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EFFECTS OF REMOVER TECHNIQUES ON STRESS DISTRIBUTION OF IMPLANT SUPPORTED FIXED PARTIAL DENTURES AND THE SURROUNDING BONE: A FINITE ELEMENT ANALYSIS

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ABSTRACT

Background & Aims: Implant retained restorations may be retrieved due to many reasons. However, implant retained restorations have many components which may be damaged during removal. The aim of this study is to observe stress concentrations in the surrounding bone, the implant and its components, during retrieval of a three-unit implant-supported fixed partial denture using two different removal techniques.

Materials and Methods: One three-dimensional digital model of an implant-supported three-unit restoration was constructed. The implants' dimensions were 3.7 mm x 10mm. A pull out force of 40 N was applied on a single support and on the connectors with a loop device. The stress values were calculated within the dental implant, abutment, abutment screw and surrounding bone.

Results: The highest stress concentration was observed at the collar of the abutment during load on a single support (16.246 MPa). The stress concentrations at the cortical bone were lower than the stress concentration at implants, while the maximum stress concentration in bone structure was 1.175 MPa. The loop device technique was enabled to share the load through both implants and reduce the stress concentration levels (9.941 MPa).

Conclusion: The pull-out force, did not show a great effect in bone structure. However, implant components were under higher stress and abutment screw was the weakest part of the system. During a crown removal, more attention is needed in order not to damage implant components rather than the bone.

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KÖPRÜ SÖKÜM TEKNİKLERİNİN İMPLANT DESTEKLİ SABİT PROTEZLER VE ÇEVRE KEMİK ÜZERİNDEKİ STRES DAĞILIMINA ETKİSİ: SONLU ELEMAN ANALİZİ

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ÖZ

Amaç: İmplant destekli restorasyonlar çeşitli nedenlerle çıkarılabilir. Ancak implant destekli restorasyonların söküm sırasında zarar görebilecek birçok parçası mevcuttur. Bu çalışmanın amacı, iki farklı çıkarma tekniğini kullanarak, üç üyeli implant destekli bir restorasyonun çıkarılması sırasında; çevre kemik, implant ve bileşenlerindeki stres yoğunluklarını gözlemlemektir.

Gereç ve Yöntem: Üç üyeli implant destekli bir restorasyonun üç boyutlu dijital modeli oluşturuldu. İmplantların boyutları 3.7 mm x 10 mm idi. 40 N'lık bir çekme kuvveti tek bir destek üzerinden ve konnektörlerden geçen bir tel ile uygulandı. Dental implant, abutment, abutment vidası ve çevre kemik içindeki stres değerleri hesaplandı.

Bulgular: Tek bir destek üzerine uygulanan yük sırasında en yüksek gerilme konsantrasyonu abutment boynunda görülmüştür (16.246 MPa). Kemik yapısındaki maksimum stres konsantrasyonu 1.175 MPa iken, kortikal kemikteki stres konsantrasyonları, implantlardaki stres konsantrasyonundan daha düşük olarak gözlendi. Abutment vidalarındaki stres konsantrasyon seviyeleri benzer ancak lokalizasyonları farklıdır. Tel ile her iki konnektör üzerinden kuvvet uygulanması, yükün her iki implant tarafından paylaşlmasına ve stres konsantrasyon seviyelerinin (9.941 MPa) azalmasına olanak sağlamaktadır.

Sonuç: Kron çıkarılması sırasında uygulanan çekme kuvveti, kemik yapısında büyük bir etki göstermemektedir. Bununla birlikte, implant bileşenleri daha yüksek gerilme konsantrasyonlarına maruz kalmıştır ve abutment vidası sistemin en zayıf bileşeni olmuştur. Bir kron sökümü sırasında, kemik yerine implant bileşenlerine zarar vermemek için daha fazla dikkat gerekir.

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Anahtar Kelimeler: Sonlu Elemanlar Analizi, Sabit Protez, İmplant, Kron Sökümü.

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INTRODUCTION

During implant therapies clinicians may deal with complications such as aesthetical, biological or mechanical problems.[1,2] Previous retrospective studies reported several minor complications which had to be interfered with.[3-5] Thus, retrievability of the superstructures of an implant-supported restoration is crucial.[6]

The clinician may prefer either cement-retained or screw-retained implant-supported restorations. Screw-retained restorations can be removed without any difficulty; however, clinical and laboratory procedures are complicated.[7] Cemented restorations have simplified clinical and laboratory procedures and have superior aesthetics as there is no occlusal screw access.[7-9] However, retrieving implant supported restorations cemented with high retentive value permanent cements may reveal severe problems.[10] In order to ensure the retrievability of restorations and prevent harming the restorations, implants and adjacent tissues, some researchers suggest provisional cements as an alternative.[8,11,12] The cement should have enough strength to maintain the restoration in place under function while it should also enable the clinician to retrieve the restoration without difficulty.[6]

Clinician's experience, patient's tolerance, type of restoration, type of cement that will be used, and the load applied on the implants while removing the restorations are the major factors that determine the type of method for the removal of the restoration.[4]

Many crown remover types and techniques are used all over the world. The purpose of all of these crown removal instruments and techniques is to break the cement seal. These removers apply high impact forces on the restoration in short durations.[7] Regardless of the technique used for the crown removal, low force must be applied at the beginning, and then if necessary, the force should be increased gradually in order to protect the implant and the surrounding tissues. Many studies were conducted on the stress distribution of implant-supported prostheses that are both fixed and removable, and many of these were focused on stresses that occur during function.[3, 5, 7, 10, 13-21] Besides, some studies have evaluated different techniques and various types of cements, and their effects on retention.[11, 12, 22-26]

In this study, it was aimed to observe the effects of loads applied during retrieval of an implant-supported fixed restoration. The null hypothesis was that applying pull-out loads on an implant-supported restoration had devastating effects on the bone and the implant.

MATERIAL AND METHODS

A three-dimensional finite element analysis (FEA) model of a three-unit fixed partial denture (FPD) comprising mandibular second premolar and molar as the fixtures and the first molar as pontic was constructed to evaluate the stress distribution and concentration levels inside and around the implants during a FPD removal. Graphic processing programs (Rhinoceros 4.0, McNeel, Seattle and Ansys 11.0, Ansys Inc. Pennsylvania) were used to construct the mathematical models that represented cortical and cancellous bones, and osseointegrated implant and components.

The geometry of the implant and the abutment was created as an experimental design, not representing any of the commercially available dental implants, in order not to distinguish any implant system from another as there is a great variety in the market. The implants were modeled with a diameter of 3.7 mm and a length of 10 mm. Implants were placed with 20 mm of distance in between. The abutments' diameters were 3.7 mm and lengths were 5 mm. The axial taper of the abutments was set to 6 degrees. Implant-abutment connection was modelled as an internal hexagonal design.

The infrastructure of the restorations respected the form of the final restoration and had rounded edges with a minimum thickness of 0.8 mm. The veneering porcelain was modelled with 2 mm of thickness.

Cortical bone height was 2 mm and bone-implant interface was assumed to be 100% osseointegrated. The bone was modelled as a part of the mandible. Although modeling an anatomical mandibular body could approximate the physiologic conditions, the study's aim was to evaluate the biomechanical response of implant components and the surrounding bone during retrieval of a FPD.

Each mathematical model included approximately 14200 nodes. The calculation of the displacement of each of the nodes was used to verify the stress throughout the structure. The bottom exterior nodes of the alveolar bone in the finite element methods (FEMs) were fixed in all directions as the boundary condition. A finer mesh was produced at the interfaces to ensure accuracy of force transfer.

The materials used in the study were considered isotropic, homogenous and linearly elastic.[18] The elastic properties (Young's modulus (E) and Poisson's ratio (μ)) used in the study were taken from the literature (Table 1).[17,20,24] The implants were assumed to be 100% osseointegrated.

Vertical pull-out loading was applied to the crown margins with a loop device that was placed on the connectors. The load applied on the restorations was 40 N and it was determined based on the mean retentive values in previous studies.[7] The stress levels at the implant components were calculated using von Mises stress values which are commonly reported in other finite element analyses studies as Von Mises stress values are used to compare the stress distribution in ductile materials.[5,14] The maximum and minimum principle stress values were used for calculating the stress levels at the bone. A color scale was used to provide comprehensible view of the stress concentrations.

RESULTS

Pull-Out Force Applied on Single Abutment

During the application of pull-out force on a single abutment of the three-unit FPD, stress concentrated in and around the adjacent implant. However, the distant implant complex and the surrounding bone were almost unaffected by the load. (Table 2)

The highest stress was observed at the abutment on the implant-abutment interface (15.729 MPa on the distal implant and 16.246 MPa on the mesial implant) (Figure. 1). On the implant collar, the stress values were 9.338 MPa for the distal and 10.132 MPa for the mesial implant (Figure. 2). The maximum stress values observed at the abutment screws were 3.041 MPa for the mesial implant and 3.093 MPa for the distal implant (Figure. 3). Stress concentrations inside the bone were relatively low (1.380MPa for the bone around the mesial implant and 1.624 MPa for the bone around the distal implant (Figure. 4).

Pull-Out Force Applied on the Connectors of the Restoration

The stress was distributed to both implants. The highest stress was concentrated at the abutment collar (9.941 MPa) (Figure 5). The stress levels of the implant body, abutment screw and the bone were 5.011 MPa, 2.274 MPa and 1.175 MPa respectively (Figures 6-8). The stress concentrated at the implant collar, and 1/3 apical portion of the abutment screw (Table 2).

DISCUSSION

Previous FEA studies on implant-supported restorations mostly focused on stress concentrations and distributions during the function. Furthermore, various types of cements were investigated for their retention abilities.[1,2,5,8,12,23]

Table 1. Elasticity modulus and Poisson's ratios for the materials used in the study

	Elasticity Modulus (MPa)	Poisson's Ratio
Titanium	117000	0.30
Metal Framework	220000	0.33
Porcelain	82200	0.35
Cortical Bone	14800	0.30
Cancellous Bone	1850	0.30
Gold	100000	0.30

Table 2. Maximum stress values observed in the study.

	Pull-Out Force Applied on One (Abutment)	Pull-Out Force Applied on the Connectors of the Restoration
Bone	1.624 MPa	1.175 MPa
Implant	10.132 MPa	5.011 MPa
Abutment	16.246 MPa	9.941 MPa
Abutment Screw	3.093 MPa	2.274 MPa

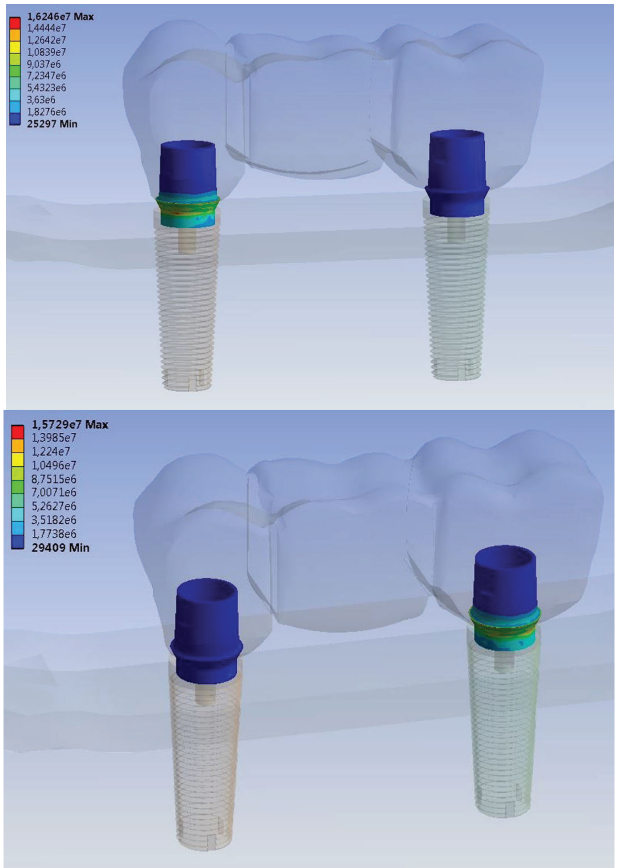

Figure 1. Stress concentrations at the abutment during restoration removal. The pull-out load was applied on a single support.

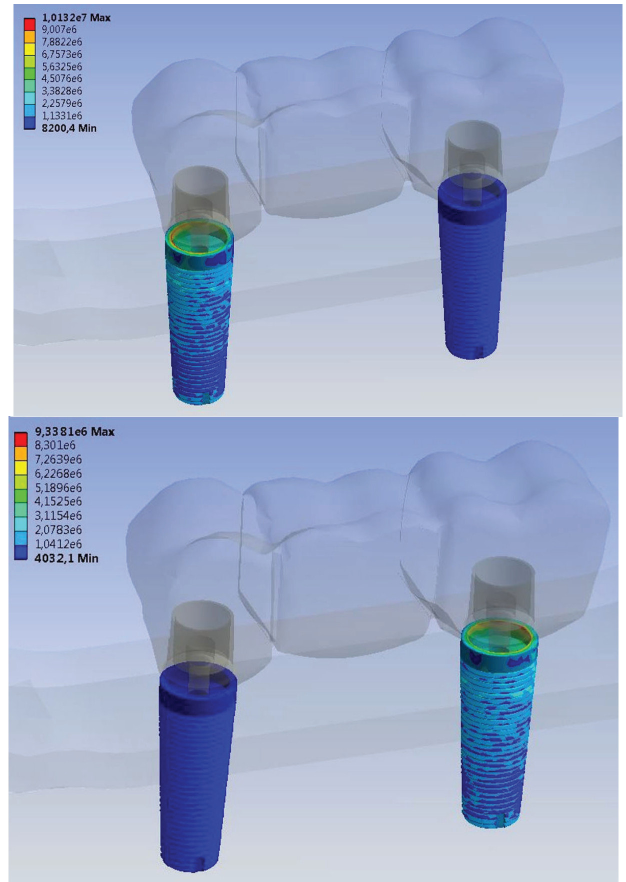

Figure 2. Stress concentrations at the implant body while load was applied on a single support.

However, all types of restorations will have to be removed over time due to various reasons.

According to previous studies no cement can be considered as an "ideal" cement. The reason is that various cements, cementation techniques, and implant-superstructure combinations had been used in such studies.[1,9,14]

The advantages and disadvantages of temporary and permanent cements have been studied in the literature. The search on an "ideal cement" for implant-retained fixed restorations in previous studies failed as there is a wide variety of cements, cementation techniques and implant-restoration combinations that have been used.[1,10,24-26] The preferable cement should be strong enough to maintain the crowns in place and weak enough to be retrieved easily.[1,10,24,25] To overcome this problem, it was suggested to initially use weaker or temporary cements and then change it with much retentive cement if necessary.[10] In the current study, in order to focus on the stress concentrations and distributions at the implant, no specific cement, neither temporary nor permanent, was distinguished. Besides, the cement thickness was ignored in order to simplify the modeling and evaluation of the results, which may be a limitation of this study.[21,24]

To evaluate the mechanical behaviors of implant complex and observe the effects at the bone is impossible in vivo. Thus, various stress analysis methods are used. FEA is one of the extensively used stress analysis methods in investigating stress formations, concentrations and distributions in and around the implants and at the bone tissue under different loading conditions.[5,14] On the other hand, FEA has its own limitations. As FEM are mathematical models, material properties are assumed to be homogenous, isotropic and linearly elastic, which are different from the actual conditions.

Stress concentrations mainly occur in the cortical bone around implant collar, and in the implant-abutment junction under functional loading.[17,18] Although the cortical bone can bear more load than the trabecular bone, excessive

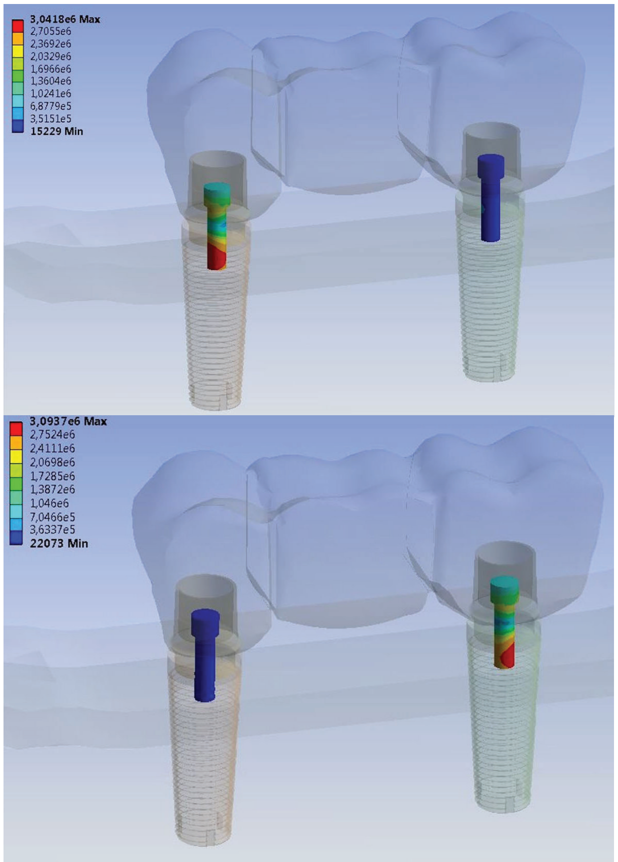

Figure 3. The stresses at the abutment screw were concentrated at the 1/3 apical portion

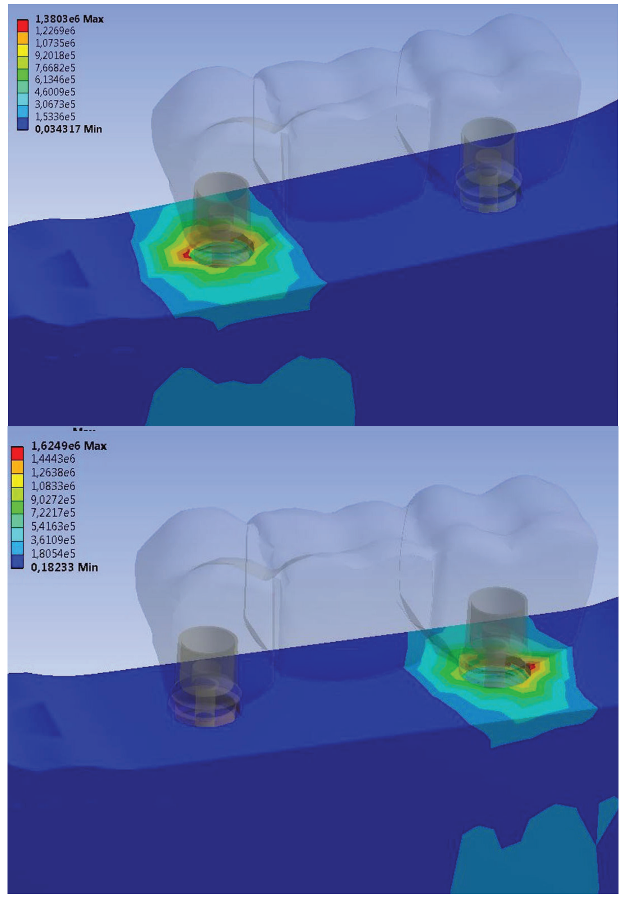

Figure 4. Stress concentrations at the surrounding bone were lower than the implant components during restoration removal.

loads can lead to bone loss. Loads over 3000 με will lead to a pathologic overload and bone loss.[5,15,27] In this study, the maximum stress level at the cortical bone was 1.62 MPa and it was within the functional stress limits. It appears that the pull-out-force effects implant components further. Thus, the null hypothesis of the study was partially rejected. Loading on the implant from a distant point would lead to an increase of stress concentration on the implant and the bone. The pull-out force applied on one implant support would act as an extension on the distal implant causing momentum effect and increase of force and stress. However, in this study, it was observed that the remaining implant did not bear the loads applied on the load bearing implant. This may occur as a result of the limitation of mathematical models. Besides, loading on two points decreases the stress concentration levels and provide much preferable stress distribution.

This study affirmed that the abutment screw is the weakest part of the implant system, under both functional forces

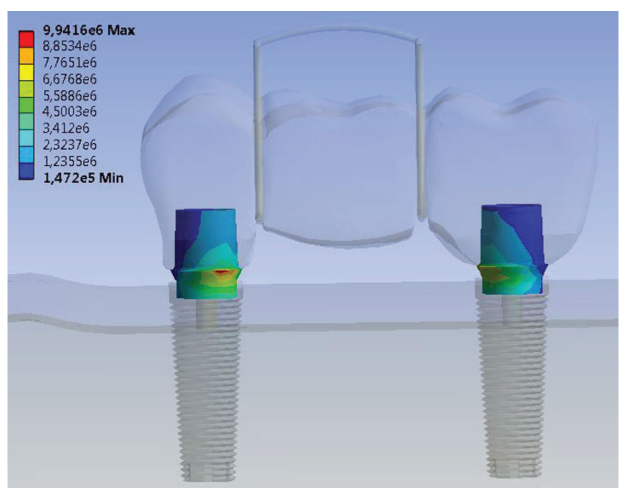

Figure 5. The highest stress levels during the restoration removal with a loop device were observed at the abutment collars.

and pull-out forces.[3,21] Moreover, overloading the abutment screw may lead to loosening or fracture.[3] Extra care and attention should be given during restoration retrieval to not

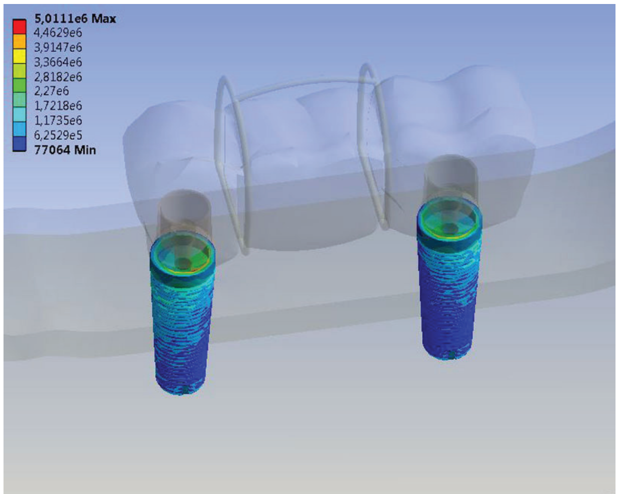

Figure 6. Stress levels at the implant bodies during restoration removal with a loop device.

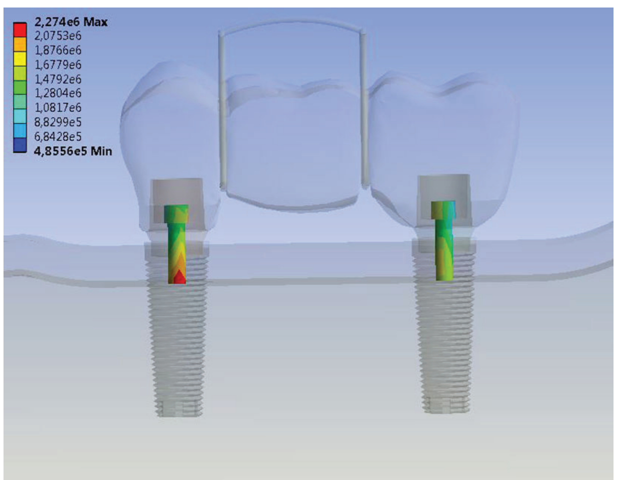

Figure 7. Stress concentrations at the abutment screws.

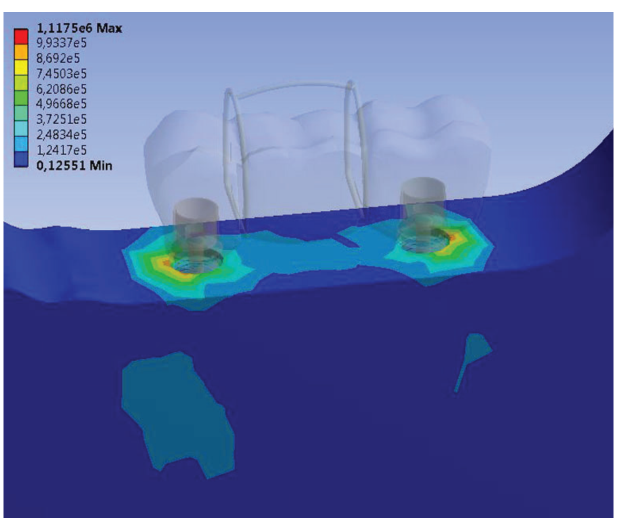

Figure 8. The lowest stress levels were observed at the surrounding bone similar to the first observation.

damage the abutment screw, especially while dealing with a loosened screw.[28]

As expected, the stress concentrations were found higher at the implant and abutment necks. However, the bulky and tough implant body's weakest part was the neck area where the abutment slot begins. Using excessive forces reveals the risk of damaging the implant body itself.

The limitations of this study were as the following. Removal of a three-unit restoration with two implant supports was simulated. Increasing the length of the restoration or the supporting implants would affect the results. Besides, only a vertical load was applied. Modelling of the cement was neglected in the study, and the cement type and thickness can also affect the outcome of the study. Further studies should be carried out with multiple implants, longer restorations, different angulations and different loading conditions.

CONCLUSION

The loads applied on the restorations during retrieval did not cause high stress concentrations in the cortical bone. Although the bone tissue does not bear much stress, the risk of damaging implant components is probable. The part that can be most probably damaged was the abutment screw. In order not to damage any component, it is recommended to cut the crown prior to retrieval.

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