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Biomechanical analysis of ultra-fine grained titanium dental implant with different geometries

H. Ghahramanzadeh Asl

Atatürk University, Engineering faculty, Mechanical Engineering Department, Erzurum, Turkey

ABSTRACT

A dental implant replaces tooth root and the bone is better preserved. A dental implant provides more advantages over other tooth replacement options. In every condition when a load is applied on the implants results stress in adjacent bone too. The amount of the stress determines the life and stability of the implants.Different factors have effect on the amount of the stress. The two main factors which have significant effect on the stress are the implants geometry and material. In the study, four models, a cylinder and three conic with various angles, built with 80% crystalline HA coated ECAP nanostructure titanium and porous titanium were analyzed.FEM analysis conducted with theANSYS 14 software. The results show the drastic effect of implant's material on the maximum equivalent stress in the bone. The results indicate that cylinder 80% crystalline HA coated ECAP nanostructure titanium implant has the minimum stress concentration.

Keywords: FEM, Dental implant, ECAP technique, Hydroxyapatite

INTRODUCTION

Dental implants along with high fatigue strength and low modulus of elasticity should have high corrosion resistance and be biocompatible. Commecially pure titanium despite itssuperior biocompatibility has low strength which is not proper for using as an implant.[1-5]Substantially, titanium alloys like as Ti (Grade5) due to their biocompatibility and high strength are good choice for implant substance.[6-11,1] However, aluminum and vanadium content of the alloy have toxic effect and in long term whenthey releasein the body may cause various diseases like as cancer and Alzheimer. [12-15]

Increasing the strength of the CP-Ti is a solution to the problem. Equal channel angular pressing (ECAP) is a new method which increases the strength of the CP-Ti with making a nanostructure. The resulted nanostructure Ti strength is almost equal to Ti(Grade5). [1, 5]Initial instability and poor osteoconductivity are weak points of nanostructured titanium. Utilizing porous Ti because of its biocompatibility and corrosion resistance is a solution to the problem. Porous Ti absorbs nutrients and oxygen and improves adhesion by increasing bones growth into implant's pores.The other solution is using HA coatings which is biocompatibility and can bond to bone instantly and promote implant stabilization. [16-19]

In the study, the two porous and HA coated nanostructure titanium as implant materials are investigated. [20, 21] The aim of the study is minimizing the stress which implant makes in the bone to decrease fracture possibility in the bone and implant. There are various factors effect stress amount with using these materials as implants. One of the important factors is the shape of the implants. This factor rarely has been investigated before. So, different designs of implants have studied by finite element method (FEM). [22-24]ANSYS 14.0 software is used to conduct the FEM analysis.

MATERIALS AND METHODS

Bone, implant and HA coatings assumed to be isotropic and their properties are shown in Table 1. [1, 3, 25, 27]

Table 1.Materials specifications

Material	Modulus of elasticity(GPa)	Poison's ratio
Porous Ti	41,36	0,35
Grained Ti	100,2	0,42
Cortical bone	13,7	0,3
Cancelous bone	1,37	0,3
80% crystalline HA	95	0,28

The outer layer of the bone has higher modulus of elasticity than the inner layer as shown in table 1. The outer layer called cortical bone and the inner layer called cancellous. Porous titanium,80% crystalline HA of 0.18 mm thickness coated ECAP nanostructure titanium are used as implant materials. In the study, four different model of implants are analyzed. 3D models of four different implantsare designed by SolidWorks 2013 software. The length of all the implants is 13mm. 10mm of the implants are threaded with the pitch of 1.2 mm and the thread depth of 0.3mm. One of the implant models is cylinder with the diameter of 3.7mm and the three others are conic with the based diameter of 3.7 and top diameters of 3.1mm, 2.5mm and 1.9mm as shown in figure 1. As shown in figure 2 a 20mm*14mm*25mm block is taken as the mandible bone. [25, 27,28]

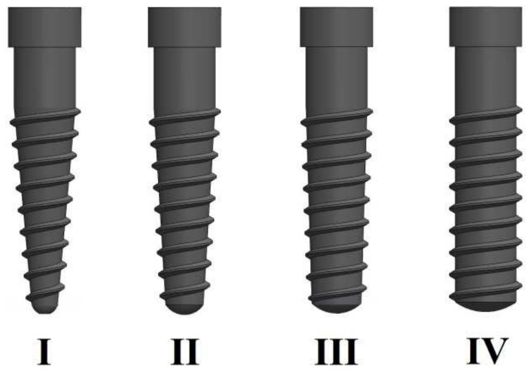

Fig. 1. Different model of dental İmplant

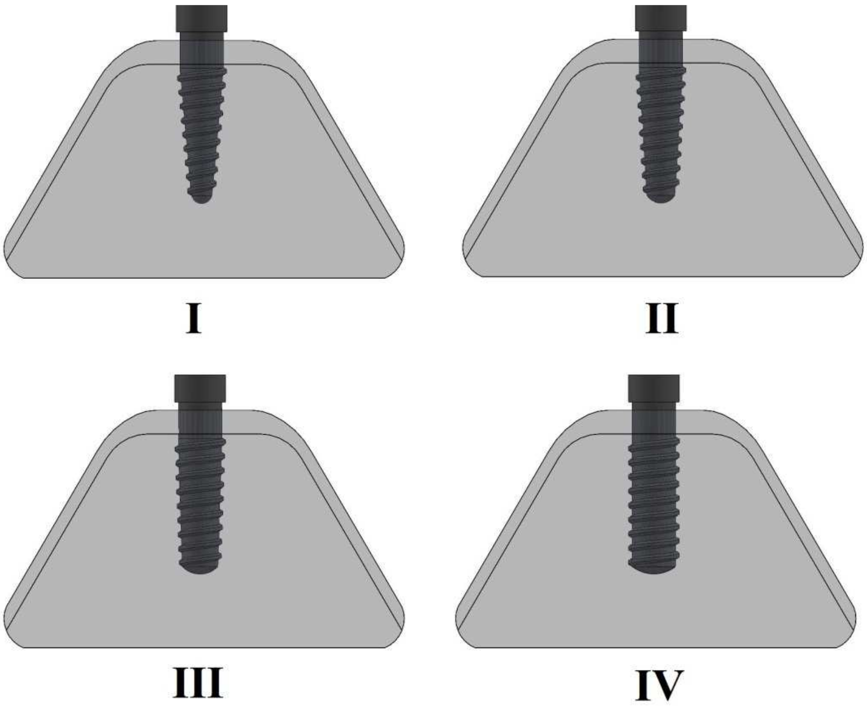

Fig. 2. Different model of implant-bone

In the ANSYS 14.0 software, bonded contact type is chosen for the all surfaces contacts and a 200N axial force applied on the top of the implants. Side surfaces and bottom of the mandible bone have been fixed. [25]Tetrahedral elements have been used to mesh the 3D model properly as shown in figure 3. Number of elements for every model is about 1370000. Element quality and skiwness are 0.85 and 0.22, respectively.

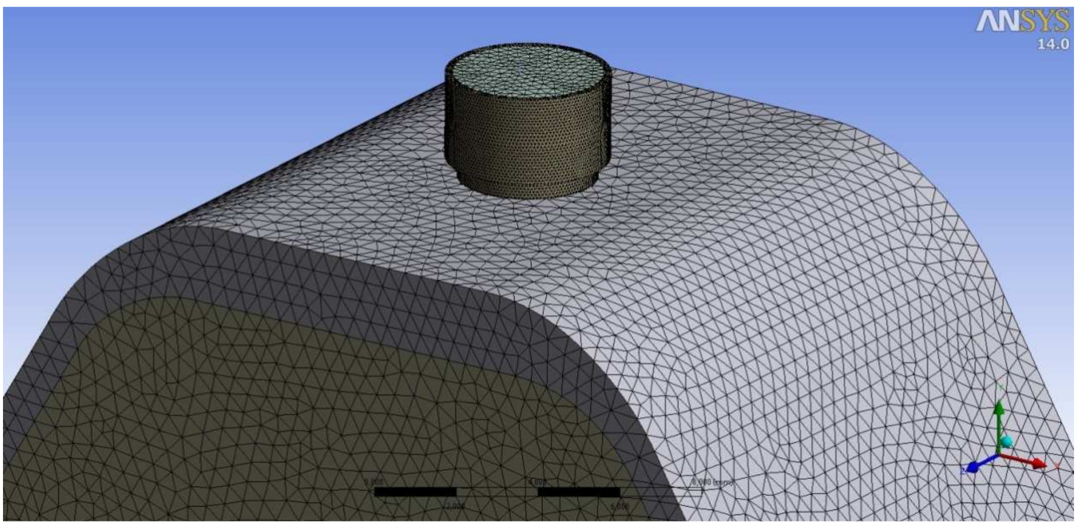

Fig. 3.Finite element model of bone-implant with HA coating

RESULTS AND DISCUSSION

Maximum equivalent stress is calculated in the cortical bone for all the four models.The resulted stresses of models I, II, III and IV are 23.9, 22.565, 21.069 and 20.139 MPa for porous titanium and 28.748, 27.681, 27.365 and 26. 024MPa for 80% crystalline HA coated ECAP nanostructure titanium as shown in figure 4.

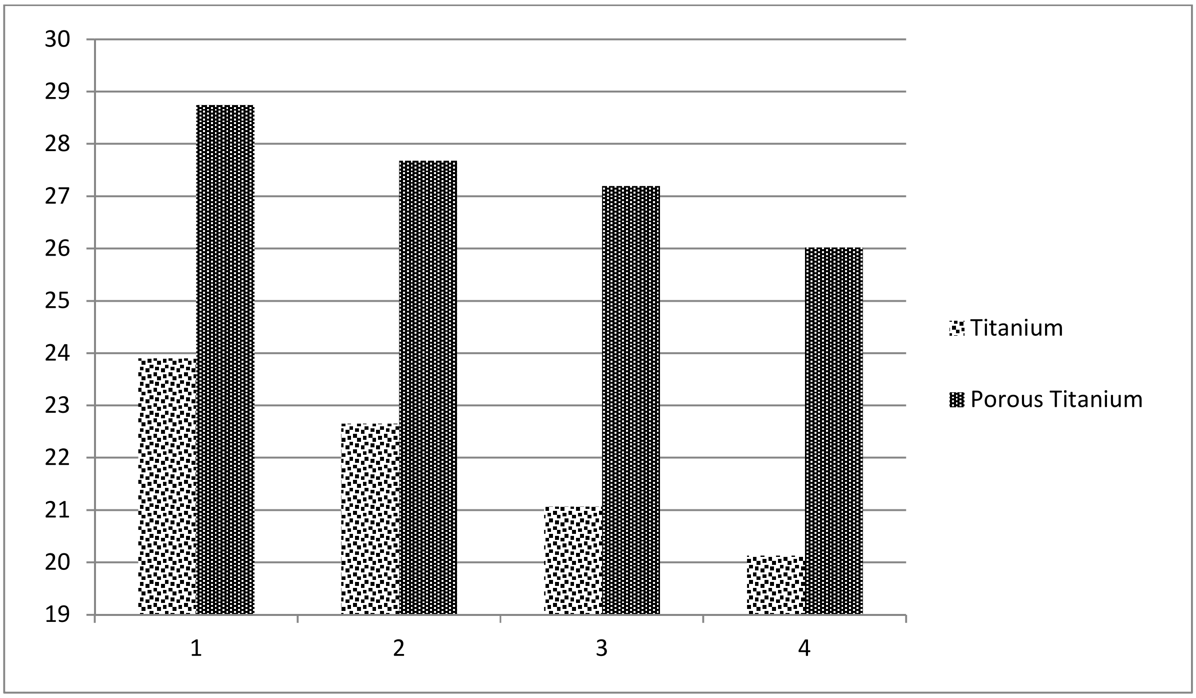

Fig. 4.Analysis results

The maximum equivalent stress in cortical bone occurs adjacent to the implants in the all models. The stress concentration in the cortical bone for the model I which possesses maximum stress among the all models is shown in figure 5.

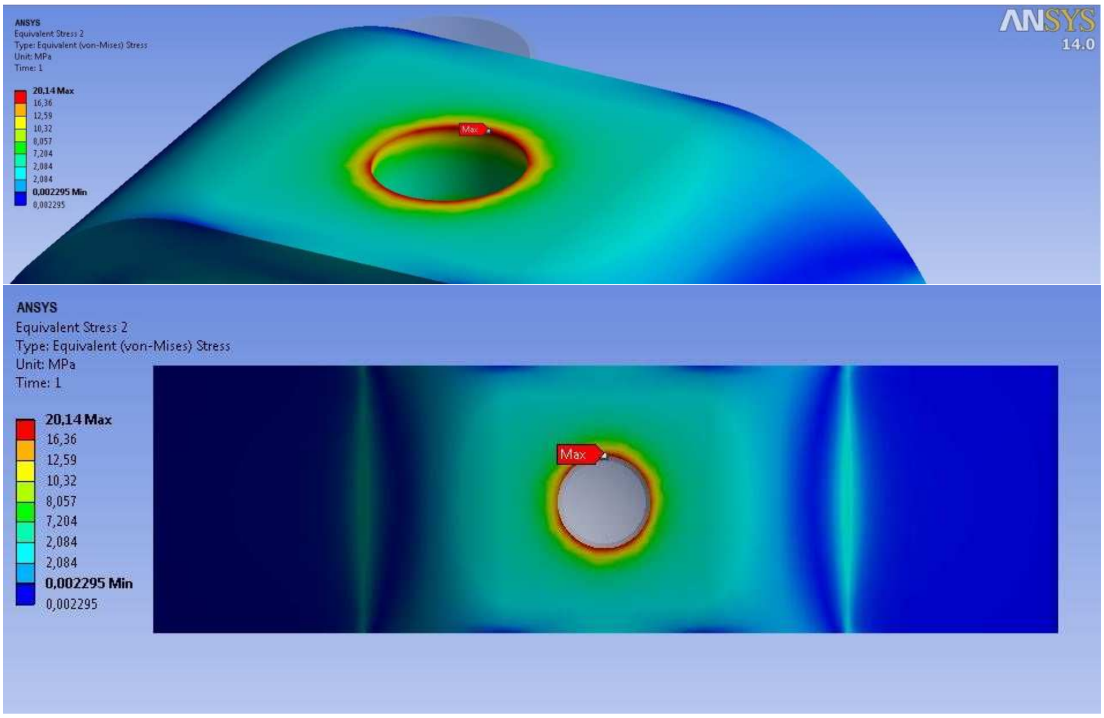

Fig. 5.The stresses in the cortical bone

The paper results indicate that 80% crystalline HA coated ECAP nanostructure titanium has better performance than porous titanium as an implant material due to maximum equivalent bone stress. The comparison of maximum equivalent stress for different models's angles shows that the models with lower angle has lower stresses and the minimum stress belongs to the cylinder model (model IV).

CONCLUSION

A dental implant's life and stability depend on the amount of occurring maximum equivalent stress in the mandible bone. So minimizing the stress is the aim of the study.For the purpose of evaluating the effect of implant models and materials on the maximum stress in cortical bone, FEM analysis has conducted. The results indicate that cylinder 80% crystalline HA coated ECAP nanostructure titanium implant has the minimum stress concentration 20.139MPa.

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