Design parameters for all-ceramic dental crowns

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Summary, conclusions and recommendations

Summary

Despite increased effort to prevent dental decay today mankind is still in need of prosthetic reconstructions. More and more patients prefer multi-layer all-ceramic crowns because of their esthetic qualities. Multi-layer all-ceramic crowns consist of a ceramic core with one or more veneering ceramic layers. The layers partly reflect, absorb, and transfer light, this produces a translucent effect, and a sense of depth to approximate as much as possible the natural tooth. Cores produced with modern production techniques and materials make the production of reliable all-ceramic crowns possible. Still all-ceramic restorations are prone to spontaneous fracture, mainly when placed in the posterior region. Various factors attribute to these phenomena, where the most important ones may be the materials used and shape of the restoration, and the cement layer. In order to make long-lasting restorations it is advisable to have specific design rules for the production of all-ceramic crowns. For manually produced restorations, design weaknesses can hardly be predicted as the design of the multi-layer all-ceramic restorations with respect to the ceramic layer design as well as the outer shape is an operator dependent property. However, for computer designed and manufactured restorations (CAD-CAM: Computer Aided Design-Computer Aided Manufacturing) these parameters as well as those of the preparation are digitally available, making stress analysis and failure prediction possible. This analysis can be done with Finite Element Analysis (FEA). The solution method of finite element analysis consists of dividing the geometry into a finite number of elements with easy to describe mechanical properties. 3D finite element analysis proved for dentistry to give reliable information concerning stress distribution in a tooth or crown.
This thesis indicates that for all-ceramic crowns in the posterior region specific design rules have to be followed and that Finite Element Analysis can be a successful tool to develop design guidelines for all-ceramic restorations. Since certain material properties were not available from literature, some material properties had to be studied before a FEA evaluation of full ceramic crowns was possible.

The results, which have led to the specification of the design rules to be applied are summarized as follows.

Chapter 1 provides a historical background of the production techniques and materials for dental restorations and describes the ceramic materials and production techniques, which make reliable crowns possible, the cementation materials of choice today, the production with CAD-CAM systems of crowns, and presents Finite Element Analysis. This chapter also describes the aim of the research.

Chapter 2 explains that the surface roughness is one of the parameters which determine the strength of ceramic materials, except where the inner structure causes greater stress concentration than the stress concentration caused by the surface roughness. In order to adjust occlusion, the functional surfaces of porcelain restorations are often ground, mechanical machining is even an essential part of the CAD-CAM process, and loading of the restoration will cause wear, reshaping the surface, which will introduce surface flaws. These phenomena will influence the porcelain strength.

For the veneering porcelains studied a significant correlation was found between surface roughness and biaxial strength, with the exception of one material where the inner structure probably induced more stress concentration than the surface roughness: the smoother the surface the stronger the material.

In Chapter 3 the subject of the study is the hindering of the transverse contraction due to the hardening of the cementation material, hindered by the adhesive bond to the tooth tissue and the restorative material. For these thin layers, the relation between stress and strain, i.e. the stiffness, in the direction perpendicular to the cementation surfaces depends on the ratio between bonded and free surface of the cement layer. The thinner the layer, the higher the stiffness (apparent Young's modulus) will be. The hindering of the transverse contraction has to be taken into account studying the mechanical properties of luting cements. Moreover, as a consequence severe shear forces may develop at the adhesive interfaces of luting cements when loaded in tensile or compression. Stresses in the cement, like stresses due to bite forces on the cemented restoration, will increase the probability of bonding failure not only by compression forces but also by shear forces.
FEA programs calculate with the influence of the transverse contraction, while for the simple calculation of stresses using Hooke’s law, one has to take the effect of neglecting the hindering of transverse stresses in the sample into account. This effect may be as large as 25% of underestimating the stresses.

Chapter 4 also deals with the hardening of the cement layer. A rather simple model is presented, which mimics the behavior of luting cements based on the division of the setting process into a liquid phase where the material shrinks but no stress develops, a visco-elastic phase where the shrinkage partly leads to stress formation and is partly relieved by viscous flow, and an elastic phase where all shrinkage is transferred into stress. With the assumption of uniform layer thickness the setting process of resin composite cements can be expressed as stress-shrinkage plots, which are time independent. The model showed to be suitable for the prediction in FEA of the magnitude of the setting stresses.

In chapter 5 the obtained material properties were used in a FEA evaluation of the crowns of three patients with multi-layer crowns for posterior tooth 46 produced with CAD-CAM technology. The model consisted of two ceramic layers, a cement layer, and the preparation of the tooth. The stress distribution due to the combined influences of bite forces, residual stresses caused by the difference in expansion coefficient of the ceramic layers, and the influence of shrinkage of the cement was investigated. The result was that the tensile stresses in crowns with chamfer knife-edge preparations might put the integrity of the currently available ceramic materials at risk, while a not uniform cement layer thickness might result in stresses exceeding the bond strength, and difference in thermal expansion for the two ceramics may increase the tensile stresses in the veneering porcelain.

For this study it was assumed that the FEA model did exactly correspond with the clinical crown. For the clinically interpretation of the results of this study it has to be taken into account that the clinically placed crowns might differ from the FEA models. Although the number of crowns is limited the support of literature to the results found may lead to the conclusion, that the results may be generalized.

Conclusions

With the improved strength of contemporary core materials, stresses in the core will not influence the longevity of the restoration. In many configurations the most critical sites will be in the veneering porcelain near the interface with the core and distal-lingual at the cervical surface.
Summary, conclusions and recommendations

Thermal contraction mismatch of the two ceramics may increase tensile stress development in the veneering porcelain; therefore, it is advisable to have the difference in thermal expansion for the two ceramics as small as possible.

The outline is critical for the veneering porcelain especially when it ends with a knife-edge; therefore, a chamfer with collar preparation is advisable.

The non-uniform cement layer does not decrease the tensile stresses in the veneering porcelain at the interface between veneering porcelain and core, but increases the maximum shear stresses in the cement layer at the bonding surfaces to values exceeding the bond strength of the cement layer to restoration and preparation. Therefore, the cement layer thickness must be as uniform and as thin as possible.

These specific design rules for full ceramic crowns in the posterior region have to be followed to ensure the longevity of these restorations.

Recommendations

The used models for the calculation of the stresses due to the shrinkage of the cement layer and the residual stresses due the difference in expansion coefficient of the core material and the veneering porcelain may not fully describe the clinical situation. The use of the model for the calculation of the stresses due to the shrinkage of the cement layer is limited to uniform cement layer thickness, where in the clinical situation the thickness of the cement layer will vary from the occlusal surface to the outline. For the model to calculate the residual stresses due to the difference in expansion coefficient of the ceramics used two of the assumptions, the distribution of the temperature during processing of the crown is uniform and the modulus of elasticity and the Poisson’s ratio are constant during processing of the crown, made in order to simplify the calculations may not describe rightly the occurring stresses for the materials used and the actual production process.

For the improvement of the, for patients, unfortunately still necessary restorative work it is recommended to do further research on these subjects.