Effect of preparation depth on stress distribution in premolars restored with MOD pressed ceramics inlays

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Abstract: The elastic modulus of the material is an important property in the longevity of the dental restoration. Ideally, the elastic properties of restorative materials should be close to those of the tooth structure to yield a more uniform stress distribution. The elastic modulus of pressed ceramics is close to that of the enamel and this is an advantage as restorative material. The existing literature revealed no clear guidelines for all the cavity parameters. The aim of the study was to assess the influence of cavity preparation depth on failure risk of pressed ceramic MOD inlays by means of finite element analysis. 3D models of maxillary first premolars, prepared for MOD inlays with different depths of the horizontal cavity were generated (between 1.5 and 3.1 mm). The mesh structure of the solid 3D model was created using the computational simulation of Ansys finite element analysis software. An occlusal load of 200 N was conducted, and stresses occurring in the pressed ceramics MOD inlays, and teeth structures were calculated. The study provides a biomechanical explanation for inlays restored teeth. MOD inlays transfer functional stress to the teeth structures. The highest stresses were registered in the enamel. It is important to avoid placing the margins of the preparations in the contact areas with the antagonists. The depth of the preparations had no significant influence on the stress values for the studied cases.

Key-Words: pressed ceramics inlays, premolar, MOD cavity depth, 3D model, finite element analysis, stresses.

1 Introduction

For prosthetic restorative materials, the ability to withstand the masticatory forces in the oral cavity is essential. The elastic modulus of the material is an important property in the longevity of the dental restoration. Ideally, the elastic properties of restorative materials should be close to those of the tooth structure to yield a more uniform stress distribution. However, the tooth consists of enamel and dentin that are very different elastically [1]. The elastic modulus of pressed ceramics is close to that of the enamel and this is an advantage as restorative material.

Ceramic inlays can be used on premolars requiring a MOD restoration instead posterior composite resins direct restorations and offer a durable alternative. In addition, with indirect restorations, the occlusion and proximal contacts can be adjusted more easily and there is better placement control. Because it is known that MOD inlays may increase the susceptibility to fracture, it is important to ensure optimal performance in selection of the adequate preparation design to reduce stresses in teeth structures and also in the restorations [2, 3]. The existing literature revealed no clear guidelines for all the cavity parameters. The tooth preparation is performed manually, which makes it difficult to maintain design accuracy, even if an ideal outline was previously defined. Precise preparations are necessary for ceramic restorations [4, 5]. There is little information regarding the preparation depth for inlays.

Teeth become more susceptible to fracture if they have been prepared for restorations. Large restorations have been considered the principal factors to predispose a tooth to fracture, and adequate preparation guidelines are important. Cavity preparations significantly weaken the remaining teeth structures. The effect of masticatory stresses on teeth is variable [6].

However, some studies show that inlays do not restore the original strength of tooth tissues. Other studies on strength of MOD prosthetic restored teeth could not resolve which restoration material provides greater strength and marginal integrity [7, 8, 9]. Current ceramic materials in inlay restorations seem to perform as well as other restorative options

for selected properties during the first years after placement [10].
Modern design and valuation in order to obtain an adequate strength involves numerical simulations. Finite element analysis (FEA) has been widely employed in many researches to investigate the impact and effect of dental materials and restorative techniques on stress distribution. FEA is deemed as an effective tool to evaluate the biomechanical characteristics of these dental restorative materials and systems, whereby the results carry significant clinical implications [11].

2 Purpose

The aim of the study was to assess the influence of cavity preparation depth on failure risk of pressed ceramic MOD inlays by means of finite element analysis.

3 Materials and Method

Experimental 3D models of the first upper premolars were achieved in order to design and analyze teeth, and ceramics MOD inlays. Surfaces were modeled according with anatomical dimensions. The nonparametric modeling software (Blender 2.57b) was used in order to obtain the shape of the crown, with enamel, dentin and pulp structures.
The collected data were used to construct three dimensional models using Rhinoceros (McNeel North America) NURBS (Nonuniform Rational B-Splines) modeling program. These points were used to extrapolate the shape of the object, a process called reconstruction.
3D models of maxillary first premolars, prepared for MOD inlays with different depths of the horizontal cavity were generated (between 1.5 and 3.1 mm). Inlay cavities designs were created using literature data (Fig. 1).

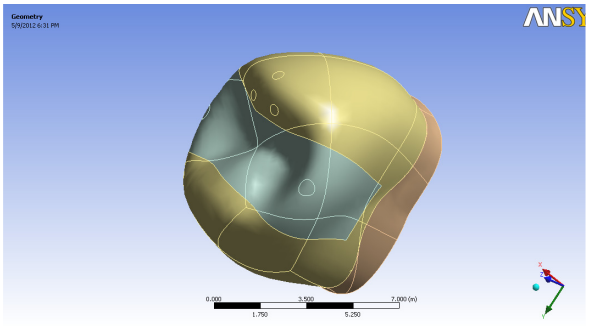

Fig. 1. Volume of the prepared premolar and the inlay.

The mesh structure of the solid 3D model was created using the computational simulation of Ansys finite element analysis software (Fig. 2).

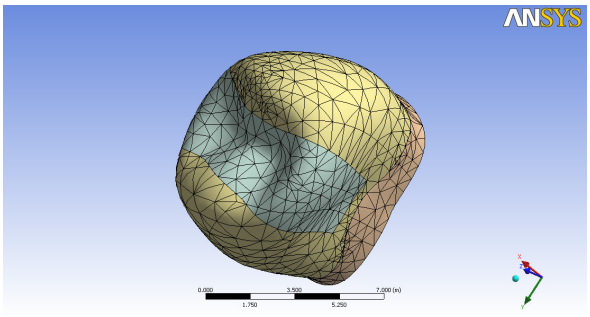

Fig. 2. Mesh structure of the inlay restored premolar.

An occlusal load of 200 N was conducted, and stresses occurring in the inlays, and teeth structures were calculated. It was applied in 5 points: to the mesial and distal marginal ridge, and buccal cusp (3 points). At each selected loading point, a load of 40 N was applied perpendicular to the surface in that point (Fig. 3).

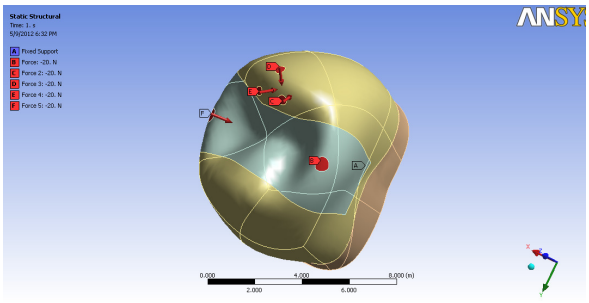

Fig. 3. Points selected for loading on the restored premolar.

In making the finite element models, the characteristics of a tooth structures, and ceramics used for the restorations were entered into the computer program.

3 Results and Discussions

For all cavity designs, stresses in the MOD restoration, enamel, and dentin were evaluated separately (Table 1).
The highest stress values were exhibited in the enamel in all cases (Fig. 4).

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Table 1. Maximal Von Mises equivalent stress values in the prepared premolar and in the inlay.

Depth [mm]	Maximal Von Mises equivalent stress [Pa]			
	total	dentin	enamel	inaly
1.5	1.03E+08	9.73E+06	1.03E+08	4.91E+07
1.7	9.24E+07	9.73E+06	9.24E+07	4.86E+07
1.9	8.54E+07	9.78E+06	8.54E+07	4.85E+07
2.1	9.11E+07	9.68E+06	9.11E+07	4.85E+07
2.3	9.02E+07	9.71E+06	9.02E+07	4.88E+07
2.5	9.19E+07	9.73E+06	9.19E+07	4.98E+07
2.7	9.02E+07	9.73E+06	9.02E+07	4.98E+07
2.9	8.98E+07	9.59E+06	8.98E+07	4.82E+07
3.1	1.00E+08	9.66E+06	1.00E+08	4.87E+07

The highest stress values were exhibited in the enamel in all cases (Fig. 4).

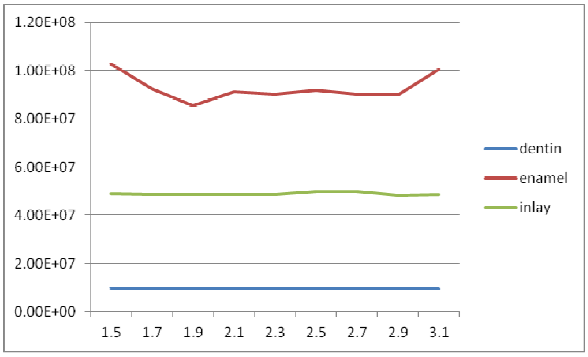

Fig. 4. Distribution of the maximal Von Mises equivalent stress values in the prepared premolar and in the inlay.

Occlusal load on an MOD restored tooth produces stress surrounding the contact areas in the restorations and in the enamel (Fig. 5 - 7). The maximal values are two times higher in the enamel. In the enamel stresses are located around the contact areas for inlays prepared teeth and therefore it is important to avoid placing the margin of the preparation in the contact area with the antagonist.
In the dentin maximal stresses were distributed around the cervical areas. The values are about ten times lower than in the enamel (Fig. 8).
The values increase in the enamel for the limits of the studied cases.

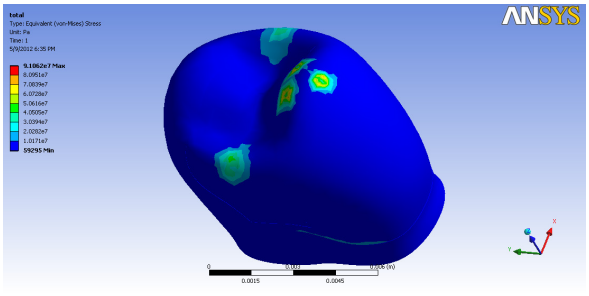

Fig. 5. Von Mises equivalent stress in the ceramic inlay restored premolar.

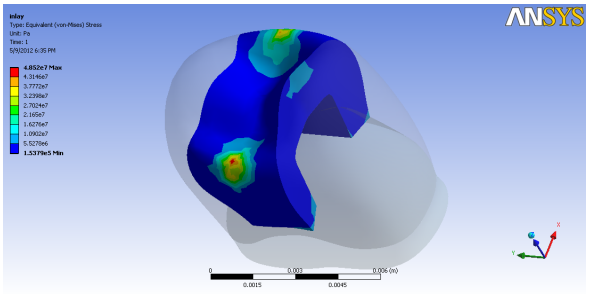

Fig. 6. Von Mises equivalent stress in the inlay.

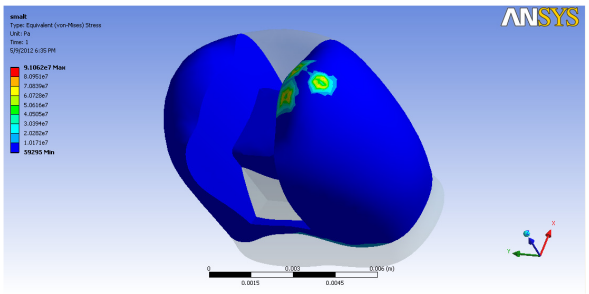

Fig. 7. Von Mises equivalent stress in the enamel of ceramic inlay restored premolar.

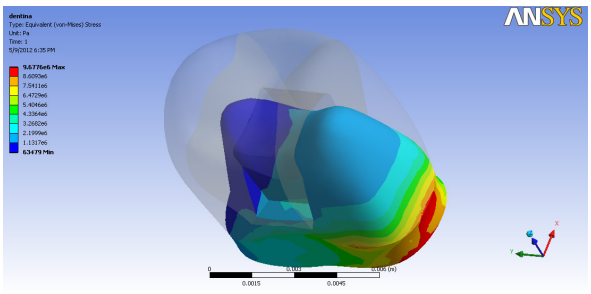

Fig. 8. Von Mises equivalent stress in the dentin of ceramic inlay restored premolar.

For other types of ceramic restorations preparation design and the amount of existing tooth structure had a significant effect on load to failure [12].

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The fracture resistant strength of teeth restored with ceramic inlay was comparable to that of the normal intact teeth or slightly higher [6]. Ceramic inlays restore the strength of the natural teeth from biomechanical point of view.

Regarding the preparation depth no significant variations were registered in the studied interval (depth of the horizontal cavity between 1.5 and 3.1 mm). Some authors indicate a proximal box elevation as an alternative to conventional techniques for deep proximal boxes ending in dentin [13].

All-ceramic restorations offer a predictable and successful restoration with an estimated survival probability of over 90% after 10 years. Significantly increased failure rates are associated with bruxism, nonvital teeth, and specific cementation agents [14, 15].

4 Conclusion

Within the limitations of this study, the following conclusions were drawn:

1. The finite element study provides a biomechanical explanation for inlays restored teeth.
2. MOD inlays transfer functional stress to the teeth structures. The highest stresses were registered in the enamel.
3. It is important to avoid placing the margins of the preparations in the contact areas with the antagonists.
4. The depth of the preparations had no significant influence on the stress values for the studied cases.

5 Acknowledgements

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