3D Analysis of the Accumulated Stresses in a Premolar Restored with a Composite Inlay versus a Ceramic Inlay

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The aesthetic composite inlay or ceramic ones are useful for restoring posterior teeth affected by decay processes. The choice of the inlay type can sometimes be a challenge for the dentist. The aim of this study is to identify the optimal type of an inlay used for second-class cavities that can assure a good long-term prognosis of dental restoration. In order to achieve this study, it was performed a 3D analysis of stresses recorded in a premolar restored with a composite inlay and a ceramic inlay, the simulation being done by finite elements method (FEM) using ANSYS program. The study results showed that stresses registered in the tooth restored through ceramic inlay are more favourable than those recorded in the case of the tooth restored with composite inlay.

Keywords: dentistry, restoration, FEM, composite material, tooth-restoration

Adhesive physiognomic restorations, such as inlays, placed in the posterior areas of the oral cavity, have become an interesting alternative to dental elements with important coronary lesions [5, 9, 11]. Inlays of composite and ceramic materials are a fairly recent alternative and often used for reconstruction of coronary decay lesions, but also for no decay lesions, in the posterior areas of dental arches. They allow an aesthetic restoration of dental hard tissue which, unlike direct restorations has several important advantages [5, 6, 8]. The aesthetic composite inlays are preferred instead ceramic ones by many practitioners because of the advantages it presents: requires minimal preparations, technique is easier thanks to the easier handling of composite material, allow future adjustment of the occlusal surface, being easily adjusted and repaired, are radiopaque and, last but not least, have a lower cost [11, 12]. The question that arises frequently in medical practice is related to inlays behaviour in case of functional requirements, depending on the material from which they are made [1, 5-8]. Configuration of preparation, the technique and the materials used for cementing, and restorative materials can influence the type of resistance to fracture of these restorations [9, 12]. The ability of restorative materials to support the masticatory forces and distribution of stresses in the vicinity of the adhesive interface constitutes a decisive factor in acquiring a restoration with a high degree of resistance to fracture [9, 12]. Inlays of composite were tracked in various clinical trials, but, unfortunately, the short-term evaluations or studies that did not include a control material have not produced clear results. Studies on the ceramic inlays behaviour are also limited on this subject.

Thus, by the present study we wanted to establish conditions of tension and stress strain present in the tooth-restoration material, in this case a premolar restored through an inlay of composite material or ceramic, of a second class cavity. The study was conducted at the University Politehnica of Bucharest, by finite elements method using ANSYS program.

Experimental part

Materials and methods

To carry out the study were imagined several situations:

Case I – ensemble tooth - restoration material requested with a compression force, F = 250 [N], inclined at 30 ° to the longitudinal axis of the tooth. Force is applied to the reporting structure in the central area of the restoration material (fig. 1). The case I comprises two numerical simulations ranging nature of restoration:

Case Ia - the restoration material considered is ceramic.

Case Ib-restoration material considered is a composite material.

Case II - ensemble -tooth restoration material requested with a compression force, F = 250 [N], sloping at 30 ° to the longitudinal axis of the tooth. Force is applied to the reporting structure in two sides, areas at the boundary between enamel and inlay (fig. 1). Case II includes two numerical simulations ranging nature of restore:

Case IIa-restoration material considered is ceramic.

Case IIb - restoration material considered is a composite material.

Case III- ensemble tooth-restoration material requested with a traction force, F = 130 [N], aiming to simulate pulling effect due to food, especially those of the sticky nature (fig. 1).

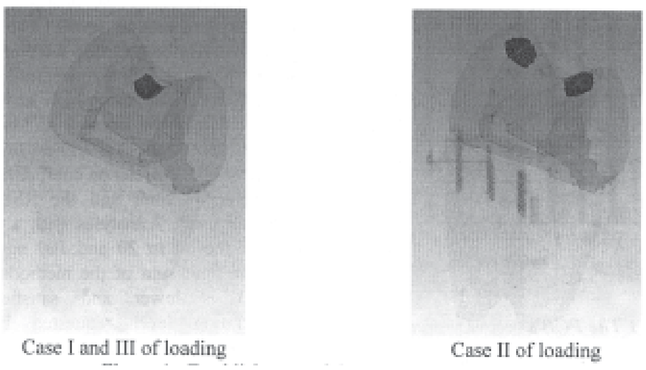

Fig. 1. Establishment of the area of external forces

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Table 1
ELASTIC CHARACTERISTICS OF THE MATERIALS

Material	Young modulus, **E**, [MPa]	Poison ratio, **ν**
Enamel	84100	0,3
Dentin	1860	0.3
Ceramic	78000	0.28
Composite	10000	0.24

Geometric model used for performing numerical simulation using finite element method was obtained on the basis of computer tomography (CT) made for a premolar. CT image processing was performed using a specialized program for reconstruction of 3D (three-dimensional), namely the MIMICSv13. After insertion of the CT files in the program MIMICS, based on the origin of black and white hue, intensity measured in unit's Hounsfield, we obtain the 3D form of the tooth, the 3D complex form due to the irregular geometry of the investigated structure. Initial it was obtained the shape of the tooth, geometrical model being represented only by exterior form like a network of triangles. In order to achieve the real tooth configuration it have been applied some reconstruction procedures for each component of the tooth (enamel, dentin, cement) taking into account the color intensity characteristic for each component. After all components have been rebuilt they were joined together, the end result being the premolar.

For doing the preparations in the enamel and dentin, using CAD tools (Boolean) type "*poly-plane cut*", it was detached a part of these components resulting in the cavity in which the inlay has to be cemented. The model obtained was exported from the program MIMICS to the ANSYS, program specializing in numerical simulations carried out aiming to establish a state of tension and stress strain that develops into a structure under the action of external loads.

On the imported model in ANSYS program there were defined areas where external loads will be applied in accordance with the cases listed above.

To geometric model, imported in ANSYS program, it was applied a process of meshing (fig. 2) aiming to transform triangular network of external and internal surfaces of the assembly into a finite element three-dimensional network.

Finite element used in meshing process is a finite element of tetrahedral shape type SOLID186. Finite element type SOLID186 represents an item with 20 nodes with three degrees of freedom per node, such as displacements on axes directions Ox, Oy, respectively Oz (fig. 3).

After the meshing process there were resulting 67738 nodes and 39545 elements. The materials used in the numerical simulations were considered to be homogeneous and isotropic. Numerical analysis performed is a static one.

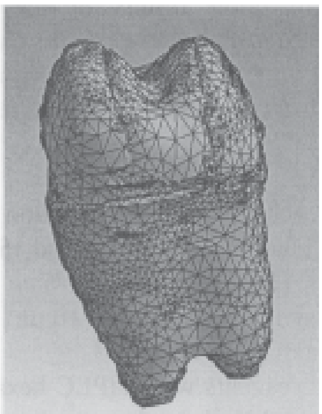

Fig. 2. Ensemble tooth –inlay in mesh form

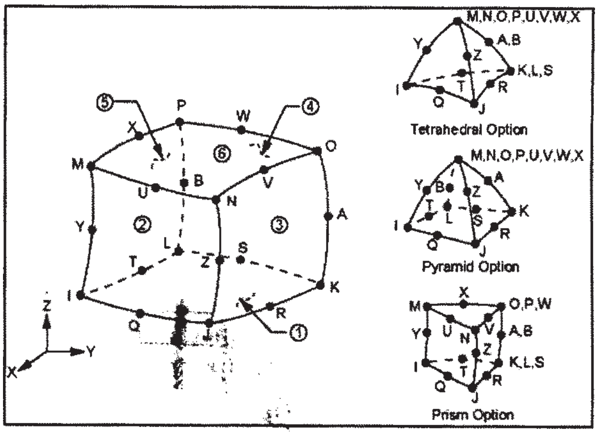

Fig. 3. Geometry of SOLID186 finite element

Results and discussions

Variation of displacements of the assembly in the case **Ia** and **Ib**

Analyzing figures 4 and 5 it can be seen that the maximum and minimum values occur on enamel-inlay interface. Also it was found that in the case of **Ib** (restore material being a composite material) values of displacements are higher, which may lead, in time, to the appearance of cracks (Caverns) which may spread leading to deterioration of inlay and finally to failure.

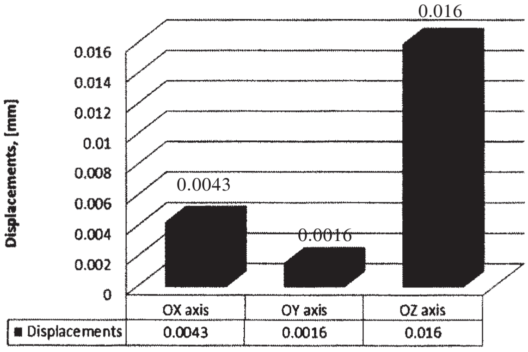

Fig. 4 Variation of displacements in the model - ceramics

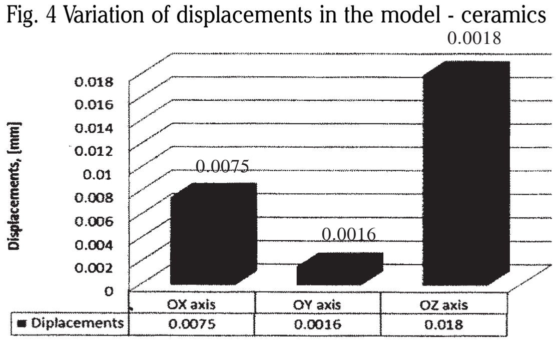

Fig. 5 Variation of displacements in the model- composite

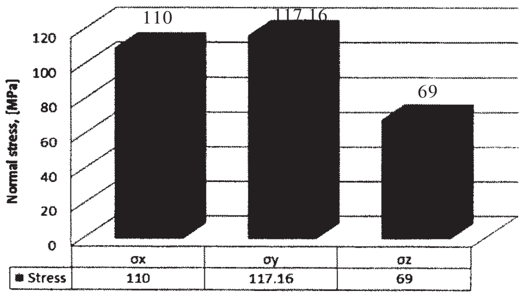

Fig. 6. Variation of normal stresses in model

The normal stresses for case **Ia** and **Ib**

The maximum stresses that appear in maps of variation (fig. 6) neglect, maximum values are due to the effect of concentration that occurs in the area of application of the force, which is local, and do not represent a real effect.

From the analysis of the variations of normal stresses it can be concluded that the integrity of the structure is not affected, the possible causes of failure can occur if the restoration procedure is not done properly.

Analyzing the variation maps of the normal stresses in figure 7 it can be seen as the stresses values vary between 40 to 85 MPa.

Variation of Displacements of assembly for the case **IIa** and **IIb**

Analyzing figures 8 and 9 it can be seen that the maximum and minimum values occur on enamel-inlay interface. Also it was find that in the case of IIb (where restored material was a composite material) values of displacements are higher which may lead, in time, to the appearance of cracks (Caverns) which may spread leading to deterioration of inlay and finally to failure.

The normal stresses for case **IIa** and **IIb**

The maximum stresses values which appear in the maps of variation (fig. 10) neglect, maximum values are due to the effect of concentration that occurs in the area of application of the force, which is local, and does not represent a real effect.

From analysis of the variations of normal stresses it can be concluded that the integrity of the structure is not affected, possible causes of failure can occur if the restoration procedure is not done properly.

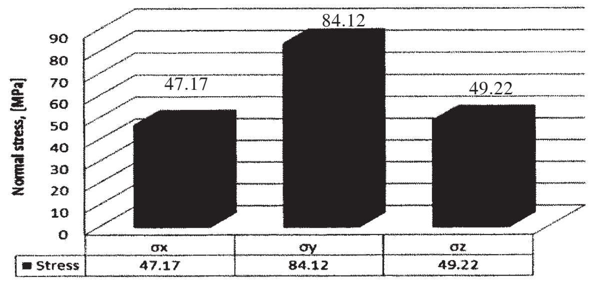

Fig. 7. Variation of normal stresses in model

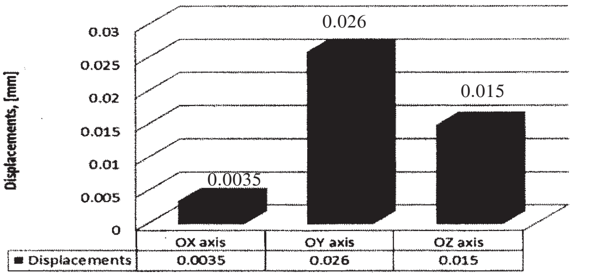

Fig. 8. Variation of displacements in the model

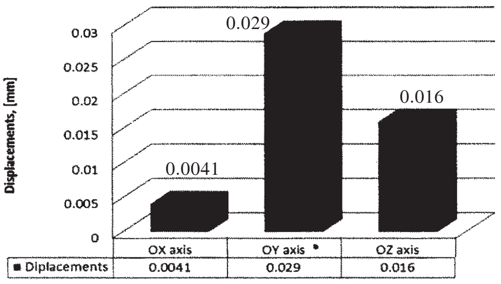

Fig. 9. Variation of displacements in the model

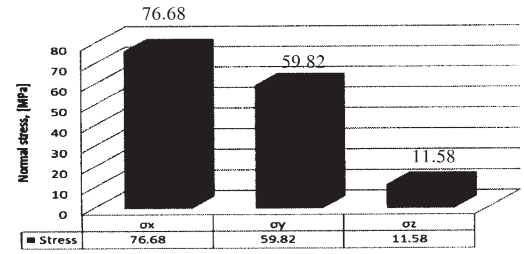

Fig. 10. Variation of normal stresses in model

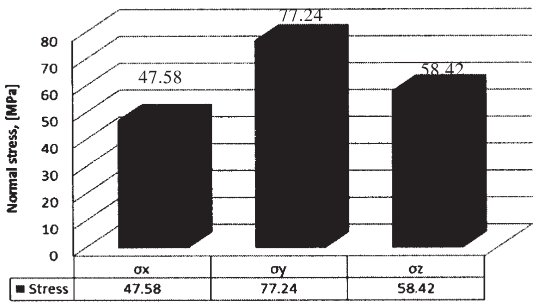

Fig. 11. Variation of normal stresses in model

Analyzing the variations of the normal stresses from the figure 13 is seen that the normal stresses that arise at the interface enamel-restoration material are due to the effect of stretching and compression, effect due to actuating force pitched under a certain angle. This condition can cause in the assembly a greater clip of the restoration material that could lead to shrinking life span of inlay.

As a general conclusion is that the structure is developing a small stresses in the case of numerical model which uses ceramic as a restoration material compared to the model on which the restore material is a composite one.

Results obtained from numerical calculation for Case III-ensemble tooth-restoration material required with a tensile force, F = 130 [N] were the following:

Traction force was applied only in the case of Ia of loading (fig. 1) analyzing the case when the material of restoration varies (ceramics and composite material).

The variation of displacements on the direction of loading (OZ) for the two materials

Analyzing figure 12 it was seen that the maximum and minimum values are occurring in the area of application of the traction force. Also is found that on the interface enamel - restoration material appear small values of displacements (Displacements in the direction of the force), which do not alter the functionality of restoration material - enamel ensemble.

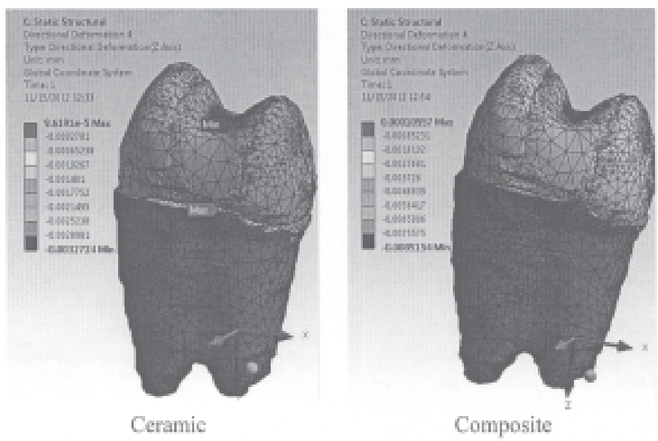

Fig. 12. Distribution of deformation in the two models explored

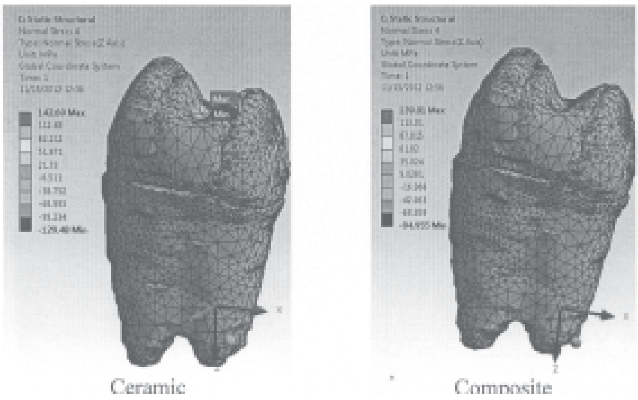

Fig. 13. Distribution of normal stresses in the two models explored

Investigating figure 13 it was found that normal stresses distribution, σ, determined on the direction of loading (in the OZ axis) throughout the entire model are tensions that do not put in jeopardy the integrity of the structure tooth-restoration material. Maximum values which can be seen in stresses maps (fig. 13) neglect, they appear locally, in the area of application of the force, stresses which do not persist by only appears when there is contact between the "sticky" substance and disappears immediately.

Conclusions

Studies that compare the behaviour of various types'of inlays which restores lateral teeth affected by decays, at the functional requirements of the dento-maxillary system, are not very numerous. One of these studies are evaluating the experimental fracture resistance of teeth restored with inlays [1, 2, 10, 13]. For this purpose the study used a feldspar ceramic (Duceram LFC) and three laboratory resins (Solidex, Artglass and Targis). The preparations were made of type MOD. The study results showed that the method of fracturing of the ceramic was predominantly an isolated fracture of restoration or a fracture of restoration involving a small portion of the tooth; these types of fracture characterizing the material bending and expressing a lower resistance of tooth structure. This represents a positive aspect, because when the restoration presents failures, fracture occurs invariably, and replacement of the restoration is preferable to achieve without removal of tooth structure. Alternatively, fracture of composite inlays was either a fracture involving more than half of the tooth or a fracture involving the periodontal tissue and lead to an uncertain prognosis of restoration. This demonstrates that the polymer materials accumulate and transmit stresses that exceed the strength of dental structure and this cause a combined fracture tooth-restoration. The results of this study show a better prediction of tooth-inlay in the case of the ceramic inlay restorations through the composite inlays.

Another study which concerns the same issues is that of Yamanel et al. [2], its results demonstrating that stresses recorded in case of a premolar restored with a ceramic inlay are lower than those recorded in case of a composite restoration.

Present study is consistent with the results shown in the specialty literature, noting that ceramics inlay behave better than the composite one when the tooth is subject to stresses that simulates natural forces during functional acts.

The maximum stresses that occur in the ensemble tooth-inlay can be found at the level of the enamel- inlay interface. These stresses have recorded higher values if the tooth was restored through a composite inlay than in the case of the tooth restored through a ceramic inlay. Thus, in the case of composite inlays, failures rate may be higher than in the case of ceramic inlays. Present study results suggest, that to ensure a long-term prognosis of a tooth restored through inlays, making a ceramic inlays and not a composite one is recommended.

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