UDK 616.31:539.3 ISSN 1580-2949
Original scientific article/Izvirni znanstveni članek MTAEC9, 45(6)561(2011)

STRESS-STRAIN ANALYSIS OF AN ABUTMENT TOOTH WITH REST SEAT PREPARED IN A COMPOSITE RESTORATION

NAPETOSTNO-DEFORMACIJSKA ANALIZA OPORNEGA ZOBA Z ZAPORNIM SEDEŽEM, IZDELANA S KOMPOZITNIM POPRAVILOM

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Prejem rokopisa – received:2011-02-02 ; sprejem za objavo – accepted for publication: 2011-04-06

Placing a composite restoration on abutments for the removable of partial dentures gives favorable aesthetic results with minimal intervention. The objective of this paper is to analyze the stress distribution of a tooth with occlusal rest-seat preparation in the composite and compare it to the biomechanical behavior of an intact tooth, assuming that the stress and strain distribution throughout the intact tooth provides the control scenario. For this finite-element study two different models were designed. The first model was the three-dimensional (3D) model of an intact tooth, and the other one was a 3D model of a tooth with a composite restoration and an appropriate occlusal rest-seat preparation. Load stimulations were performed when the rest was fully seated on its corresponding rest seat and abutment tooth in order to obtain data about the biomechanical behavior of the abutment tooth compared to the intact tooth's stress-distribution pattern. The results of our analyses are presented and analyzed qualitatively. The occlusal loading effect along the sound tooth exhibits a wider high-stress area, localized in correspondence with the occlusal enamel, than the restored teeth. This is due to the rigidity of the enamel. The reduction in the stress values occurs in the composite restoration, which is less rigid. Its lower rigidity allows larger cusp movements. The stress-distribution pattern of the restored tooth with the rest seat showed that introducing an occlusal restoration does not differ from the intact tooth globally, but locally. Our findings indicate that the composite rest-seat restoration absorbs the loading, so reducing the stresses inside the tooth's structure.

Key words: composite rest seat, abutment tooth, stress distribution, finite element method (FEM)

Postavitev kompozitnega popravila opore za odstranljive dele zobovja daje dobre estetske rezultate z minimalno intervencijo. Cilj tega članka je analizirati porazdelitev napetosti na zobu z zapornim sedežem s kompozitno zaporo in jo primerjati z biomehanskim vedenjem intaktnega zoba s predpostavko, da odloča razdelitev napetosti in deformacije intaktnemu zobu. Za to študijo sta bila na podlagi končnih elementov razvita dva različna modela. Prvi je tridimenzionalen (#D) model intaktnega zoba, drugi pa je 3D-model zoba s kompozitno restoracijo in ustrezno pripravo zapornega sedeža, da bi tako dobili podatke o biomehanskem vedenju mostičnega opornika in o porazdelitvi napetosti v intaktnem zobu. Rezutati so prikazanai in analizirani kvalitativno. Zaporna obremenitev povzroči široko področje visoke napetosti v zdravem zobu zaradi stika s sklenino in ne restoriranega zoba. To je posledica velike togosti sklenine. Manjše so napetosti v manj togi kompozitni restoraciji, kar omogoča večje premik opornega vrha. Porazdelitev napetosti restoriranega zoba z opornim sedežem kaže, da uporaba zaporne restoracije ne vpliva globalno, ampak lokalno. Ugotovitve kažejo, da popravilo zob z oporo absorbira obremenitev, ker zmanjša napetosti v strukturi zoba.

Ključne besede: kompozitna opora, oporni zob, porazdelitev napetosti, FEM

1 INTRODUCTION

The preparation of occlusal rest seats on the supporting, corresponding surfaces of the abutment teeth is widely recommended as a way of promoting axial load[1]. A removable partial denture (RPD) designed and manufactured in that manner fulfils the functional, prophylactic and aesthetic demands placed upon it. Occlusal rest-seat preparation demands cutting the enamel tissue in order to achieve "spoon-shaped" depressions with the proper dimensions.[2] The integrity of the remaining tooth structure is deteriorated from the biomechanical point of view with a resultant change in the intact tooth's pattern of stress and strain distribution. The change of the natural tooth's biomechanical balance could lead to increased potential for further trauma and eventual loss of the remaining tooth's structure. Although many studies with different methodologies have been implemented and performed, no clear cut and clinically relevant conclusions were drawn for the minimal dimensions of the cavity preparation that would minimize the tooth-fracture potential when subjected to occlusal loading. In particular, when an RPD abutment tooth is considered where most occlusal forces are distributed to the abutment from the occlusal rest to the rest seats in the tooth/tooth- or tooth/mucosa-supported RPD. When planning prosthetic restorations one is facing the presence of two different biological tissues and the need for an even distribution of the occlusal and other forces on the periodontal tissue of the remaining teeth, and in the mucoperiosteum on the edentulous alveolar ridge. The stress distribution throughout an RPD and the supporting tissues may be evaluated easily using the finite-element method (FEM) [3].

In order to manufacture an RPD that fulfills both the functional and prophylactic demands, a non-invasive modality treatment for preparing the abutment tooth may be suggested. It is a good option for preparing the supporting dental tissues for receiving the elements of the RPD. The minimal appropriate intervention in that case could be placing a composite restoration, as stated by Shimizu & Takahashi [4]. Using a highly filled composite resin for the restoration of an abutment preparation for removable partial dentures gives favorable aesthetic results with the minimum intervention.[4]

The discussed treatment modality highlights the objective of this paper, which is to analyze the stress-strain distribution of the tooth with an occlusal rest-seat preparation in a composite filling and compare it to the biomechanical behavior of an intact tooth, assuming that the stress-strain distribution throughout the intact tooth provide the control scenario.

2 MATERIALS AND METHODS

The problem of the biomechanical behavior of a complex structure with irregular geometry such as a tooth could be analyzed using the finite-element method (FEM). Applications of the FEM are expanding rapidly, not only in the field of engineering but in science globally, especially as it appears that the FEM is a useful and convenient method for solving problems related to macrostructures, but also might give a precise insight into the problems related to microstructures.[5]

For this study two different models were created. The first model was a three-dimensional (3D) model of an intact tooth – **Model 1** (**Figure 1**), and the other was a 3D model of a tooth with a composite filling and an appropriate occlusal rest-seat preparation – **Model 2** (**Figure 2**). The 3D model of the second upper premolar was generated by combining the inner and outer geometry profiles obtained from literature data.[6,7] The mentioned morphologic details and dimensions were used to define a series of planes at different levels with the outlines of the tooth cross-section at each level. (**Figure 1**) The distance between the sliced planes was three slices in one mm, where over two hundred planes were generated. As this was time-consuming data for the software processing, the distance between the slices was increased afterwards to 2 mm for the crown portion of the model, and 3 mm for the root portion of the model.

The PRO-ENGINEER (Parametric Technology Corporation / Needham Massachusetts) and SOLID WORKS (Solid Works Corporation) software packages were employed for these procedures. The next step was to describe the relations between the planes, from where the solid model was constructed by connecting these contours. The dentine part of the tooth structure's crown and root portions were modeled separately from the enamel shell. Afterwards, the enamel and dentine were assembled into the final model of the intact tooth (**Figure 2**).

Subsequently, a model of a tooth with a composite filling and an appropriate occlusal rest seat was obtained, where additional cutting planes were defined in order to perform the cavity preparation. The occlusal rest preparation's size and location were chosen to conform to the standard cavity-design recommendations for a rest seat. The rest seat was 1.5 mm deep, occupying one half of the mesio-distal dimensions of the tooth crown and was approximately one third of the crown in the bucco-lingual direction. The recommended dimensions were adopted from literature recommendations.[8] The final FEM model of the restored tooth was realized by

Figure 1: Solid model of an intact tooth
Slika 1: Trdni model intaktnega zoba

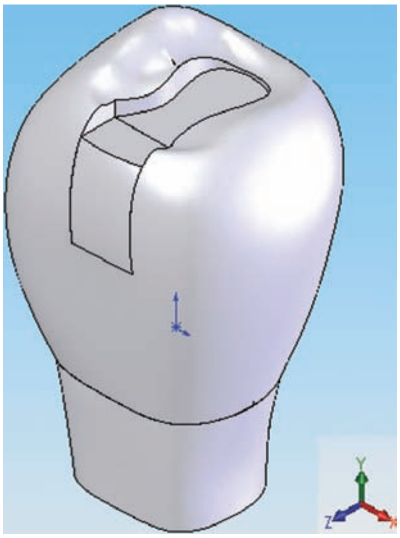

Figure 2: Solid model of a tooth with rest-seat preparation in a composite
Slika 2: Trdni model zoba z opornim sedežem iz kompozita

changing the element material properties in the zone of the cavity preparation.

Table 1: Young's modulus and Poisson's ratio of the materials used in this study[9,10]

Tabela 1: Youngov modul in Poissonovo razmerje za materiale, uporabljene v tej raziskavi[9,10]

	Young's modulus	Poisson's ratio
Enamel	84.1 GPa	0.33
Dentin	14.7 GPa	0.31
Composite resin	10.0 GPa	0.30
Co-Cr alloy	154.0 GPa	0.33

All the materials were considered to be isotropic and homogeneous and were assigned the appropriate physical properties according to literature data[9,10].The material properties are listed in **Table 1**. The dental pulp was modeled as a void because of its negligible stiffness and strength.[11] The cement was not included in the models due to its small dimensions and because it had no influence on the analysis.[12] Perfect bonding was considered between the enamel and the composite.

Both models were constrained at the top, 2 mm from the cement-enamel junction, representing the normal level of the alveolar crest and, in that way, the boundary conditions in this stress-strain analysis were defined. Therefore, the influence of the periodontal ligament (PDL) was not involved in the study.

Creating the finite-element mesh (pre-processing) for the described models was performed using the NASTRAN program (Noran Engineering Inc / Westminster Ca), where all the subsequent procedures (processing and post-processing) were done. The intact tooth-model mesh consisted of 15 092 finite elements with 23 300 nodes, while the mesh for the second model had 15 089 finite elements with 23 334 nodes. Each model was meshed by structurally solid elements defined by 10 nodes and having three degrees of freedom in tetrahedral bodies.

The loads were determined with an emphasis on load intensity, the direction and the point of the loading. Because of the variety of occlusal forces (differing among individuals, types of food chewing, conditions of occlusion) this study adopted vertical loading with 250 N in intensity. The existence of possible horizontal forces were ignored, where the RPD was assumed to be a rigid and stable appliance resisting the horizontal component of the masticatory forces[13]. As the analysis was considered linear in nature, sliding and friction phenomena that might occur between a rest and an abutment tooth were also ignored. Load stimulations were performed when the rest was fully seated on its corresponding rest seat and abutment tooth. The loads for both models were applied vertically at right angles to the inner aspects of the cusp slopes, away from the cusp tip. The simulated direction and intensity of the loads represent the loading pattern found in the centric occlusion, as stated by Rees and Jacobsen [16].

3 RESULTS

Based on the assumptions involved in the study and the fact that computer simulations simplified the real problems, the results of the study might be different to the values of stresses encountered by teeth in real situations. Therefore, the results were presented and considered qualitatively, not quantitatively, in order to offer more insight into the general influence of the prosthetic devices placed on teeth.

The results of the study are presented graphically as maps of the stress distribution within both investigated models. The total displacement (translation), maximum principal stress $\sigma_{\max}$, and minimum principal stress $\sigma_{\min}$ were evaluated for each of the models.

The total displacement of the intact tooth after occlusal loading is shown in **Figure 3**. The largest displacement values are recorded at the cusp tip, due to tooth structure deformation encountered as a result of loading. Obviously, a lot of deformation happens in the points where the load is applied and therefore the greatest displacement values are observed there. Moving away from the loading point along the longitudinal axis of the tooth in an apical direction, the displacement decreases. This is probably the mechanism for the occlusal load amortization within the intact tooth's structure. Such findings are partly recognized as a consequence of the applied boundary conditions.

The values for $\sigma_{\max}$ and $\sigma_{\min}$ are also found to be the highest at the occlusal portion of the tooth. The concentration of stresses is higher at the location of the loading. These stresses rapidly decrease in the occluso-gingival direction. Close to the cement-enamel junction (CEJ) the stresses again increase and concentrate at that location. The pattern of stress distribution throughout the rest of the tooth structure shows a reasonably symmetrical distribution with the exception of the occlusal surface and the location close to the CEJ. (**Figures 4 and 5**)

As shown in **Figure 6**, the total translational displacement of the tooth with rest seat preparation is greatest at the cusp tip, as a result of the whole structure deformation. The occlusal loading of the model with rest-seat preparation induced a large deformation of the tooth structure. The observed total displacement values are similar to the values obtained for the intact tooth model. Similarly, as with the intact tooth model, the total displacement values are the largest at the location of the loading where great deformation happens. The displacement decreases in an apical direction as the distance from the loading location increases.

The general trend of stress distribution through the tooth with a rest-seat preparation is similar to that of an intact tooth, but some regional variations were observed.

The concentration of the stresses $\sigma_{\max}$ and $\sigma_{\min}$ is higher occlusally at the location of the loading, but very high stresses are concentrated at the bottom (pulpal

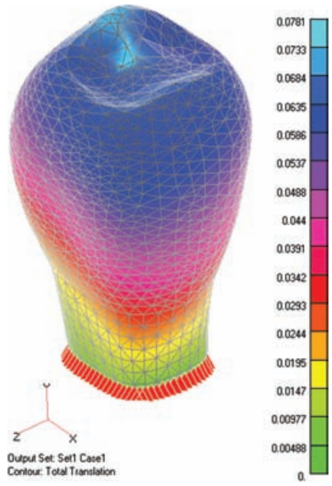

Figure 3: Total translational displacement of the intact tooth model

Slika 3: Totalni premik modela intaktnega zoba

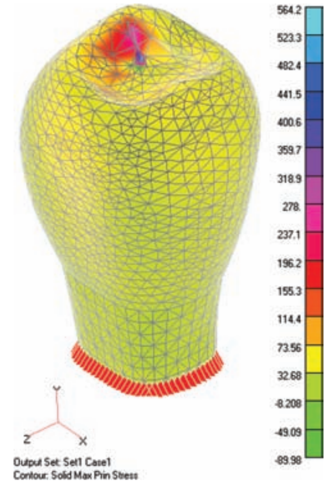

Figure 4: Distribution of the maximum principal stress of the intact tooth model

Slika 4: Porazdelitev največjih glavnih napetosti v modelu intaktnega zoba

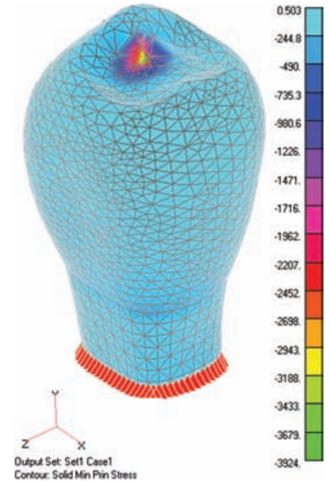

Figure 5: Distribution of the minimum principal stress of the intact tooth model

Slika 5: Porazdelitev najmanjših glavnih napetosti v modelu intaktnega zoba

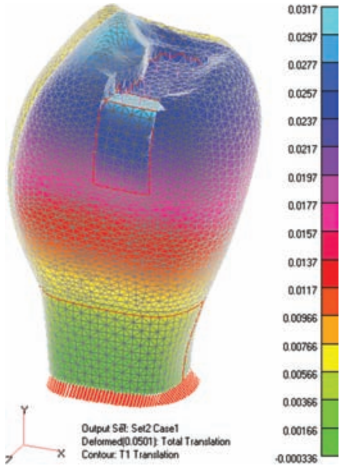

Figure 6: Total translational displacement of the tooth with occlusal rest-seat preparation in a composite

Slika 6: Popoln premik zoba z opornim sedežem, izdelanim iz kompozita

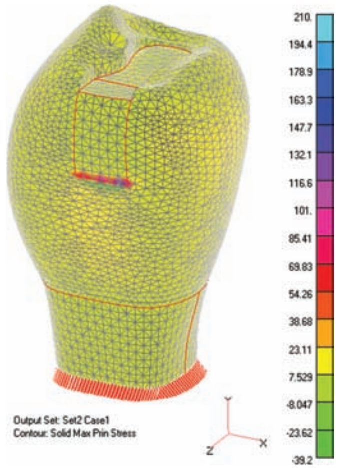

Figure 7: Distribution of the maximum principal stress of the tooth with the occlusal rest-seat preparation in the composite restoration

Slika 7: Porazdelitev največjih maksimalnih napetosti v zobu z zapornim sedežem in kompozitno restoracijo

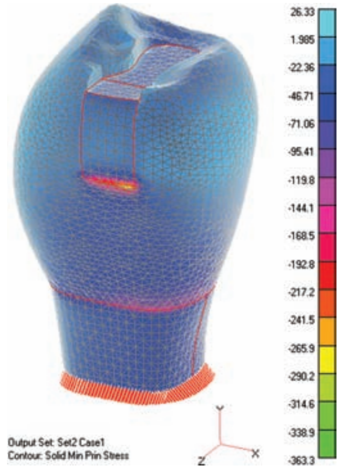

Figure 8: Distribution of the minimum principal stress of the tooth with the occlusal rest-seat preparation in the composite restoration

Slika 8: Porazdelitev najmanjših glavnih napetosti v zobu z opornim sedežem s kompozitno restoracijo floor) of the rest-seat preparation (**Figures 7 and 8**). The trend of a symmetrical stress distribution through the rest of the tooth structure with decreasing intensity is also observed in this model. Again, the stresses rapidly increase close to the CEJ and reach their highest peak concentration at the CEJ. The stresses $\sigma_{\max}$ and $\sigma_{\min}$ resulting from the application of the occlusal load on the tooth with rest-seat preparation have lower values than those obtained after the intact tooth loading.

4 DISCUSSION

This investigation was focused on the mechanical behavior of a critical system such as the second upper premolar restored by a class II cavity preparation (where an accordant amount of dentine and enamel tissue is lost and the integrity of the structure is altered by placing an occlusal rest).

The relative behavior of composite restoration and the abutment tooth under the mastication load is shown, although some assumptions were made in order to simplify the calculations. Despite their intrinsic anisotropic nature, dentine and enamel can be assumed to be homogeneous and isotropic because their anisotropy belongs to the microscopic scale, whereas the tooth model is macroscopic.[14,15] Furthermore, all the materials were considered to be elastic throughout the entire deformation, which is a reasonable assumption for brittle materials in non-failure conditions.[16]

From the mechanical point of view, considering dentine as elastic and isotropic is an acceptable assumption, while enamel does not show such behavioral characteristics. Enamel is a more anisotropic material and some authors have modeled the enamel as anisotropic[14,16] Although such enamel modeling was more orthotropic, where the principal material axes coincided with the direction of enamel prisms, they were assumed to be perpendicular to the enamel-dentine junction. Following the recommendations of Darendeliler [14] and Versluis [15], materials which comprise the tooth structure could be modeled as isotropic and homogeneous,[14,18] especially because there is still no competent literature data on dental structure inhomogeneity and anisotropy.

Considering the occlusal loading effect alone, the sound tooth exhibits a wider high stress area, localized in correspondence to the occlusal enamel, than the restored teeth. This is due to the rigidity of the enamel. The reduction in stress occurs in the composite restoration, which is less rigid, and its lower rigidity allows greater cusp movements. The composite restoration will only cause deformation of the surrounding tooth structure through a well-bonded interface. So, the average stress in the entire structure is lower, but the stress values in the buccal and lingual cusps are higher. However, placement of a composite restoration with included a rest seat does not deteriorate the tooth's ability to withstand occlusal loading. The tooth with a composite restoration was less sensitive to occlusal loading than the intact one, probably due to the cusp reinforcement achieved by dentine and enamel bonding.

However, the concentration of stresses along the pulpal floor must undoubtedly be considered. The presence of cracks in the enamel introduced during cavity preparation may be a primary factor contributing to the stress concentration and eventual restoration failure. Also, some variance in the enamel mineralization between the surface and deep portions might interfere in homogeneous stress distribution throughout the restored tooth. The degree of enamel mineralization decreases as one approaches the amelo-dentinal junction, with a decreased elastic modulus[19]. Therefore, it seems that the peak stresses found in the tooth model with composite restoration with an included rest seat may be attributed to different causes.

These preliminary considerations, however, do not take into account setting composite shrinkage. These findings correlate with the statement of Ausiello [20] that more rigid composites lead to lower cusp movements under occlusal loading, but exhibit a higher pre-loading effect. A good composite for restoration has to balance the two opposite effects. In this way, a low pre-load on the cusps can be accepted in order to reach a sufficient restoration rigidity.[20] The size and configuration of the composite restoration affects the amount of tooth deformation due to resin polymerization shrinkage. In a small restoration (Class I and small Class II), deformation could hardly be visualized, which means that it was consistently lower or close to the measurement resolution.[21] The cavity designed for the rest seat in the study was of smaller dimensions than the standard Class II restoration, allowing us to speculate that the obtained deformation was a consequence of the applied loading by the occlusal rest and may not be partly the result of resin polymerization shrinkage. The study adopted the absolute bonding between the tooth and composite restoration, which may be the reason for the high stress concentration found along the pulpal floor. An infinitely rigid interface layer produces high stress areas all around the tooth-restoration interface. Accompanied by the polymerization shrinkage, stress and occlusal load stress exists as a very complex biomechanical system. An appropriate way to limit the intensity of all the stress transmitted to the remaining tooth tissues under occlusal loading by the rest would be the proper selection of the adhesive layer. Ausiello[22] stated that a substantially thicker layer of a more flexible adhesive (lower elastic modulus) would partially absorb the composite deformation.[22]

5 CONCLUSION

Within the limitations of the finite-element simulation study, the results suggest that a composite restoration with a rest seat included reduces the generation of stresses inside the tooth structure. Findings indicate that a composite restoration absorbs the loading and, due to its resilient nature, acts as a cushion beneath the occlusal rest. The simplifications used in the study have also been shown to affect the results. The detailed modeling of dental hard-tissue anisotropy, along with the more precise modeling of the adhesive interface, should be considered as a goal for any future study on this topic.

The potential of the system composite-occlusal rest seat is that it represents the minimum intervention procedure and acts as an absorbent of occlusal loading. Furthermore, the eventual use of a composite restoration may be suggested as a way of preparing abutments for receiving elements of the RPD. However, clinical trials are required to ensure that a composite restoration with rest seat included can survive under long-term clinical conditions.

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