

RESEARCH

Evaluation of Stress Distributions of Zirconia Connecting Screw in Bruxism: A Finite Element Analysis

Efe Can Sivrikaya(0000-0001-6798-7610)^α, Mehmet Sami Güler(0000-0003-0414-7707)^β,

Muhammed Latif Bekci(0000-0003-4900-2739)^γ

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ABSTRACT

Evaluation of Stress Distributions of Zirconia Connecting Screw in Bruxism: A Finite Element Analysis

Background: The purpose of the present study was to evaluate the stress distributions of zirconia or titanium connecting screws under different loads (vertical and oblique) in bruxism patients and to indicate its applicability by comparing with physiological stress limit values.

Methods: Four different models were created in which the implants were the same size and design, with dental implant, abutment and connection screws made of zirconia or Ti (only screw). 3D-Finite element analysis (3D-FEA) was applied to study the effect of a vertical load (1000 N) and oblique load (an angle of 30°) on abutments in the models. The placement of implants are mandibular right first molar. Computerized tomography imaging of cadaver mandibles was used. Von Mises stresses of the different screw materials were compared with each other and the physiological stress limit values for zirconia.

Results: Von Mises stress values increased in oblique loading in all models. The von Mises stress values were significantly reduced in the titanium screw than zirconium under both loading simulations.

Conclusion: In patients with a high biting force physiological stress limit values for zirconia were not exceeded. Zircon connection screw may be used in patients with bruxism.

KEYWORDS

ÖZ

Bruksizm Hastalarında Zirkon Bağlantı Vidasının Stres Dağılımlarının Sonlu Elemanlar Analizi İle Değerlendirilmesi

Amaç: Çalışmanın amacı, bruksizm hastalarında farklı materyallerdeki implant-abutment bağlantı vidasında meydana gelen stress dağılımının değerlendirilmesidir. Ayrıca fizyolojik stress limit değerleri ile karşılaştırılarak uygulanabilirliğini belirtmektir.

Gereç ve Yöntemler: İmplantların, abutmentlerin ve bağlantı vidalarının aynı dizayn ve boyutta olduğu 4 model oluşturuldu. Bağlantı vidası titanium veya zirkon olarak modellendi, diğer materyaller ise titanium olarak modellendi. Bruksizmlili hastaların ısırma kuvvetinin taklidi için 1000 N dikey veya 30° açılı yüklem abutmentlerin orta noktalarına uygulandı. Modellenen implant sağ mandibular birinci molar hizasındadır. Mandibulanın modellenmesinde kadavranın bilgisayarlı tomografi görüntüleri kullanıldı. Farklı bağlantı vidası materyallerinde meydana gelen (zirkon veya titanium) von Mises stress değerleri karşılaştırıldı. Ayrıca zirkonyum bağlantı vidasındaki von Mises stress değerleri zirkonyumun fizyolojik stress limit değeri ile karşılaştırıldı.

Bulgular: Von Mises stres değerleri tüm modellerde 30° açılı yüklemde artmıştır. Von Mises stres değerleri, her iki yüklem simülasyonunda titanyum vidada zirkonyuma göre önemli ölçüde azaldı.

Sonuç: Isırma kuvveti yüksek olan hastalarda zirkonyum fizyolojik stress limit değerleri aşılmamıştır. Bruksizm hastalarında zirkon bağlantı vidası kullanılmasında sakınca yoktur.

ANAHTAR KELİMELER

Zirconia is a ceramic oxide, with similar osseointegration and biocompatibility properties to Ti.¹ At present, zirconia materials are favored in cases of a Ti allergy (estimated prevalence: 0.6%), galvanic side effects, and esthetic requirements.²⁻⁵ The biomechanical properties of materials affect stress formation. Under compression, ceramic materials are brittle and have limited tensile strength.⁶ Unlike Ti metals, they do not exhibit significant deformation before failure.⁶ Ytria-stabilized tetragonal zirconia polycrystal (Y-TZP), a type of ceramic is a suitable material for the manufacturing of dental implants.^{1, 7, 8}

Bruxism can be defined as a parafunctional activity on the masticatory system during sleep or while awake

and is characterized by teeth clenching.^{9,10} High bite strength of patients with bruxism causes implant, connection screw, abutment and surrounding bone stress.⁹ In a meta-analysis, Zhou et al.¹¹ described that bruxism could cause technical complications, such as porcelain chipping, connection screw/implant loosening, connection screw/implant fracture. It also causes biological complications such as marginal bone loss or peri-implantitis.¹¹ There are many studies that compare to stresses on different materials of implants and abutments in patients with bruxism.^{9,12} Although the connection screw fracture is a common phenomenon in the clinic, there is no study about stress analysis on different connection screws in patients with bruxism.

^α Karadeniz Technical University Faculty of Dentistry, Department of Oral Maxillofacial Surgery, Trabzon, Turkey

^β Ordu University Technical Sciences and Vocational School, Department of Machine and Metal Technologies, Ordu, Turkey

^γ Ordu University Technical Sciences and Vocational School, Department of Motor Vehicles and Transport Technologies, Ordu, Turkey

The 3D-Finite element analysis (3D-FEA) method has become an increasingly useful tool for predicting the effects of stress values on implants system.^{1,13} In present study, zircon implant applied to mandibular first molar region. Von mises stress values of zirconia or titanium screw were evaluated using vertical and 30° loading that mimic bruxism. The aim of this study was to evaluate the applicability of zircon connection screws at mandibular first molar region in patients with bruxism.

MATERIALS AND METHODS

3D-FEA models: Four implant systems were modelled, as below:

Model 1: A zirconia implant, zirconia abutment, zirconia connecting screw, and vertical load, Model 2: As in model 1 above but with an oblique load, Model 3: A zirconia implant, zirconia abutment, Ti connecting screw, and vertical load, Model 4: As in model 3 but with an oblique load.

Mandible, dental implant, abutment, and connection screw models: The mandible, implant, abutment, and connecting screw were transferred to a computer for 3D-FEA. Computerized tomography imaging of cadaver mandible was performed, and the data were transferred to a computer environment in DICOM format (651 px × 651 px, 96 kV, 0.2 mm thickness; Aquillion 16, Toshiba, Tokyo, Japan). Using Mimics 10.01 (Materialise, Leuven, Belgium) and SolidWorks 15 (Solidworks Corporation, Waltham, MA, USA) software, a three-dimensional (3D) model of the mandible was created (vertical alveolar dimension 13 mm and lingual bone width greater than 6mm). Using the same software, an implant (diameter: 4.3 mm, length: 11.5mm), abutment (Conical Connection 6 x 7 mm) and connection screw (7mm) was modeled according to the Nobel Active implant system (Nobel Active, Kloten, Switzerland) and placed vertically in FE models of the mandible to simulate in vivo conditions (Figure 1a)

3D-FEA: The models were exported to ANSYS Workbench 13 (Swanson ANSYS Inc., Houston, PA, USA). A mesh was automatically obtained using the same software (Figure 1b). The mesh contained 1963222 elements and 2341922 nodes. Those values were obtained according to the mean of all models. In this study, 100% implant–bone osseointegration was assumed.

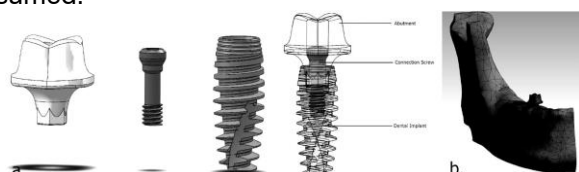


Figure 1

The models transferred to a computer environment (a). A mesh was obtained using the ANSYS 13 Workbench software placement (b). abutments.

Properties of the materials: The length, diameter, and design of the Y-TZP implants, Y-TZP abutments, and Y-TZP or titanium connecting screws were the same in all models (Table 1).

Table 1.

Young's Modulus (GPa) and Poisson's Ratio values used for the analyses.²⁶⁻²⁹

Material	Young Modulus (GPa)	Poisson's Ratio
Titanium	110	0.35
Cortical bone	13.7	0.30
Trabecular bone	1.37	0.30
Y-TZP	200	0.33

Boundary conditions and loading: The boundary conditions were assumed to be fixed at each edge of the condyles, inferior border of the corpus, and distal border of the ramus as described previously.⁹ The applied forces were static.

The implants were loaded at 1,000 N vertically and then at a 30-degree angle onto the abutments (Figure 2). Vertical loading and 30° loading were perpendicular to the midline. The implants were applied to the mandibular first molar tooth region.

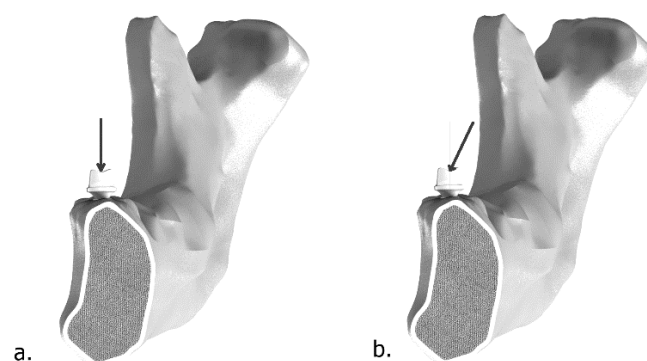


Figure 2

The models transferred to a computer environment (a). A mesh was obtained using the ANSYS 13 Workbench software placement (b). abutments.

RESULTS

In zirconia screw models von Mises values was 258.67 (Vertical loading)(Figure 3a) and 650.38 (Oblique loading) (Figure 3b). In titanium screw models von Mises values was 162.48*(Vertical loading) (Figure 3c) and 377.37*(Oblique loading) (Figure 3d) von Mises stress values increased under an oblique load in all the models (Figure 3 b,c>a,b, Table 2). The von Mises stress values were relatively

reduced in the titanium screw than zirconium under both loading simulations (Figure 3a,b>c,d, Table 2).

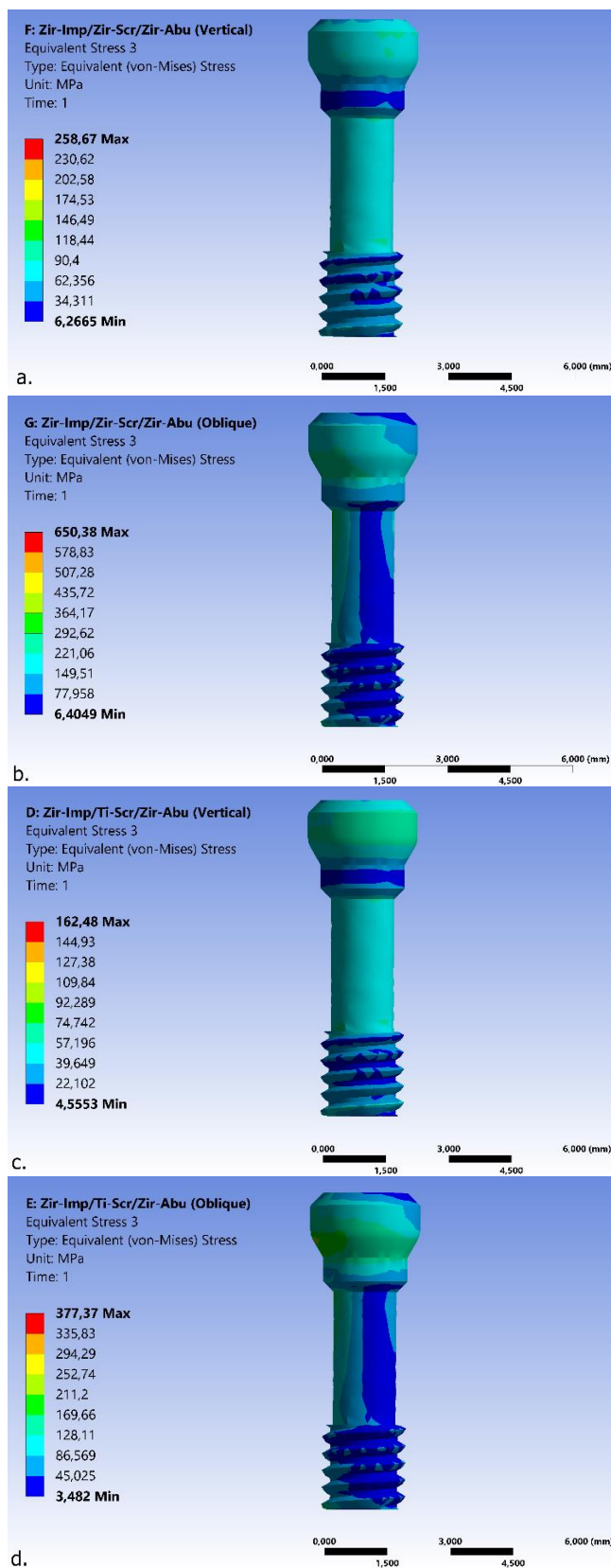


Figure 3

Von Mises stress values in connection screws under vertical and oblique loading. Model1 (a), Model2 (b), Model 3 (c), Model 4 (d).

Table 2.

Young's Modulus (GPa) and Poisson's Ratio values used for the analyses.²⁶⁻²⁹

		Model 1	Model 2	Model 3	Model 4
Screw	VMS	258.67*	650.38*	162.48*	377.37*
Material		Z(I-A-S)v	Z(I-A-S)o	Z(I-A-) T(S)v	Z(I-A-) T(S)o

*: MPa VMS: Von Mises Stress PS:Principal Stress Z(I-A-S)v= Implant, abutment and connection screw are zirconia in vertical loads.

DISCUSSION

Zirconia are used as implant materials because of their osseointegration properties and biocompatibility.^{2-4,6} Due to the materials of Ti and zirconia, stress formation differs under an occlusal force, especially in patients with bruxism, where stress values increase. No studies in the literature have evaluated zirconia dental implants applied mandibular first molar region under heavy bruxing forces. In the present study, we compared the stresses in connection screws (Y-TZP or Ti) in bruxism patients using the 3D-FEA method. The ultimate aim of the study was to determine the effects of the material type (zirconium) on stress distribution values.

As described in the introduction, Zhou et al. et al.¹¹ described that overload may occur easily in bruxers and it could cause technical and biological complications. Technical complications were ceramic chipping, framework misfit, porcelain fracture, acrylic resin base fracture, screw loosening, screw fracture, implant loss and abutment loosening. Biological complications were marginal bone loss and peri-implantitis. Similarly, there are several studies have reported that breakage of connection screws can occur, depending on the increase in biting force.^{14,15} According to Silva et al.,¹⁵ the most important drawback of dental implant/abutment assemblies is the need for a fixing screw. One-piece abutments, morse tapers, and platform switching techniques have been developed to combat this problem.^{15,16} Previous studies demonstrated that zirconium materials had flexural strength at 900–1200 MPa^{13,17,18} and compression resistance at 2,000 MPa.¹⁸ In the present study, the von Mises stress values were lowest in the connection screws between 162.48 and 377.37 MPa under static loading, and the von Mises stress in the screws did not exceed the value at which micro-crack formation occurs (i.e., < 900–1200 MPa) (Table 2). However, screw-related complications may also occur due to dynamic loading. There is insufficient information in the literature on such complications.

In previous studies on patients with bruxism, the researchers analyzed forces of 200–2,500 N.^{9,19,20} Goito et al.²¹ reported that the bite force was

greatest at central incisors and first molar regions. According to the rule of 1:1:2 (incisor:premolar:molar), a maximum bite force of 2,500 N in a bruxism patient indicates that there is a force of 1,000 N in the first molar tooth region.¹⁹ Ayranci et al.⁹ simulated the bite forces of patients with bruxism and loaded 1,000 N. Previous studies examined angles of oblique force of 30, 45, 60, and 75 degrees.^{9,20,22-24} In the present study, implants were loaded at 1,000 N vertically. To simulate lateral movements, a 30-degree angle force was applied. In common with the findings in the present study (Table 2), previous research showed that oblique forces increased von Mises stress values.^{1,9,20,22}

3D-FEA and limitations

In the present study, all the models (cortical bone, trabecular bone, implant, abutment and screw) were assumed to be homogeneous and isotropic and to have linear elasticity. However, this is not the case under in vivo conditions.²⁵ Furthermore, only an Inter-X connection design and static force were used in present study. In addition, a 100% implant–bone interface was simulated, which is impossible in clinical situations.²⁵

CONCLUSION

Zirconium connection screw may be applied in bruxism patients because it is resistant to high biting force. Preferring this material instead of titanium with appropriate planning will increase aesthetics.

ABBREVIATIONS

3D-FEA: Three dimension finite element analysis

Ti: Titanium

DICOM: Digital imaging and communications in medicine

mm: Milimeter

Y-TZP: Yttria stabilized zirconia

MPa: Megapascal

N: Newton

Z(I-A-S)v: Implant, abutment and connection screw are zirconia in vertical loads.

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Corresponding Author:

Efe Can SİVRİKAYA
Karadeniz Technical University Faculty of Dentistry
Department of Oral Maxillofacial Surgery,
Trabzon, Turkey
E-mail : efecans@msn.com