Load values influence on stresses in monolithic ceramic molar crowns

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Abstract: Zirconia is considered a proper material for posterior teeth restoration, because of the excellent aesthetic quality, biocompatibility, and mechanical properties, in order to replace existing ceramic systems. Even computer-controlled techniques are used in producing dental crowns in order to improve the accuracy during the manufacturing process, not enough studies have been conducted on stresses in aesthetic monolithic crowns regarding the load values. Therefore, the goal of this study was to compare the stresses in anatomic contour zirconia crown to that of glass ceramic crown regarding the load values, from biomechanical point of view. A static structural analysis was performed to calculate the stress distribution using the computer-aided finite element analysis software. The maximal principal stresses in the crowns don't exceed the strength of the materials in case of 200 N load for both studied materials. For glass ceramic at a load of 400 N maximal principal stresses exceed the tensile strength value of the material. Stress values and distribution results can provide design guidelines for new and varied aesthetic crowns, in order to withstand functional loads in the posterior areas.

Key-Words: monolithic ceramic crown, posterior teeth, zirconia, glass ceramic, load, finite element analysis, maximal principal stresses.

1 Introduction

Zirconia is considered a proper material for posterior teeth restoration, because of the excellent aesthetic quality, biocompatibility, and mechanical properties. Thus, zirconia is getting attention to replace existing ceramic systems. Processing of zirconia is closely linked to the development of CAD/CAM systems [1-3]. CAD/CAM technology has been increasingly used to fabricate dental crowns in recent years. It resulted in new restorative materials that would otherwise have been infeasible to use in the dental market, like Yttria-Stabilized Tetragonal Zirconia Polycrystals (Y-TZP). Recently, the introduction of new computerized milling technologies and new zirconia made it possible to manufacture full contour zirconia crowns with higher strength [4-6]

Several manufacturers have improved the aesthetics of the zirconia materials mainly by reducing the opacity of the material and by addition of colouring pigments. It might also be assumed that, by omitting the veneering, a more solid framework can be made and a conservative preparation similar to full-cast metal-alloy restorations can be performed [7].

Monolithic crowns offer other advantages such as reduced production time and improved cost-effectiveness. Crown preparation always involves a risk, causing preparation trauma to the vital tooth, a risk that is increased the more extensive the preparation is. Eliminating the veneering material in monolithic crowns creates possibilities for more minimally invasive preparations and restorations [8-10].

Finite element analysis (FEA) is an appropriate method for stress analysis. Since FEA was developed in the engineering field, it has been a popular option to analyze stress. In dentistry, FEA has been used to study stress distributions in the teeth and restorative materials [11-13].

2 Purpose

Even computer-controlled techniques are used in producing dental crowns in order to improve the accuracy during the manufacturing process, not enough studies have been conducted on stresses in aesthetic monolithic crowns regarding the load values. Therefore, the goal of this study was to compare the stresses in anatomic contour zirconia crown to that of glass ceramic crown regarding the load values, from biomechanical point of view.

3 Materials and Method

For the experimental analyses first upper molars were chosen in order to simulate the biomechanical behaviour of the teeth restored with complete aesthetic monolithic crowns made of yttria-stabilized tetragonal zirconia polycrystals (Y-TZP) and glass-ceramic. The prepared dies were designed with a chamfer finishing line and an 6° occlusal convergence angle of the axial walls was chosen for the preparations.

Geometric models of monolithic crowns were designed to occupy the space between the original tooth form and the prepared tooth form. At first a nonparametric modeling software (Blender 2.57b) was used to obtain the 3D tooth shapes. The collected data were used to construct three dimensional models using Rhinoceros (McNeel North America) NURBS (Nonuniform Rational B-Splines) modeling program. The geometric models were imported in the finite element analysis software ANSYS, meshed and finite element calculations were carried out (Fig. 1).

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 glass ceramic, and 205 for zirconia and Poisson's ratio 0.27 for dentin, 0.21 for glass ceramic, and 0.31 for zirconia.

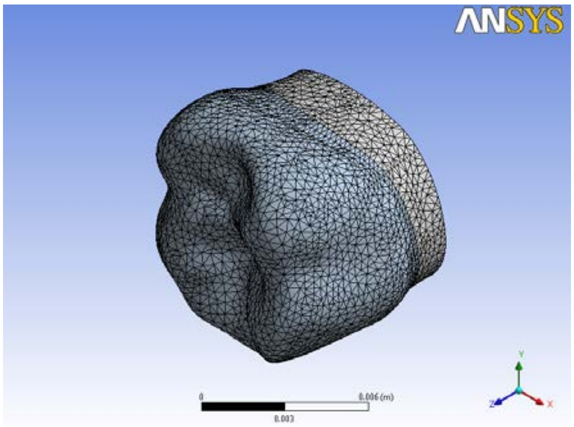

Fig. 1. Mesh structure of the molar.

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 between 200 N, respective 800 N was allocated to these areas as pressure load normal to the surfaces in each point. The bottom of the abutment teeth models was fully constrained for all simulations.

A static structural analysis was performed to calculate the stress distribution using the computer-aided engineering software. First principal stresses were recorded in the tooth structures and in the restorations for all load values.

4 Results and Discussions

Stresses were calculated in the crowns for both materials and in the teeth structures, under different load values (Table 1-4, Fig. 2-5).

Table 1. Maximal principal stress values in the crowns and dentin for a 200 N load.

Maximal principal stress values [Pa]	Crown	Dentin
Zirconia	$3.23x10^7$	$2.02x10^6$
Glass ceramic	$4.07x10^7$	$1.69x10^6$

Table 2. Maximal principal stress values in the crowns and dentin for a 400 N load.

Maximal principal stress values [Pa]	Crown	Dentin
Zirconia	$6.47x10^7$	$4.03x10^6$
Glass ceramic	$8.14x10^7$	$3.37x10^6$

Table 3. Maximal principal stress values in the crowns and dentin for a 600 N load.

Maximal principal stress values [Pa]	Crown	Dentin
Zirconia	$9.70x10^7$	$6.05x10^6$
Glass ceramic	$1.22x10^8$	$5.06x10^6$

Table 4. Maximal principal stress values in the crowns and dentin for a 800 N load.

Maximal principal stress values [Pa]	Crown	Dentin
Zirconia	$1.29x10^8$	$8.072x10^6$
Glass ceramic	$1.63x10^8$	$6.74x10^6$

Between the materials, the highest stresses were recorded in glass ceramic, followed by zirconia.

In the dentin, the lowest stresses were recorded for the teeth restored with glass ceramic, followed by zirconia.

Compared to the tensile strength of the materials, 745 MPa for zirconia, and 48,8 MPa for glass ceramic, the maximal principal stresses in the crowns exceed them for 600 N and 800 N load for zirconia crowns, respective for 400 N, 600 N and 800 N load for glass ceramic crowns.

The maximal principal stresses in the crowns doesn't exceed the strength of the materials in case of 200 N load for both studied materials. For glass ceramic at a load of 400 N maximal principal stresses exceed the tensile strength value of the material.

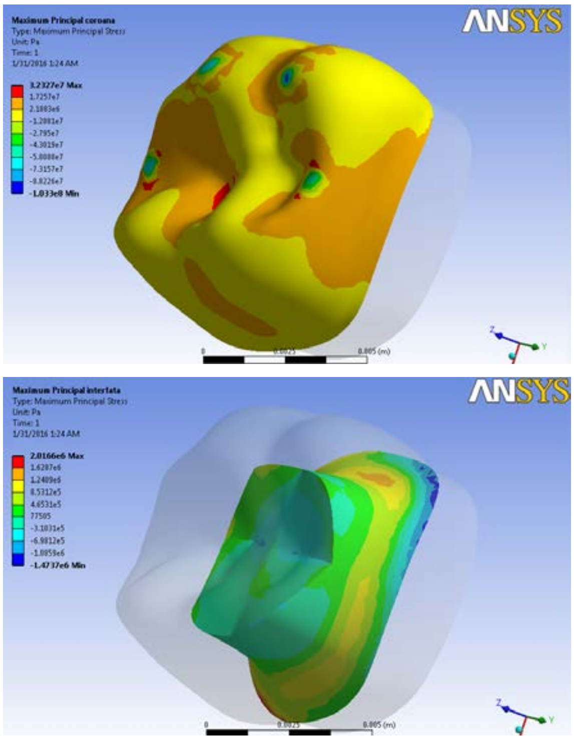

Fig. 2. First principal stress distribution in the zirconia crowns and subjacent dentin (for 200 N load).

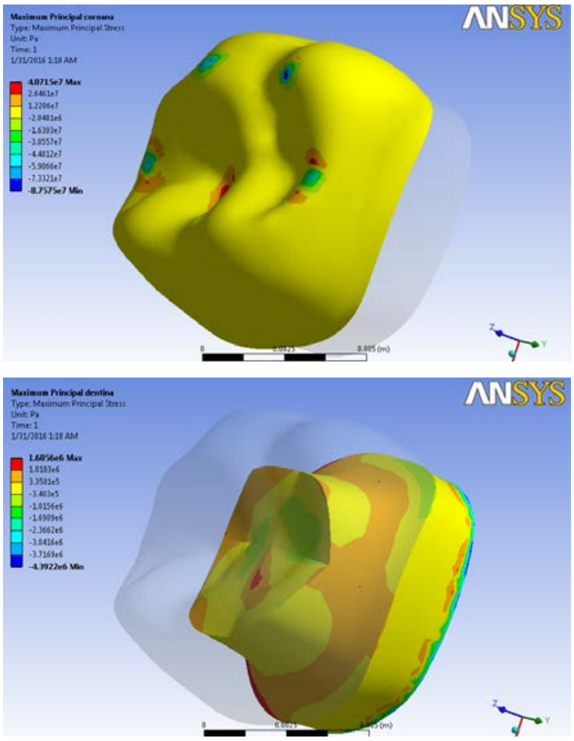

Fig. 3. First principal stress distribution in the glass ceramic crowns and subjacent dentin (for 200 N load).

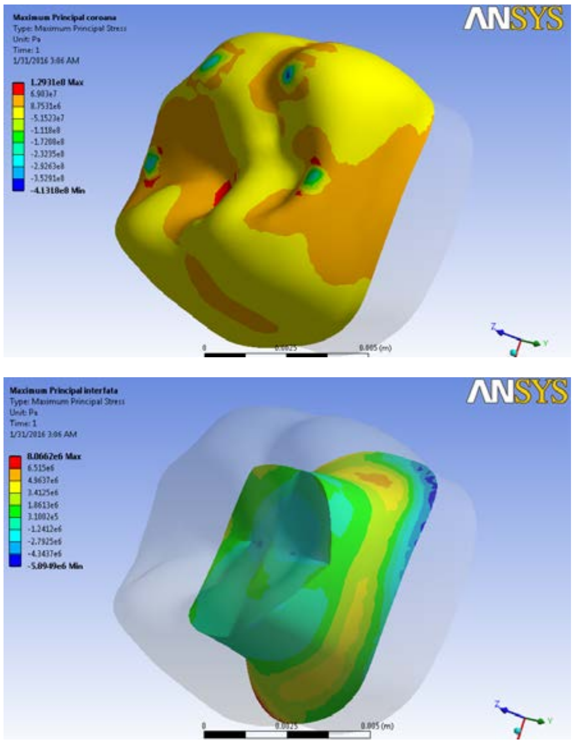

Fig. 4. First principal stress distribution in the zirconia crowns and subjacent dentin (for 800 N load).

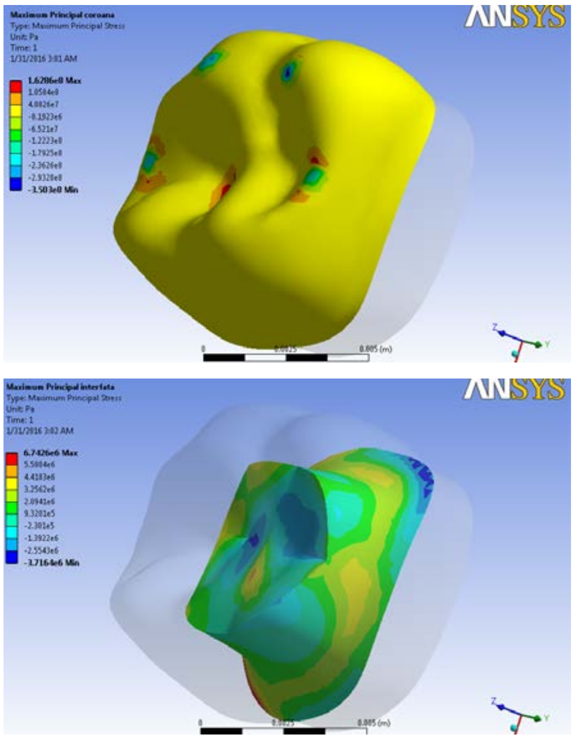

Fig. 5. First principal stress distribution in the glass ceramic crowns and subjacent dentin (for 800 N load).

Regarding stress distribution, in the crowns high stresses are concentrated around the contact areas with the antagonists, and they are larger for the zirconia crowns. In the dentin for molars high stresses were distributed around the shoulder, and under the preparation line for all type of restorations.

The material is important to withstand increased loads which occur during functions. Reported loads during normal function vary considerably; there is no accepted consensus on either loads present in vivo or how they should be replicated in vitro. Some authors use lower loads, 100-200 N, others use loads in the range of 500-800 N [14].

According to the literature data [15, that the tensile strengths of dentin ranged from 44.4 MPa to 97.8 MPa, no harmful effects occur in hard teeth structures, because in all cases first principal stresses in dentin are much lower.

When compared with some reported clinical failure rates, it can be stated that the theoretical predictions showed relevant quantitative values for some materials. Even though there are some differences in assumptions between clinical and theoretical models, differences can be justified and an even more accurate prediction tool for single crowns may be developed by incorporating better mechanical models in the future [16].

5 Conclusion

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

1. The biomechanical behaviour of aesthetic monolithic crowns for the posterior areas can be assessed using finite element analyses.
2. The maximal principal stresses in the crowns doesn't exceed the strength of the materials in case of 200 N load for both studied materials. For glass ceramic at a load of 400 N maximal principal stresses exceed the tensile strength value of the material.
3. The material is important to withstand increased loads which occur during functions.
4. Stress values and distribution results can provide design guidelines for new and varied aesthetic crowns, in order to withstand functional loads in the posterior areas.

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