RESEARCH ARTICLE / *Araştırma Makalesi*

Stress Analysis Of Fixed Dental Prostheses Produced With Different Materials According To The All-On-Four Concept

All-On-Four Konseptine Göre Farkli Materyaller İle Üretilmiş Sabit Dental Protezlerin Stres Analizleri

Ahmet Çalışkan[1], İsa Yöndem[2]

[1] Eskişehir Diş Hastanesi, Eskişehir
[2] Department of Prosthotontics, Faculty of Dentistry, University of Selçuk, Konya

ORCİD

Ahmet Çalışkan https://orcid.org/0000-0002-8424-5886
İsa Yöndem https://orcid.org/0000-0001-9608-7830

Yazışma Adresi / *Correspondence:*
Dt. Ahmet Çalışkan
Eskişehir Diş Hastanesi, Eskisehir
E-mail: **dt.ahmetcaliskan@gmail.com**

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Abstract

Objective The most important factor affecting the long-term success of implant supported systems is biomechanics after prosthesis delivery. The aim of this study was to investigate the prosthetic restorations designed by using different substructure materials on the implants placed according to All-On-4 technique in atrophic mandible with different stress analysis methods and compare the methods each other.

Materials and Methods For this purpose, a photo-elastic resin model, according to All-On-4 concept was prepared. After taking impression, fiber-reinforced resin, PEEK, zirconia and metal substructures were manufactured with Cad/Cam. Photo elastic stress analysis was performed. On the other hand 3D virtual models of the same substructures were formed with the .stl data of the CAD. Then finite element stres analysis was applied at the same circumstances.

Results In the photoelastic and finite element stres analysis, rigid substructures such as metal and zirconia showed lower stres values than elastic materials such as PEEK and fiber. As a facility of the finite element analysis internal stresses of the substructures were evaluated. Lower stresses were observed in fiber and PEEK infrastructures with low elastic modulus.

Conclusion İncreased modulus of elasticity of the infrastructure, reduced.stresses transmitted to the implants When the internal stresses of the materials were evaluated, lower stresses were seen in infrastructures such as fiber and PEEK with low elastic modulus .Photoelastic and finite element stress analyzes gave similar stress results to the implant and surrounding tissues. Therefore, the results supported each other.

Keywords All-On-Four, Dental İmplant, Stress Analysis, Substructures.

Özet

Amaç *İmplant destekli sistemlerin protez tesliminden sonra uzun vadeli başarısını etkileyen en önemli faktör biyomekaniktir. Bu çalışmanın amacı, atrofik mandibulada All-On-4 tekniğine göre yerleştirilen implantlarla farklı alt yapı materyalleri kullanılarak tasarlanan protez restorasyonlarını farklı stres analiz yöntemleri ile incelemek ve yöntemleri karşılaştırmaktı.*

Materyal ve Metod *Bu amaçla, All-On-4 konseptine göre foto-elastik bir rezin model hazırlandı. Ölçü alındıktan sonra, fiberle güçlendirilmiş rezin, PEEK, zirkonya ve metal alt yapılar Cad / Cam ile üretildi. Foto elastik stres analizi yapıldı. Öte yandan, aynı alt yapıların 3 boyutlu sanal modelleri, CAD'in .stl verileriyle oluşturuldu. Daha sonra aynı koşullar altında sonlu elemanlar stres analizi uygulanmıştır.*

Bulgular *Fotoelastik ve sonlu elemanlar stres analizinde metal ve zirkonya gibi sert alt yapılar PEEK ve fiber gibi elastik materyallere göre daha düşük stres değerleri göstermiştir. Sonlu elemanlar analizi imkanlarıyla alt yapıların iç gerilmeleri değerlendirildi. Düşük elastik modüllü fiber ve PEEK altyapılarında düşük gerilimler gözlendi.*

Sonuç *Altyapının elastikiyet modülü arttığında implantlara iletilen stresler azalmaktadır. Malzemelerin iç gerilmeleri değerlendirildiğinde, düşük elastik modüllü, fiber ve PEEK gibi altyapılarda düşük gerilmeler görülmektedir. Fotoelastik ve sonlu elemanlar stres analizleri implant ve çevre dokularda benzer stres sonuçları vermiştir. Yani sonuçlar birbirini desteklemiştir.*

Anahtar Kelimeler *All-On-4, Alt Yapı Dental İmplant, Stres Analizi*

INTRODUCTION

Dental implants are recognized as a breakthrough in functional and aesthetic rehabilitation. Treatment of the edentulous jaws with implants is often complicated by problems such as poor bone quality in the posterior region, lack of bone volume due to prolonged edentulism, and anatomical limitations of the alveolar bone. In order to overcome such restrictions, 'All-On-4 'technique has been developed. This treatment technique includes a complete arc fixed prosthesis supported by a total of 4 implants including 2 anteriors and 2 posteriors in the lower jaw and upper jaw[1].

Considering implant complications, the vast majority of problems are related to implant science[2]. However, unlike natural teeth, the biological aspects of implant dentistry have relatively few complications. For example, the formation of a direct bone-implant contact is substantially biological. The latest reports show that the surgical phase of the implants produces more than 95% successful contact, regardless of the implant system used. Thus, the biological aspect of implantology is highly predictable [1].

The most important factor affecting the long-term success of implant supported systems is biomechanics. Long-term implant failures after prosthesis delivery are generally based on biomechanical complications [3,4].

The success of restorative materials depends on their resistance to occlusal forces and their ability to successfully support the remaining oral structure. Studies examining the biomechanical behavior of oral structures require complex simulations on the foundations of the stomatognathic system[5].

The aim of this study was to investigate stress distribution of the prosthetic restorations designed by using different substructure materials around the implants with different stress analysis methods and compare the methods each other. The hypothesis claimed in the study; elastic substructure materials such as PEEK and fiber are less likely to transmit stress to surrounding tissues of the implants than rigid substructures such as cr/co and zirconia.

Method

Study was carried out in Selçuk University Faculty of Dentistry Research Center, Set Dental Laboratory (Kayseri, Turkey) and Ay Tasarim (Ankara, Turkey).

Photoelastic Stress Analysis

Placing the implants

A wax model in the form of the lower jaw arch was prepared and took impression. Cold acrylic was poured into the resulting negative space. In the acrylic model, four implants (Nucleoss T6, İzmir - Türkiye) were placed in the space prepared with the help of surgical guide (Fix-On-4) (Figure 1). 30° angled multi-unit abutments screwed on posterior implants and straight multi-unit abutment screwed on anterior implants.

Figure 1: Placing the implants according to Fix-On-4 protocol

Making photoelastic model

Impression was taken from the acrylic model with polyvinylsiloxane-based silicone impression material placing the impression posts of the manufacturer. Then the impression posts were removed from the acrylic model and placed in the impression with same position.

An epoxy resin and hardener (PL–2 ve PLH–2, Measurements Group Inc., North Carolina) was used for the photoelastic analysis. They were weighed with 1: 1 proportion according to manufacturer's instructions. The oven was heated to 52° C to reach sufficient viscosity. It was mixed homogeneously with a glass rod. The mixture, which reached 55° C at the start of polymerization, was poured. Air bubbles were removed on the vibration device while pouring to the impression thus a photoelastic model was obtained (Figure 2).

Figure 2: Photoelastic model

Fabricating the prothesis

Obtained photoelastic model was transferred to computer with optical scanner (DOF Inc. Seoul, 04790 Korea) by attaching multiunit CAD-CAM scanning parts in the laboratory. Prothesis was designed with a design program (Exocad GmbH Darmstadt Germany). With this design, substructures from fiber reinforced resin (TRINIA Arborway Boston, MA 02130 USA) , PEEK (JUVORA™, Thornton Cleveleys, Lancashire, United Kingdom), zirconia discs (Shenzhen Upcera Dental Co., ltd.Guangdong, China) were grinded in the milling machine (vhf camfacture AG, Ammerbuch, Germany). Cr-Co substructures manufactured on laser sinter device (EOSINT M 270, Munih, Germany). Fabricated prothesis are shown at figure 3.

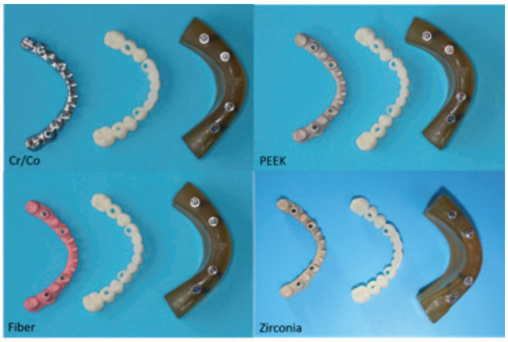

Figure 3: Fabricated substructures

Force loading in the polariscope

Photoelastic stress analysis was performed in Selcuk University Faculty of Dentistry Research Laboratory. Following the fabrication of the prostheses, the photoelastic model was lubricated with machine oil to take images clearly and the 250N force was applied to the central fossa of the mandible right first molar tooth with the Universal tester.

A polariscope was used to monitor the isochromatic frings and a digital camera was connected to the polariscope to photograph the load sequences. For each model loaded, images were obtained when the tester reached 250 N. A chart expressing quantitative properties of the colors formed were used to evaluate of stress levels.

In order to evaluate the models, a scheme including implant parts was prepared. In this diagram, the implant root surface is divided into five sections and each section has a separate number (Figure 4).

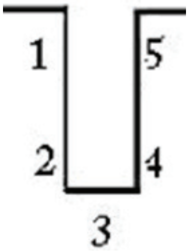

Figure 4: The diagram including implant parts

Finite Elemental Stres Analysis

One model and 4 different substructure materials (Cr / Co, zirconia, PEEK and fiber) was used in the study. Physical properties of the materials used shown in the Table 1. 250 N vertical force to 1st molar tooth's central fossa region was applied and a total of 4 analyzes were performed in three dimensional static linear form.

Intel Xeon ® R CPU with 3.30 GHz processor, 500gb Hard disk, 14GB RAM and Windows 7 Ultimate Version Service Pack 1 operating system computer, optical scanner (Activity 880 (smart optics Sensortechnik GmbH,Sinterstrasse 8, D-44795 Bochum, Germany) and 3D scanning (Rhinoceros 4.0 3670 Woodland Park Ave N, Seattle, WA 98103 USA), 3D modeling software (VRMesh Studio, VirtualGrid Inc, Bellevue City, WA, USA) and analysis program (Algor Fempro, ALGOR, Inc. 150 Beta Drive Pittsburgh, PA 15238-2932 USA) were used to arrange of 3-D mesh structure, make it more homogeneous, and create 3-D solid model.

Table 1. Physical properties of the materials

Materials		
	Young Modulus (Mpa)	Poisson's Ratio
Cortical bone	13700	0,30
Spongious bone	1370	0,30
Titanyum (implant, abutment, vida)	110000	0,30
Zirconia	205000	0,30
Peek	4000	0,36
Cr/co	218000	0,33
Fiber (Trinia)	18800	0,22
Porcelain	82800	0,35

Properties of solid objects have been considered linear elastic, homogeneous and isotropic in the program.

The models were converted into solid models in the form of Bricks and Tetrahedra elements. In the Bricks and Tetrahedra solid modeling system, 8-nodes elements were used as much as they could in the Fempro model. 7-nodes, 6-nodes, 5-nodes and 4-nodes elements were used when 8-nodes elements could not reach the required detail.

In this way, cortical bone, spongious bone, prosthetic substructure parts and implants were transferred to the model to reflect the true morphology. The models were placed to the correct coordinates in 3-D in the Rhinoceros software and the modeling process was completed.

The model is fixed at the bottom of the jawbone to have 0 movements per DOF (Degree of freedom).

As in the photoelastic analysis, 250 N vertical force was applied from the central fossa of the right first molar tooth.

Results

Photoelastic Stress Analysis Results

The findings were interpreted on the color photographs obtained by the photoelastic stress analysis method, the findings of the photoelastic modeling method were compared separately for each sample and the similarities and / or differences between them were revealed.

Fringes that occur when 250 N force is applied from the central fossa of the right 1st molar tooth extended as a cantilever is shown in Figure 5. Stress lines were formed around the implant closest to the point where the force was applied, while there were no visible changes around the other implants.

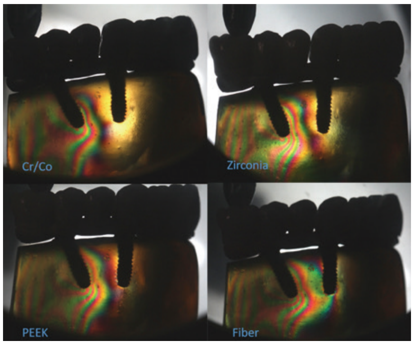

Figure 5: Izochromatic fringes

The distribution of isochromatic fringe lines occurring when loading from the central fossa of right 1st molar tooth is examined, the stress values are as high to low;
Zone 5; fiber infrastructure (2 N)> PEEK infrastructure (1.22 N)> zirconia infrastructure (1.08 N)> Cr / Co (O N).
Zone 4; fiber infrastructure (3.65 N)> PEEK infrastructure (3 N)> zirconia infrastructure (2.65 N)> Cr / Co (2.35 N).
Zone 3; fiber infrastructure (4 N)> PEEK infrastructure (3.1 N)> zirconia infrastructure (3 N)> Cr / Co (2.65 N).
Zones 2 and 1 stress values are higher than 4.15N in all groups but high-low fiber infrastructure> PEEK infrastructure> zirconia infrastructure> Cr / Co.

Finite Element Stress Analysis Results

Von Mises Stresses Around Implants

When the stresses around the implant were examined, all models showed the highest values at the selected nodes in zone 1 (1, 2, 4 and 3, respectively) closest to the force-applied region. Stress values were from high to low; fiber (128.76 MPa)> PEEK (126.88 MPa)> zirconia (104.04 MPa)> Cr / Co (103.37 MPa).

Stresses of Von Mises Around Abutments

When the stresses around the abutment were examined, the highest values were observed at the selected nodes in the zone 1 closest to the force applied region in all models (1, 2, 4 and 3, respectively). Stress values from high to low fiber (272.35 MPa)> PEEK (261.67 MPa)> zirconia (216,80 MPa)> Cr / Co (215,42 MPa) is in the form.

Von Mises Stresses in the substructures

In all substructures, stresses at the selected nodes were highest in implant zone 2 (2, 1, 3 and 4, respectively). Stress values are Cr / Co (543.98 Mpa)> zirconia (548.89 Mpa)> PEEK (428.78 Mpa)> fiber (441,17 Mpa) respectively from high to low (Figure 6).

Compression stresses in cortical bone

In all models of cortical bone, the highest compression stress values were seen around implant # 1 (1, 2, 4 and 3 respectively), while the stress values at the selected nodes were high to low PEEK (-43.38 Mpa)> fiber (-41.37 Mpa)> zirconia (-36.35 MPa)> Cr / Co (-36.22 MPa).

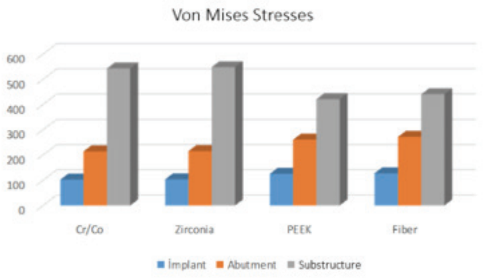

Figure 6: Comparison of von mises stresses in implants, abutments and substructures

Tensile Stresses in Cortical Bone

The highest tensile stress values were observed around implant number 2 (2, 1, 3 and 4 respectively) in all models in cortical bone while the stress values at the selected nodes were high to low fiber (15,31 Mpa) > PEEK (14,90 Mpa)> zirconia (14.35 MPa)> Cr / Co (14.27 MPa)

Compression stresses in spongious bone

In spongious bone, the highest compressive stress values were seen around implant number 1 (1, 2, 3 and 4, respectively) in all models, while the values seen at selected nodes were quite similar to each other from high to low PEEK (2.63 MPa)> fiber (2, 50 Mpa) zirconia (2.30 Mpa)> Cr / Co (2.29 Mpa).

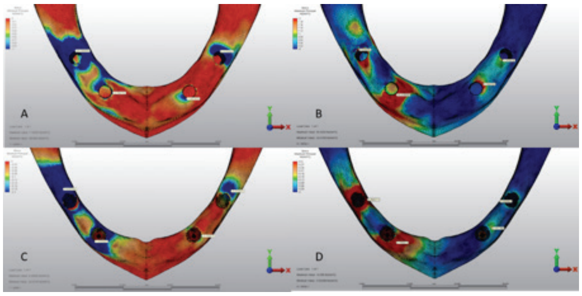

Figure 7: A: Compression stresses on cortical bone PEEK substructures, B: Tensile stresses on cortical bone fiber substructures, C: Compression stresses on spongious bone PEEK substructures, D: Tensile stresses on spongious bone fiber substructures

Tensile Stresses in spongious Bone

The highest stress values were seen around implant # 1 (1, 2, 3 and 4, respectively) in all models in the spongious bone, while the values seen at the selected nodes in the models were high to low fiber (6.28 MPa)> zirconia (6.19 MPa). > Cr / Co (6.18 MPa)> PEEK (5.96 MPa).

Discusssion

The All-On-4 treatment concept has proven to be a successful rehabilitation of edentulous jaws with high survival rates since the beginning of the last century. However, there is a seeking for the superstructure and continues to develop new materials.

The use of dental implants in the rehabilitation of partial and complete edentulous patients has a long history. Long-term clinical success has been achieved, especially in fully edentulous jaws, which largely eliminates the need for removable dentures [6]. Treatment of edentulous patients with implant-supported fixed prostheses has been shown to improve chewing function and strength as well as increase self-confidence when compared to implant-tissue supported removable overdentures [7].

However, there are some limitations in implant rehabilitation of edentulous jaws. Inadequate bone volume, poor bone quality, and anatomical limitations of the alveolar bone (such as the mental foramen and mandibular nerve) are some of them. In order to overcome such problems, Maló introduced the concept of 'All-on-4 [8]. The All-On-4 treatment technique allows the construction of a fixed full-arch prosthesis with 2 axially placed implants in the anterior and 2 tilted posterior implants 30-45 ° just in front of the mental foramen[9]. This facilitates the preservation of important anatomical structures and patients can be rehabilitated quickly with early loading procedures [10]. Studies have reported a high success rate (92.2% - 100%) in implants supported by fixed full arch prostheses made with this concept [11-13].

As accepted in many clinical studies, osseointegrated implants may fail mainly due to weakening or loss of bone around the implant [14]. Concentrated stress in the alveolar crestal bone is thought to cause bone resorption leading to aesthetic and functional defects[15]. The bone resorption process mostly affects the implant neck region and begins with an overload at the implant bone interface[16]. In view of these complications, it is aimed to evaluate the effect of various substructure materials on the stress distribution around the implant with different stress analyzes and to compare them with different studies in the literature in order to obtain results in choosing suitable materials that transmit stress to implant and surrounding tissues in full jaw implant supported prosthesis.

Frocht[17] reported that photoelastic analysis is indicated in cases where finite element analysis is not possible. Today, advances in technology have changed this situation. The results of the presented study are consistent with other authors on some technical limitations[18-21]. In addition to the disadvantage of overlapping results in photoelastic stress analysis, photoelasticity has no physical resolution to distinguish the stress gradient around the teeth and heterogeneous materials cannot be produced[19]. For this reason, we aimed to increase accuracy by using two different stress analysis methods

Stress analysis results cannot be compared numerically with each other due to different model geometries and different boundary conditions[22]. However, the results obtained can be compared in terms of the areas where stresses occur and their intensity.

Duyck et al. showed that the highest streses value is around closest implants to cantilever in any situation [23]. Also, studies have reported that marginal bone loss is often around the implant closest to the cantilever[24,25]. This assessments shows that high stress in the implant-supporting support bone may have negative consequences at the marginal bone level.

Likewise in our study, it was observed that stresses intensified around the implant and abutment closest to the molar tooth in the position of the cantilever where force was applied in all models. According to the abutment material used, when the stresses around the abutment and implant were compared, the highest von mises stress values were seen in the fiber infrastructure and the lowest von mises stress values were observed in the Cr / Co substructure. So the hypotesis that claimed in the present study is rejected. Zaporolli et al., examined the stress distribution in fiber, titanium, Cr-Co infrastructures produced with CAD / CAM and Cr-Co produced with conventional casting technique and they reported that fiber reinforced resin infrastructure had better stress distribution than other metals and less stress transmission in the implant cervical region.[26] This contradicts the results of the presented study; Zaporolli applied 150 N force to be considerably lower than the force of 250 N applied in our study. It is stated in the literature too that this force value for the first molar tooth is lower than average[27-29]. This difference may affect to the results.

The results of our study are consistent with many studies that showed low-elasticity modulus materials to transmit stresses to implants and surrounding bone more[30-32].

Lee et al. performed stress analysis on titanium, zirconia and PEEK infrastructures on implants placed according to All-On-4 technique. They reported the highest values in tensile and compression stresses in the bone around the implant in the PEEK substructure[33]. Von Mises stresses within the substructures were less common in PEEK material. In our study, stress transmission in PEEK material was consistent with the study of Lee et al.

Akca et al. compared strain gauge stress analysis method and finite element stress analysis methods. They obtained similar stress values; however, it is emphasized that finite element stress analysis method gives more accurate and detailed results[34].

Inan et al. stated that both finite element and photoelastic stress analyzes provide information about stress distribution in the support bone, but finite element analysis provides more detailed information about the location, shape and mathematical value of stress[35].

In our study, it was seen that more accurate and realistic models can be provided with finite element analysis when compared with photoelastic analysis. Photoelastic stress analysis method also provides the location and intensity of stress concentrations, but with advanced computer programs, finite element analysis to determine the stress locations clearly and has the advantages of seeing these values separately in implant, abutment, bone and substructures. Forces applied only vertically in the present study differently intraoral structures are subject of oblique and lateral forces too 36. This is one of the limitation of this study. Appliying this complex forces in the stress analysis could make them more reliable. Also mandible is supported various muscles from different points. The model is fixed at the bottom of the jawbone to have 0 movements per DOF (Degree of freedom) in our study. These difference may effect the results.

Conclusions

Lower stress values were measured in rigid infrastructures such as metal and zirconia in the implant and surrounding tissues compared to elastic materials such as fiber and Peek.

As the modulus of elasticity of the material used as the infrastructure increases, stresses transmitted to the implants were reduced.

When the internal stresses of the materials were evaluated, lower stresses were seen in infrastructures such as fiber and PEEK with low elastic modulus.

As the elasticity modulus of the material used in the infrastructure increases, the stresses within the infrastructure were increasing. It showed stresses remained more, inside the rigid substructures and transmitted less to the implants and surrounding tissues.

Photoelastic and finite element stress analyzes showed similar stress results to the implant and surrounding tissues. Therefore, the results supported each other.

Competing interests: The authors declare that they have no competing interest.

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Kaynaklar

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