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Original research

EVALUATION OF BIOMECHANICAL EFFECTS OF PROSTHETIC COMPONENTS WITH DIFFERENT MATERIALS ON THE ABUTMENT SCREW

ABSTRACT

Objectives: The aim of this study was to assess the effects of different resin-based and ceramic superstructure materials and two different abutment types on the stress distribution of the abutment screw using the method of three-dimensional finite element stress analysis.

Materials and Methods: A three-dimensional implant, abutment (zirconia and titanium), abutment screw, crown (zirconia reinforced lithium silicate, lithium disilicate, polymer-infiltrated resin ceramic, and PEEK), and alveolar bone were designed using Rhinoceros 3D modeling software and VRMesh Studio software to form 8 simulations. On the models prepared, loading was made on the lingual tubercle of the maxillary right first premolar crown at an angle of 30° with 150 N force obliquely in the buccolingual direction. The von Mises stress values obtained from the abutment screw were compared according to the types of abutment and crown materials.

Results: The von Mises stress values in the abutment screw were higher in the models using a titanium abutment (on average 1336.24 MPa), and the lower stress values were obtained in the models using a zirconia abutment (on average 964.26 MPa). When the prosthetic material used was changed, the stress values on the abutment screw was similar.

Conclusions: Considering that the abutment screw is the weakest component of the implant-system, zirconia abutments can be used reliably in the maxillary first premolar region where aesthetic expectations are high.

Keywords: Dental stress analysis, dental abutments, glass ceramics

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INTRODUCTION

The improvements in dental implant technology since the end of the last century have opened a new era in the field of prosthetic dentistry. Compared to traditional restorations, implant-supported restorations offer a wide range of options for both clinicians and patients. Thus, highly satisfactory aesthetic and functional results are achieved with them. However, implant treatments are not perfect under all conditions. In implant practice, high material cost, surgical trauma, and long duration of treatment, biological and mechanical complications associated with implant-supported restorations cause troubles.[1,2] In the implant system, complications such as peri-implantitis, loosening or fracture of the abutment screw, fracture of the abutment or prosthetic superstructure, loosening or decementation of the crown, and separation of the veneer porcelain are the most common.[2,3] Among these complications, loosening of the abutment screw is one of the main mechanical complications.[3,4] The rate of loosening of abutment screw was found to be 5.3% in the first year after loading[5] and 5.8-12.7% after 5 years of follow-up.[2,4] If abutment screw loosening is not noticed and intervened, it has a high risk of resulting in screw or implant fracture.[6]

In addition to managing the manufacturing process using the chairside/laboratory procedure, the selection of the appropriate crown material can contribute to lasting success. Resin-based or highly resistant monolithic ceramics with shock-absorbing capacity can be preferred to overcome or minimize the risk of fracture in prosthetic components. Nevertheless, despite the promising results of resin-based materials in implant-supported restorations[7,8], their mechanical strength is lower compared to ceramics.[9] Resin-based prosthetic materials provide a biomechanical advantage by compensating the lack of periodontal ligament in implant-supported restorations and minimize the risk of mechanical complications between the implant-abutment-crown complex.[9]

The abutment screw is generally known as the weakest component in the implant system, as the screw head and the surrounding area have the highest concentration of torque and stress.[10] In the clinical and laboratory studies, technical complications (loosening or fracture) related to abutment screws were the most frequently reported problems for two-piece systems.[10,11] An implant-supported single crown is more prone to screw loosening compared to an implant-supported fixed partial dentures. While the incidence of screw loosening was 5.6% in the 5-year follow-up in fixed partial denture restorations, it reached 12.7% in single crowns.[12] Screw loosening may lead to mechanical problems such as loss of function due to excessive prosthesis displacement, loosening of other screws in a multi-unit prosthesis, fracture of screws due to fatigue, loss of restoration, and loss of the implant due to inadequate osseointegration, and biological problems such as microleakage, soft tissue irritation and peri-implantitis.[13,14]

Zirconia abutments have become popular in prosthetic treatments due to their superior optical properties compared to titanium and higher fracture resistance than alumina. *In vitro* studies have reported that the fracture resistance of zirconia abutments exceeds their maximum bite force of 90 to 370 N.[15,16] Unlike the classical failure models described for titanium systems, crack initiation and propagation caused by fatigue in zirconia due to plastic deformation of screw and implant parts cause fractures in thin parts of the ceramic structure.[11,17]

In this study, unlike other stress analysis studies, the biomechanical effects of different types of abutment and superstructure materials on the abutment screw with frequent complications were evaluated. Finite element analysis (FEA) method may contain dimensions and shapes, loads and support conditions suitable for clinical conditions, and despite the versatility of the analysis, the use of a single computer program is the reason for using this analysis method in the study.

The aim of this study was to assess the effects of different resin-based (PEEK and polymer-infiltrated resin ceramic) and ceramic (lithium disilicate and zirconia reinforced lithium silicate) superstructure materials and two different abutment types (stock titanium abutment and zirconia abutment) on the stress distribution of the abutment screw using the three-dimensional finite element stress analysis method. The null hypothesis of this study was established by assuming that the force transmission of zirconia abutment and resin-based superstructure systems on the abutment screw would be low due to force absorption.

MATERIALS AND METHODS

The geometric designs of 3D models were obtained for the implant, abutment, abutment screw, crown, and alveolar bone included in the study by using the Rhinoceros 4.0 (3670 Woodland Park Ave N, Seattle, WA 98103 USA) 3D modeling software and VRMesh Studio (Virtual Grid Inc, Bellevue) and Algor Fempro (ALGOR, Inc.150 Beta Drive Pittsburgh, PA 15238-2932 USA) analysis program. Ethical approval was acquired from the Clinical Research Ethics Committee of Afyonkarahisar Health Science University (decision date: 11.09.2020, ID number: 2020/407)

Implant model

A three-dimensional (3D) model of the bone level threaded conical implant with a 3.75 mm diameter and a 10 mm long internal hexagonal connection (Parallel Conical Connection, Nobel Biocare) was designed.

Abutment models

A zirconia abutment (Universal Base Conical Connection-Nobel Biocare) and titanium abutment (Universal Base Conical Connection-Nobel Biocare) were selected to be used in the study. Both abutments were designed as a narrow platform and flat with a gingival height of 3 mm, a crown length of 5 mm, and a total length of 8 mm (Figure 1).

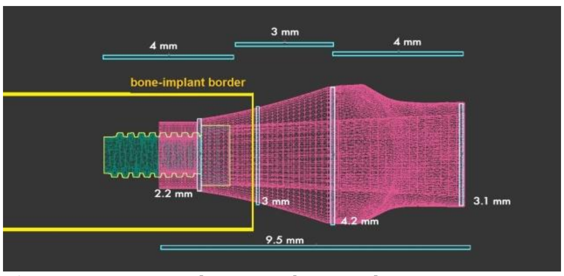

Figure 1. Titanium and zirconia abutment design

Abutment screw models

A 9-threaded long screw with Ti_6Al_4V alloy content with a 0.17 mm and 0.15 mm pitch and having a screw pitch with a length of 3.9 mm and a body thickness of 1.1 mm was designed (Figure 2).

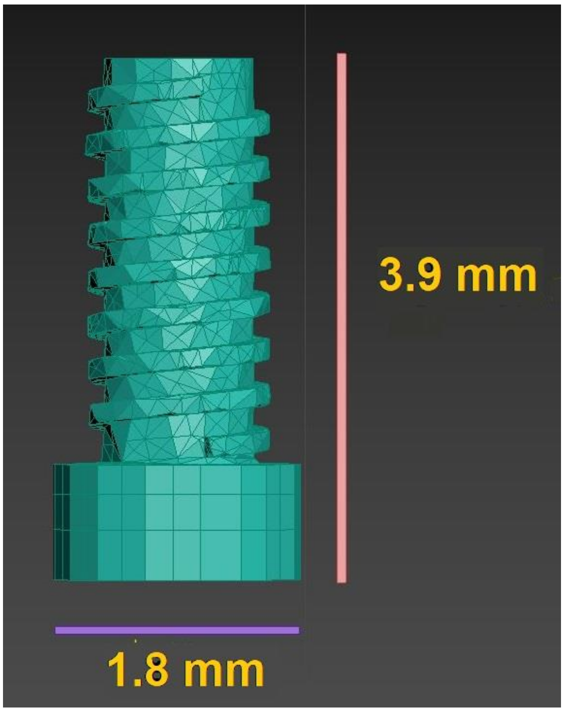

Figure 2. Titanium abutment screw design

Crown models

Zirconia reinforced lithium silicate (ZLS) (Vita Suprinity, Vita Zahnfabrik, Germany), lithium disilicate (IPS e.max CAD, Ivoclar Vivadent, Germany), polymer-infiltrated resin ceramic (PICN) (Vita Enamic, Vita Zahnfabrik, Germany), and PEEK (JUVORA, Invibio/ Juvora Ltd., England) aesthetic materials were selected as crown materials. The crown suitable for the anatomy and morphology of the maxillary right first premolar with a crown width of 7 mm, a crown thickness of 9 mm, and a crown length of 8.5 mm was modeled (Figure 3).

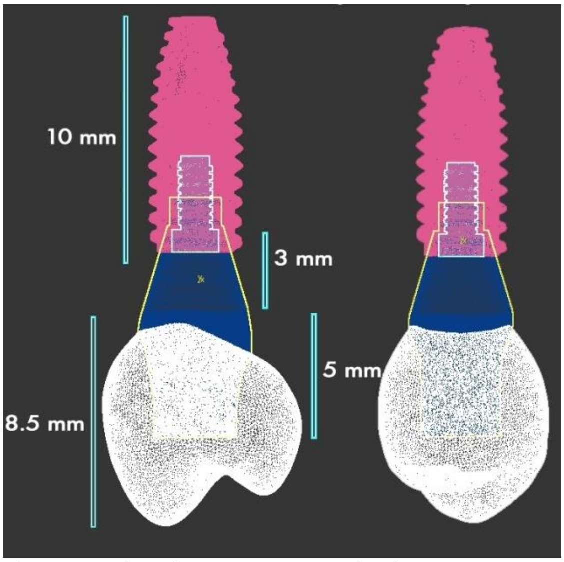

Figure 3. Implant-abutment-crown complex design

Alveolar bone model

A total bone model was obtained by modeling 2 mm thick Type 2 cortical bone in the form of a rectangular prism with a dimension of 40x30x20 mm and the trabecular bone 2 mm inside the borders of the prism in the maxillary right first premolar region and combining cortical and trabecular bone with the Boolean command.

The physical properties of the materials included during the geometric design of the 3D models are presented in Table 1.

Table 1. Physical properties of the materials used in the study

	Elastic Modulus (MPa)	Poisson's ratio	Reference
Zirconia reinforced lithium silicate	104 900	0.208	18
Lithium disilicate	102 700	0.215	18
Polymer-infiltrated resin ceramic	37 800	0.24	19
PEEK	3 500	0.36	Manufacturer company information
Titanium	110 000	0.35	20
Zirconia	210 000	0.30	21
Cortical bone	13 700	0.30	20
Trabecular bone	1 370	0.30	20

All models obtained were combined to form a total of 8 different simulations (4 different crown materials and 2 different types of abutment). The abutment body was tightened with the abutment screw with a torque of 30 Ncm in accordance with the company's recommendations, and friction between the implant internal threads and the abutment screw was ignored.

The discretization procedure involved forming the mesh and defining the elements with nodes and boundary conditions. An axisymmetric model of the implant was created, and the alveolar bone was assumed to have linear, homogeneous, and isotropic material properties. In the meshing process, the models were created as much as possible from 8-node (brick type) elements. The convergence study, which determines the minimum mesh size required to eliminate its effect on stress, was used to validate the finite element model. The total numbers of elements and nodes for each model are presented in Table 2.

Table 2. Numbers of elements and nodes of the created models

	Number of Elements	Number of Nodes
Crown material *- zirconia abutment	901 202	168 582
Crown material *- titanium base abutment	901 978	167 219
Crown material *- titanium abutment	901 202	168 582

* Zirconia reinforced lithium silicate, lithium disilicate, polymer-infiltrated resin ceramic and PEEK

The boundary conditions of the implants were modeled as part of the alveolar bone. The geometry of the alveolar bone model surrounding the implant was simplified by linear elastic description, both anterior and posterior regions of the bone were limited to represent the actual clinical condition, and the support at the bottom allowing the bending of the model was removed.

On the models prepared, loading was made on the lingual tubercle of the maxillary right first premolar crown at an angle of 30° with 150 N force obliquely in the buccolingual direction. Finite element stress analysis was performed using the VR Mesh Studio and Algor Fempro (ALGOR Inc) software. The von Mises stress was detected on the abutment screw due to the ductility characteristic of metallic materials.

RESULTS

The stress distribution of all models is presented in Table 3. The higher von Mises stress values in the abutment screw were obtained in the models using a titanium abutment (on average 1336.24 MPa), and the lower stress values were obtained in the models using a zirconia abutment (on average 964.26 MPa).

Table 3. The von Mises stress values of abutment screws

Numerical models (Crown material-Abutment type)	Abutment screw (MPa)
ZLS-Zr	966.03
ZLS-Ti	1341.33
PICN-Zr	963.69
PICN-Ti	1331.01
LD-Zr	965.97
LD-Ti	1341.33
PEEK-Zr	961.36
PEEK-Ti	1331.32

***** ZLS: Zirconia reinforced lithium silicate, LD: Lithium disilicate, PICN: Polymer-infiltrated resin ceramic, PEEK: Polyether ether ketone, Zr: Zirconia abutment, Ti: Titanium abutment

When the prosthetic material used was changed, no significant difference was observed in the stress values on the abutment screw. However, the stress values in the model using the resin-based crowns and titanium abutment were approximately 10 MPa lower than the ceramic-based crowns. In all models, the highest von Mises stresses were concentrated on the head of the abutment screw (Figure 4).

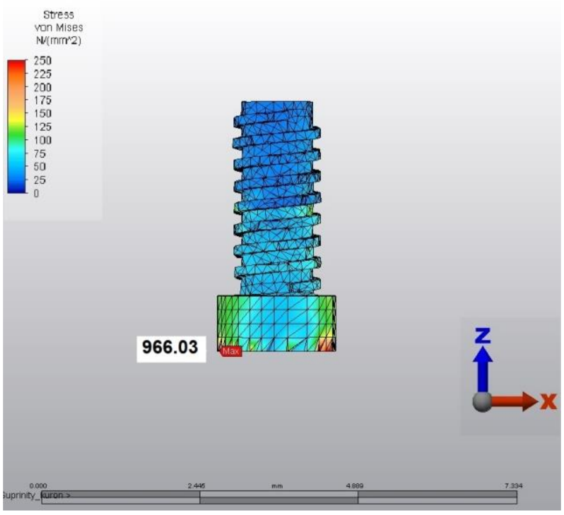

Figure 4. The von Mises stress on the abutment screw in the ZLS-Zr model

DISCUSSION

Within the scope of the study results, the established hypothesis was partially accepted, and the abutment type had an effect on the stress values on the abutment screw. However, the effect of the crown material used was not observed.

In the literature, there was a limited number of studies revealing the stress change and failure types of abutment screws due to different abutment materials.[10,17,22-24] Nevertheless, studies conducted with two-piece titanium implants with metal or porcelain abutments revealed that abutment screws fractured regularly in case of metal abutment.[10,17] Porcelain abutments had complications due to screw loosening or deformation at a similar rate to metal abutments. However, abutment fracture was encountered before the screw fracture. While fractures in metal abutments are usually observed in the abutment screw, they occur in the abutment itself in ceramic abutments. Therefore, it is assumed that the fracture of the zirconia abutment occurs before the fracture of the abutment screw.[10]

Although previous studies mainly focused on the effects of titanium and zirconia abutments on stress distribution, research results were inconsistent.[22-24] The use of porcelain abutments has eliminated the aesthetic disadvantage of the titanium abutment, especially for the restoration of the maxillary anterior teeth. Studies on porcelain abutments with a proven aesthetic advantage reported some functional disadvantages.[25,26] Zirconia and alumina abutments have higher fragility and higher young modulus compared to conventional titanium abutment, thus affecting the screw preload and torque loss. The modulus of elasticity of the titanium implant and abutment screw is lower than that of the porcelain abutment. Thus, stress will be concentrated more on the implant and abutment screw, so it will increase the risk of implant fracture and screw loosening.[25] Dhingra *et al.*[27] showed that zirconia and titanium abutments had similar torque loss after cyclic loading. Debris between the zirconia abutment-abutment screw and implant-abutment can contribute to delaying torque loss and keeping the connection stable. Therefore, zirconia abutment may still be considered a choice for clinical applications.[26]

The tensile strength of the titanium screw was between 860-965 MPa.[28] When the stress values obtained were examined, it was observed that they remained in this range in the models using zirconia abutment and that stresses were higher than the physiological limit in the models with titanium abutment. Accordingly, while failure is not predicted in the zirconia abutment screw, failure may occur in the abutment screw in the titanium abutment.

Resin-based ceramics have low elastic modulus previous compared to many other ceramic materials. In the studies, it was concluded that PICN[29] and PEEK[30] materials absorbed the masticatory forces and reduced the stress values on the peripheral bone. In their study, Duan and Griggs[31] examined the stress distribution in resin nanoceramic and lithium disilicate crowns, and it was reported that resin nanoceramic materials had low-stress values under vertical loading. Similarly, in this study, resin-based crown materials had slightly lower stress values than ceramic-based crown materials in the models with titanium abutments. However, this difference could not be detected in the models with zirconia abutment.

In vitro studies evaluating the effect of different prosthetic materials on stress distribution in peripheral bone structure and implants showed that prosthetic material changes did not lead to considerable differences or had only a minor effect on stress patterns.[20,32] Furthermore, In addition, Bassit *et al.*'s[33] *in vivo* study result were in line with these results. Although resin-based ceramics were recommended in implant-supported restorations due to their shock-absorbing properties[7-9], in this study, in parallel with these studies mentioned above, no considerable decrease in stress concentrations in the abutment screw was observed. Several layers or structures are involved in the transmission of masticatory forces to the abutment screw, including the prosthetic superstructure, the cement layer, or the prosthetic screw and abutment. It can be considered that some of the total energy transferred to the abutment screw is absorbed by the intermediate layers, which may explain the similar biomechanical effects of different superstructure materials on the abutment screw.

In this FEA study, it was assumed that all models were linear, homogeneous, and isotropic, and 100% osseointegration of the implant into the alveolar bone was assumed. In the model created with these assumptions, the diversity of stress and deformation rates was limited. Therefore, *in vivo* conditions could not be fully reflected. Furthermore, only internal hexagonal connection and static force were used in this study. However, the above-mentioned limitations do not considerably affect the accuracy and results of the FEA. The result of this FEA study can be used as a guide in clinical trials.

CONCLUSIONS

Within the limitations of this study, it can be concluded that the effect of the prosthetic superstructure material on the stress distribution in the abutment screw was not significant. It was revealed that the zirconia abutment and the prosthetic materials used in the study did not have high stress values enough to cause a failure of the abutment screw. Considering that the abutment screw is the weakest component of the implant-system, zirconia abutments can be used reliably in the maxillary first premolar region where aesthetic expectations are high.

ACKNOWLEDGEMENTS

There is no acknowledgement for this study.

CONFLICT OF INTEREST STATEMENT

There is no conflict of interest.

Farklı Materyallere Sahip Protetik Bileşenlerin Dayanak Vidası Üzerine Biyomekanik Etkilerinin Değerlendirilmesi

ÖZ

Amaç: *Bu çalışmanın amacı; farklı rezin bazlı ve seramik üstyapı materyalleri ve farklı dayanak tiplerinin dayanak vidasının stres dağılımı üzerine etkilerini 3 boyutlu sonlu elemanlar stres analiz yöntemi ile değerlendirmektir.* ***Gereç ve Yöntemler:*** *3 boyutlu implant, dayanak (zirkonya ve titanyum), dayanak vidası, kuron (zirkonya ile güçlendirilmiş lityum silikat, lityum disilikat, polimer infiltre cam seramik ve PEEK) ve alveolar kemik, Rhinoceros 3 boyutlu modelleme yazılımı ve VRMesh Studio yazılımı kullanılıp tasarlanarak 8 simülasyon oluşturacak şekilde birleştirildi. Hazırlanan modeller üzerinde maksiller sağ 1. küçük azı diş kronun lingual tüberkülüne 30° açı ile bukkolingual yönde oblik olarak 150 N kuvvet uygulaması ile yükleme yapıldı. Dayanak vidasında elde edilen von Mises değerleri dayanak tipleri ve kuron materyallerine göre karşılaştırıldı.* ***Bulgular:*** *En yüksek von Mises stres değerleri titanyum dayanak kullanılan modellerde (1336,24 MPa), en düşük stres değerleri ise zirkonya dayanak kullanılan modellerde (964,26 MPa) elde edildi. Kullanılan protetik materyal değiştirildiğinde dayanak vidasındaki stres değerlerinde belirgin fark görülmedi.* ***Sonuçlar:*** *Dayanak vidasının implant sisteminin en zayıf halkası olduğu düşünüldüğünde estetik beklentinin yüksek olduğu maksiller 1. küçük azı bölgesinde zirkonya dayanak güvenilir olarak kullanılabilir.* ***Anahtar kelimeler:*** *Dental stres analizi, diş dayanakları, cam seramikler.*

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