Varied simulation-based stress analyses on zirconia all-ceramic crowns

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Abstract: The development of high-strength ceramics and its use in posterior areas has been a field of constant investigation. The performance of all-ceramic molar crowns fabricated with new CAD/CAM techniques is a subject of interest. The studies available in literature focused on the analysis of all-ceramic restorations failures, investigating several parameters involved on the tooth structure. The goal of this study was to investigate the stress distributions of zirconia - all ceramic crowns, under loads using varied stress distribution analyses. A static structural analysis was performed to calculate the stress distribution using the computer-aided engineering software. Equivalent stresses were recorded in the tooth structures and in the restoration for all these designs. Since ceramic materials exhibit brittle behavior, the first principal stress criterion was adopted to compare the stress values and distribution with those obtained for the first simulations. Under the same loading conditions, the stress distribution patterns for the zirconia all-ceramic crown using differential stress analyses exhibited similarities. Only the values are lower for the maximal principal stresses. The present study suggests that varied simulation methods are promising to assess the biomechanical behaviour of all-ceramic systems.

Key-Words: zirconia all-ceramic crown, molar, simulation methods, stresses.

1 Introduction

The trend for development of high-strength ceramics and its use in posterior areas has been a field of constant investigation [1,2]. Yttria-Stabilized Tetragonal Zirconia Polycrystals (Y-TZP) was introduced as a core ceramic in attempt to reduce restoration bulk fracture. Its high mechanical properties have resulted in successful use of Y-TZP as a core ceramic in short- and medium-term clinical studies, where framework fractures were seldom reported [3,4]. While Y-TZP provides strength, the clinical success of these restorations has been hampered by fractures within the veneering porcelain. With regard to chipping and/or delaminating of the veneer, the performance of all-ceramic molar crowns fabricated with new CAD/CAM techniques is a subject of interest [5**]**. This material is indicated for posterior crowns but due to its high opacity requires veneering with glass ceramics. High strength zirconia core can be manufactured through CAD/CAM technology and subsequently veneered conventionally. According to *in vivo* observation, the clinical survival of zirconia-based restorations are comparable to metal–ceramic restorations [6]. In recent years it has become obvious that cohesive and adhesive failures of zirconia - ceramics veneered restorations often occur [7,8]. The studies available in literature focused on the analysis of all-ceramic restorations failures, investigating several parameters involved on the tooth structure - restoration complex, in order to improve clinical performances. Some of the parameters, like the framework design, are technique-sensitive and during the manufacturing of the restorations can easily influence the failure rates and fracture modes of final restorations, similarly to metal ceramic crowns. In order to predict the clinical behavior of porcelain layered zirconia crowns, some studies evaluating fracture resistance have been performed [9,10]. The focus was on framework design and how different coping designs may influence possible clinical failures. They show that the coping design affected the fracture load and the mode of fracture of zirconia all-ceramic crown [11].

Simulation-based medicine and the development of complex computer models of biological structures is becoming ubiquitous for advancing biomedical engineering and clinical research. Finite element analysis (FEA) has been widely used in the last few decades to understand and predict biomechanical phenomena. Modeling and simulation approaches in biomechanics are highly interdisciplinary, involving novice and skilled developers in all areas of biomedical engineering and biology. While recent advances in model development and simulation platforms offer a wide range of tools to investigators, the decision making process during modeling and simulation has become more opaque [12]. Establishing guidelines for model development and simulation, particularly for complex structures and different materials poses a challenge in the field of dental technology.

2 Purpose

The goal of this study was to investigate the stress distributions of zirconia - all ceramic crowns, under loads using varied stress distribution analyses.

3 Materials and Method

For the experimental analyses a maxillary right first molar was chosen in order to simulate the biomechanical behaviour of the teeth restored with zirconia - all ceramic crowns. The prepared die was designed with a chamfer finishing line and an 6° occlusal convergence angle of the axial walls was chosen for the preparation.

A geometric model of a bilayer crown with a uniform thickness of 0.5 mm for the framework and ceramic veneer designed to occupy the space between the original tooth form and the prepared tooth form was developed. At first a nonparametric modeling software (Blender 2.57b) was used to obtain the 3D tooth shape. The collected data were used to construct three dimensional models using Rhinoceros (McNeel North America) NURBS (Nonuniform Rational B-Splines) modeling program. In order to obtain a 3D solid model of the tooth, a surface following the cervical line was achieved, to close the surfaces.

The geometric models were imported in the finite element analysis software ANSYS, meshed and finite element calculations were carried out.

In order to simulate the stress distribution, the Young's module and Poisson's ratios were introduced: Young's modulus (GPa) 18 for dentin, 64 for veneering ceramics, and 205 for zirconia and Poisson's ratio 0.27 for dentin, 0.21 for veneering ceramics, and 0.31 for zirconia.

To simulate physiological mastication behavior five loading areas were defined on the occlusal surface. Each defined loading area had a diameter of 0.5 mm. A total force of 250 N was allocated to these areas as pressure load normal to the surfaces in each point. The bottom of the abutment teeth model was fully constrained for all simulations.

A static structural analysis was performed to calculate the stress distribution using the computer-aided engineering software. Equivalent stresses were recorded in the tooth structures and in the restoration for all these designs. Since ceramic materials exhibit brittle behavior, the first principal stress criterion was adopted to compare the stress values and distribution with those obtained for the first simulations.

3 Results and Discussions

Stresses were calculated for all compunds of zirconia all-ceramic crown and teeth structures (Fig. 1-3, Table 1).

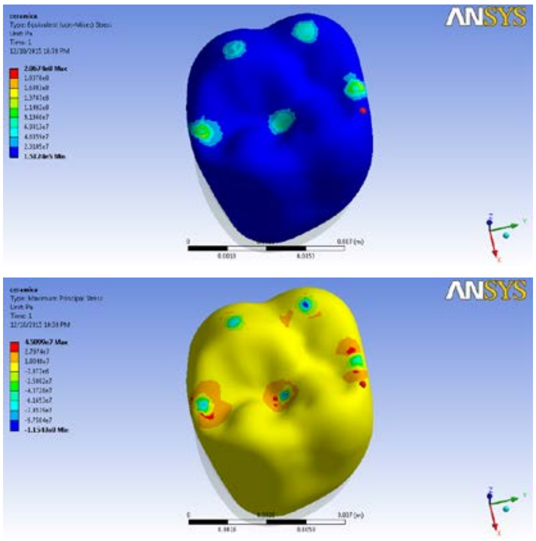

Fig. 1. Equivalent stress and principal stress distribution in the ceramic veneer.

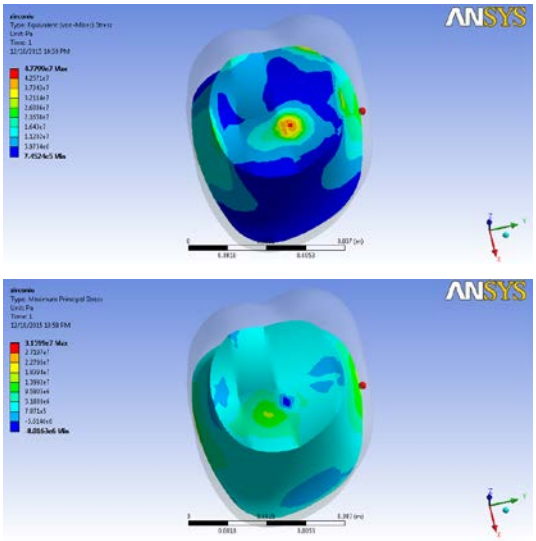

Fig. 2. Equivalent stress and principal stress distribution in the zirconia framework.

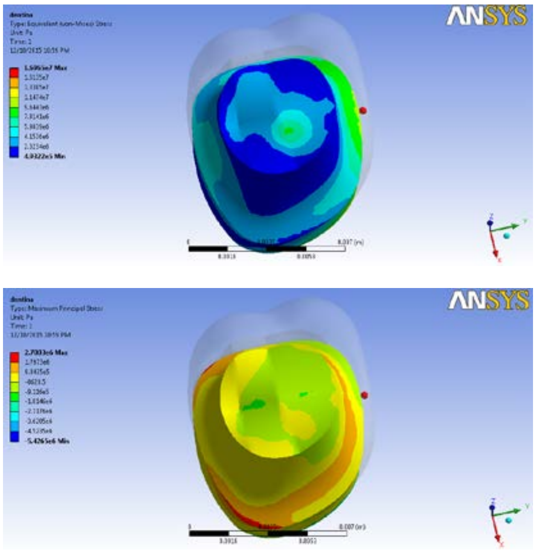

Fig. 3. Equivalent stress and principal stress distribution in the dentin.

Table 1. Maximal equivalent stress and principal stress in zirconia all-ceramic crown compounds and dentin.

Stress values in the structures	Maximal equivalent stress [MPa]	Maximal principal stress [MPa]
Ceramic veneer	206.74	45.89
Zirconia framework	47.79	31.59
Dentin	16.96	2.70

In both cases the values were higher in the veneers. In the veneers stresses were distributed around the contact areas with the antagonists. The values of the maximal stresses in the frameworks are low and distributed occlusal and in the cervical areas buccal and oral. In dentin stresses are concentrated around the marginal preparation line. Within the studied range stresses are not influenced by the veneer thickness in case of an anatomical design of the framework.

Under the same loading conditions, the stress distribution patterns for the zirconia all-ceramic crown using differential stress analyses exhibited similarities. Only the values are lower for the maximal principal stresses.

According to different authors, the material will fail when the values of the equivalent stresses exceed the tensile strength of the material [13].

Factorial analysis performed studies showed that material and thickness of prosthetic crowns are of primary importance in stress magnitude. The higher the tensile strength of crown material, the thinner can be the crown's walls [14].

With the increasing number of FEA studies, FEA practice in biomechanics continues to pose a challenge for model development, sharing and reporting. In FEA, model definitions and development procedures are tightly coupled to the simulation method and the solver capabilities. FEA software commonly relies on embedded mathematical models of physical phenomena, e.g., solid mechanics. In many cases, decisions made during model development depend on the specific solver capabilities [12].

Because most FEA share common features during model development and simulation process, it is possible to compile parameters for reporting items that may be important for model reproducibility and may help the scientific community to assess the overall quality, scientific rigor, and utility of the model [12].

4 Conclusion

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

1. The present study suggests that varied simulation methods are promising to assess the biomechanical behaviour of all-ceramic systems.
2. FEA results can be used in rebuilding the design guidelines in CAD/CAM systems for zirconia all-ceramic restorations.

5 Acknowledgements

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