Biomechanical impact during protrusion loading on an incisor restored with a ceramic crown

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Abstract: The fracture resistance of all-ceramic restorations is one of the major concerns in clinical applications of these materials. Finite element analysis is usually applied in the studies of this area without considering changes in contacts with the antagonists teeth during the occlusal movements. A 3D model of a incisor was created: intact teeth, unrestored teeth; the same teeth restored with full ceramic crown. A virtual analysis of the protrusion was carried out and a trajectory path was designed and divided in 6 areas. The contact areas were visualized and loaded separately. Stress distribution of the restored incisor during protrusion stages was analyzed. These were exported in Ansys finite element analysis software for structural simulations. In the crowns the stresses were distributed around the contact areas with the antagonists and in the cervical areas. Regarding the stress distribution in the prepared teeth, the areas were larger around the marginal line, especially under the line. The biggest disadvantage is that high stresses are present around the marginal areas. During protrusion and moving of the contact area incisaly, the maximal values of the stresses increase and also the stress areas become greater in the oral part of the crown. Considering changes in contacts with the antagonists teeth during the occlusal movements is very important for a biomechanical analysis.

Key-Words: ceramic crown, incisor, protrusion, finite element analysis, stresses.

1 Introduction
Ceramic materials become more important in dental prosthodontics in the last years due to their esthetics and biocompatibility [1, 2].
Dental ceramics have a composite structure with a crystalline phase and a glassy matrix. Materials for all-ceramic restorations use a wider variety of crystalline phases as reinforcing agents and contain up to 90% by volume of crystalline phase. The nature, amount, and particle size distribution of the crystalline phase directly influence the mechanical and optical properties of the material [1]. Increasing flexural strength and fracture toughness are desirable to resist the fracture of ceramic restoration [3]. The strength increase of hot-pressed leucite-based ceramics is attributed to a good dispersion of the fine leucite crystals as well as the tangential compressive stresses arising from the thermal contraction mismatch between the leucite crystals and the glassy matrix. [1].
However they are, brittle, have limited tensile strength, and are subjected to time-dependent stress failure [1, 2, 4]. The fracture resistance of all-ceramic restorations is one of the major concerns in clinical applications of these materials. Therefore before initiating a time-consuming and costly clinical investigation, an in vitro study can help to estimate the in vivo usability of a new dental material. [5].
Numerical predictions of generated models have to be compared with experimental and theoretical results obtained from the literature [6].
Simulations based on finite element analysis (FEA) have attracted increasing interest in dentistry and dental prosthodontics for evaluating the stress distribution in teeth under occlusal loading conditions. FEA is usually applied in the teeth studies without considering changes in contacts with the antagonists teeth during the occlusal movements. Occlusal information can be used to investigate the stress distribution with 3D FEA in restored teeth [7].

2 Purpose
The objective of this study was to evaluate, by finite element analysis, stresses induced in an incisor restored with a ceramic crown during protrusion loading.

3 Materials and Method
For the experimental analysis, a 3D model of a central incisor was created: intact teeth, unrestored
teeth with chamfer marginal preparation, the same tooth restored with full pressed ceramic crown. The geometry of the intact tooth was obtained by modeling using the anatomical dimensions and morphology of the tooth (Fig. 1). The nonparametric modeling software (Blender 2.57b) was used to obtain the shape of the teeth structures.

The collected data were used to construct three dimensional models using Rhinoceros (McNeel North America) NURBS (Nonuniform Rational B-Splines) modeling program. The tooth preparation was designed (Fig. 2). A complete pressed ceramic crown was designed (Fig. 3).

Fig. 1. Modeling of the intact tooth.

Fig. 2. Tooth preparation for pressed ceramic crown.

Fig. 3. Design of the pressed ceramic crown.

Models were exported in Ansys finite element analysis software for structural simulations (Fig. 4). An occlusal load of 50 N was applied, according to the contact points with the antagonists.

Fig. 4. Points selected for loading on the restored incisor.

The forces were applied perpendicular to the tooth surface in each point. A virtual analysis of the protrusion was carried out and a trajectory path was designed and divided in 6 areas. The contact areas were visualized and loaded separately. Stress distribution of the restored incisor during protrusion stages was analyzed. The mesh structure of the solid 3D model was created using the computational simulation of Ansys finite element analysis software (Fig. 5).
Von Mises equivalent stresses were calculated and their distribution was plotted graphically.

Fig. 5. Mesh structure of the restored incisor.

3 Results and Discussions
Maximal equivalent stresses were recorded in the tooth structures and in the restoration for all contact areas. The values were higher in the crowns, and increase in the marginal segments of the contact areas (Table 1, Fig. 6).

Table 1. Maximal Von Mises equivalent stress values in the crown and prepared tooth during protrusion.

<table>
<thead>
<tr>
<th>Contact area</th>
<th>Maximal Von Mises equivalent stress [Pa]</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>crown</td>
</tr>
<tr>
<td>1</td>
<td>7.36E+07</td>
</tr>
<tr>
<td>2</td>
<td>3.29E+07</td>
</tr>
<tr>
<td>3</td>
<td>4.41E+07</td>
</tr>
<tr>
<td>4</td>
<td>4.13E+07</td>
</tr>
<tr>
<td>5</td>
<td>4.16E+07</td>
</tr>
<tr>
<td>6</td>
<td>7.97E+07</td>
</tr>
</tbody>
</table>

In the crowns the stresses were distributed around the contact areas with the antagonists and in the cervical areas (Fig. 7, 9). Regarding the stress distribution in the prepared teeth, the areas were larger around the marginal line, especially under the line. The biggest disadvantage is that high stresses are present around the marginal areas (Fig. 8, 10). During protrusion and moving of the contact area incisally, the maximal values of the stresses increase and also the stress areas become grater in the oral part of the crown.

Fig. 6. Distribution of the maximal Von Mises equivalent stress values in the prepared incisor and in the crown.

Fig. 7. Von Mises equivalent stress in the complete ceramic crown during cervical loading.

Fig. 8. Total Von Mises equivalent stress in the restored tooth during cervical loading.

Fig. 9. Von Mises equivalent stress in the complete ceramic crown during incisal loading.
Fig. 10. Total Von Mises equivalent stress in the restored tooth during incisal loading.

The future of ceramics for dentistry is clearly open to new technologies. However, the greatest challenge in developing all-ceramic compositions or processing methods suitable for dental applications is satisfying strength as well as esthetics [1, 8].

FEA studies show that the stress pattern changes considerably during the power stroke, suggesting that wear facets have a crucial influence on the distribution of stress on the whole tooth. Properly accounting for the power stroke kinematics of occluding teeth results in quite different results than usual loading scenarios based on parallel forces to the long axis of the tooth. This leads to the conclusion that functional studies considering kinematics of teeth are important to understand biomechanics and interpret morphological adaptation of teeth [7].

4 Conclusion

Within the limitations of the present study, the following conclusions can be drawn:

1. Numerical simulations provide a biomechanical explanation for stress distribution in prepared teeth and overlying crowns during kinematics.
2. Considering changes in contacts with the antagonists teeth during the occlusal movements is very important for a biomechanical analysis.
3. In all cases the maximal equivalent stress values were higher in the crowns. The stresses are distributed around the contact areas with the antagonists and cervical.
4. Regarding the stress distribution in the prepared teeth, the areas were larger around the marginal line, especially under the line.

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References: