



HOW IMPORTANT ARE THE IMPLANT INCLINATION AND THE INFRASTRUCTURE MATERIAL USED IN IMPLANT SUPPORTED FIXED PROSTHESES?

ABSTRACT



Objectives: The aim of this study is to evaluate the stress, which is caused by the fixed prosthesis under oblique forces around dental implants and bone by using different infrastructure materials and different inclinations, by 3-dimensional (3D) finite element analysis (FEA) method.

Materials and Methods: 3D-FEA models of mandible, dental implants and prostheses were designed. The anterior and posterior implants were designed 10 mm in length and 4.3 mm in diameter. The anterior implant was placed parallel to each model. Posterior implant designed to make inclinations those mesial 17°, distal 17°, buccal 17°, lingual 17°. Implant supported fixed restorations were divided into 3 main groups according to the infrastructure materials. These materials were; chromium-cobalt, zirconia, polyetheretherketone (PEEK). In each model, a total of 500 N oblique force was applied from the buccal tubercle crests to the buccolingual direction at an angle of 30 degrees to the long axis of the tooth. Maximum principal (tensile) stress and minimum principal (compressive) stress values in the bone models were taken. In addition, von Mises stress values were obtained from implants and substructure materials.

Results: When the stress findings in the mandible during oblique loading were evaluated, it was found that the stresses on the cortical bone were higher than the stresses on the trabecular bone. It was observed that the highest stress values occurred in the implants.

Conclusions: It is thought that chromium-cobalt and zirconia-based ceramic bridge restorations are more positive in terms of stress distribution than PEEK-based ceramic bridge restorations.

Keywords: Finite element analysis, implant-supported dental prosthesis, polyetheretherketone, zirconia.

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INTRODUCTION

Dental implant applications have become a current treatment option in dental clinics due to the increase in success rates.^{1,2} Implant-supported dental prosthesis are divided into two classes as fixed or removable. The biggest advantage of implant-supported fixed dental prosthesis is that patients are psychologically satisfied and have a longer life span compared to implant-supported partial prostheses. Implant-supported fixed prostheses have increased function, stabilization and more satisfactory results compared to partial removable prostheses.³

In order to achieve functional and aesthetically satisfactory results with successful implant placement in the mandibular region, appropriate angulation and positioning are required.⁴ The direction of implant placement is closely related to the transmission of occlusal loads. The placement angle or inclination of the implant is very important in terms of biomechanics.^{5,6}

In implant-supported fixed prosthesis, the infrastructure material plays an important role in stress transmission to implant and the bone around the implant. It has been reported that zirconium, which is used as a infrastructure thanks to its aesthetic properties, provides very good marginal compatibility and sufficient durability with the implant. In addition, since metals are not used as a substructure material, there are no disadvantages such as the emergence of toxic and allergic reactions caused by ion release.⁷⁻⁹ PEEK; which is a high performance polymer, has been used as an alternative to metal alloys in many industries since the late 1970s. There are many areas of use in dentistry such as endocrowns, infrastructures of fixed prostheses, implant materials and parts, and removable prosthetic skeleton.¹⁰⁻¹⁴ The mechanical properties of PEEK are similar to dentin and enamel, making this material more advantageous and positive than alloy and ceramic restorations.¹⁵ Chrome-cobalt alloys are resistant to abrasion and corrosion. They are biocompatible, high modulus of elasticity that do not stain easily. Their high elastic modulus allows them to be prepared thinner.¹⁶ Among the prosthetic restorations on implants, porcelains with metal substructure are still the most

preferred materials today. Their biggest advantages are their durability, good bonding to porcelain, cheap and easy access. However, metal-based porcelains have many disadvantages. Corrosion and allergy are the main disadvantages.¹⁷

The aim of this study is to evaluate the stresses around dental implants and bone which is caused by the oblique forces on 3-member fixed prosthesis which was made by different infrastructure materials [chrome-cobalt (Cr-Co), zirconia, polyetheretherketone (PEEK)] and different implant inclinations (mesial 17°, distal 17°, buccal 17°, lingual 17°) by using 3D-FEA method.

MATERIALS AND METHODS

Ethical approval was granted by the University of Tokat Gaziosmanpaşa, Ethics Committee of the Clinical Research (Project no: 21-KAEK-266). 3D-FEA model of the edentulous mandible is designed. While modeling the mandibular bone, Division - A bone with a width of more than 5 mm in the bucco-lingual direction and a vertical bone dimension of 10 mm was chosen. The NobelActive (Nobel Biocare, Gothenburg, Sweden) implants were used in the models of the study. The anterior and posterior implants were 10 mm in length and 4.3 mm in diameter. Implants were placed in teeth 45-47 position. The posterior implant was placed in 4 different directions with 17° inclination (mesial 17°, distal 17°, buccal 17° and lingual 17°). Anterior implant was placed in parallel in each model (Figure 1).

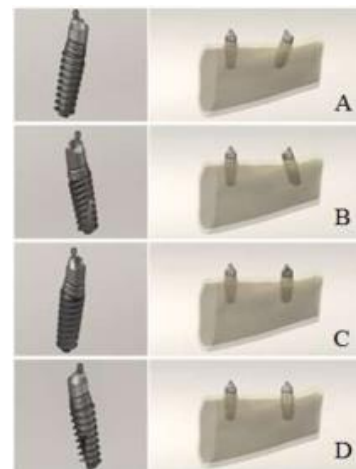


Figure 1. 17° inclined implant to mesiale (A), 17° inclined implant to distale (B), 17° inclined implant to buccal (C), 17° inclined implant to lingual (D).

The distance between implants were positioned to be 16 mm. Cr-Co alloy, zirconia, PEEK material

was used as infrastructure during the modeling of implant prostheses. Three different infrastructures were designed and the connector thickness was 2.5 mm. (Figure 2).

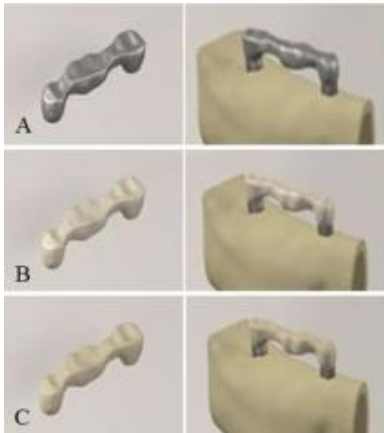


Figure 2. Cr-Co infrastructure (A), Zirconia infrastructure (B), PEEK infrastructure (C).

The implant and prosthesis parts supplied in the

Table 1. Young’s modulus (elasticity modulus) and Poisson’s ratios of the materials used in the study

MATERIALS	Young’s Modulus (MPa)	Poisson’s Ratio
Cortical bone	13700	0.30
Trabecular bone	1370	0.30
Titanium (implant and screws)	110000	0.35
Zirconia (infrastructure)	205000	0.22
Chrome-Cobalt (infrastructure)	218000	0.33
PEEK (infrastructure)	4000	0.36
Acrylic resin	3000	0.35
Feldspathic porcelain	82800	0.35

As a result, 4 subgroups were created according to the posterior implant angulation. Three different subgroups were created according to the infrastructure materials used in implant-supported bridge prosthes. In total, 12 finite element analyzes were performed. In each model, 500 N total oblique force was applied at an angle of 30 degrees from the buccal tubercle crests to the long axis of the tooth in the buccolingual direction. 100 N to the second premolar tooth, 200 N to the first molar and 200 N to the second molar (Figure 3).

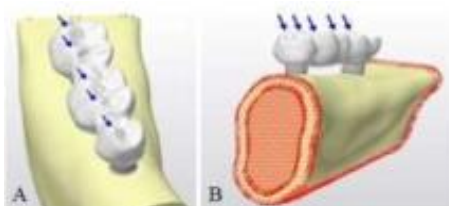


Figure 3. Oblique loads loaded from the buccal tubercle crests of restorations at an angle of 30° (view from the mesial) (A) , Oblique loads and red color in the meshed model the peripheral points are given zero degrees of freedom (B).

study were scanned in 3D optical scanner (Activity 880-Smart Optics, Sensortechnik GmbH, Bochum, Germany). The models obtained in.stl format were sent to Rhinoceros 4.0 (Robert McNeel & Associates, Seattle, USA) 3D modeling software. With the Boolean method in Rhino software, harmonization was made between prosthesis upper and lower parts, implant screws and bone tissues and force transfer was achieved.

Thanks to this modeling technique, it has been tried to create the highest quality network structure with the highest possible node elements in order to facilitate the calculation. Young's modulus and Poisson’s ratios of the materials and tissues that make up our study models are given in Table 1.

The highest tensile stress and compressive stress values those occur in cortical and trabecular bone were analyzed. In addition, von Mises stress values were obtained from implants and infrastructures.

RESULTS

When the stress findings in the mandible during oblique loading were evaluated, it was found that the stresses on the cortical bone were higher than the stresses on the trabecular bone. It was seen that the highest stress values occurred in implants. When the stress values formed in the infrastructures were examined, it was seen that lower stress values occurred in the PEEK infrastructure models. When the stress values in posterior implants were examined, it was seen that higher stress values occurred in PEEK models.

Maximum principal (tensile) stress (σ_{max}) distributions in cortical bone during oblique loading

are shown in Figure 4. In oblique loading, the maximum principle stress (σ_{max}) findings in cortical bone are shown in Figure 5.

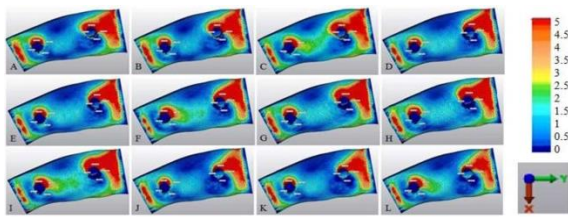


Figure 4. Maximum principal (tensile) stress (σ_{max}) distributions in cortical bone during oblique loading. Cr- Co / mesial 17° (A), Zirconia/mesial 17° (B), PEEK/mesial 17° (C), Cr-Co/distal 17° (D), Zirconia/distal 17° (E), PEEK/distal 17° (F), Cr-Co / buccal 17° (G), Zirconia / buccal 17° (H), PEEK / buccal 17° (I), Cr- Co / palatinal 17° (J), Zirconia / palatinal 17° (K), PEEK / palatinal 17° (L),

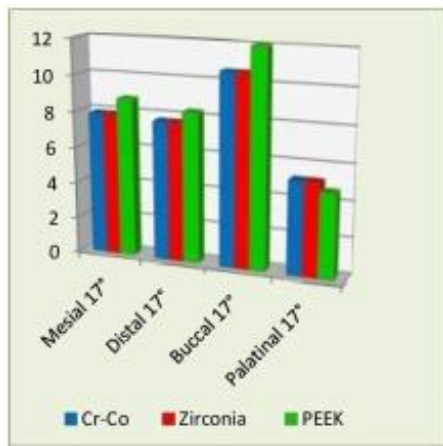


Figure 5. Maximum principal (tensile) stress (σ_{max}) values in cortical bone around the implant in oblique loading.

In this installation; the highest value in the selected node points in the cortical bone around the implant was 12 MPa in the PEEK model with a 17° inclination to the buccal, and the lowest value was 4.69 MPa in the PEEK model with a 17° inclination to the palatinal.

The findings of the minimum principle (compressive) stresses occurring in the cortical bone in oblique loading are shown in Table 2. In this installation; the highest value in the selected node points in the cortical bone around the implant was found to be -30.74 MPa in the mesiale 17° inclined PEEK model and the lowest value was found as -18.35 MPa in the palatinal 17° inclined Cr-Co model.

Table 2. Stress values in oblique loading (MPa)

GROUP	Maximum principal (tensile) stresses (σ_{max})	Minimum principal (compressive) stresses (σ_{min})	Von Mises stresses		
	Cortical bone	Infrastructure	Implant (Posterior)	Implant (Anterior)	
Cr – Co / mesial 17°	7.88	-27.58	17.27	162.37	155.34
Zirconia / mesial 17°	7.88	-27.58	16	162.24	155.30
PEEK / mesial 17°	8.77	-30.74	8	182.33	152.18
Cr – Co / distal 17°	7.70	-21.42	14.76	180.43	148.80
Zirconia / distal 17°	7.70	-21.43	14.47	180.41	148.83
PEEK / distal 17°	8.32	-23.06	8.19	202.25	155.49
Cr – Co / buccal 17°	10.60	-20.45	18.38	155.97	163.06
Zirconia / buccal 17°	10.59	-20.45	18.08	156.02	163.03
PEEK / buccal 17°	12	-22	8.23	193.16	155.88
Cr – Co / palatinal 17°	5.18	-18.35	13.44	198.24	137.61
Zirconia / palatinal 17°	5.18	-18.35	13.14	198	137.68
PEEK / palatinal 17°	4.69	-18.59	8.25	207.11	150.02

Von Mises stress distributions observed in infrastructures during oblique loading are shown in Figure 6. In oblique loading, the highest von Mises stress findings occurring in the infrastructure are shown in Figure 7. In this installation; the highest value was found to be 18.38 MPa in the group of Cr-Co buccal-17° inclination and the lowest value was found in the group of PEEK mesial-17° inclination as 8 MPa.

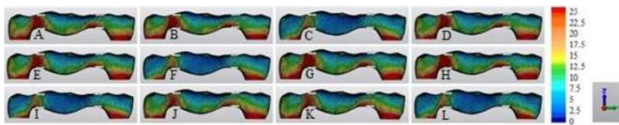


Figure 6. Von Mises stress distributions in infrastructures during oblique loading. Cr- Co / mesial 17° (A), Zirconia / mesial 17° (B), PEEK / mesial 17° (C), Cr- Co / distal 17° (D), Zirconia / distal 17° (E), PEEK / distal 17° (F), Cr- Co / buccal 17° (G), Zirconia / buccal 17° (H), PEEK / buccal 17° (I), Cr- Co / palatinal 17° (J), Zirconia / palatinal 17° (K), PEEK / palatinal 17° (L).

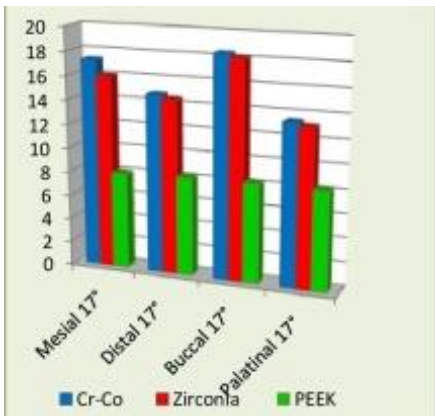


Figure 7. Von Mises stress values in infrastructures during oblique loading.

The von Mises stress distributions on implants are shown in Figure 8. The highest von Mises stress values in posterior implant during oblique loading are shown in Figure 9.



Figure 8. Von Mises stress distributions in anterior and posterior implants during oblique loading. Cr- Co / mesial 17° (A), Zirconia / mesial 17° (B), PEEK / mesial 17° (C), Cr- Co / distal 17° (D), Zirconia / distal 17° (E), PEEK / distal 17° (F), Cr- Co / buccal 17° (G), Zirconia / buccal 17° (H), PEEK / buccal 17° (I), Cr- Co / palatinal 17° (J), Zirconia / palatinal 17° (K), PEEK / palatinal 17° (L).

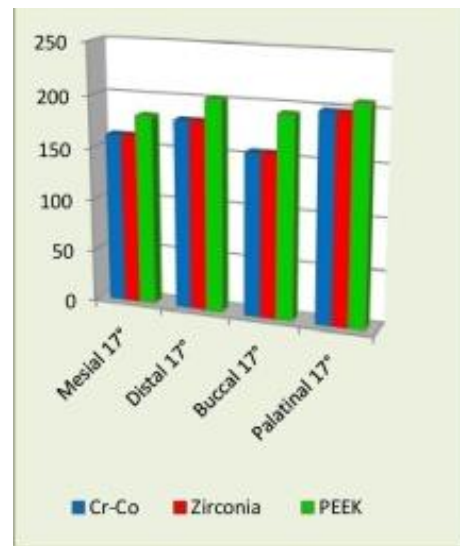


Figure 9. Von Mises stress values in posterior implant during oblique loading.

When the stress values were calculated, except for the groups with inclusion in the buccal direction, posterior implant values were found to be higher than the stress values in the anterior implant. In this installation; the highest value was found in the group of PEEK palatinal - 17° inclination posterior implant (207.11 MPa) and the lowest value was found in the group of Cr-Co palatinal - 17° inclination anterior implant as 137.61 MPa (Table 2).

DISCUSSION

It is impossible to determine the effect of biomechanical factors on the success of implant-supported prostheses by *in vivo* studies alone. In addition, it is very difficult to achieve standardization of *in vitro* and *in vivo* studies. Standardization can be achieved with finite element stress analysis and stress distributions can be determined digitally.¹⁸ At the same time, finite element analysis allows analysis to be carried out by changing only the determined factors and keeping all other factors constant.¹⁹ Due to these advantages, our study was carried out with finite element stress analysis.

Bone; although it is an inhomogeneous, anisotropic, viscoelastic structure, it is assumed that trabecular and cortical bone are homogeneous, isotropic and linear elastic in order to complete the analysis by simplifying the model.²⁰ Therefore, in this study, trabecular and cortical bone was assumed to be homogeneous, isotropic and linear elastic, as in other studies.²¹⁻²³

In our study we used the values for the Young's modulus (elastic modulus) and Poisson's ratios that which were used the mostly in the literature.²³⁻²⁵

Sarot *et al.*¹⁰ said that oblique forces have a more destructive effect than vertical forces. Contrary to this, no study reporting was found. In our study, 200 N oblique force was applied to the molars and 100 N to the premolar tooth, in total 500 N oblique force. An angle of 30 degrees was preferred to use for oblique force.

Lee *et al.*²⁶ compared PEEK material with titanium and zirconia as a substructure material for implant-supported prostheses in a study they conducted with finite element analysis. As a result of this study, they found that the stress absorbing effects of the low elastic modulus substructure were limited in some areas and the stiffer substructure material showed a positive stress distribution in the components of the prosthesis.

In another study in the literature; cobalt-chrome, titanium and zirconia prosthetic infrastructures were compared. Regardless of the treatment concept, harder materials such as cobalt-chromium and zirconia showed better biomechanical results; they created lower levels of stress on the bone, implant, abutment, abutment screw.²¹

In a finite element analysis study; 2 different 3-member fixed prostheses were designed as porcelain on metal infrastructure and particulate composite coating on fiber reinforced composite infrastructure. After all; It was reported that while lower stress values were observed in the prosthesis parts in the composite content group, higher stress values were obtained in the implant - abutment parts.²⁷

In a study in which a finite element analysis was performed using titanium, zirconium and gold as an implant fixed prosthesis infrastructure; As a result of splinting implants with titanium or zirconia infrastructures, less stress values were observed around the implant and bone compared to gold.²⁸

In our study, when the stresses on bone tissues and implants were examined, the highest values were observed in models using PEEK, and similar stresses were observed in models using zirconia and Cr-Co materials compared to PEEK, and it is seen that these results are compatible with the results of the above mentioned studies.

Zampelis *et al.*²⁹ in their study, they evaluated the effect of the connection of distal inclined implants with a fixed restoration on the stress distribution with two dimensional finite element analysis. In this study, 45° distally inclined implants were compared with those placed vertically, and no significant increase was observed in bone stress in the neck region of the implant.

Satoh *et al.*⁵ prepared working models by inclining the implants placed in the mandibular bone to 10° and 20° mesial. The researchers used straight cylinder implants in their models, and the force applied in the study was applied parallel to the long axis of the tilted implant. The results showed that inclined placement of the implants did not adversely affect bone stress.

In our study, maximum principle stress value in the cortical bone was observed in the PEEK buccal 17 degrees inclined group, the lowest cortical bone tensile stress value was observed in the PEEK palatal 17 degrees inclined group. The highest values observed in the buccal may be due to the application of oblique forces from the buccal direction.

CONCLUSIONS

PEEK material has the highest tensile and compressive stress values in cortical bone. When stresses occurring in implants are evaluated, the highest stresses occurred in models using PEEK material. Similar stresses were found at lower levels in models using Cr-Co and zirconia material. When the von Mises stresses occurring in the substructures were evaluated, the highest stresses occurred in Cr-Co and zirconia models, and the lowest stresses occurred in PEEK models.

In the light of the results we have obtained; It is thought that Cr-Co based ceramic bridge restorations and zirconia supported ceramic bridge

restorations applied with the correct indication in fixed prostheses on implants will be more successful in terms of stress distribution compared to PEEK infrastructure restorations. It is thought that different inclination directions at the same angle have no important effect on stress values. Besides the advantages of the finite element analysis method, it also has some limitations. Therefore, the results obtained need to be supported by clinical studies.

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CONFLICT OF INTEREST

The authors declare to have no conflict of interest.

İmplant Destekli Sabit Protezlerde İmplant Eğimi ve Kullanılan Altyapı Malzemesi Ne Kadar Önemlidir? ÖZ

Amaç: Bu çalışmanın amacı, sabit protezlerin farklı altyapı malzemeleri ve farklı inklüzyonlar kullanarak dental implantlar ve kemik etrafındaki eğik kuvvetler altında neden olduğu stresi 3 boyutlu (3B) sonlu elemanlar analizi (SEA) yöntemi ile değerlendirmektir.

Gereç ve Yöntemler: Mandibulada dental implant ve protezlerin 3B-SEA modelleri hazırlandı. Anterior ve posterior implantlar 10 mm uzunluğunda ve 4,3 mm çapında tasarlandı. Anterior implant her modele paralel olarak yerleştirildi. Posterior implant; mesiale 17°, distale 17°, bukkale 17°, linguale 17° eğimli olacak şekillerde tasarlandı. İmplant destekli sabit restorasyonlar alt yapı malzemelerine göre 3 ana gruba ayrıldı. Bu malzemeler; krom-kobalt, zirkonya, polietereeterketon (PEEK). Her modelde bukkal tüberkül tepelerinden bukkolingual yöne dışın uzun eksenine 30 derecelik bir açıyla toplam 500 N eğik kuvvet uygulandı. Kemik modellerinde maksimum asal (çekme) gerilme ve minimum asal (basma) gerilme değerleri alındı. Ayrıca implant ve alt yapı malzemelerinden maksimum von Mises stres değerleri elde edildi. **Bulgular:** Oblik yükleme sırasında mandibulada meydana gelen stres bulguları

değerlendirildiğinde, kortikal kemik üzerindeki streslerin trabeküler kemik üzerindeki streslerden daha yüksek olduğu bulundu. En yüksek stres değerlerinin implantlarda meydana geldiği görüldü. **Sonuçlar:** Krom-kobalt ve zirkonya esaslı seramik köprü restorasyonlarının, stres dağılımı açısından PEEK esaslı seramik köprü restorasyonlarından daha olumlu oldukları düşünülmektedir. **Anahtar kelimeler:** Sonlu elemanlar analizi, implant destekli diş protezi, polietereeterketon, zirkonya

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