Heat pressed ceramics crowns with and without zirconia framework – a biomechanical study

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Abstract: The patient demand for metal-free and tooth-colored restorations has driven substantial effort to increase the strength and reliability of dental ceramic systems. Heat pressed ceramic crowns with and without zirconia frameworks are restorations of choice from this point of view. Simulation of occlusal function during laboratory material's testing becomes essential in predicting long-term performance before clinical usage. The aim of the study was to assess the influence of chamfer preparation depth on failure risk of heat pressed ceramic crowns with and without zirconia framework by means of finite element analysis. 3D models of maxillary first premolars, prepared for MOD inlays with different depths of the chamfer preparations were generated (between 0.6 and 1.3 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 100 N was conducted, and stresses occurring in the prepared teeth, pressed ceramic crowns, zirconia frameworks and pressed ceramic veneers were calculated. The highest stresses were registered in the pressed ceramics. The depth of the preparations had no significant influence on the stress values of the teeth and pressed ceramics for the studied cases, only for the zirconia framework. Stresses in teeth were not influenced by achieving of zirconia frameworks of pressed ceramic crowns.

Key-Words: premolar, pressed ceramic crown, zirconia framework, pressed ceramic veneer, 3D model, finite element analysis.

1 Introduction

The patient demand for metal-free and tooth-colored restorations has driven substantial effort to increase the strength and reliability of dental ceramic systems [1].

Great effort has been expended in the development of more reliable ceramics. Fracture strengths have been progressively increased from glass ceramic to alumina and zirconia. The intermediate elastic modulus of zirconia is an advantage in reinforced layered structures, shifting damage and fracture modes into the porcelain veneer layer. Fracture of the veneer or the framework is a major reason for technical complications of all-ceramic crowns. Only recently reported is a fatigue study on anatomically correct crowns which reported cohesive failure in the porcelain veneer and in the veneer/core bond. Different studies were designed to evaluate an all-ceramic crown fatigue test method that would reproduce clinical failure modes [2].

Simulation of occlusal function during laboratory material's testing becomes essential in predicting long-term performance before clinical usage [1]. Finite element analyses indicated high stress levels below the load and at margins, in agreement with only single-cycle fracture origins [2].

This investigation tested the hypothesis that metal ceramic restorations presents higher reliability than two yttria-tetragonal zirconia polycrystals all-ceramic crown systems under mouth-motion fatigue conditions [1].

FEA studies showed higher levels of stress for yttria-tetragonal zirconia polycrystals (Y-TZP) core designs and veneer layers compared to metal ceramic restorations (MCR). Core design modification resulted in fatigue reliability response of Y-TZP comparable to MCR [3].

Residual stress plays a critical role in failure of ceramic crowns. The magnitude and distribution of residual stress in the crown are largely unknown. Determining the residual stress quantitatively is challenging since the crown has such complex contours and shapes [4].

For prosthetic restorative materials, the ability to withstand the masticatory forces in the oral cavity is

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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 [5].

The effect of masticatory stresses on teeth is variable [6].

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 [7].

Some studies evaluated the effect of finish line design on the fatigue, fracture resistance, and failure type of veneered zirconia restorations and showed that the finish line design did not influence the fatigue or the fracture resistance of veneered zirconia crowns. The selection of any of the finish line designs should be based on the clinical condition of the restored tooth [8].

2 Purpose

The aim of the study was to assess the influence of chamfer preparation depth on failure risk of heat pressed ceramic crowns with and without zirconia framework 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 full ceramic crowns with different depths of the chamfer margin (between 0.6 and 1.3 mm) (Fig. 1) and 6-degree tapered walls together with the overlying crowns were generated using literature data (Fig. 2, 3). The heat pressed ceramic crowns were designed with and without a zirconia framework with a thickness of 0.4 mm.

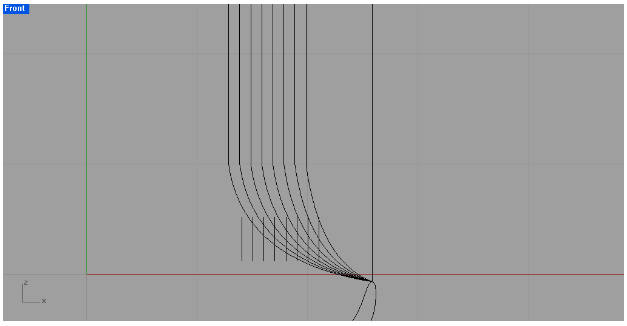

Fig. 1. Different depths of the chamfer margin (between 0.6 and 1.3 mm).

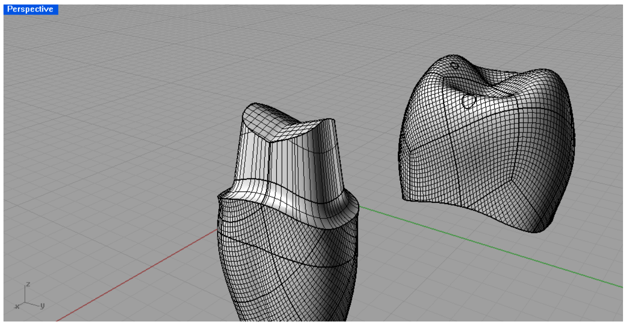

Fig. 2. 3D models of the prepared tooth and the overlying complete pressed creamic crown.

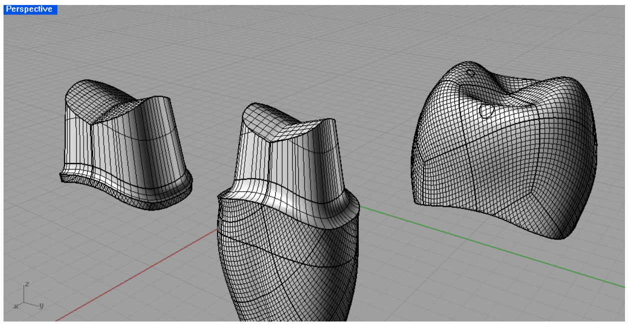

Fig. 3. 3D models of the prepared tooth and the overlying complete pressed creamic crown with zirconia framework.

The mesh structure of the solid 3D model was created using the computational simulation of Ansys finite element analysis software (Fig. 4).

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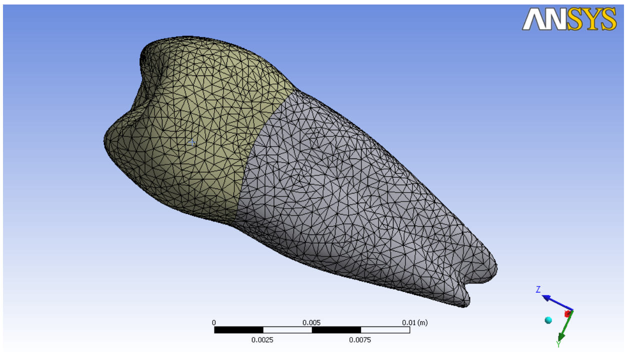

Fig. 4. Mesh structure of the premolar covered with a ceramic crown.

An occlusal load of 100 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 20 N was applied perpendicular to the surface in that point (Fig. 5).

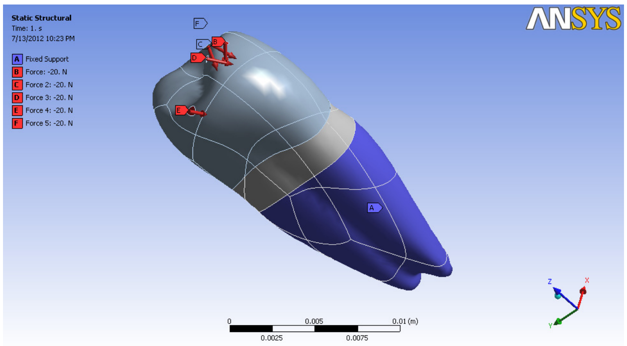

Fig. 5. Points selected for loading on the restored premolar.

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 preparations and crowns, stresses in the pressed ceramic crown, zirconia framework, pressed ceramic veneer, and dentin were evaluated separately (Table 1, 2).
The highest stress values were exhibited in the pressed ceramics in all cases and are about five times higher than in the dentin.

Table 1. Maximal Von Mises equivalent stress values in the prepared premolar and in the pressed ceramics crown.

Chamfer depth [mm]	Maximal Von Mises equivalent stress [Pa]	
	dentin	ceramic crown
0.6	2.29E+07	1.01E+08
0.7	2.31E+07	1.07E+08
0.8	2.19E+07	8.74E+07
0.9	2.22E+07	1.16E+08
1.0	2.39E+07	9.69E+07
1.1	2.70E+07	1.09E+08
1.2	2.01E+07	9.17E+07
1.3	2.35E+07	1.06E+08

Table 2. Maximal Von Mises equivalent stress values in the prepared premolar and in the crown: zirconia framework and pressed ceramics veneer.

Chamfer depth [mm]	Maximal Von Mises equivalent stress [Pa]		
	dentin	zirconia	ceramic veneer
0.6	2.28E+07	1.55E+07	9.21E+07
0.7	2.29E+07	1.50E+07	1.04E+08
0.8	2.19E+07	1.48E+00	1.06E+08
0.9	2.22E+07	1.45E+07	9.89E+07
1.0	2.38E+07	1.47E+07	9.20E+07
1.1	2.69E+07	1.36E+07	1.01E+08
1.2	2.00E+07	1.31E+07	1.10E+08
1.3	2.34E+07	1.30E+07	8.69E+07

In the dentin maximal stresses were distributed around the cervical areas, the most under the preparation line, oral (Fig. 6, 8, 10, 13).
Occlusal load on a tooth restored with ceramic crown produces stress around the contact areas in the restorations (Fig. 7, 9, 12, 15).
The lowest stress values were registered in the zirconia framework and decrease with the increase of the chamfer depth. The stress distribution is in the oral part of the framework and the values are higher in the cervical areas (Fig. 11, 14).

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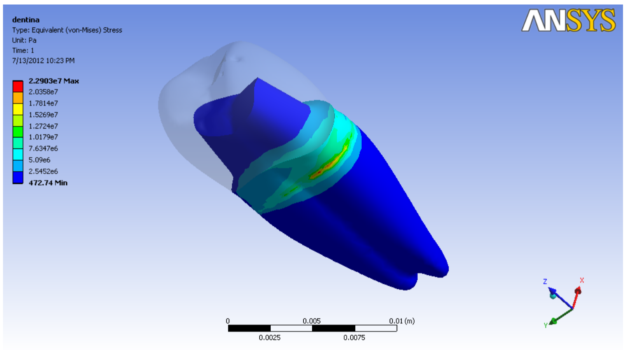

Fig. 6. Von Mises equivalent stress in the dentin of the premolar prepared for pressed ceramics crown (preparation with chamfer depth of 0.6 mm).

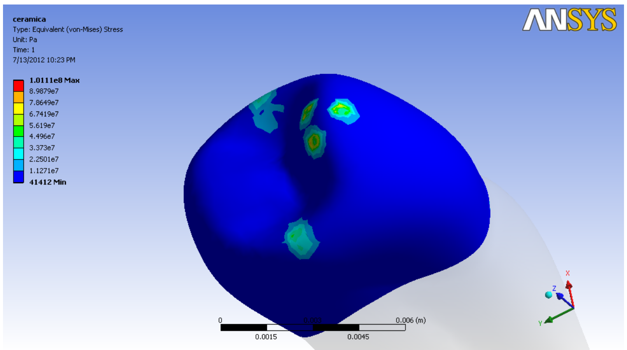

Fig. 7. Von Mises equivalent stress in the pressed ceramics crown (preparation with chamfer depth of 0.6 mm).

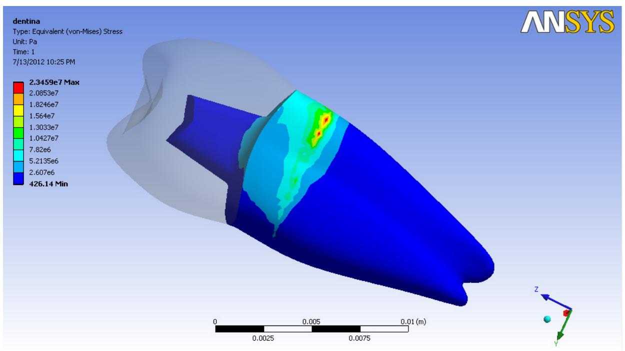

Fig. 8. Von Mises equivalent stress in the dentin of the premolar prepared for pressed ceramics crown (preparation with chamfer depth of 1.3 mm).

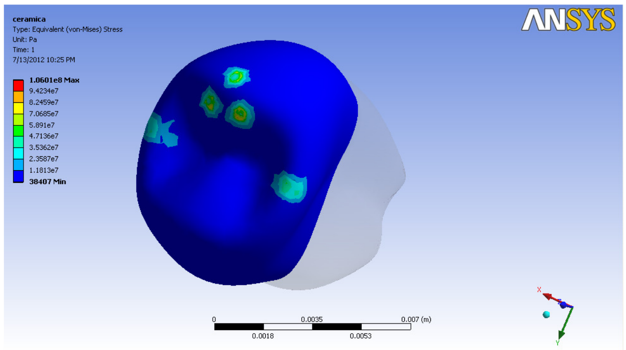

Fig. 9. Von Mises equivalent stress in the pressed ceramics crown (preparation with chamfer depth of 1.3 mm).

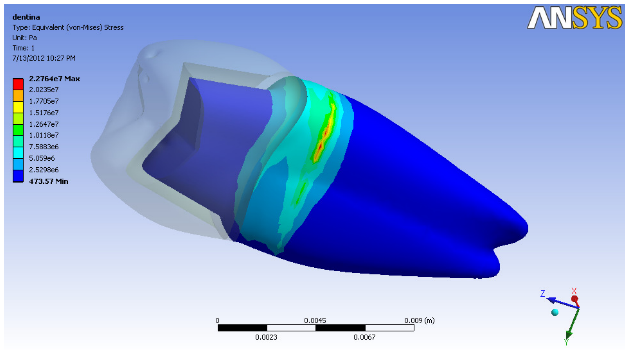

Fig. 10. Von Mises equivalent stress in the dentin of the premolar prepared for a crown with zirconia framework and veneered with pressed ceramics (preparation with chamfer depth of 0.6 mm).

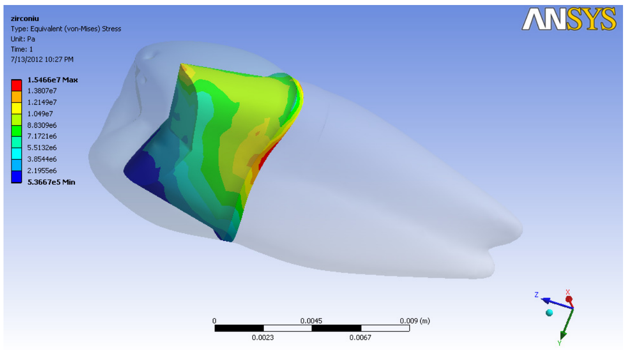

Fig. 11. Von Mises equivalent stress in the zirconia framework of a crown veneered with pressed ceramics (preparation with chamfer depth of 0.6 mm).

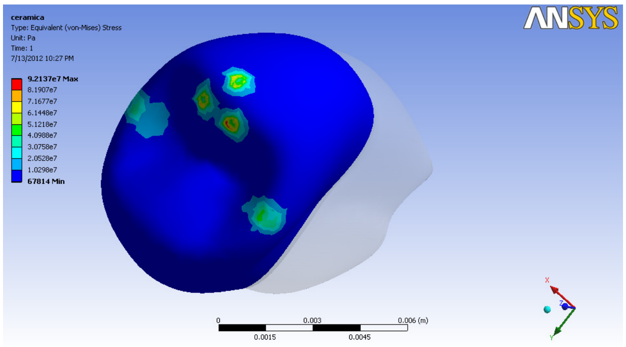

Fig. 12. Von Mises equivalent stress in the pressed ceramics veneer of a crown with zirconia framework (preparation with chamfer depth of 0.6 mm).

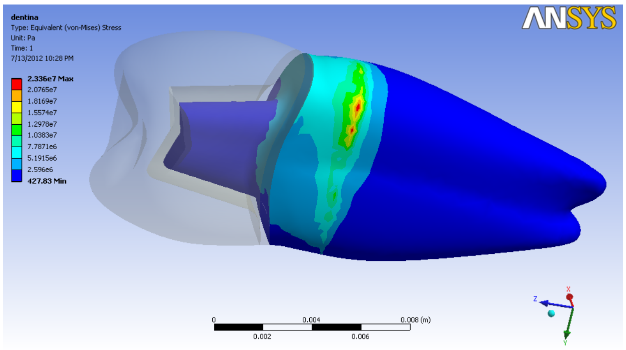

Fig. 13. Von Mises equivalent stress in the dentin of the premolar prepared for a crown with zirconia framework and veneered with pressed ceramics (preparation with chamfer depth of 1.3 mm).

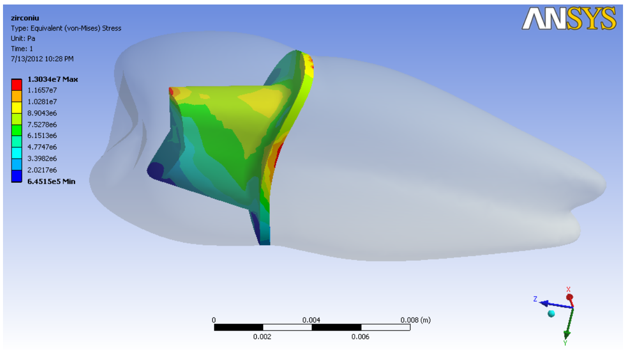

Fig. 14. Von Mises equivalent stress in the zirconia framework of a crown veneered with pressed ceramics (preparation with chamfer depth of 1.3 mm).

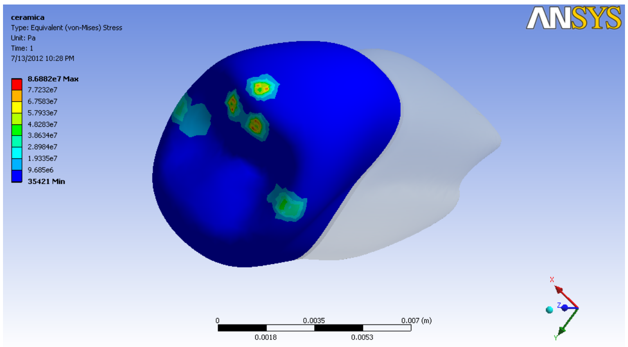

Fig. 15. Von Mises equivalent stress in the pressed ceramics veneer of a crown with zirconia framework (preparation with chamfer depth of 1.3 mm).

Regarding the chamfer preparation depth no significant variations regarding stress values in the prepared teeth and pressed ceramics were registered in the studied interval (0.6 and 1.3 mm). The only influenced is the zirconia framework.

4 Conclusion

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

1. The finite element study provides a biomechanical explanation for teeth covered with ceramic crowns.
2. Ceramic crowns transfer functional stress to the teeth structures. The highest stresses were registered in the pressed ceramics.
3. The depth of the preparations had no significant influence on the stress values of the teeth and pressed ceramics for the studied cases, only for the zirconia framework.
4. Stresses in teeth were not influenced by achieving of zirconia frameworks of pressed ceramic crowns.

5 Acknowledgements

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