3D MODELING AND SIMULATION OF INLAY RESTORED POSTERIOR TEETH

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ABSTRACT

Objectives: The aim of the study was to obtain 3D models of molars with different preparations restored with ceramic inlays, in order to evaluate and compare stress distributions under occlusal loads. Methods: For the experimental analysis, 3-D models of first upper molars were created, teeth with class II cavity preparations and restored with ceramic inlays. The preparations were made with divergences between 0 and 10 degrees. The initial geometries of the intact tooth were obtained by 3D scanning, using an original manufactured laser device. The 3D model was used as a support for the modeling of the inlays. Each model was subjected to a force of 200 N directed to the occlusal surface. Stresses were calculated in the tested inlays, and tooth hard tissues. Results: In teeth restored with ceramic inlays, the von Mises equivalent stress values were higher than in intact teeth. High stresses were located at the junction of the butt joint margin inlay and enamel. The values depend on the preparation shape and decrease with the increase of the taper. Conclusions: From biomechanical point of view, it resulted that ceramic inlays do not restore the original strength of the teeth, and the preparation shape is decisive for the stress values and distribution, hence the susceptibility to fractures. Key words: ceramic inlay, 3D modeling, stress distribution

INTRODUCTION

Dental restorations are very complex systems, heterogeneous in structure, made up from various materials, and there is an essential question mark on the physical, chemical and mechanical compatibility between these materials.¹ For these reasons, and as a response to the actual trend of metal-free restorations in recent years, the demand for non-metal dental prostheses has grown considerably.²,⁵ Amongst the most popular alternatives to metal restorations on class II cavities of posterior teeth are ceramic or composite inlays retained by an adhesive resin.⁴
Deficiency.

Number of ceramic restorations exhibit some marginal as fracture resistant as natural intact teeth, and a large developing stresses.2,7 Thickness of the cement determine the totality of the magnitude and kinetics, the Young’s modulus and the cement properties and on its mechanical behavior. Not only the shrinkage-strain, but the shrinkage-stress magnitude and kinetics, the Young’s modulus and the thickness of the cement determine the totality of the developing stresses.2,7

Tooth fracture resistance decreases with increased width and depth of caries and cavity preparation. Extensive class II cavities in molars may be restored with esthetic ceramic inlays.8,9 The average width of these restorations is two thirds of the intercuspal distance of teeth. Ceramic materials are characterized by low flexural strength and fracture toughness.10 Restorations made of these materials are luted with resin cements, which have the highest bond strength to tissue among luting agents.11 The optimum bond of these restorations to teeth enhances the strength of ceramics and prepared tissues, and assists in stabilizing weakened cusps.12 However, these restorations are not as fracture resistant as natural intact teeth, and a large number of ceramic restorations exhibit some marginal deficiency.13,14

In the literature, controversy exists as to what type of ceramic restoration should be used for the restoration of large defects, in an attempt to prevent fracture and microleakage.5

There are various criteria that are used to assess the possibility of failure of a material. In finite element analysis (FEA), a large structure is divided into a number of small simple shaped elements, for which individual deformation (strain and stress) could be more easily calculated than for the whole undivided large structure. By solving the deformation of all the small elements simultaneously, the deformation of the structure as a whole can be assessed. Using the traditional biophysical knowledge database in a rational validation process, the use of FEA in dental research has been significantly refined.2,3,15 For isotropic materials with similar values of compressive and tensile strength, the most commonly used is the von Mises criterion.12 However, dental tissues and enamel, in particular, have anisotropic properties.16,17

The errors that occur in the manufacturing of complex prostheses are due to the biomechanically faulty projects and the laborious, energy- and time-consuming manufacturing technologies. For this reason, computer-assisted means of evaluation and even design have emerged. Computer-created projects stay at the basis of running complex tests for prosthetic pieces, without actually damaging them, thus having favorable effects on their design. The studies carried out until now, using the finite element method, are revealing the areas of stress, distortion and fatigue, which have a direct effect on the restorations period of using.18

Nowadays, experimental–numerical approaches undoubtedly represent the most comprehensive in vitro investigation method in restorative dentistry.15 They allow the researcher to reduce the time and cost required to bring a new idea from concept to clinical application, to increase their confidence in the final concept/project by virtually testing it under all conceivable loading conditions. The dates obtained with numerical simulation can be compared with photoelasticity19 or other invasive or noninvasive investigational methods.

The purpose of this study was to obtain 3D models of molars with different class II preparations restored with ceramic inlays and to investigate the effect of preparation design and occlusal load direction, in order to evaluate and compare the stress distributions under masticatory forces.

**MATERIALS AND METHODS**

For the experimental analysis, 3-D models of first upper molars were created, teeth with class II cavity preparations and restored with ceramic inlays. The initial geometries of the intact tooth were obtained by 3D scanning, using an original manufactured laser device. Files were imported in LeiosMesh (Enhanced Geometry Solutions Corporations, Italy), where the point clouds from the teeth surfaces were cleaned and assembled, and then merged to create a complete model. NURBS surfaces were built and imported in Rhinoceros (McNeel North America) modeling program (fig.1). The preparations were made with divergences between 0 and 10 degrees (fig.2). The 3D model was used as a support for the modeling of the inlays (fig.3). These were exported in ANSYS finite element analysis software (Ansys Inc., Philadelphia, USA), to be used for structural simulations. The intact tooth model was divided into 19162 solid elements connected at 31593 nodes, the prepared tooth structure into 22568 elements connected at 36935 nodes, and the inlay into 4615 elements connected at 8378 nodes (fig.4). Each model was subjected to a force of 200 N
directed to the occlusal surface (fig.5). Stresses were calculated in the tested inlays, and tooth tissues.

Figure 1. The initial geometries of the intact tooth were obtained by 3D scanning using an original manufactured laser device.

Figure 2. The preparations were made with divergences between 0 and 10 degrees.

Figure 3. The 3D model was used as a support for the modeling of the inlays.

Figure 4. Structural simulations in ANSYS finite element analysis software (Ansys Inc., Philadelphia, USA).

Figure 5. Each model was subjected to a force of 200 N directed to the occlusal surface.

RESULTS

It is not possible to consider within an FEA study all of the variables operating in an oral environment. In this study, it was assumed that ceramic material is homogenous, without artifacts. Anisotropic properties of enamel were accounted for in the model. Detailed three dimensional finite element models of a molar tooth with different cavities and restored with ceramic inlays were generated.

Figure 6. In teeth restored with ceramic inlays, the von Mises equivalent stress values were higher than in intact teeth.

The investigations confirmed that restorations are not as fracture resistant as natural intact teeth. In teeth restored with ceramic inlays, the von Mises equivalent
stress values were higher than in intact teeth (fig.6). High stresses were located at the junction of the butt joint margin inlay and enamel and at occlusal level (fig.7). The values depend on the preparation shape and decrease with the increase of the taper.

**DISCUSSIONS**

Ceramic inlays are primarily composed of leucite-reinforced ceramics. This material is characterized by an elastic modulus similar to enamel.\(^1\)\(^,\)\(^2\)\(^,\)\(^2\)\(^0\)\(^,\)\(^2\)\(^2\)\(^,\)\(^2\)\(^6\)\(^,\)\(^2\)\(^7\) Clinically, these failures are manifested by marginal discoloration and secondary caries.\(^2\)\(^8\)\(^,\)\(^2\)\(^9\) Microleakage at margins in enamel has been found to be significantly lower than at dentin interfaces.\(^3\)\(^0\)

Mainly, ceramic inlays maintain better anatomic form of the surface and exhibit better marginal integrity, as well as stabilize the weakened cusps better than composite resin inlays.\(^3\)\(^1\)\(^,\)\(^3\)\(^2\)

It is a well-established claim that mechanical testing is of paramount importance in biomedical research. To limit the costs and risks involved in live experiments, virtual models and simulation approaches have become unavoidable: an iterative optimization of the design of the experiment is performed on the computer and is seen in virtual prototyping and virtual testing and evaluation. The value is that the modeling and simulation step saves time and money for conducting the live experiment or clinical trial. Yet dental research seems to make very little use of virtual models, such approaches representing a minor part of the scientific publication volume.\(^3\)\(^5\)

The reconstruction methods using laser scanning data or micro-CTscan generate detailed and valid 3D models of teeth and dental restorations.\(^3\)\(^5\),\(^3\)\(^3\) This method is rapid, open and doesn’t depend on a specific scanner or system. The results depend only on the scanning accuracy and the file types resulted after scanning. The precision of the models obtained by three dimensional scanning depends on the working procedures, from scanning to volume generation, and is higher than that obtained using other modeling methods.\(^3\)\(^4\)

Although CAD/CAM methods for producing fixed restorations are of increasing interest, little information has been published about their mode of operation and functionality. At this time, a lot of devices for digitizing model surfaces for dental CAD/CAM applications are available in dentistry.\(^3\)\(^5\)

The requirements imposed nowadays considering the modern calculation of the dental restorations design, as well as the manner of taking decisions in case of their life duration assessing, need good knowledge in the field of biomechanics. Modern design and evaluation calculus of prosthetic restorations in order to obtain an adequate strength cannot be imagined without using numerical simulations. Analyses in this field continuously advance, both in three-dimensional modeling, computer aided design and numerical simulation methods.\(^3\)\(^0\)

**CONCLUSIONS**

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

1. This investigation describes a rapid method for the generation of finite element models of dental structures and restorations;
2. The study provides a biomechanical explanation for inlays restored teeth;
3. From biomechanical point of view, it resulted that ceramic inlays do not restore the original strength of the teeth;
4. The preparation shape is decisive for the stress values and distribution, hence the susceptibility to fractures;
5. The stress values decrease with the increase of the taper.

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