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Three Dimensional Finite Element Analysis of Dynamic Stress Analysis Pattern in Class II Cavity Restored with Amalgam and Composite

[1]Dr. Dhanasekarn Sihivahanan, MDS, Associate Professor, Department of Conservative Dentistry and Endodontics, SRM Kattankulathur Dental College and Hospital, SRM Nagar, Kattankulathur, Tamil Nadu 603203

[2]Dr. P. E. Mukundan, MDS, Post Graduate Student, Department of Conservative Dentistry and Endodontics, SRM Kattankulathur Dental College and Hospital, SRM Nagar, Kattankulathur, Tamil Nadu 603203

Corresponding Author: Dr. Dhanasekarn Sihivahanan, MDS, Associate Professor, Department of Conservative Dentistry and Endodontics, SRM Kattankulathur Dental College and Hospital, SRM Nagar, Kattankulathur, Tamil Nadu 603203

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Abstract

The aim of the study was to evaluate the stress values on dynamic stress in class II cavity restored with composite and amalgam using finite element analysis. For developing finite element analysis model, an extracted mandibular first molar without any external defects was selected and scanned using CBCT and a 3D model was developed. From the CBCT image, the FEA model was developed. Ideal class II cavity preparation dimension and the properties of amalgam and composite were used for the modelling. After the modelling is completed,the FEA model is subjected to cyclic loading to evaluate the stress patterns in class II cavity restored with amalgam and composite. Based on the stress distribution in tooth resulting from simultaneous mechanical loads, the composite holds the better result. In the past, studies have done using static loading to evaluate the stress patterns in class II cavity restored with amalgam and composite. Since the restoration done in oral cavity undergoes a dynamic loading over a period of time, till date dynamic loading analysis on the stress distribution on the class II cavity restored with amalgam and composite has not been performed.

Keywords: Amalgam, Composite, ClassII cavity, Stress

Introduction

In dentistry, advances in technology happens through advancement in application of physics. One of the most important applications of physics is the study of forces applied to the dental structures1. Application of forces on any restoration produces different types stress such as compression stress, tension stress, or shear stress along the tooth restoration interface. Cavity design preparation has a great impact on stress values and fracture resistance of a tooth. The longevity of the posterior restoration depends on its ability to resist occlusal loads2. They must be able to withstand the sheer forces/pressures that are developed due to masticatory process. Stress transfer and stress development will vary depending on the type of restoration and the occlusal loads1.

It is difficult to measure what is the normal reaction to the force applied on the tooth and what is potentially harmful. The state of stress is due to two loading conditions i.e. mastication and distalization in human tooth. This can be evaluated using the finite element analysis method. With this method, the stress and displacement acting in the tooth can be analyzed

Finite element modeling (FEM) for stress analysis stands superior when compared with laboratory testing and it offers several advantages such as, variables can be changed easily, and without human materials the simulation can be easily performed. FEM can minimize laboratory testing requirement. As the field of dentistry is advanced, the incorporation of such a faster technique in material science gives a precise and faster solutions in the field.3

The objective of the study is to compare the stress values in class II cavities in mandibular first molar restored with composite and amalgam using FEA.

Materials and Methods

An extracted human tooth with fully formed roots and absence of cracks, fractures, and caries was selected for the study. To develop a 3D Finite Element Analysis model mandibular first molar were first scanned with Cone Beam Computed Tomography (CBCT).

The CBCT images were acquired using a CBCT scanner (Galileos, Sirona, Germany) at 85 kV and 35 mA by an experienced radiologist. The entire acquisition process was performed according to the manufacturer’s recommended protocol. The exposure time was set at 2–6 seconds, the voxel size of the images was 0.125 mm, and the slice thickness was 1.0 mm.4

The CBCT image of mandibular first molar is then transferred to Finite Element Analysis software to analyze the stress distribution. To analyze stress distribution, FEA and solidworks 2006 software (Dassault Systems S.A., Concord, MA USA) was used to prepare the mandibular first molar teeth with all the anatomical and morphological details.5 Different parts of the tooth including dentin and enamel were designed using the FEA software, ANSYS Workbench Ver.18.1 software (ANSYS Inc., PA, USA).

The three individual finite element models created, were as follows,

1. Unprepared and Unrestored Molar
2. Class II – Preparation and restored with Amalgam
3. Class II – Preparation and restored with Composite

The border conditions, defined by external limitations, contact structures and loading definition, are defined at the time of construction of lines and surfaces

The models were meshed for Mesio - Occulusal 106096 nodes and 69701 elements and for Disto – Occulusal 150673 nodes and 93715 elements. As boundary condition all nodes at the base of models were restrained so that all rigid bodily motions were prevented.5

The models were then transported to a limited element program to yield limited element networks. The following step included uploading the mechanical properties of each structure and selecting the loading conditions. All living tissues were assumed to be elastic, homogenous and isotropic. Then the respective elastic properties namely the Young’s modulus and the Poisson’s ratio were defined for dissimilar parts of the tooth, composite and amalgam.5

The restoration extent, location, and cavosurface line angles were chosen to adapt with standard cavity design for amalgam and composite preparations.6 The Class II cavity preparations were modeled to a width of No.245 bur (0.8mm) and depth of 1.5mm as measured at the central fissure and 2mm on prepared external walls.7,8 The width of the gingival seat in the proximal box is 0.8mm and the length of axial wall is 0.6mm. The cavosurface margin of the restored molar was modelled according to clinical practice. The molar with a composite restoration was presumed to be restored with dentin and enamel bonding, which needs the tensile and compressive stress components stay continuous across the cavosurface margin. To compare, the molar with amalgam restoration was modelled with unbounded margins to permit finite sliding interaction while preserving compressive stress continuity. A study of interfacial friction between the amalgam and margins has not been stated. Hence, the coefficient of friction (m) of 0.5 was randomly chosen to account for interfacial friction along the unbounded margins of the molar with an amalgam or composite restoration. It was anticipated that the definite value would be between 0.25 and 0.75 according to the standard range reported for different materials with rough surfaces.5

Cyclic compressive load equal to masticatory load (200N) was applied along the long axis of the tooth to the buccal cusp tip and mesial and distal ridges. The Von Misses stress distribution was investigated in dentin and enamel.

Result

The Finite element analysis was done for all the 3 models created using the finite element analysis software. Equivalent elastic stress and the Life Time of the restoration were analyzed.

Analysis of Unrestored Tooth

Equivalent Elastic Stress: The above figure 1 represents the unrestored tooth which is analyzed for the Equivalent (von-Mises) Stress with Cyclic load. The equivalent (von-Mises) Stress for Unrestored tooth is 3.3MPa.

Analysis of Class II Cavity Restored With Amalgam And Composite

Equivalent (von-Mises) Stress: The above figure 2 represents the amalgam restored tooth and figure 4 represents the composite restored tooth which is analyzed for the equivalent (von-Mises) stress of the restoration with cyclic load. The equivalent (von-Mises) stress on the tooth for the amalgam has stress of 3.7859MPa and composite has 3.524 MPa. Composite restored tooth has less load of the stress when compared to the amalgam.

Lifetime: The above figure 4 represents the amalgam restored tooth and figure 5 represents the composite restored tooth which is analyzed for restoration. Life time of the tooth for the amalgam of 5157.2 cycle and composite is 6358.2 cycle.

The Table1 shows the cyclic life time of the amalgam restoration of the restored teeth. As the life goes on the stress on the tooth also decreases.

The Table 2 shows the cyclic life time of the tooth restored with the composite restorations. The stress on the tooth restored with composite has stress values with several ups and downs.

Discussion

Human dental structures, and the restorations experience the internal stresses which are of great concern for both dentists and researchers. Once the tooth structure is compromised, it becomes further profound to fracture due to stress concentration in these area.9 Thermal variations on restored teeth or the abnormal biting force initiated by solid food or irregular chewing will also effect stress concentration and create teeth more vulnerable to fracture. The highest concentrated stresses in dental structures is significant for several type of dental treatments. Hence it is important to analyse the manner of stress distribution in dental structure and the access of highest concentration of stress.

The principal computational method used for stress analysis is finite element analysis (FEA). Finite element analysis can stimulate the stress distribution and predicting the sites of stress concentration and pointing of failure initiation within the structure of the material. Advantages of FEA when compared to other methods that they are low cost effective, less time to carry out the investigation and provides information which cannot be obtain by other methods.10

In direct filling materials, amalgam and composite resin are used in posterior stress-bearing area. Amalgam is used most commonly in posterior stress-bearing occlusal surfaces, especially for class II restorations in some countries. Due to patients, esthetic concern and hazards over mercury the use of amalgam is gradually declined.11

For the longevity of amalgam and composite resin as posterior restoration there has been a controversy. Composite resin restorations exhibited less longevity than amalgam restorations in a cross-sectional retrospective study. In a prospective randomized clinical trial it showed a higher 7 year survival rate in amalgam restoration than composite resin restorations.11,12

The reasons for amalgam replacement is due to poor margins and resulting secondary caries in posterior region were ascribed to biting force and creep. The initiation of creep occurs due to low – frequency cyclic stresses caused by mastication and thermal changes during ingestion of cold and hot foods. The reasons for composite restoration replacement is decrease in fracture strength and fatigue limit of adhesive within at adhesive – dentin interface, microleakage, unpredictability, unacceptable wear, time, postoperative sensitivity and placement and technique sensitivity in moisture control and polymerization shrinkage. 12,13,14

As the improvement occurred in composite resin materials and techniques in bonding which used as direct posterior restoration material. The comparative data are needed for longevity of amalgam and composite restoration for direct restoration under same conditions.12,14

The inherent physical properties of a material and the inadequate bonding plays a major role in failure of a restoration. Since the restoration function in a moist and dynamic environment they are exposed to thermal and mechanical fatigue by the opposing teeth and the result of this is a catastrophic failure of the restoration.15,16

Knowledge of the failure phenomenon and the bonding properties of the failed restorative material should be well known before planning for the replacement of a failed restoration.

The finite element analysis provides a better understanding of the failure phenomenon of a dental restoration.

Analysis of Class II Cavity Restored With Amalgam and Composite

The analysis compared the stress value for an unrestored tooth with the tooth restored with amalgam and composite restorations. The properties of the tooth and the restorative material used as per reference from previous studies.

All the previous studies compared only the static load analysis on the restoration, since the longevity of the restoration depends on the cyclic load and not on the static load, the analysis of this study will mimic the behavior of the restoration in an oral environment

The cyclic load of class II cavity restored with amalgam and composite shows that, the cyclic load on a ductile material like composite, makes the material to deform more than the stiffer material like amalgam.

The stress value for amalgam is 3.7859 MPa, which is more than the composite stress value of 3.524 MPa. The increase in stress in amalgam is due to the rigid nature of the material. Because of the rigidity there is not much of distribution of stress pattern, hence there is increase in the stress values in amalgam restoration.

Under cyclic load the life time of a composite restoration has a higher value of 6358.2 cycle than for the amalgam restoration, which has a value of 5157.2 cycle. Because of the decrease in the stress value the number of cycles of a restoration in use is also increased.

Based on the stress distribution in tooth resulting from simultaneous mechanical loads, the composite holds the better result. Further research has to be done to evaluvate the longevity of different composite resin restorations.

Conclusion

Within the limitations of the study, it can be concluded that,

Class II cavity restored with composite resin has less stress value and more life cycle when compared to an amalgam restoration.

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Legends Table and figure

Table 1: Life time analysis with alternate stress of amalgam restored tooth

Amalgam	
Cycles	Alternating Stress (Pa)
10	39990000
20	25270000
50	20960000
100	19130000
200	15690000
2000	9910000
10000	3620000
20000	2540000
100000	1880000
200000	1240000
1000000	892000