Finite Element Analysis of MOD Prosthetic Restored Premolars

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Abstract: Inlays and onlays can be used on premolars requiring a MOD restoration instead posterior composite resins or amalgam direct restorations and offer a durable alternative. Because it is known that MOD restorations 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. However, inlays and onlays do not restore the original strength of tooth tissues. The aim of the study was to determine, using finite element analysis, the optimal shapes of metal and ceramics MOD restorations in premolars in order to minimize the potentially damaging effects of stress on teeth structures and restorations. The study was performed on an upper first premolar, using a finite element analysis. 3D models of maxillary first premolars, prepared for MOD inlays and onlays with different tapers were generated. 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 metal and ceramics inlays, onlays and teeth structures were calculated. In the MOD onlays recorded maximal stresses were higher than in the MOD inlays in the most cases. In the ceramics restorations the stresses were higher than in the cast metal. Regarding the prosthetic restorations material, in the ceramics inlays and onlays the stress values were higher. MOD inlays transferred more functional stress to the teeth structures compared to the MOD onlays.

Key-Words: premolar, MOD cavity design, cast metal restoration, inlay, onlay, 3D model, stress analysis.

1 Introduction

Inlays and onlays can be used on premolars requiring a MOD restoration instead posterior composite resins or amalgam direct restorations and offer a durable alternative. Because it is known that MOD restorations 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. Inlays restore central cavities in teeth. Onlays restore one or more cusps and may completely cover the occlusal surfaces, resulting in a favorable distribution of stresses in teeth and a decreased risk of fractures. However, preparation for onlays requires additional tooth reduction relative to inlay restorations [1, 2].

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 [1]. Large restorations have been considered the principal factors to predispose a tooth to fracture, and adequate preparation guidelines are important. Irrespective of the cavity preparation design, preparations weaken teeth. To reduce loss of tooth tissue and to improve biomechanical results, inlay and onlays restorations are good treatment choices for extensive cavities in posterior teeth [3, 4].

Cast metal inlays and onlays can prove to be extremely long-lived restorations because of the excellent mechanical properties of the gold alloys. Ceramic inlays are primarily composed of leucite-reinforced ceramics. The disadvantages of ceramic are its hardness, which is greater than enamel, low fracture resistance, and low fatigue strength. The primary causes of failure of ceramic inlays are cohesive bulk fractures and marginal deficiencies. Ceramic inlays maintain better anatomic form of the surface and exhibit better marginal integrity, as well as stabilize the weakened cusps better than composite resin inlays [5-12]. However, inlays and onlays do not restore the original strength of tooth tissues. Previous studies on strength of MOD prosthetic restored teeth could not resolve which restoration material provides greater strength and marginal integrity [13,14].
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 [15,16]. Modern design and valuation in order to obtain an adequate strength involves numerical simulations.

2 Purpose

The aim of the study was to determine, using finite element analysis, the optimal shapes of metal and ceramics MOD restorations in premolars in order to minimize the potentially damaging effects of stress on teeth structures and restorations.

3 Materials and Method

Detailed three-dimensional models are required to better understand the mechanical behavior of teeth structures and prosthetic dental restorations. The first step of the study was to achieve 3D models in order to design and analyze teeth, metal and ceramics MOD inlays and onlays. The study was performed on an upper first premolar, using a finite element analysis. Surfaces were modeled according with anatomical dimensions. The nonparametric modeling software (Blender 2.57b) was used in order to obtain the shape of root, enamel, dentin and pulp structures (Fig. 1).

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 (Fig. 2). Reconstruction involves finding and connecting adjacent points in order to create continuous surfaces. Nonuniform rational B-spline (NURBS) is a mathematical model commonly used in computer aided design, manufacturing and engineering.

3D models of maxillary first premolars, prepared for MOD inlays and onlays with different tapers (between 0 and 10 degree from the cavity base to the surface) were generated (Fig. 3). In the onlay cavity, cusps were reduced and included in the preparation. Inlay and onlay cavities designs were created using literature data.

The mesh structure of the solid 3D model was created using the computational simulation of Ansys finite element analysis software (Fig. 4).
An occlusal load of 200 N was conducted, and stresses occurring in the inlays, onlays 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. In making the finite element models, the characteristics of a tooth structures, gold alloy and ceramics used for the restorations were entered into the computer program (Table 1).

### Table 1. Elastic properties of the isotropic materials.

<table>
<thead>
<tr>
<th>Material/component</th>
<th>Elastic modulus [GPa]</th>
<th>Poisson’s ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dentin</td>
<td>18.6</td>
<td>0.32</td>
</tr>
<tr>
<td>Enamel</td>
<td>84.1</td>
<td>0.33</td>
</tr>
<tr>
<td>Gold</td>
<td>70</td>
<td>0.30</td>
</tr>
<tr>
<td>Ceramics</td>
<td>204</td>
<td>0.31</td>
</tr>
</tbody>
</table>

### Results and Discussions

For all cavity designs and restoration type, stresses in the restoration, enamel, and dentin were evaluated separately (Fig. 5).

In the onlays recorded maximal stresses were higher than in the inlays in the most cases. In the ceramics restorations the stresses were higher than in the cast metal.

Stresses in the enamel were approximately 10 times lower in the teeth prepared for onlays, compared to the teeth prepared for inlays. Between the values for ceramics and cast metal restorations there were no significant differences.

In the dentin maximal stresses were also similar for ceramics and cast metal restorations, for the same preparation design. Depending on the taper, they were higher for inlays or onlays, in the most cases for inlays.
For teeth restored with cast metal inlays stresses were higher in enamel than for those restored with ceramic inlays. Regarding the restorations, in the ceramic inlays the stress values were higher. In the dentin the stresses were more than 10 times lower for both type of inlays (Fig. 6, 7).

Fig. 6. Von Mises equivalent stress values for cast metal inlay.

Fig. 7. Von Mises equivalent stress values for ceramic inlay.

Regarding the stresses in the onlay restored teeth values in enamel and dentin were about 15 times lower than in the restorations with no significant differences between the two structures. In the ceramic onlays stresses were higher than in the cast metal (Fig. 8, 9).

Fig. 8. Von Mises equivalent stress values for cast metal onlay.

The highest stress values were exhibited in the restoration in the most cases. Occlusal load on an MOD restored tooth produces stress surrounding the contact areas in the restorations and in the enamel (Fig. 10). In the enamel stresses are located around the contact areas for inlays prepared teeth and distributed in the functional cusp and around the buccal cervical area for the onlays prepared teeth. For onlays restored teeth the variations for different tapers were smaller than for inlays restored teeth.

Fig. 9. Von Mises equivalent stress values for ceramic onlay.

Fig. 10. Von Mises equivalent stress in the ceramic inlay restored premolar.

Regarding the distribution of stresses in dentin, they are located in the cervical areas, around the teeth for all cases (Fig. 11, 12).

Fig. 11. Von Mises equivalent stress in the dentin of ceramic inlay restored premolar.
4 Conclusion
Within the limitations of this study, the following conclusions were drawn:
1. In the MOD onlays recorded maximal stresses were higher than in the MOD inlays in the most cases. In the ceramics restorations the stresses were higher than in the cast metal.
2. Regarding the prosthetic restorations material, in the ceramics inlays and onlays the stress values were higher.
3. MOD inlays transferred more functional stress to the teeth structures compared to the MOD onlays.
4. The taper of the preparations had no significant influence on the stress values for all the studied cases.

4 Acknowledgements
This work was supported by CNCSIS-UEFISCSU, project number PN II-RU TE_217/2010.

References: