Cavity Depth vs Cavity Width in Generating Stress Patterns: A FEA Study

ABSTRACT

Indirect tooth restoration involves customized tooth replacements in the form of crowns, onlays, or inlays. The preparation design for an indirect restoration must maintain a balance between preserving the tooth structure and obtaining sufficient retention and resistance. Ceramic inlays have gained popularity because of their esthetic appearance and improved physical and mechanical properties. The resistance to fracture is directly related to the amount of remaining tooth structure. The widened marginal ridges, the increased width of the isthmus and the increased depth of preparation are the main reasons for the decrease in resistance. The masticatory loads in the posterior region are much higher than in the anterior region. Amongst the posterior teeth, the premolars suffer the most from vertical fracture. The finite element method is considered as an important tool to study stress distribution. Hence, in this study, we will compare the influence of cavity depth and width in generating stress patterns in premolars restored with ceramic inlays using finite element analysis (FEA).

KEYWORDS ceramic inlays, cavity depth, cavity width, stress patterns, FEA (finite element analysis)

INTRODUCTION

Ceramic inlays are very popular nowadays because of their esthetic appearance and improvement in physical and mechanical properties. Their primary use is in compromised posterior teeth with intact buccal and lingual walls. These restorations offer the opportunity to conserve tooth structure while taking advantage of the mechanical benefits of modern adhesive technology, which can strengthen the compromised tooth. Ceramic inlays are more susceptible to failure on either external or internal surface of the restoration. They can be bonded to tooth structure and some restorative materials, to decrease micro leakage and strengthen the restored tooth.

The amount of cavity preparation is directly related to the decrease of cusp stiffness. The depth and width may affect cusp deflection and tooth fracture strength. The resistance to fracture is directly related to the amount of remaining tooth structure. The removal of marginal ridges, the increase in the width of the isthmus, and the increase in the gingival depth of the preparation are the main reasons for the decrease in resistance.

The finite element method (FEM) is considered an important tool in the study of complex systems. It offers significant information that can assist the identification of sites within the tooth/restoration complex that are more susceptible to failure on either external or internal surface of the models. FEM also allows the identification of stress distribution that cannot be evidenced by other methods.

The aim of this study was to investigate the effect of the increased width of the isthmus and the increased depth of preparation using finite element analysis. The null hypothesis was that stress values were not significantly influenced by the increased width of the isthmus and the increased depth of preparation.

MATERIALS AND METHODS

Finite element models

A 3D model of a human mandibular second premolar was generated using its anatomical considerations. The external and internal contours were outlined and subsequently assembled. Crown and roots were constructed in two different phases and assembled. Literature data on the tooth mor-
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A parametric cutting plane was chosen to generate two cavities i.e. (conventional depth & increased width and conventional width & increased depth) keeping the volume of the cavities constant. The cavity design was characterized by flat floor and sharp internal line angles. No bevel was considered at the proximal and occlusal margins. The solid model was transferred into an FEA program (ANSYS 13.0) where a 3D mesh was created.

Different material properties were now assigned to the elements, according to the volume definition. The modeling of the adhesive area in the Class II inlay preparation was differently realized. The other part was modeled to be the resin luting cement, contacting adhesive layer from one side and the restorative material from the other side. Then, these inlay cavities were restored with two different ceramic inlay materials i.e. LAVA and EMAX. A 200 N force was applied on occlusal surface.

Following this, four groups were made

Group A Conventional depth + increased width + LAVA
Group B Conventional width + increased depth + LAVA
Group C Conventional depth + increased width + EMAX
Group D Conventional width + increased depth + EMAX

Properties of the material used are presented in Table 1.

Table 1 Properties of the material used.

<table>
<thead>
<tr>
<th>Material</th>
<th>Modulus of elasticity (E) Gpa</th>
<th>Poisson’s ratio (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enamel</td>
<td>84.1</td>
<td>0.33</td>
</tr>
<tr>
<td>Dentin</td>
<td>18.6</td>
<td>0.31</td>
</tr>
<tr>
<td>Pulp</td>
<td>0.002</td>
<td>0.45</td>
</tr>
<tr>
<td>Cortical bone</td>
<td>13.7</td>
<td>0.30</td>
</tr>
<tr>
<td>Cancellous bone</td>
<td>1.37</td>
<td>0.30</td>
</tr>
<tr>
<td>EMAX</td>
<td>95</td>
<td>0.30</td>
</tr>
<tr>
<td>LAVA</td>
<td>12.77</td>
<td>0.30</td>
</tr>
<tr>
<td>Resin cement</td>
<td>10</td>
<td>0.24</td>
</tr>
</tbody>
</table>

RESULTS

The results are presented in terms of von Mises stress maps in MPa, which were computed within ANSYS using the von Mises shear-strain-energy failure criterion, as an outcome of the 200 N occlusal loading.

Figures 1 and 2 depict the use of ceramic material LAVA to restore the tooth. It shows that on increasing the width of the cavity, the maximum stress on tooth increased to 36.5 Mpa, while keeping the volume of cavities constant, we increased the depth of the cavity, the maximum stress decreased to 33.6 Mpa. The results also portrayed that the maximum stress occurs on the tooth rather than on the inlay material itself.

Figures 3 and 4 depict EMAX was used in both the groups. It shows that on increasing width of the cavity the maximum stress on tooth increased to 26.1 Mpa when we increased the depth of the cavity, the maximum stress decreased to 24.6 Mpa. The results also show that the maximum stress occurs on the inlay material. Here too, the volume of both cavities was kept constant.

From the above two comparisons, it is also clear that on keeping the volume of preparation constant, the increased width of preparation generated more stresses as compared to increased depth of preparation.

While comparing Figs. 1 and 3 having same cavity preparation (Conventional depth + increased width) but with different restorative materials, that is, LAVA and EMAX, it was seen that maximum stress was with LAVA, which was 10% more and also LAVA distributed the stress to tooth while the EMAX distributed stress amongst itself.

On comparing Figs. 2 and 4 with the same cavity preparation (conventional width + increased depth) but different restorative materials, that is, LAVA and EMAX, it was seen that maximum stress was with LAVA, which was 9% more and also LAVA distributed the stress to tooth while the EMAX absorbed the stress and did not transfer it to the tooth.

DISCUSSION

The present study evaluated the effect of different ceramic materials and the effect of inlay width and inlay depth
on stress distribution. The material of the ceramic inlay significantly influenced the level of tensile stress within the ceramic inlay. Accordingly, EMAX inlays consistently showed lower peak stress values than LAVA inlays. Since, additionally, the modulus of elasticity for EMAX inlays (95 MPa) is significantly higher than for LAVA inlays (12.77 MPa). Materials with lower elastic modulus may lead to decreased strength of the restoration\textsuperscript{13} and result in increased stress concentration in regions adjacent to it\textsuperscript{14}.

Due to this, in the case of EMAX inlay stress remains within the inlay, but in the case of LAVA, stress is transferred to tooth structure. Hence, EMAX was better than LAVA in extensive inlay preparation as it prevented fracture of tooth structure better than LAVA.

Preservation of sound tooth structures is the primary goal of modern restorative dentistry. However, from a biomechanical point of view, protection of remaining tooth structures from unfavorable mechanical responses
should be considered a priority, even if it requires the removal of additional dental tissue\textsuperscript{17,18}. Due to their unfavourable anatomy, maxillary premolars with extensive MOD cavities are at great risk of fracturing if restored without regarding protective principles\textsuperscript{19,20}. In the present study, it was seen that on increasing width of preparation more stresses were generated as compared to increased depth and this increased width may also cause cuspal deflections.

**CONCLUSION**

From this, FE analysis on stress-distribution in inlay restored with different ceramic materials it was seen that Inlay width generates more stresses than inlay depth. EMAX is better than LAVA in extensive inlay preparation so EMAX should be preferred over LAVA in case of extensive inlay preparations. Also, the width of a cavity plays a pivotal role in prognosis of a tooth in comparison to its depth.

**REFERENCES**