Influence of the material on stress distribution in aesthetic monolitic complete dental crowns

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Abstract: The development of different materials for the use in posterior areas for aesthetic monolitic crowns has been a challenge in dental technology. The goal of this study was to develop 3D posterior teeth covered with complete aesthetic monolitic crowns and to compare the stress distributions under loads, revealing the effect of various materials on the biomechanical performance of the crowns. For the experimental analyses premolars and molars were chosen in order to simulate the biomechanical behaviour of the teeth restored with complete aesthetic monolitic crowns (zirconia, glass ceramic, composite). 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 restoration for all these materials. Stresses recorded in the ceramic restorations are direct proportional with the elasticity of the material. Crowns made of materials with high elasticity (composite) show better behaviour for premolars then for molars, compared to ceramic materials. Stress values and distribution results can provide design guidelines for new and varied materials, regarding to the restored teeth.

Key-Words: monolitic complete dental crown, aesthetic materials, molar, premolar, finite element analysis, stresses.

1 Introduction

The development of different materials for the use in posterior areas for aesthetic monolitic crowns has been a challenge in dental technology.

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), or other like glass–ceramic, resin-based composites, which usually require a very long processing time in a well-controlled environment. In addition to the ceramic blocks, which are more frequently used for CAD/CAM applications, composite resin based blocks have been developed.

All-ceramic crowns often are made of leucite-reinforced ceramic. This types of glass ceramic ensures high aesthetics and biocompatibility, but it is brittle and has low flexural strength. Glass ceramic materials can perform successfully in the anterior region but the long-term outcomes of posterior crowns are not so encouraging [1-3]. Zirconia based ceramic is characterized by higher flexural strength and fracture toughness [4]. This material is indicated for posterior crowns but due to its high opacity requires veneering with glass ceramic. 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 [5]. Recently, a new idea of milling solid monolithic (full-contour) zirconia crowns has occurred [6]. Prosthetic crowns can also be fabricated with composite resin. Although some authors recommend composite crowns as a permanent restoration, the application of these restorations should be limited to interim purpose. This is due to its occlusal wear especially in molar region, gradual loss of marginal adaptation, discoloration and increased plaque accumulation [7-11].

However, dental composites have a discontinuous ceramic phase, and so are limited to much lower elastic modulus values than glass–ceramic materials. It has been found that thin-walled crowns made of low elastic modulus material (composite resin) are

more prone to debonding than those made of stiffer materials such as ceramic and gold alloy, while thin-walled crowns of stiffer materials can protect tooth structures from damage better than composite resin ones [12, 1]. This lack of stiffness may result in increased stress levels under the same bite force compared to glass–ceramic restorations, eventually leading to a compromised long-term clinical performance. In the absence of long-term clinical data or a reasonable in vitro simulation of clinical conditions, manufacturers must be cautious in specifying the indications for their new products. Simulation of fatigue loading for new materials resulted in failure modes which are rarely observed in the clinic [13]. Failure originated adjacent to the point of loading instead of at the cemented surfaces of the crowns. Two subsequent simulations had stiff substrates that did not simulate the clinical case [14, 15]. Further investigations are still needed to analyze and evaluate the biomechanical behaviour of this new type of CAD/CAM composite material over ceramic ones.
Finite element analysis (FEA) is a powerful and flexible computational tool to model dental structures and devices, simulate the occlusal loading conditions and predict the stress and strain distribution [12, 16, 17].

2 Purpose
The goal of this study was to develop 3D posterior teeth covered with complete aesthetic monolitic crowns and to compare the stress distributions under loads, revealing the effect of various materials on the biomechanical performance of the crowns.

3 Materials and Method
For the experimental analyses premolars and molars were chosen in order to simulate the biomechanical behaviour of the teeth restored with complete aesthetic monolitic crowns. 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 a monolitic 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.
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, 16 for composite and 205 for zirconia and Poisson's ratio 0.27 for dentin, 0.21 for glass ceramic, 0.24 for composite 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 200 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 restoration for all these materials.

4 Results and Discussions
Stresses were calculated for in the crowns for all type of materials and in the teeth structures (Table 1, Fig. 1-3).

Table 1. Maximal principal stress in the crowns and dentin for molars (M) and premolars (PM).

Maximal principal stress values in the structures [Pa]	Crown (M and PM)	Dentin (M and PM)
Zirconia	$3.23x10^7$ (M) $2.53x10^7$ (PM)	$2.02x10^6$(M) $1.34x10^7$ (PM)
Glass ceramic	$4.07x10^7$ (M) $2.81x10^7$ (PM)	$1.69x10^6$ (M) $1.30x10^7$(PM)
Composite	$4.16x10^7$ (M) $2.76x10^7$ (PM)	$2.72x10^6$ (M) $1.20x10^7$ (PM)

In the molar crowns stresses were higher than in the premolars ones, for all kind of materials. Between the materials, the highest stresses were recorded in zirconia, followed by glass ceramic and composite, direct proportional with elasticity of the material.
In the dentin, the lowest stresses were recorded for the teeth restored with glass ceramic crowns, followed by the zirconia and composite. In the dentin, for all used materials, in the premolar stresses were several times higher than in the molars (4.41-7.69x).

Compared to the tensile strength of the materials, 745 MPa for zirconia, 48,8 MPa for glass ceramic and 54.4 MPa for composite, the maximal principal stresses in the crowns were 23.06, respective 29.44 times lower than the tensile strength of the zirconia based ceramic, for composite resin 1.30 respective 1.97, and for glass ceramic only 1.19 respective 1.73.
In none of the studied models did the maximal principal stresses in the crowns exceed the strength of the materials of which they were made.
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 for zirconia and glass ceramic and occlusal for composite, and for premolars under the preparation line for all type of restorations.

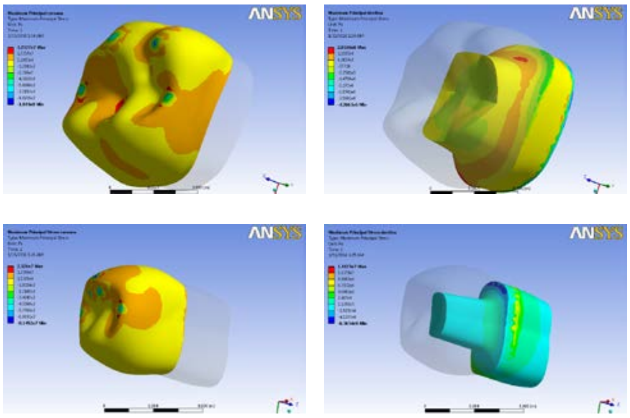

Fig. 1. First principal stress distribution in the zirconia crowns and subjacent dentin (for molar and premolar).

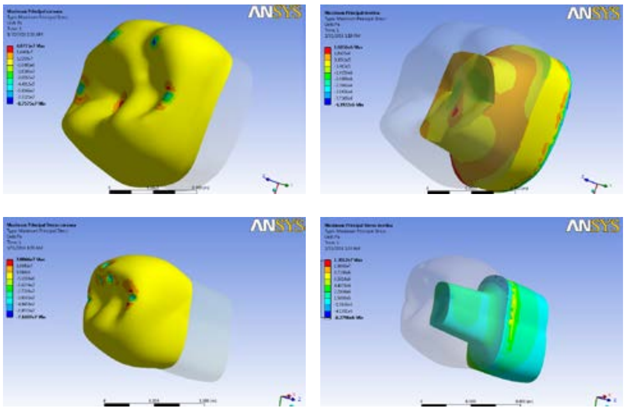

Fig. 2. First principal stress distribution in the glass ceramic crowns and subjacent dentin (for molar and premolar).

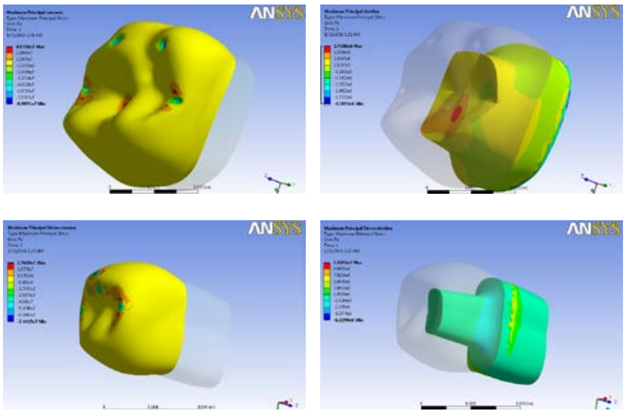

Fig. 3. First principal stress distribution in the composite crowns and subjacent dentin (for molar and premolar).

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 [18].
The applicability of FEA results to oral conditions depends upon, among other factors, the similarity between the shape, dimensions, material data, load application of the models, and the natural teeth. In this study, calculations were made on the 3D tooth models patterned after intact natural molars [1].
Generally it is assumed that the materials used in the models are linearly elastic, homogeneous, and isotropic, but they had different compressive and tensile strengths. Unfortunately, the properties of tooth structures are not homogeneous and are anisotropic like dentin or enamel. Furthermore, during laboratory fabrication of prosthetic crowns some material artifacts can occur that can not be taken into consideration.

5 Conclusion

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

1. The biomechanical behaviour of aesthetic monolitic crowns for the posterior areas can be assessed using finite element analyses.
2. Stresses recorded in the ceramic restorations are direct proportional with the elasticity of the material.
3. Crowns made of materials with high elasticity (composite) show better behaviour for premolars then for molars, compared to ceramic materials.

4. Stress values and distribution results can provide design guidelines for new and varied materials, regarding to the restored teeth.

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