Determining the Effect of the Occlusal Rest Localization on the Stress Distribution over Abutment Teeth and Periodontal Tissues by Finite Element Analysis

Okluzal Tırnak Konumunun Dayanak Dişler ve Periodontal Dokular Üzerindeki Kuvvet Dağılımına Olan Etkisinin Sonlu Elemanlar Analizi ile Saptanması

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ABSTRACT Objective: In removable partial prosthetics, distributing masticatory loads evenly along the abutment teeth and supportive mucosa is related to the design of direct retainers. Design of clasps as direct retainers, plays a major role in the preservation of the abutment teeth. The purpose of this study is to evaluate the effect of occlusal rest localization on the stress distribution over supporting tissues by finite element analysis. **Material and Methods:** A bilateral distal extension removable partial denture supported by cast akers and modified back-action clasps on mandibular first premolars was modelled. A 100-N load simulating the masticatory forces was applied to the denture in the z axis direction. σ_Y stress ditributions over the supporting tissues generated by different localization of occlusal rests along the x-x axis were evaluated. **Results:** The highest stress concentrations were located on the alveoler bone and metal framework of the denture. The rest of the stress were concentrated on the teeth and periodontal tissues. In the mesially localised occlusal rest model, masticatory forces distributed to the supporting tissues were lower. On the other hand, on the distally localised occlusal rest model, detrimental masticatory tensile forces occurred over the supporting tissues. **Conclusion:** In the distal extension removable partial dentures, mesially localised occlusal rests showed more favorable stress distributions over the abutment teeth.

Key Words: Finite element analysis; denture, partial, removable

ÖZET Amaç: Hareketli bölümlü protezlerde çiğneme yüklerinin destek dişler ve destek dokular boyunca dengeli olarak iletilebilmesi direkt tutucuların tasarımı ile yakından ilişkilidir. Destek dişlerin korunmasında, direkt tutucular olan kroşelerin tasarımı önemli rol oynamaktadır. Çalışmanın amacı, okluzal tırnak konumunun destek dokular üzerindeki kuvvet dağılımına olan etkisini sonlu elemanlar analizi ile değerlendirmektir. **Gereç ve Yöntemler:** Mandibular birinci premolar dişlere döküm akers ve modifiye geri etkili tipi kroşelerle tutunan çift taraflı serbest sonlanan bir hareketli bölümlü protez modellenmiştir. Proteze z ekseni doğrultusunda çiğneme yüklerini taklit edecek şekilde 100 N'luk kuvvet uygulanmıştır. x-x ekseni boyunca, farklı okluzal tırnak konumlarına bağlı olarak destek dokular üzerinde oluşan σ_Y stres dağılımları değerlendirilmiştir. **Bulgular:** Stres birikimleri daha çok alveoler kemik ve protez metal kaidesinde gerçekleşmiştir. Geriye kalan yükler dişler ve periodontal dokular üzerinde birikmişlerdir. Meziyale konumlandırılmış okluzal tırnak modelinde destek dokulara iletilen çiğneme kuvvetleri daha düşük bulunmuştur. Diğer yandan, distale konumlandırılmış okluzal tırnaklı modellemede, destek dokular üzerinde yıkıcı gerilme kuvvetleri oluşmuştur. **Sonuç:** Serbest sonlanan hareketli bölümlü protezlerde meziyale yerleştirilmiş okluzal tırnaklar, destek dişlerde daha dengeli yük dağılımları göstermiştir.

Anahtar Kelimeler: Sonlu elemanlar analizi; hareketli bölümlü protez

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Removable partial dentures are fabricated to restore the decreased masticatory function, phonetics and esthetics. In removable partial denture applications, there exists an interaction among the teeth, periodontal tissues and bone that effects the stomatognatic system. Therefore, prothetic restorations should be compatible with the surrounding tissues while restoring function and esthetics.[1] In removable partial prosthetics, distributing masticatory loads evenly along the abutment teeth and supportive mucosa is related to the design of direct retainers.[2] Design of clasps as direct retainers, plays a major role in the preservation of the abutment teeth. Retention and tension on clasp arms are of big importance for the long term use without deformation or fracture of removable partial dentures.[3] Rigidity of clasp arms and also the localisation of abutment teeth influence the clasp retention. Occlusal rest is one of the structural components of the clasp located on the occlusal surface of the abutment tooth. Most of the occlusal loads are distributed to the abutment teeth via occlusal rests. Therefore, occlusal rest localization on the abutment teeth is proven to be important by most of the researchers.[4,5]

Biomechanical methods can be used for the assessment of the loads subjected to the abutment teeth in removable partial dentures.[6] These methods can be classified as; finite element analysis (FEA), photoelastic analysis, geometrical analysis and stress analysis.[7-10] In finite element analysis, a model that simulates the original situation can be prepared, properties of the materials can be changed and also desired load values can be applied to the model.[11]

The purpose of this study was to analyse the stress distributions occured on the abutment teeth of a bilateral distal extension removable partial denture retained with akers and modified back-action clasps by three-dimensional finite element analysis method.

MATERIAL AND METHODS

In the study, an impression of a bilateral distal extension mandible was made and a model was prepared. On the right first premolar an akers clasp with distally located occlusal rest and on the left first premolar a modified back-action clasp with mesially located occlusal rest were designed and a removable partial denture framework of Cr-Co-Mo alloy (Bioseal F, Kulzer, Hanau, Germany) was cast accordingly. The roots of the premolars were modelled with the geometry of the anatomic tooth form described by Wheeler.[12] A 0.25 mm thick periodontal tissue surrounding the teeth was also modelled. Measurement values of the master model were calculated by a digital micrometer (Mitutoyo Euro Apex 7106 CNC-Germany) and modelled with the use of SolidWorks software (Dassault Systemes, Suresnes, France). The thickness of the mucosa differs from site to site and also individually, but was accepted to be 2 mm on average. Alveoler bone was modelled under the mucosa. The length, thickness, width and curvature radius of the cast clasps were measured. The saddle component of the denture framework was modelled as a plate in order to provide an even stress distribution by whole surface contact. In order not to complicate the designed model and calculations, acrylic parts of the denture were not taken into account. To assess the effect of the occlusal rest localisation on the stress distribution more precisely, no indirect retainers were included in the model. By entering the measured values to the computer, a three-dimensional finite element model was designed (Figure 1). Any movement on the joints of the clasps was prevented.

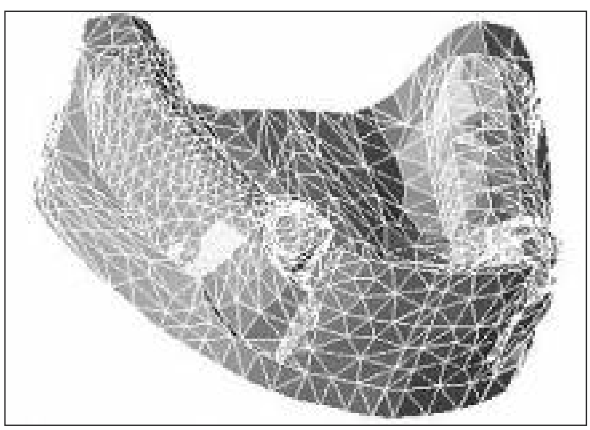

FIGURE 1: Three dimensional finite element model (FEA).

Two important mechanical properties of the materials; modulus of elasticity and Poisson's ratio determined from the literature are given in Table 1.[11,13-17]

In the study, all the analysis was conducted with ANSYS 7.0 (Swanson Analysis System Co., Houston, TX, USA) finite element analysis software. The model was assumed to be isotropic, homogeneous, elastic and axisymmetric and consists of 16307 solid elements with 12000 nodes and 3 degree of freedom. In the solution of the problem SOLID 45 type element was used.

A unit vertical load of 100 N force was applied unilaterally.[18] In the first condition, the load was applied on the saddle with a distance of 17 mm to the akers clasp. In the second one, the load was applied 17 mm far from the modified back-action clasp (Figure 2). A static load was applied to the numerical model and the system made a rotational movement. x-x and y-y axis on which tensile and compressive stress occured and stress distributions on the abutment teeth and periodontal tissues were evaluated. sy stress distributions on x-x axis that were higher in value were taken into account.

RESULTS

In both loading conditions, the highest tensile and compressive stress concentrations were located on the alveoler bone and metal framework of the denture. The rest of the stress were concentrated on the teeth and periodontal tissues (Table 2).

In the first loading condition, compressive stress was concentrated at the disto-cervical third of the root of right abutment tooth while tensile stress was concentrated at the apico-vestibular area (Figure 3a). In the second loading condition, compressive stress was distributed on a wide area at the disto-cervical third of the root of left abutment tooth and tensile stress was distributed on the apical and vestibular side (Figure 3b).

The distribution of stresses on the left abutment revealed compressive stress concentration at the mesial side of the apex of the abutment while tensile stress was concentrated at the disto-cervical third of the root in the first loading condition (Figure 4a). In the second loading condition, compressive stress was distributed on the occlusal rest seat and vestibular side of the apex of the right abutment tooth while tensile stress was not intensive and distributed on the disto-cervical third of the root (Figure 4b).

TABLE 1: Physical properties of the materials.[11,13-17]

Material	Modulus of Elasticity (N/mm²)	Poisson's ratio
Enamel	41400	0.30
Dentin	18600	0.31
Periodontal tissues	68.9	0.45
Mucosa	2	0.40
Cortical bone	14700	0.26
Metal alloy (Cr-Co-Mo)	125000	0.30

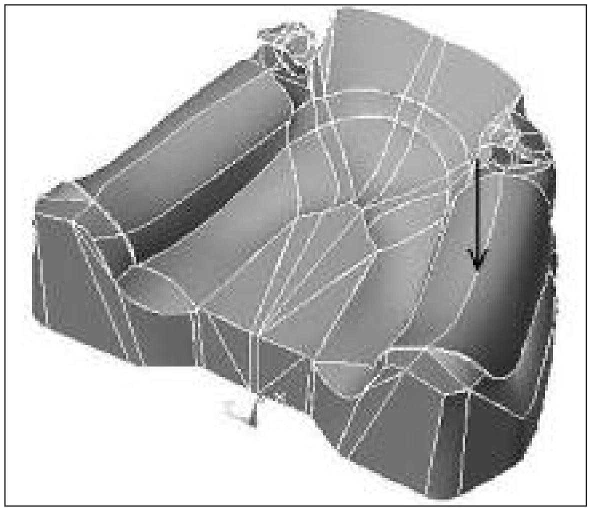

FIGURE 2: Application of masticatory force onto the model.

TABLE 2: Stress distributions on the abutment tooth and periodontal tissues.

	Compressive stress (N/mm²)	Tensile stress (N/mm²)
F_1-A_1	-0.012	0.011
F_2-A_2	-0.010	0.017
F_1-A_2	-0.021	0.014
F_2-A_1	-0.012	0.020
F_1-A_3	-0.017	0.006
F_2-A_4	-0.022	0.004
F_1-A_4	-0.008	0.042
F_2-A_3	-0.011	0.041

(F_1:First loading condition, F_2: Second loading condition, A_1: First abutment tooth, A_2: Second abutment tooth A_3: Periodontal tissue of first abutment tooth, A_4: Periodontal tissue of second abutment tooth)

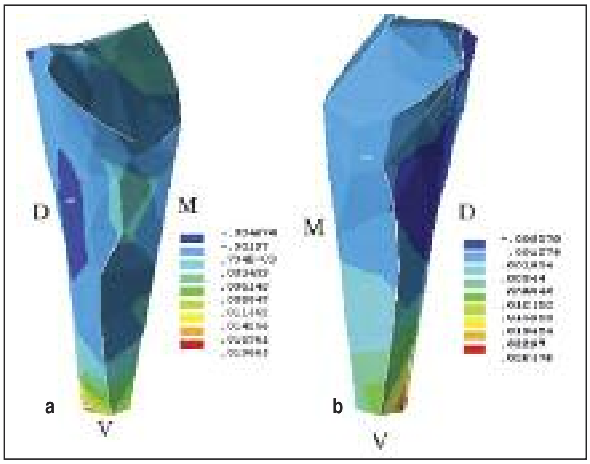

FIGURE 3: a: Stress distribution on the 1st abutment tooth in the 1. loading condition, **b:** Stress distribution on the 2nd abutment tooth in the 2nd loading condition.

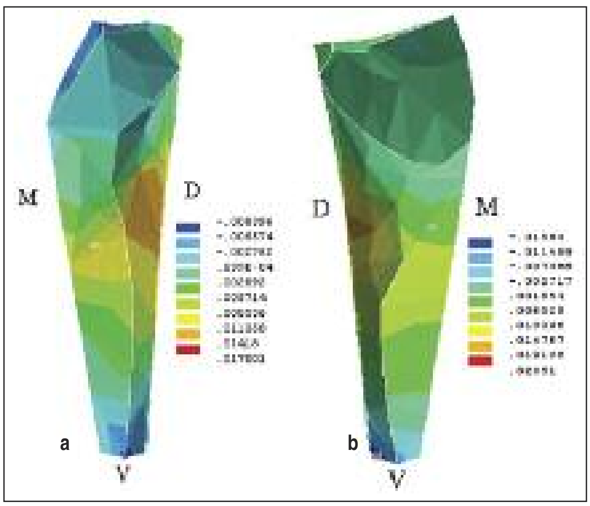

FIGURE 4: a: Stress distribution on the 2nd abutment tooth in the 1st loading condition, **b:** Stress distribution on the 1st abutment tooth in the 2nd loading condition.

Compressive stress on the periodontal tissue was concentrated at the disto-cervical third of the root of the right abutment (Figure 5a) in the first loading condition while it was concentrated on one point at the mesial cervical third of the root of the left abutment tooth (Figure 5b) in the second loading condition. Tensile stress on the periodontal tissue was concentrated at the cervical third and apico-vestibular area of the right abutment (Figure 5a) in the first loading condition while it was distributed on the mesial and distal sides of the apex of the left abutment tooth (Figure 5b) in the second loading condition.

In the first loading condition, compressive stress on the periodontal tissue was distributed along the cervico-apical direction on the left abutment tooth (Figure 6a) while compressive stress on the periodontal tissue was distributed on the mesial side of the right abutment tooth (Figure 6b) in the second loading condition. In the first loading condition, tensile stress on the periodontal tissue was concentrated at the disto-cervical third of the root of the left abutment tooth (Figure 6a). However, tensile stress was distributed on the disto-cervical third of the root of the right abutment tooth (Figure 6b) in the second loading condition.

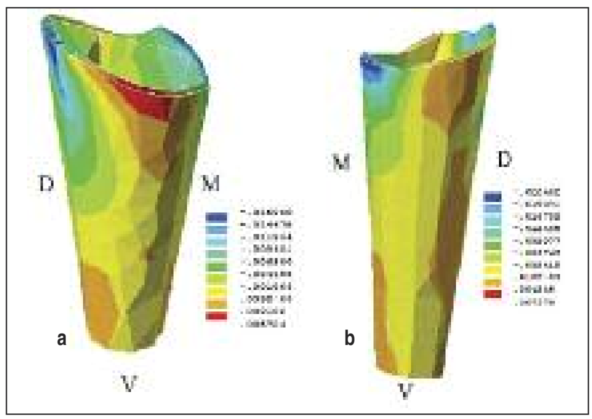

FIGURE 5: a: Stress distribution on the periodontal tissue on the 1st abutment tooth in the 1st loading condition, **b:** Stress distribution on the periodontal tissue on the 2nd abutment tooth in the 2nd loading condition.

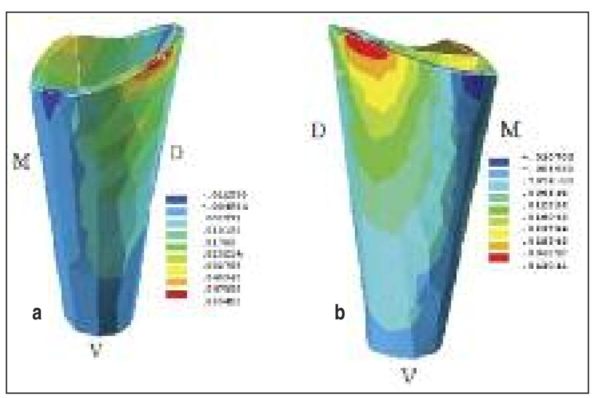

FIGURE 6: a: Stress distribution on the periodontal tissue on the 2nd abutment tooth in the st loading condition, **b:** Stress distribution on the periodontal tissue on the 1st abutment tooth in the 2nd loading condition.

DISCUSSION

For removable partial prosthetics, intensity of the applied masticatory force and the mechanical properties of the materials bearing this force should be known well. An understanding of biomechanical principles is also of primarily importance in the design of the dentures. Otherwise, uncontrolled forces may compromise the harmony between the denture and the supportive components and thus a long-term success could not be reached.

Various framework designs are suggested in order to distribute the masticatory forces evenly and protect the supportive tissues. In the design, localisation of the rests plays a great role for the success of the removable partial denture.[11,19-21]

The effect of occlusal rest localisation on the forces distributed to the abutment teeth is shown to be important by three dimensional finite element analysis of removable partial dentures.[3,6] Many authors suggest that mesially located occlusal rest decreases the stress concentrations on the abutment teeth and is suitable for the distal extension removable partial dentures.[22-25] Moreover, it was reported that using different types of clasp designs bilaterally in one distal extension prosthesis may cause unbalanced force distribution over abutment teeth and supporting tissues.[23,24] In our study, higher amounts of the functional load were distributed over the saddle, edentolous alveoler ridge and mucosa and; the rest is distributed to the abutment teeth and periodontal tissues.

In some studies it is suggested that by locating occlusal rest on the mesial side, first class lever movement of the denture is changed to second class lever movement.[23,25] In the second class lever movement, occlusal forces are distributed along the long axis of the abutment teeth and detrimental forces are prevented.[5,24,25]

Sato et al showed that locating the rest on the lingual occlusal surface distally caused harmful stress concentrations on the abutment premolar.[6] Locating the rest on the buccal occlusal surface mesially is suggested to cause even stress distributions on the abutment tooth. In our study, mesially located occlusal rest formed lower tensile and compressive stress concentrations on the abutment teeth and periodontal tissues. When stress distributions are taken into account, compressive stresses were intensely located at the mesial cervical third of the root. At the distal apical third of the root tensile stresses were observed. Distally located occlusal rest formed high compressive and tensile stress concentrations on the abutment teeth and periodontal tissues. These stress distributions were intensely located at the distal cervical third and at the mesial apical third compressive stresses were observed. According to our study and the related literature, premolars had less root surfaces than molars, are prone to failure against such kind of stress distributions.[6] Distally located occlusal rest causes higher compressive stresses at the distal side and makes to easy distal movement of the abutment tooth had no distal contant support.[6] With the distally located occlusal rest, denture tends to rotate on the hinge axis. During this movement, retantive arm that is positioned anterior to the occlusal rest might be detrimental to the abutment tooth by moving upwards in the opposite direction.[8] By locating the occlusal rest mesially, compressive stresses occur at the mesial side of the root and with the help of mesial tooth contact support abutment tooth is protected against horizontal forces.[3,6] When occlusal rest is located mesially, masticatory loads are directed vertically to the alveoler ridge and mucosa under the saddle and contribute to the indirect retention. Moreover, under masticatory loads retentive clasp arm and plate move in the mesio-gingival direction so that abutment teeth can be prevented from tilting effect.[6] Locating the support more mesially, rotation curve of the plate flattens on any point and becomes more perpendicular to the alveoler ridge. As a result, a wider alveoler region could support the denture against occlusal forces and gingival tissue compressive stress at the distal side of the abutment would be decreased.[20,22,23] Results of our study support and confirm the suggestion that occlucal rest should be located mesially.

When stress distributions on the abutment teeth and periodontal tissues are evaluated, in the first loading condition compressive stress distribution were seen at the mesial apical third and tensile stress distribution occured at the distal cervical third of second abutment tooth. In the second loading condition, compressive stress concentrations were located at the vestibuler apical third and tensile stress concentrations at lower values were seen at the distal cervical third of first abutment tooth. When the occlusal rest is located distally, both abutment teeth are affected similarly. Therefore, it may be proposed that by locating the occlusal rest mesially, detrimental masticatory forces applied on the abutment teeth could be decreased.[23,24]

Mechanical properties of the alloys used for casting the framework of the removable partial dentures, acrylic materials and denture teeth also affect the stress distribution and concentration.[26,27] Non-precious alloys such as, Cr-Co-Mo, Cr-Ni and precious alloys Au-Pt-Pd, and Ti can be used for casting the denture framework.[28] In our study regarding its mechanical properties, Cr-Co-Mo alloy, which is widely used in our dental clinic was preferred. Not to complicate the design and calculations, acrylic parts of the denture and denture teeth were not included.[25] Therefore, small changes in the stress distribution values might have occurred. It was assumed that these small deviations did not influence the results of our study.

In order to provide the stabilizing function of the clasp retained removable partial denture, shape of the occlusal rest should be considered. Some factors should be taken into account to distribute the forces evenly and appropriately to the soft and hard supportive tissues during function.[8,28] In addition, dentists should have knowledge about the biomechanical principles regarding removable partial dentures.

CONCLUSION

Within the limitations of this study, locating the occlusal rest mesially is of paramount importance in distal extension removable partial prosthetics regarding biomechanical principles. By this way, occlusal loads can be balanced and abutment teeth and surrounding tissues can be protected. This feature makes mesially located occlusal rest prior to its alternatives.

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