The Effect of Artificial Tooth Materials on Stress Distribution in Complete Dentures

Tam Protezlerde Yapay Diş Materyallerinin Stres Dağılımına Etkisi

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ABSTRACT Objectives: The artificial tooth material for an edentulous patient has an important effect on success of treatment; however, information about the influence of artificial tooth material on forces transmitted to the residual ridge is limited. The aim of this study was to compare the stress distribution on supporting bone of porcelain and hard acrylic resin materials, and to compare photoelastic and finite element methods by this manner. **Material and Methods:** Three dimensional finite element models and photoelastic models simulating two complete dentures with porcelain and hard acrylic resin teeth were prepared. 300 N occlusal load was applied at both methods to the flattened occlusal surfaces of modeled teeth. The differences in occlusal load transfer ability of acrylic and porcelain teeth were investigated. **Results:** Maximum stresses were concentrated on force application areas (28 Mpa) and cervical regions of artificial teeth (24 MPa). The stress values observed with the use of porcelain teeth (4-8 MPa) were lower than the hard acrylic resin teeth (4-12 MPa). The stress distribution on supporting bone was similar for both models. **Conclusion:** The result of this study showed that the use of porcelain as artificial teeth in complete dentures reduces the compressive stress levels on supporting bone structure. Finite element method provided more detailed information about the stress distribution than photoelastic method, and gave information about all of the model components.

Key Words: Artificial tooth; finite element analysis; complete denture

ÖZET Amaç: Tam dişsiz hastalarda yapay diş materyali tedavi başarısında önemli bir etkiye sahiptir; bununla birlikte, yapay diş materyalinin alveoli sırtına iletilen kuvvetler üzerindeki etkisi yeterince bilinmemektedir. Bu çalışmanın amacı, porselen ve akrilik rezin materyallerinin destek kemik dokularındaki stres dağılımlarını karşılaştırmak ve bu yolla fotoelastik ve sonlu eleman stres analiz yöntemlerini kıyaslamaktır. **Gereç ve Yöntemler:** Porselen ve sert akrilik rezin dişlere sahip iki tam protezi betimleyen üç boyutlu sonlu elaman ve fotoelastik modeller hazırlandı. Her iki yöntemde de modellenen dişlerin düzleştirilen okluzal yüzeyinden 300 N okluzal yükleme yapıldı. Akrilik ve porselen dişlerin okluzal yük transfer kabiliyetlerindeki farklılıklar incelendi. **Bulgular:** Kuvvet uygulama alanları (28 MPa) ve yapay dişlerin servikal bölgelerinde (24 MPa) en yüksek stres değerleri gözlendi. Porselen dişler kullanıldığında gözlenen stres değerleri (4-8 MPa) sert akrilik rezin dişlerde gözlenenlerden (4-12 MPa) daha düşüktü. Destek kemik yapısındaki stres dağılım şekli her iki modelde de benzerdi. **Sonuç:** Bu çalışmanın bulguları, porselenin tam protezlerde yapay diş olarak kullanılmasının destek kemik yapısındaki sıkıştırma tipi stres seviyelerini düşürdüğünü göstermiştir. Sonlu eleman stres analiz yöntemi fotoelastik analiz yönteminden stres dağılımı hakkında daha detaylı bilgi sağlamış ve modeldeki tüm yapılardaki dağılımın incelenebilmesine olanak vermiştir.

Anahtar Kelimeler: Yapay diş; sonlu eleman analizi; tam protez

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The selection of artificial teeth for an edentulous patient requires knowledge and understanding of a number of physical and biologic factors that are directly related to the patient. Dynamic behavior of the denture under occlusal force has an important effect on success of treatment. The dentist must accumulate, correlate, and evaluate the biomechanical information in selection of artificial teeth to meet the individual esthetic and functional needs of the patient.[1] Not only the masticating efficiency consideration but also comfort, esthetics, and preservation of the underlying bony and soft tissue structures are important in selection of posterior teeth.[2] Vacuum-fired porcelain, acrylic resin, and hard acrylic resin are used in fabrication of artificial teeth, but all have some advantages and disadvantages.

A variety of factors are involved in residual ridge resorption, some local, others systemic.[3,4] For example, compressive forces are known to be harmful to bone.[5] Therefore, it is important to lessen the pressure on the supporting tissues. Since the loads are transferred through the teeth to the rest of prosthesis, the selection of artificial teeth material has an important role on stress distribution in supporting structures.[6]

In this context of forces transmitted to the residual ridge the question arises of whether a material with a higher coefficient of elasticity, such as that used in acrylic resin artificial teeth, would be less harmful to the residual ridges.[5]

Variations in denture technique that may affect bone loss have been investigated.[7] No differences of statistical significance were found in the amount of bone lost, whether a simple or a conventional denture technique was used.[5] Unfortunately, the authors of the study did not specify whether the teeth were made of acrylic or porcelain.[5]

The effect of the setting of artificial teeth, and the effect of the cusp angle have also been investigated.[8,9] But there is little knowledge about the effect of artificial teeth material in the literature. Furthermore, a review of literature revealed that the question of ridge resorption in relation to the material used in artificial teeth (porcelain or acrylic resin) remains unsolved to date.[5,10,11]

Grant has summarized the advantages and disadvantages of porcelain and acrylic resin artificial teeth.[10] The simplicity of adjustments to acrylic teeth, which can be ground without any severe effect on their adhesion to the denture base, as well as the ease of denture fabrication and polishing after adjustments, stand out as the main factors for the choice of these teeth by most clinicians.[5] The great popularity of acrylic resin teeth was also acknowledged in a survey of North American dental schools.[11] Nevertheless, porcelain remains an outstanding material, recognized in particular for its durability, which is superior to that of acrylic, despite progress in the development of highly cross-linked acrylic resins that are less susceptible to wear than conventional ones.[5] But it is necessary for dentures to be used for a long period of time because of the premature contacts caused by the abrasion of artificial teeth and absorption of the alveolar ridge.[12]

In the light of this information, the purpose of this study was to compare the stress distribution on supporting bone of porcelain and hard acrylic resin materials, and to compare photoelastic method (PM) and finite element method (FEM) by this manner.

MATERIAL AND METHODS

In this study, three-dimensional FEM and the photoelastic stress analysis methods were used. Two types of mathematical models simulating two complete dentures with porcelain and hard acrylic resin teeth have been prepared with supporting structures. Porcelain and hard acrylic resin teeth have been also used in PM.

Photoelastic Method: Acrylic resin (Major Dent, Major Prodotti Dentari S.p.A., Moncalieri, Italy) and porcelain (Real, ENTA B.V., Holland) artificial first -second premolar and first molar teeth have been used. Occlusal plane of teeth have been flattened to apply a uniform load. Thickness of base part of denture was prepared as 1.5 mm. To simulate supporting structure part a 30 x 50 mm wax model with 10 mm thickness has been prepared. Then impression of this wax pattern has been acquired by a Polysiloxane silicon-based impression material (Zetaplus, Zhermack Italy). PL-2 (Measurments Group, Inc., Raleigh. NC) epoxy resin has been used in fabricating model (Figure 1).

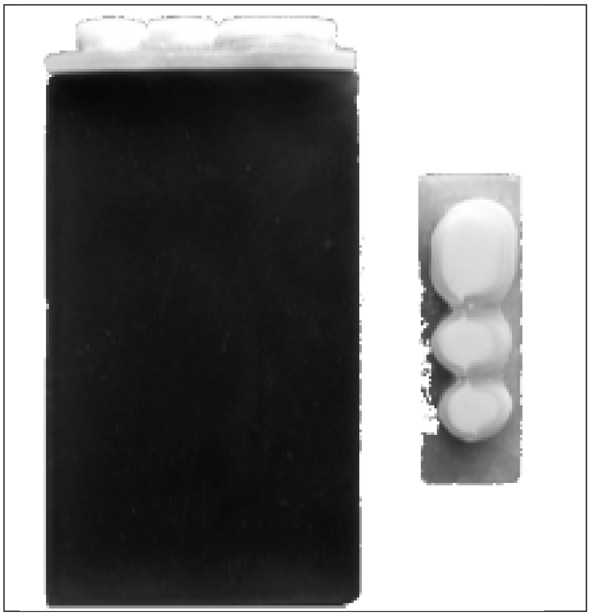

FIGURE 1: Model prepared for photoelastic stress analysis.

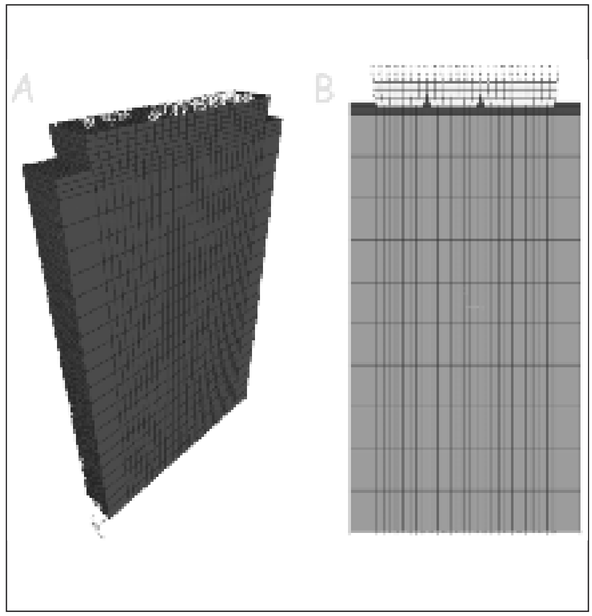

FIGURE 2: (A) 3D finite element model. (B) Boundary conditions of FE model.

300 N occlusal load have been applied by a Polariscope (Sharples Stress Engineers Ltd., Preston, UK) uniformly to flattened occlusal surface of teeth.

Finite Element Method: The study was conducted using a three-dimensional FEM and the SAP 2000 Advanced 9.0.3 structural analysis program (Computer Structures Inc., Berkley, CA).

The geometry of structures in the model was acquired from the photoelastic model. The standard model composed of 17283 nodes and 15360 eight nodes brick solid elements with three degree of freedom per node (Figure 2A). Points at bottom border of model were considered fixed in all directions for resistance of the FEM model to the occlusal loads.

Total 300 N load have been applied uniformly to flat occlusal surfaces of all three teeth. The applied forces were static (Figure 2B).

Mechanical properties of the materials were taken from previous literature (Table 1).[13,14] To enable the logical comparison of the results of FEM and PM, mucosa tissue was ignored. All materials were presumed homogenous and isotropic. Elastic modulus and Poisson's ratio of the materials, along with the coordinate and geometry of each node and element, were entered to computer. Sap2000 structural analysis program was used to solve the stress analysis problems. Calculated numeric data were transformed into color graphics to better visualize mechanical phenomena in the models. Stress levels were calculated using von Mises stress values.[15]

TABLE 1: Mechanical properties of materials.

Material	Elastic Modulus (E) (GPA)	Poisson's Ratio (μ)
Acrylic artificial teeth	2940	0.3
Porcelain artificial teeth	82800	0.35
Acrylic resin	1960	0.3
Compact bone	19600	0.3

RESULTS

PHOTOELASTIC METHOD

In presentation of the stress data, the following terminology has been used:

a) Low stress – 1 fringe or less;

b) Moderate stress - between 1 and 3 fringes; and

c) High stress – more than 3 fringes.[16]

After applying the same vertical load to two different materials, fringe orders have been evaluated. In evaluation of both models high stress values have been observed at alveolar ridge region (Figure 3, 4).

FIGURE 3: Stress distribution of porcelain teeth model in photoelastic method.

FIGURE 4: Stress distribution of acrylic teeth model in photoelastic method.

In comparison of porcelain (Figure 3) and acrylic (Figure 4) teeth models, more fringe orders have been observed at acrylic teeth models than porcelain teeth model.

FINITE ELEMENT METHOD

The analysis of stress values for all models revealed that maximum stresses were concentrated on force application areas, cervical regions of artificial teeth and mesial-distal alveolar ridge region.

When the porcelain and acrylic teeth models were compared, lower stress values were observed with the use of porcelain teeth (Figure 5) than the hard acrylic resin teeth (Figure 6).

In porcelain teeth model, stresses were accumulated in porcelain structure, and stresses transferred to the bone structure were minimal. But in acrylic teeth model stresses were directly transferred to the bone structure

When FEM and PM models were compared, the stress distribution on supporting bone was similar. But FEM method gave information about the type and amount of stress addition to the distribution.

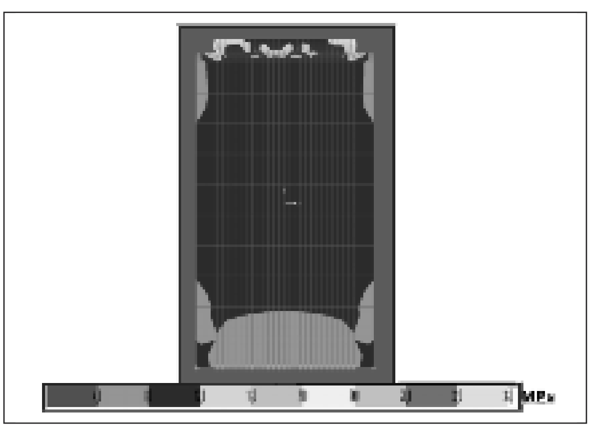

FIGURE 5: Stress distribution of porcelain teeth model in FE method.

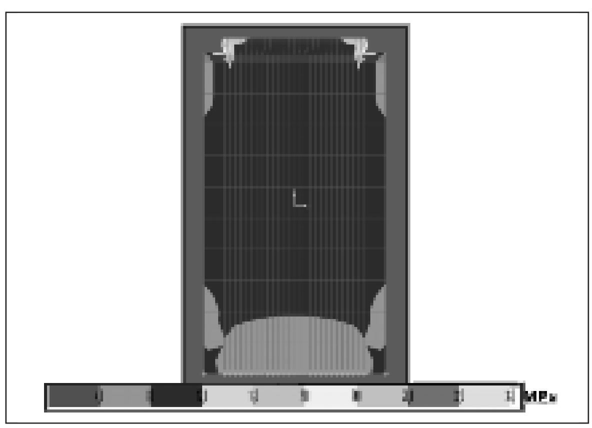

FIGURE 6: Stress distribution of acrylic teeth model in FE method.

DISCUSSION

Although finite element analysis was originally used in shipbuilding and civil engineering, it has been utilized for stress analysis in dentistry.[13] In the present study, using theoretical (FEM) technique, the effect of the artificial teeth material on stress amount and distribution was evaluated. Direct experimental measurements of the stress distribution at these locations are difficult. However, a theoretical well known method for calculating stress distribution within complex structures is the FEM which allows the investigator to evaluate the influence of model parameter variation once the basic model have been correctly defined.[17]

The FEM results are presented in terms of the von Mises stress values. Von Mises stresses depend on the entire stress field and are a widely used indicator of the possibility of damage occurrence.[18] It was observed that artificial teeth material has an effect on stress distribution on supporting structures.

The advantages and disadvantages of porcelain and acrylic resin artificial teeth were reported previously.[5,10,11] Despite the progress in the development of highly cross-linked acrylic resins that are less susceptible to wear than conventional ones, porcelain remains an outstanding material as it is much more resistant to wear.[5] It is necessary for dentures to be used for a long period of time because of the premature contacts caused by the abrasion of artificial teeth and absorption of the alveolar ridge.[12] Landa stated that 90% of the trouble resulting from dentures is caused by traumatic occlusion.[19] Thus, a strong material like porcelain is needed in treatment, and in the light of findings of current study that the lower stress values were observed with the use of porcelain teeth, porcelain teeth can be recommended as an option for treatment.

There were no previous publications about the comparison of influence of porcelain or acrylic artificial tooth material on stress distribution. The FEM model created for this study was a multilayered complex structure involving artificial tooth, denture base, and supporting structures. It is important to note that the stress following loading may be influenced greatly by the materials and properties assigned to each material. It is known, that when force is applied to composite or layered materials, stresses tend to maximize within the material with the highest elastic modulus.[20] Therefore, the stresses were more concentrated in the porcelain tooth material and less transmitted to supporting structures since porcelain has a higher elastic modulus than other structures and acrylic.

PM can give similar stress distribution pattern on supporting bone, but FEM gave information about the type and amount of stress addition to the distribution. Furthermore, with FEM, stress distributions of all structures investigated in study can be evaluated.

The model used in this study implied several assumptions regarding the simulated structures. The structures in the model were all assumed to be homogeneous, and isotropic. The properties of the materials modeled in this study, particularly the living tissues, however, are different. Also, it is important to point out that the stress distribution patterns may have been different depending on the materials and properties assigned to each layer of the model and the model used in the experiments.[21] Also, the effect of mucosa layer was ignored to enable the comparison of FEM and PM results. Thus, the inherent limitations in this study should be considered.

The in vivo greatness of occlusal force is selected standard 300 N value. However, it is not necessary for this force to match the reality exactly because of the standardization between conditions has been ensured in current study and the conditions have been compared qualitatively with each other. Chen and Xu have emphasized that the value of FEM modeling is in relative values calculated at distribution pattern.[22]

As with many in-vitro studies, it is difficult to extrapolate the results of this study directly to a clinical situation. The load application area can influence the stress distribution pattern. Thus, to simulate equal conditions for different materials the occlusal surfaces of teeth have been assumed as flat, this have also standardized the conditions for PM and FEM. These flat occlusal surfaces have been specifically described as the locations for the force applications. Considering the limitations of current study, further studies that better simulate the oral environment and including fatigue loading are recommended.

CONCLUSION

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

This study showed that the use of porcelain as artificial teeth in complete dentures resulted in less stress levels on supporting bone structure.

When investigating the stress distributions on multilayered dental complexes, although PM gives similar results, FEM allow detailed information about stress transfer and distribution. Thus, FEM is advantageous compared to PM.

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