

Comparison of two different restoration materials and two different implant designs of implant-supported fixed cantilevered prostheses: A 3D finite element analysis

Ahmet Kursad Culhaoglu, Serhat Emre Ozkir², Gozde Celik², Hakan Terzioglu³

Departments of Prosthodontics, Kirikkale University, Faculty of Dentistry, Kirikkale,
¹Afyon Kocatepe University, Faculty of Dentistry, Afyonkarahisar, ²Bezmi Alem University, Faculty of
 Dentistry, Fatih, Istanbul, ³Ankara University, Faculty of Dentistry, Besevler, Ankara, Turkey

Address for correspondence:

Dr. Ahmet Kursad Culhaoglu,
 Doktor Mediha Eldem Sokak.
 No: 70/11 Kocatepe, Ankara, Turkey.
 E-mail: ahmetculhaoglu@hotmail.com

ABSTRACT

Purpose: A key factor for the success or failure of a dental implant is the manner of stresses transferred to the surrounding bone. Parallel to this situation, cantilever extensions where it is not possible to place another implant, would cause greater stress and it should be avoided if possible. Manufacturers and clinicians try to develop new implant designs and superstructure materials to reduce the stresses around the implant and supporting bone tissue. This study analyzed the influence of superstructure materials and implant designs on stress distribution around dental implants supporting cantilever restoration under loading conditions. **Materials and Methods:** Three-dimensional finite element models of a 3-unit cantilever bridge were subjected to 150 N occlusal load to evaluate two different superstructure materials (conventional metal ceramic, fiber reinforced composite) and two different implant designs, cylinder type (Institut Straumann AG, Waldenburg, Switzerland) and cylinder type with micro threads around implant neck (Astra Tech AB, Mölndal, Sweden). To evaluate the distribution of stresses within the bone surrounding the implants, 3-dimensional finite element analysis was conducted using four mathematical models of unilateral 3-unit cantilever fixed partial dentures supported by two implants. **Results:** The stress distribution patterns and stress values were similar and stress concentrations were similar in both restoration materials. The highest stress concentrations were around the adjacent ITI implant, which supports the conventional metal porcelain restoration. **Conclusions:** Although, there was no significant difference in stress distribution between fiber reinforced composite (FRC) and conventional metal porcelain, stress values were lower in FRC restorations. The Astra-Tech micro-thread design reduced the stress that was distributed throughout the implant body, but it should be noted that the peak stress was still present on the implant neck.

Key words

Cantilevers, fiber reinforced composites, finite element analysis, implant design

INTRODUCTION

Since dental implants were introduced for the rehabilitation of patients in the late 1960s, an awareness demand for this form of therapy has increased. The use of implants has revolutionized dental treatment modalities and provided excellent long-term results. The clinical success of dental implants depends largely on initial stability and long-term osseointegration with optimal stress distribution that provides lasting incorporation with bone and also on implant design features such as materials, geometry.^[1]

A key factor for the success or failure of a dental implant is the manner in which stresses are transferred to the surrounding bone. Manufacturers try to develop implant designs and materials that reduce the stresses around the implant. Considering the expanded indications for implants and changing clinical protocols, the relationship between implant design and load distribution at the implant-bone interface continues to be an important issue.^[2] From an engineering perspective, it is important to design the implant with a geometry that will minimize the peak bone stress caused by loading.^[3]

To accelerate osseointegration and to control the stresses in the bone, the most common approach is alteration of dental implant designs such as macro-design and micro-design (surface alterations).^[4-7] Implant manufacturers have produced different implant designs to reduce the stresses around the implant and supporting bone tissue, and have particularly attempted to minimize stress magnifications around the collar of

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Quick Response Code:	Website: www.ejgd.org
	DOI: 10.4103/2278-9626.112315

the implant, in cortical bone and transfer such stresses to the apical site.

Implant designs incorporate thread-cutting profiles to reduce interfacial shear stress such as a 15° thread profile (ITI/Straumann, Institut Straumann AG, Waldenburg, Switzerland) with a rounded tip to reduce shear forces at the tip of the thread. Other thread designs (Microthread™ Astra Tech AB, Mölndal, Sweden) have focused on reducing the surrounding transcortical shear forces by reducing the height of the thread profile (thus reducing the contribution of any one thread) with an increase in the number of threads per unit area of the implant surface.^[3,8] The collar region of implants are designed with micro threads may offer optimal load distribution and lower stress values at the critical point of implant-bone interface, marginal cortical bone where peak stresses occur.

Superstructures of the implants may also affect the stress distribution. Because of the lack of micro-movement of osseointegrated implants, most of the force distribution is concentrated on the crest of the ridge, and this may lead to bone resorption and subsequent loss of the implant. It has been suggested that stress-absorbing or load-damping systems be incorporated into the superstructures supported by osseointegrated implants, to reduce loading on the implant due to the lack of viscoelasticity at the bone-implant interface.^[9] An alternative to metal-ceramic and full ceramic restorations in implant-supported fixed partial denture (FPD) is fiber reinforced composite (FRC).^[10,11] FRC has been suggested to absorb energy from the masticatory cycle due to the lower flexural modulus of the material.^[12]

Anatomical limitations such as maxillary sinus or mental foramen/inferior alveolar nerve would preclude insertion of implants. Unfavorable local conditions of the residual edentulous ridges may lead to treatment of a partially edentulous site with cantilever fixed prosthesis. As a simple and economical procedure, edentulous ridges next to implants may be reconstructed by means of cantilevers or pontics. Some mechanical studies have demonstrated that the cantilever FPDs supported by dental implants could induce excessive stress concentration in the supporting alveolar bone. This excessive stress concentration might facilitate bone resorption under the functional occlusal loads, especially in the cervical region of the implants, and thus compromise the longevity of the implant-supported prostheses.^[13,14]

There are several ways of observing stress distributions. The finite element analysis (FEA) involves dividing a structure into small segments each with specific physical properties. The use of FEA in implant analysis has been widely demonstrated and published. As an important computing tool, the FEA is particularly convenient for evaluating and improving implant design without the

risk and expense of real implantation.^[15] However, it is important to recognize the effect of implant design, superstructure material type and the effects of the distal cantilever on stress distribution in a FPD. It is not properly documented whether in an implant supported FPD, the effect of the implant design and superstructure material type at the load exerted on the cantilever extension may cause undesirable bone loss.

The aim of this study was to evaluate the stress distribution levels which occur around two different types of dental implants with two different restorative materials as superstructures as cantilever FPDs.

MATERIALS AND METHODS

This study compared two commercially available dental implants, cylinder type and cylinder with micro threads around implant neck (Sweden Institute Straumann AG, Waldenburg, Switzerland and Astra Tech AB, Mölndal) and two different prosthetic materials (conventional metal ceramic, FRC). Three-dimensional finite element models of a 3-unit cantilever bridge were subjected to 150 N occlusal loads over functional cusps to evaluate the prosthetic materials and implant designs [Figure 1]. All structures of implants and superstructures' defined contours were scanned using a NextEngine 3D scanner (California, USA).

To evaluate the stress distributions within the bone around dental implants, 3-dimensional FEA was conducted using four mathematical models of unilateral 3-unit cantilever FPDs supported by two implants.

Finite element models

A graphic processing program (Algor FEMPro V20) was used to construct the mathematical models, consisting of bone, two osseointegrated implants and the FPDs. The bone was modeled as a cancellous core surrounded by 2 mm thick cortical bone. The diameters and heights

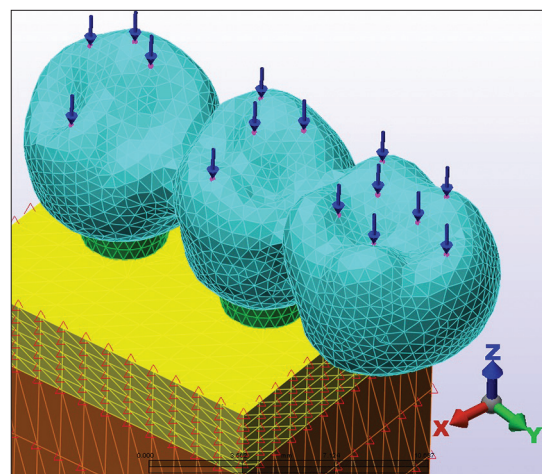


Figure 1: Meshed model with simulated loading condition. The arrows indicate loading points and angles

of the implants were selected to be comparable in size: 4.0 mm in diameter and 11 mm in length for Astra and 4.1 mm in diameter and 10 mm in length for ITI implants. These were scanned using a NextEngine 3D scanner and transferred to an interactive finite element program. The implants were inserted 7 mm apart from each other.

Material properties

The FPDs were modeled as mandibular first premolar and mandibular second premolar and first molar as a cantilevered superstructure over the implants. Porcelain fused metal (PFM) and FRC were modeled as superstructure materials.

All materials were considered as isotropic, homogenous, and linearly elastic.^[16,17] For bone, this enabled the creation of complex models. The elastic properties used in the model were taken from the literature, as shown in Table 1.

Interface conditions

All interfaces between the materials were assumed to be bonded or osseointegrated. The cement layer between the crown and abutment was too thin to adequately model in the finite element simulation and was considered to be negligible for modeling purposes.^[18,19]

Loading conditions

Based on previous reports, a static, vertical load of 150 N was applied to the model.^[18-20] The loads were applied simultaneously over the crowns on functional cusps [Figure 1]. The stress levels were calculated using von Mises stress values.

RESULTS

Maximum stress levels were shown in Table 2.

Loading on implants with PFM restoration

When loading on implants with porcelain restorations, the maximum stresses were observed at the cortical bone around the implant adjacent to the cantilever. While the highest von Mises stress concentrations were observed at the cortical bone in both implants, (Micro-thread neck cylinder implant: 10.07 N/mm², cylinder implant: 14.62 N/mm²) Stress concentrations around the distant implants (Micro-thread neck cylinder implant: 3.02 N/mm², cylinder implant: 6.35 N/mm²) were much lower than the adjacent implant.

The maximum stresses in the cancellous bone were observed at the apical regions of the adjacent implants. Compressive stress concentrations in cancellous bone around the distant implant were lower (Micro-thread neck cylinder implant: 2.01 N/mm², cylinder implant: 5.103 N/mm²) [Figures 2-5].

Table 1: Mechanical properties of oral and prosthetic materials in FEA

	Modulus of elasticity GPa	Poisson's ratio
Metal framework	86	0.33
Feldspathic porcelain	82.2	0.35
Cortical bone	14	0.30
Cancellous bone	1.37	0.30
Composite resin	14	0.24
Fiber	40	0.25
Titanium	117	0.33

FEA – Finite element analysis

Table 2: Stress levels

Implant type	Maximum N/mm ²			
	Cylinder implant		Cylinder implant with microthreads	
Superstructure	Cortical	Cancellous	Cortical	Cancellous
Metal porcelain	14.62	5.103	10.07	2.01
Fiber reinforced	14.16	5.06	9.81	2.65

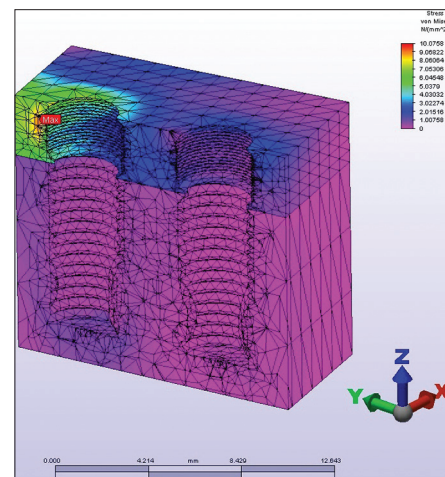


Figure 2: Stress distributions at the cortical site on Astra implants with porcelain restoration

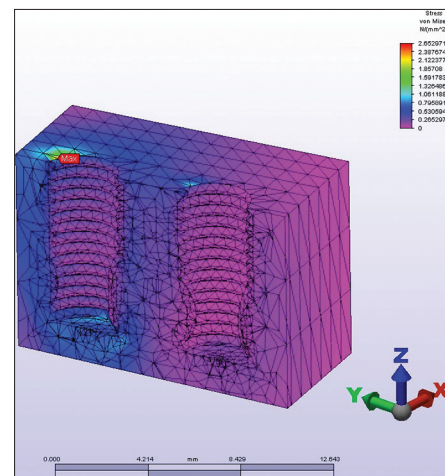


Figure 3: Stress distributions at the cancellous site on Astra implants with porcelain restoration

Cylinder implant with micro threads around implant neck showed lower stress values than the cylinder implant.

Loading on implants with FRC restoration

Stresses were concentrated around the implant adjacent to cantilever as with the previous porcelain restoration where stresses in FRC restoration were concentrated around the implant adjacent to the cantilever. Maximum stress (Micro-thread neck cylinder implant: 9.81 N/mm², cylinder implant: 14.16 N/mm²) was observed at the cortical bone, around the adjacent implant. The stress levels around the implant distant from the cantilever were lower (3.92 N/mm²) than the adjacent implant but they were higher than those observed with porcelain restoration (3.02 N/mm²) [Figures 6-9].

The maximum stresses in the cancellous bone were at the apical region of the adjacent implant to the cantilever extension and were considerably lower (Micro-thread neck cylinder implant 2.65 N/mm², cylinder implant:

5.06 N/mm²) than in the cortical bone. The stresses were much lower around the mesial implant.

As the stress distribution patterns were similar for both restorative materials, the highest stress values were observed around the cylinder implants. All the stress values observed in the four models indicate that there was a reduction in stress with the micro-thread design.

DISCUSSION

Different prosthetic designs can be utilized to restore missing teeth. In some situations, it is not possible to use two abutment teeth at each end of the edentulous area to support FPDs. In such a clinical situation, a FPD can be designed with a distal cantilever to replace missing teeth.

Cantilevered ends of fixed implant-supported prostheses increase the load on the first implant nearest to the cantilever arm.^[21,22] A previous FEA study demonstrated

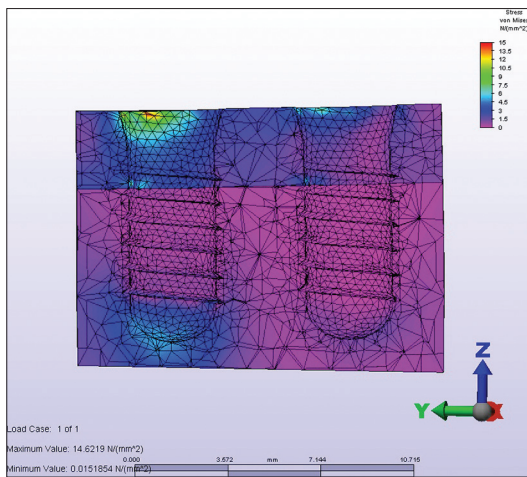


Figure 4: Stress distributions at the cortical site on ITI implants with porcelain restoration

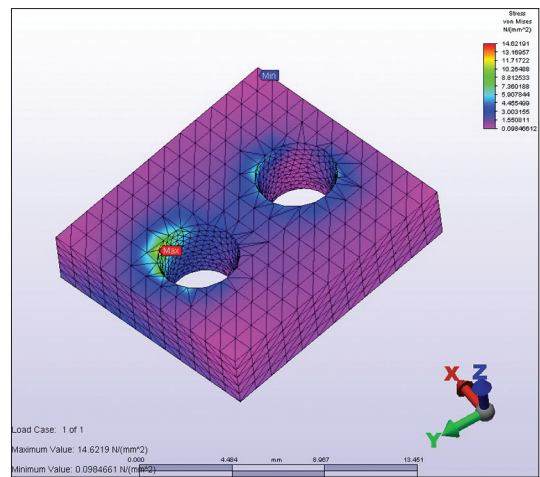


Figure 5: Stress distributions at the cortical site on ITI implants with porcelain restoration occlusal view

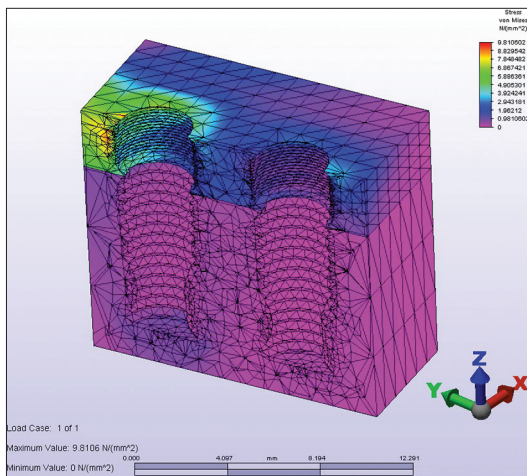


Figure 6: Stress distributions at the cortical site on Astra implants with fiber reinforced composite

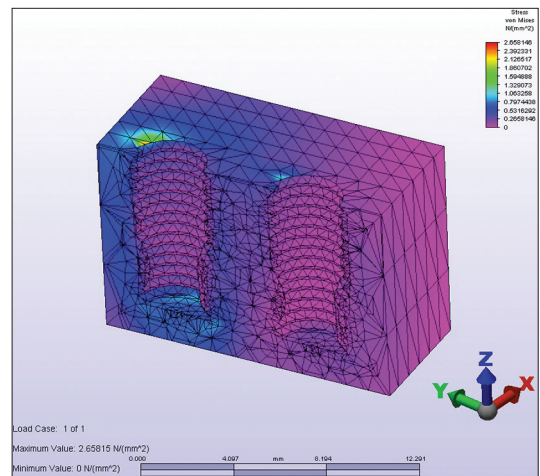


Figure 7: Stress distributions at the cancellous site on Astra implants with fiber reinforced composite

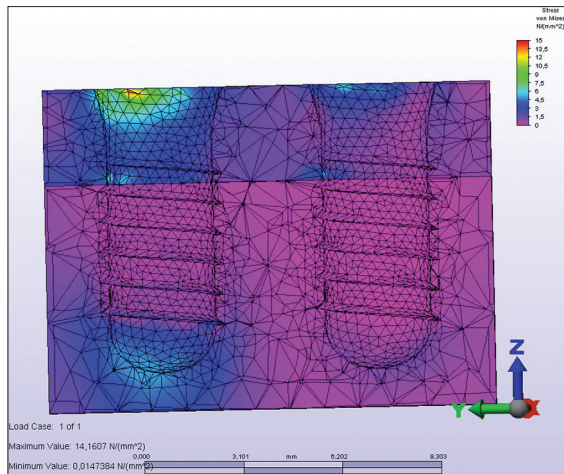


Figure 8: Stress distributions at the cortical site on ITI implants with fiber reinforced composite restoration

that the maximum equivalent stress in an FPD with a central pontic was less than half that of the cantilever FPDs.^[23] Cantilever length plays a key role on the stresses around the implants.^[24] With increased length of the cantilever increased stress occur around the implants.^[25]

The results of this study are in accordance with other previous studies, reporting in cantilevered prostheses the most distal implants serve as a fulcrum, and subjected to compression forces, while distant implants suffer tension.^[26-28]

Metal-porcelain, gold alloys, acrylics and fiber-reinforced composites are used as superstructure materials in implant supported fixed restorations.^[29,30] Some researchers reported a more resilient superstructure material would be useful at reducing stresses around the implant by the materials' elastic deformation behaviors.^[23,31]

On the contrary, there are studies that reported changing the superstructure material did not influence the stress levels.^[13,32,33]

The results of the present study, it was found that although stress values were lower in FRC restorations, changing the superstructure material did not significantly affect the stress concentration or distribution around the implants, in accordance with the previous studies. Although, the resilient superstructure material (FRC) showed more dislocation, it did not affect the stress intensity. This finding may be related to the selected loading type in the present study. In the literature, it is stated that under static loading, changing the resilience properties of different superstructure materials does not result in significant differences in stress concentrations and distributions around the implants.^[13,19,34,35] The advantages of using resilient materials become apparent under dynamic loads and impact forces.^[13,33,36]

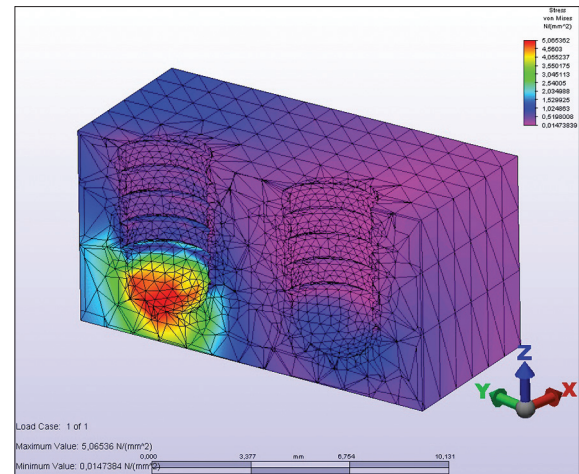


Figure 9: Stress distributions at the cancellous site on ITI implants with fiber reinforced composite restoration

The current study investigated the most appropriate material and implant design for an implant supported cantilever bridge, recognizing the uncertainty of the implant design, the effects of differing restorative materials and of the distal cantilever on stress distribution in a FPD. The FEA used in the present study is one of the most frequently used methods in stress analysis both in industry and science.^[37] The structures in this study were assumed to be homogenous and isotropic and to possess linear elasticity. However, the mandible is in fact transversely isotropic and not homogenous, and is especially subjected to functional elastic deformations originating from masticatory forces, as the bone is a living tissue.^[24,38] Furthermore, implants were simulated as 100% osseointegrated, as in previous studies.^[18-20,32,39,40] However histomorphometric data have indicated that there is never 100% bone-implant contact. Therefore, the inherent limitations of FEA must be acknowledged.

The average maximum occlusal force was approximately 200 N for premolars and molars.^[41] Therefore, a mean occlusal force was selected, considering these values. A load of 150 N was applied to the FEA models. However, it may not be necessary for this force to exactly match the reality, because standardization between conditions has been ensured in the current study and the conditions have been compared qualitatively with each other.

The loads over implants show differences according to the localization. The risk of overloading implants increases at the posterior regions.^[42] Most serious stresses occur when cantilever restorations are used. However, cantilever extensions are used in many cases, especially, when it is not possible to use another implant. Pull-out force at cantilever extensions, is increased up to 40% of the vertical load.^[38] In order to minimize the cantilever effect, occlusal table should be reduced, occlusal contacts should be reduced, and contacts at lateral movements should be eliminated.^[43]

Bone loss is not always due to the implant itself but, in dental implant design, it is important to determine the implant shape that maximizes anchorage strength within the bone. According to general engineering, this is achieved by using an implant geometry that minimizes the peak bone stress caused by standardized load upon the implant.^[3]

Palmer *et al.* reported remarkably high marginal bone levels for an implant, provided with retention elements at the neck.^[44] Lee *et al.* and Hansson suggested that retention elements at the implant neck would increase the axial load that an implant can support.^[3,45,46] Compared to a thread of standard dimensions, a small thread gives the additional advantage of increasing the axial stiffness of the implant, resulting in an additional reduction of the peak interfacial shear stress. For most systems, this neck portion of the implant is smooth. Various designs include parallel, converging and diverging sides. It has been shown that although peak principal stress values were higher around a micro-threaded implant, peri-implant bone volume exhibited smaller strain level compared to a smooth implant.^[47] Recently, Ferraz *et al.* stated that the implant with micro-threads showed higher stress concentration for cortical bone in comparison with the smooth implant, an lower stress concentration for cancellous bone.^[48] The results of these studies are in accordance with the present study.

In the present study, the implant design was shown to affect the stress intensity or distribution around the implants. The highest stress values were observed at the cortical bone. Lower stress levels were observed around the cylinder with micro-threads type implants. AstraTech micro-thread design reduced the stress that was distributed throughout the implant body, but the peak stress was still present on implant neck. The ITI/Straumann cylindrical implant design was shown to successfully transfer the stress throughout the implant body and to the apical region, but the stress values were higher than those seen in the AstraTech design.

Within the limitations of this study, changing the superstructure material did not affect the stress intensity or distribution, but implant macro-design affected the stress distribution under static loading.

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How to cite this article: Culhaoglu AK, Ozkir SE, Celik G, Terzioglu H. Comparison of two different restoration materials and two different implant designs of implant-supported fixed cantilevered prostheses: A 3D finite element analysis. *Eur J Gen Dent* 2013;2:144-50.

Source of Support: Nil, **Conflict of Interest:** None declared.