prone to fracture under the occlusal load.

Keywords: Finite Element Analysis (FEA); ANSYS; Von Mises Stress.

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1. Introduction

Indirect restorations, as they are fabricated under ideal lab- oratory conditions, have more desirable physical properties than direct restorations [1,2]. Fracturing of the inlays is an acceptable complication that can lead to failure of the restoration. The quality of the adhesive technique, the material suitability and the form and dimension of the cavity preparation affect the likelihood of long-term success. For a successful restoration, suitable cavity design is of great importance in addition to the material selected. Inlays are fabricated using different materials like gold, porcelain or a cast metal alloy. Difference in the modulus of elasticity of the material and tooth structure would lead to generation of stresses leading to failure of the restoration or loss of tooth structure.
Because restoration success depends on the stress and the physical properties of the materials used, restoration materials must be evaluated under compressive loading to determine their fatigue strength. Three-dimensional (3D) finite-element (FE) analysis has been used extensively in dental biomechanical studies to produce detailed and realistic animate or inanimate structures.

The model resulting from 3D FE analysis is divided into mathematically meaningful parts or elements. The elements are connected by 'nodes' of various geometric shapes. Certain nodes have a fixed displacement range or load value. A physical change in one element (e.g., an applied force or load) is transmitted to the other elements by the nodes, allowing the determination of stress/strain information for the particular system under investigation.

Von Mises stress is a combination of normal and shear stresses occurring in all directions. This stress has to be considered when evaluating the appropriate restorative material to use, as well as the tooth tissue damage that may occur. By doing so, it is possible to determine whether or not permanent deformation or breakage has occurred in the material [3,4].

The purpose of the present study was to analyse the biomechanical performance of class II inlays fabricated using Type II Gold Alloy, Zirconia Ceramic, Indirect Composites and Base Metal Alloys under a load of 200N and 800N applied to the occlusal surface of the first molar. The von Mises stress values in the enamel, dentin, ceramic materials and cement linings were simulated using 3D FE analysis.

2. Material and Method

In this in silico study, stress analysis was performed on the first molar teeth, using a stress analysis software (ANSYS Rel.6.0, ANSYS Inc., Houston, TX, USA). The FE analysis model consisted of dental fillings, enamel and dentin. The tooth size and shape were compared with data from 'Wheeler's dental anatomy, physiology and occlusion.' A computer model of the mandibular molar was generated. An additional inlay-shaped volume, having a 3.5 mm wide and 2.5 mm deep isthmus, was created using the FE analysis software pre-processor. The cavity preparation was created by deleting the inlay volume. A tooth model with an inlay-prepared cavity was obtained (Figure 1). Inlays with a 0.1-mm cement layer were overlapped on the models in a similar way. The inlays were bonded to the tooth structure with composite resin cement.

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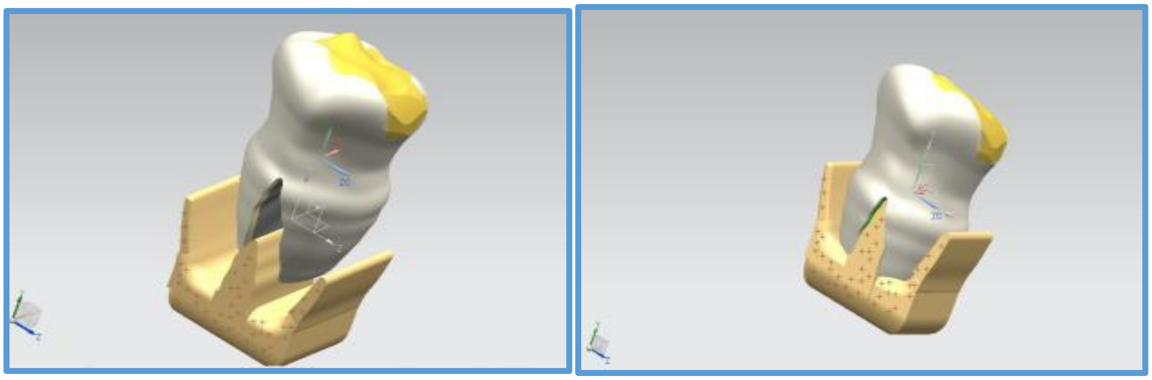

Figure 1: Three-Dimensional Model and Inlay Volume Created

Table 1: Mechanical properties of the tooth and materials.

Material	Young's Modulus (Gpa)	Poisson's Ratio
Enamel	84.10	0.30
Dentine	18.60	0.31
Pulp	0.002	0.30
Periodontal Ligament	0.0689	0.45
Alveolar Bone	11.50	0.30
Type 2 Gold Alloy	78.5	0.42
Zirconia	205	0.33
Base Metal Alloy (Nicr)	150	0.26
Indirect Composite Resin	25	0.30

The models with the class 2 inlays of different materials were subjected to 200N and 800N load simulating normal masticatory force and bruxism respectively. Maximum and minimum stresses were calculated for each model separately.

3. Results

Von Mises stress distribution for different materials for normal masticatory forces and bruxism were studied and evaluated.

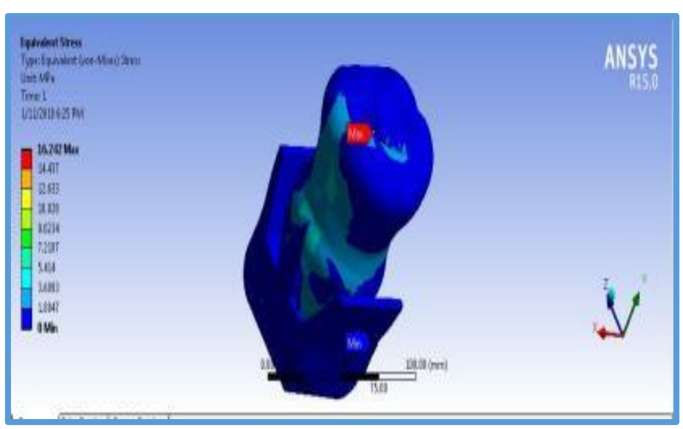

Figure 2: Visualization of Von Misses stresses produced

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Table 2: Results obtained

Force Applied	**Type 2 Gold Alloy**		**Base Metal Alloy**		**Zirconia Ceramic**		**Indirect Composites**	
		Stress		Stress		Stress		Stress
200n		16.24		19.75		21.30		12.97
800n		281.78		225.93		226.67		377.44

The results produced depict least stresses produced by Indirect composites under Normal Masticatory Forces (200N). The increasing order of stresses produced were,

Indirect Composites < Type 2 Gold Alloy < Base Metal Alloy < Zirconia Ceramic

Ceramic inlays featured more detrimental stresses at the occlusal surface compared to composite inlays and demonstrate more stresses than the Composite Inlays.

Stresses produced under the forces of 800N simulating bruxism were in the order,

Base Metal Alloy < Zirconia Ceramic < Type 2 Gold Alloy < Indirect Composites

The stresses produced depicted that the elastic modulus of a material has a direct relation with the stresses produced while in the case of bruxism due to routine wear and tear of the occlusal surface Base Metal Alloy inlays proved to be more promising in terms of stresses and deformation produced.

4. Discussion

In this study, the maximum and minimum stress values for enamel, dentin and dental fillings for cavity restored with different inlays were compared under vertical occlusal.

forces in 04 models. The model exhibiting the lowest stress value corresponded to the preferred material for restoration.

The results indicate that minimal forces were concentrated in the dentin, whereas maximum forces were present in the enamel. The stress values in the dentin and inlay material for the porcelain ceramic and zirconia ceramic groups were similar. However, in the enamel, the stress values in the zirconia ceramic group were considerably lower than those in the porcelain ceramic group. This indicates that the structure of zirconia ceramic retains the stress inside (i.e., less stress is transferred through the tooth structure). Also, the results indicate the enhanced stress distribution by the rounded corners [5,6].

Because the values obtained by FE stress analysis are variances that occur as a result of non-mathematical calculations, statistical analysis was not performed. Instead, careful review and analysis of the stress distributions were carried out [7,8].

Ceramic inlay restorations offer optimal aesthetics, biocompatibility and longevity. The use of adhesive bonding materials and resin composites improves the clinical success of the ceramic inlay restoration and significantly increases the fracture resistance. Zirconium can be used safely in inlay and onlay restorations, due to its high durability and superior detail ability.

The elasticity modulus describes the relative stiffness of the materials within their elastic range and is deter- mined by tensile, bending, compressive and indentation techniques. The use of low-modulus restorative materials has been shown to facilitate stress release [9,10].

In the present study, biomechanical analysis of the parametric inlay models was carried out using the FE method, which is used frequently in dental studies. Using the FE technique, von Mises stress values were evaluated under loading of inlay restorations. Indirect Composites showed least stress under the normal masticatory forces. Moreover, our results were in agreement with the previous reports that the cavity with rounded corners better distributes the stress under an applied vertical force [11-15].

5. Conclusion

Within the limitations of this study, the obtained results showed the following. (1) The most preferable inlay restoration material was indirect composite, because its structure held the stress inside, i.e., less stress was transferred through the tooth structure. (2) In the cases with bruxism base metal alloy inlay is preferred over the indirect composite inlay. (3) In materials with a low elasticity modulus, stresses formed on the surface; these stresses did not spread to the other parts of the tooth or restoration. Stresses on the surface of the material induced deformation and material wear.

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