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Study By Finite Elements Of Stress Distribution by Comparing Behaviour Of 2 Types Of Composite

Research Article

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Abstract

The Finite Element Method (FEM) is a standard method used to simulate the stress distribution in dental restorations. The aim of this study is to compare, given their mechanical properties, the behavior of the composite resin "Saremco ELS® " (Saremco ELS, Rebstein Switzerland) to that of the nano-hybrid composite resin "TetricEvoFlow® " (Ivoclar, Vivadent, USA) in filling a class V cavity on a lower central incisor using the finite element method. An incisive load of 250 N acting at an angle of 60 ° with the axis of the tooth was simulated in order to highlight the possible consequences on the behavior of the two restorations, the effects of different loads and loading angles were also studied.

Keywords: Finite Element Method; Class V; Nanohybrid Composite; Fluid Composite; Comparative Study; Composite Resin.

Introduction

The aesthetic concepts of restorative dentistry have seen an important evolution in the last 30 years and have been the driving force behind the development of direct dental restoration materials [1].

The success of a composite dental restoration depends on many factors. Choosing the type of product based on the specific needs of the patient is a key element of this success. Elements of answers to these questions can be provided by examining mechanical magnitudes such as displacements, deformations and stresses [2].

These can be obtained by experimental measurements or numerical modelling. Finite Element Analysis (FEA) is commonly used to assess the biomechanical behaviour of biomaterials [3].

The objective of this study is to introduce the basic concepts of resolution of equations to partial derivatives by the finite element method.

The study of predictive deformations that follows this analysis then allows a better understanding of the patterns of distribution of constraints. In order to be able to estimate, with good precision, all of these mechanical sizes and to decide on the reliability of the composite material used, the method of the finished elements appears as a preferred tool.

This method consists of secreting a structure, such as a prosthesis, into a set of sub-domains, called finished elements or mesh, bound together by knots. In structure calculation, it consists of establishing a system of equations for the movement of all nodes of the mesh and deducing, following their resolution, the approximations of the fields of deformations and stresses.

The Finite Elements (MEF) method analyzes complex problems through mathematics. It was developed in 1943 by the Russian-

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Canadian Alexander Hrennikoff and the German-American Richard Courant to solve problems of elasticity and structural analysis in civil and aeronautical engineering. This method, easily programmable, has given rise to many software, called simulation by finite elements, to size parts in the industry.

The MEF is a secretisation (division) of the volume to be studied in a finite number of structural elements. Each subset is connected to the others by nodes to form the mesh of the room. The principle of the method is to postulate, within each element, the mathematical form solution to a problem posed. Continuity between adjacent elements ensures the functionality of the method [4].

Each node is therefore in equilibrium conditions (i.e. the forces are equivalent on either side of this node) and the solution will be in continuity between the adjacent elements.

The dissecting of the model is an approximation, which implies that the MEF is an approached analysis and that the quality of the calculated solution depends on the number of elements.

The problem posed on the original physical piece to be studied is represented on the model by a system of differential equations. Applying the constraint to the model generates simpler equations at each node. These solutions are then passed on to the entire structure [5].

Materiels and Methods

Four lower incisors were extracted from a patient who presented to the office.

After extraction, human teeth are carefully washed with running water and all blood and adhesive tissue removed using sharp-edged instruments. These teeth are then placed in a bacteriostatic /bactericidal chloramine-T trihydrate solution at 1.0% for up to one week and then stored in distilled water (ISO 3696: 1987, grade 3) in a refrigerator, at 4 degrees C rated in accordance with ISO 3696: 1987 1987 [6].

To minimize deterioration, it is essential that no other chemicals are used as it can be absorbed by the dental substance and impair its behaviour. Only one healthy, cavity-like incisor, 41, was selected.

Before any intervention, the digital acquisition of the external surface of the intact tooth is carried out using a scanner (Ceramill Map400, Amman Girrbach, Germany).

The cavity is prepared according to BLACK Class V principles [4]:

It is located at the level of 1/3 gingival in the occluso-gingival direction and at the median 1/3 level in the mesio-distal sense.

The side edges are straight, the fittings are rounded, no right angles, the axial wall is convex, the diverging side walls towards the outer surface, the horizontal occlusal wall parallel to the occlusal plane and the gum wall tilted towards the pulp provides a form of retention and resistance for restoration.

For the finish, the angle between the edges and the outer surface of the tooth will be 90 degrees and without bevels.

The cavity, 3 mm wide, 2 mm high and 2 mm deep, is prepared with a small caliber diamond ball strawberry (5801-314, Bush AG, Deutschland) mounted on a turbine. The cavity is finished with a strawberry diamond flame yellow ring (860EF-314-012, Bush AG, Deutschland [7].

Once the preparation is complete, the V-class tooth is scanned using the same scanner, and in the same way. Thus, the physical model will be transformed into a digital model that will be backed up in a STL file format.

For more precision, and as we work in the field of mechanics, not to neglect the presence of the pulp within the tooth, we take a CBCT.

At this point, our goal is to design a 3D model of a composite resin on a segmented and edited CBCT scanner of a central incisor incisor with a Class V cavity (according to Black). CBCT images in DICOM form are obtained from the Saint Joseph laboratory and imported into the segmentation software "SIMPLEWARE Scan IP".

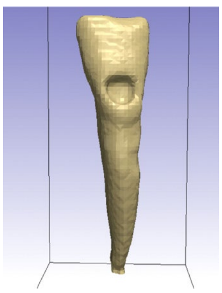
After setting a specific threshold, we manually modified the body in 3D to remove any uncertainty related to the scan.

The tooth model, with volume 3.27 x 102 mm3, was polished using a ratio of 1. (Fig 1)

The digital filling of the V-Class is made by the Ansys software of finished elements according to the criteria known for restoration by composite resin, using two materials characterized by different mechanical properties:

Saremco ELS ® and TetricEvoflow ®. (Fig 2)
These two composite resins are tested in this study.

Figure 1.



A. Digital simulation (Fig 3)

The tooth cavity restored by Saremco ELS ® and restored by TetricEvoflow ® is subject to a load of 250 N and applied to the palatal face, 2 mm from the free edge, with an angulation of 60 degrees in relation to the large axis of the tooth [4].

This study examined the strength properties of two resin-based restoration materials known to be recommended or used in Class V applications. (Fig 4)

The purpose of the study is to evaluate the mechanical behavior of the two materials under different load characteristics. Possible changes in the structure of the tooth due to the cavity and restoration material used and their consequences are studied in detail. With respect to the properties of the shutter materials used, it was considered that [8]:

a. The tooth under consideration is made of enamel, dentin and restoration material. The effect of the pulp is not studied since it is a soft material but it is still present.

b. The effects of the periodontal ligament, cement are neglected because of their low thickness.

c. The materials considered are supposed to be homogeneous, isotropic and linearly elastic.

Once the recording of the different parameters is made and the force applied, the analysis of the distribution and behavior of each material is carried out.

The mesh is generated in ScanIP and has the following characteristics: 10948 all tetrahedral elements and a roughness of -25.

These different data-setting steps are completed, (fig 5) the software enters the resolution phase. The method, applied in the context of the mechanics of structures in odontology, leads to the calculation in each node the field of movement and in each element the components of deformations and stresses. These quantities are the solutions of the differential equation system [8] The values of the finite element analysis are presented as maximum and minimum main constraints.

Figure 2.

Figure 3.

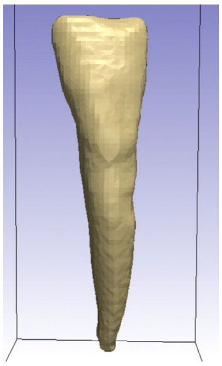


Figure 4.

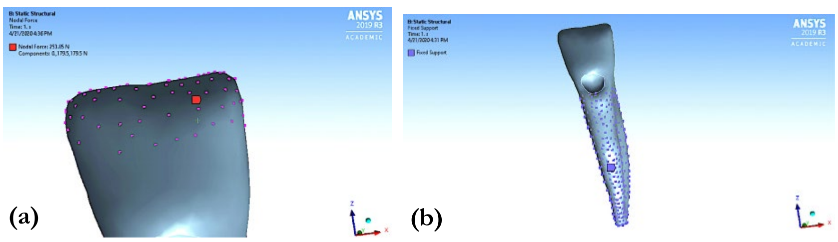
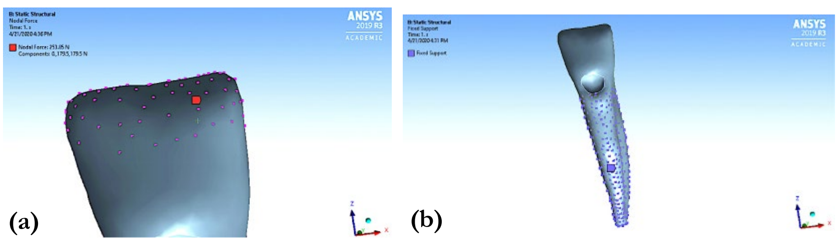


Figure 5.



In order to visualize these physical amounts on the model, a color scale is used to characterize the zones according to the calculated values. The majority of scales used are made up of several colors, classically warm colors (dark red) for the larger values in cold colors (dark blue) for the lowest values, although some authors use variations of gray, ranging from white to black or use a scale of their own.

Most previously published studies have analyzed the maximum values of the Von Mises plasticity criterion [9]. This is probably related to the fact that it is the main and most studied criterion for most engineering analyses, which generally deal with ducile materials such as steel and aluminum and not materials used in the biological environment [10].

The Von Mises test is known to be valid only for ductious materials with equal compression or traction resistance, but materials with fragile behaviour such as ceramics and cements have compression resistance values significantly higher than traction resistance [11].

Material properties [12]:

Different properties of the materials are attributed to both bodies.

The lower central incisor body than 18500 MPa Young module and a Fish coefficient of 0.35.

The Saremco ELS ® material has a 9000 MPa shear module while TetricEvoFlow ® has a 10,000 MPa shear module.

Due to a lack of reference for these two types of materials due to professional secrecy, we took a uniform fish coefficient of 0.3 for the two composite resins. This is an assumption we have made in order to fix an unknown value that is vital for our finite elements analysis.

After defining all the necessary engineering data, the constraint and strength are defined. The stress zone, as indicated in the node set 2, is defined to have a very limited movement in order to reproduce the biological condition.

No movement along the X, Y and Z axes and no movement around the Y and Z axes. Only a slight movement around the Y axis is allowed.

A region defined by the intersection of the two bodies: tooth and composite resin is also defined. This type of contact region reproduces the bond between the tooth and the Class V composite resin. No friction is allowed to minimize the parameters of the study.

A magnitude 250N force and a normal 60^{o} inclination to the Y axis is applied. This force is the result of two forces of 179.5 N along the X and Z axes.

The force is defined in "Ansys Static Structural" as a nodal force in order to be applied to the specific predefined area.

Results

Stress Analysis

The Von Mises stress is a theoretical stress value that represents the comparison between the general 3D stress and the uni-axial stress yield limit (Simscale), which is the maximum voltage stress limit that a specific material can retain without losing energy or permanently deforming.

Thus, it is necessary to evaluate the equivalent elastic stress and deformation of Von Mises as well as shear stress and maximum elastic deformation. Elastic deformation (initial deformation/length) is the maximum possible deformation without permanent deformation, being equivalent caused by the 3D combination of stresses in the case of a Von Mises stress as previously mentioned or maximum shear deformation by a shear stress. Both constraints are the result of the applied nodal force mentioned above. The finite element analysis result performed on Ansys Workbench was as follows:

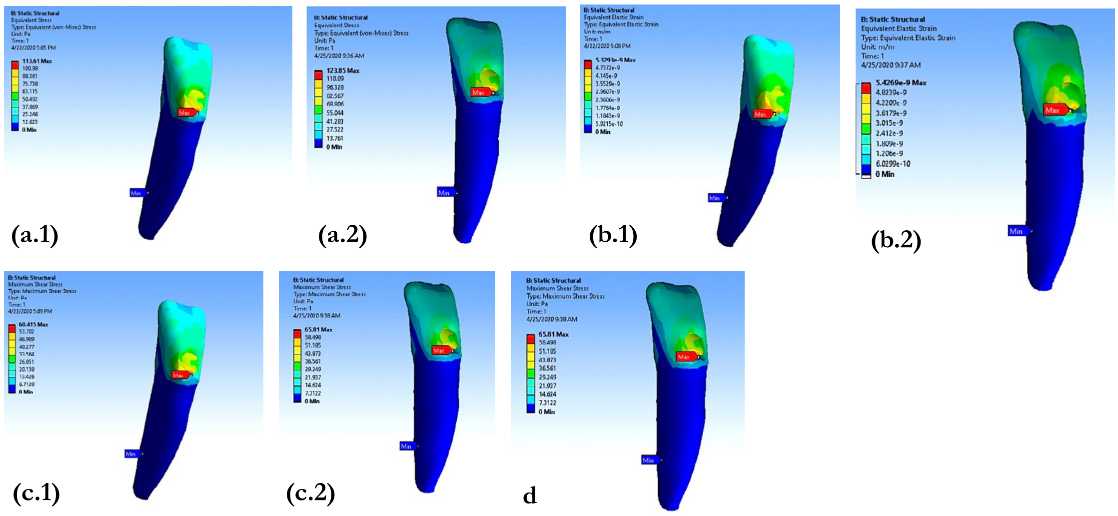
All of these models showed five stress concentration zones, identified and located in identical areas between the two models. They were on the cervical part of the cavity. (Fig 6-A,B,C,D)

Discussion

During modeling, dental roots and periodontal tissues were not represented to simplify the calculations by the finished elements. In addition, the absence of periodontal tissues and the recessing of dental bases have eliminated natural dental mobility. However, the absence of the periodontal ligament, giving an ankyllosis situation, increases the value of stresses within the composite material. The composition of the model was also simplified to limit the calculations: the endodonte was not represented and the teeth were considered to be entirely made up of dentin. In addition, the interface between the tooth and the V-Class dental cavity has been defined as a perfect contact. The collage was therefore not taken into account. The results are therefore to be nuanced. Indeed, the collage allows to absorb some of the stresses transmitted to the tooth. In physiological situations, the loads were applied to all the occlusal faces. The occlusal load applied to models 1 and 2 corresponds to a chewing force at the end of the dental cycle. The load was distributed perpendicular to the occlusal surfaces of the infrastructure. The most commonly used occlusal loads range from 100 N to 250 N depending on the teeth studied with a 60o inclination applied to two types of composite resins. We evaluated Von Mises stresses and equivalent elastic deformations on composites as well as shear stresses and elastic deformations. The equivalent and maximum maximummaximum shear stresses have significantly higher values when using the Saremco ELS material ® in the Class V composite, while the deformations are almost the same with a 0.0e1 mm increase in elastic deformation equivalent in the TetricEvoFlow material®.

Based on the unavailability of certain necessary mechanical properties for the two materials used for the composite, such as higher and lower yield values, our study is limited to comparing Saremco ELS materials® and TericEvoFlow® without comparing maximum equivalent stresses to their corresponding yield values.

Figure 6.



The maximum Von Mises equivalent stresses were 113.61 MPa for Saremco ELS® material and 123.85 MPa for TetricEvoFlow material®.

The structure studied would therefore be able to absorb occlusal stresses. The maximum stresses of models subjected to physiological occlusion were localized on the cervical faces. The action of chewing forces on different stress zones is almost identical to the two materials used in this study.

However, the TetricEvoFlow® material can withstand higher stresses (equivalent and shearing) and therefore greater forces while showing approximately the same deformation as the Saremco ELS material®. It is essential to mention again that a random fixed set value of 0.3 has been assigned to the two Fish coefficients due to the lack of available referenced information. We also note that these values can be generated experimentally in other studies on samples of both materials using a Universal Testing Machine (UTM).

The use of THE MEF has led to several simplifications concerning the volumes considered, the supposed isotropy and homogeneity of the materials, as well as the consideration of the main component of the chewing forces. This modelling by the finite elements was based on a specific situation and did not take into account the clinical variability of the different situations.

Conclusion

In conclusion, MEF analysis is a widely used technique, but one that has its limitations. Indeed, it allows to study a piece under a certain constraint, but can not anticipate cyclic fatigue. The limitations of the method are inherent in the simplifications made in modeling. In particular, heterogeneous or anisotropic materials are considered homogeneous isotropic due to the scale of studies [12]. Nevertheless, these model simplifications are inevitable in medical fields. The recorded properties allow the mechanical characteristics of materials to be assessed, but cannot account for the biological characteristics of living tissues during stresses. Moreover, the materials are supposed to be perfectly set up, which neglects the vagaries of the technical act in real-life situations [13]. Similarly, it is impossible to simulate dynamic biomechanical phenomena accurately. In odontology, occlusion has some variations in the same individual and is therefore not actually represented [14]. The MEF therefore allows to represent specific situations, but the individuality of clinical situations does not necessarily make its conclusions applicable to a set of situations.

The results must therefore be nuanced. It should be added that an analysis by the finite elements gives indications of the feasibility of a structure, a project, but does not replace clinical evaluations [15]. However, the MEF avoids the manufacturing phase. It allows the optimization of a geometric model. Indeed, the same model can be used with different characteristics. In addition, for a calculation performed, it is possible to extract different data. The use of this method can therefore replace multiple tests. It saves time and reduces the cost of studying mechanical behaviour.

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