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Structural Analysis of Dental Implants with Various Micro Grove Profiles

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Abstract— *The goal of this research was to determine the effect of changing micro-groove profile on an implant to the stress transfer to surrounding bone. Different types of parametric groove profiles was designed on the cylindrical implant by using Solidworks and Visual Basic. Finite element analysis was carried out on the designed model by applying pullout test conditions. The boundary condition for the finite element model was generated from an in vivo experimental model. The results showed that implant with square groove profile shows better performance than V-shaped grooves for long-term implant stabilization. Such grooving can be engraved in dental implants in order to obtain long-term stabilization of the implant.*

I. Introduction

Dental implants increasingly used to replace missing teeth in a variety of situations ranging from the missing single tooth to complete edentulism [1].Titanium or titanium alloys are the most suitable material choice for dental implants. Screws on the titanium are still the most important application for oral implant applications, first due to their surpassing biocompatibility and their ability to gain osseointegration, i.e., an intimate and direct contact with bone by a cement-free connection at the light-microscopic level [2].

Stress shielding of bone, which is the reduction in bone density because of removal of stress from the bone by the implant is one of the reasons for implant loosening. Implant loosening due to stress shielding has been reported by several researchers. Moussa *et al*. (2017) introduced a novel evolutionary technique to optimizing stem designs in a cemented hip prosthesis with the objective of minimizing stress shielding and cement damage [3].

One of the influential parameters on the bone remodeling surrounding the implant is the surface topography of implants. Gefen (2002) studied the characterization the general screw designs that could minimize stress shielding by allowing similar loads to be shared between the screw and the surrounding bone, and by providing a more uniform stress state within the bone, which is expected to generate the mechanical stimuli for adequate bone modeling and osseointegration. Also stated that finite element computer simulations can be used as a powerful tool for design and evaluation of bone screws, including geometrical features, material characteristics and even coatings [4].

Bozkaya et al. (2004) investigated the effects of external geometry and occlusal load magnitude on bone failure modes for five commercially available dental implant systems with using FEA [5].

Baggi et al. (2004) analyzed the influence of implant diameter and length on stress distribution and to analyze overload risk of clinically evidenced crestal bone loss at the implant neck in mandibular and maxillary molar peri-implant regions. They stated that implant designs, crestal bone geometry, and site of placement affect load transmission mechanisms [6].

Frost (2004) explained that bone carries out functions such as remodeling in the range of 50-1500 microstrain values. Bone losses occur in the presence of strain values below this threshold range and strain values above 3000 microstrains [7]. This response acts in accordance with Wolff's law of functional adaptation. Mechanical stimuli such as stress and strain required for bone remodeling, which does not reach the adjacent bone with the implant, are prevented because of stress shielding effect. If required mechanical stimuli do not reach to surrounding bone, bone loss occurs. This may result in implant loosening [8].

Research showed that, strong influences of groove topography on stress, strain transfer from the implant to bone for initiating the bone remodeling process. However, the effects of groove dimensions and shapes are not known. Such knowledge is important for finding the suitable groove topography for implants that will provide the optimum biomechanical compatibilities of the implants. In this study, we aimed to develop a finite element model to quantify the mechanical stimuli (the maximum equivalent strain and stress due to grooving) to the bone adjacent to titanium alloy (Ti-6Al-4V Eli) due to the presence of microgrooves on titanium.

II. FEA Model

A 3D model of the titanium and bone was generated in Solidworks 2013 based on Khandaker *et al*. [9] *in vivo* animal model. Two different microgroove profiles were designed as square and V-shaped (Fig. 1).

The created CAD model was imported to ANSYS Workbench for static structural finite element analysis. To carry out FEA, material properties and boundary conditions were defined. For describing bone material properties, linear elastic and homogeneous isotropic material models are used. Titanium alloys properties were chosen from the datasheet of Ti-6Al-4V ELI. The material properties for titanium and bone were shown in table I.

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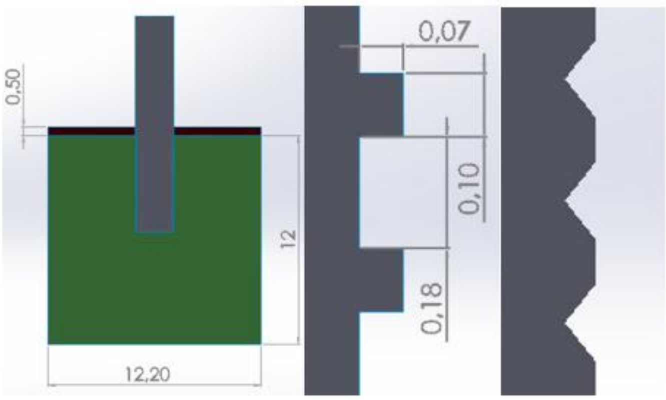
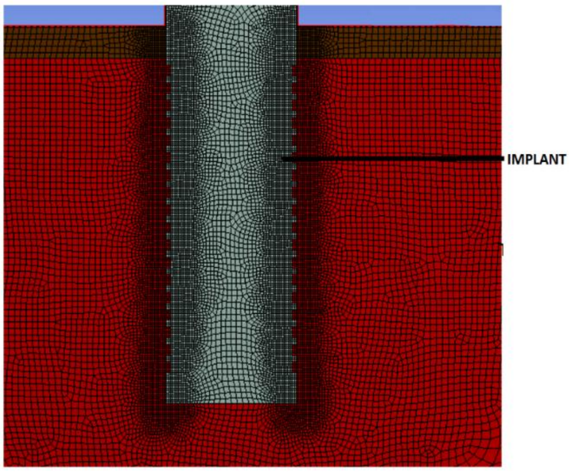


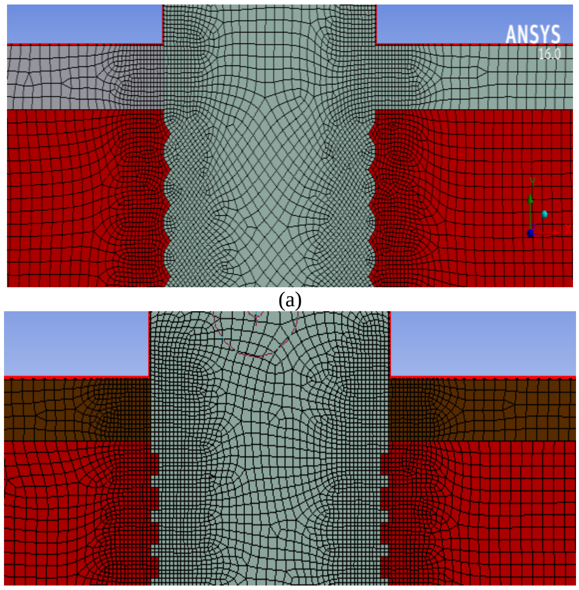
Fig. 1. Ti/bone sample model and two different microgroove profiles.

TABLE I. Material properties for titanium/bone model.

	Titanium	Cortical	Trabecular
Young Modulus (GPa)	116	3.3	71
Poisson's Ratio	0.32	0.35	0.35
Shear Modulus (GPa)	43.9	7.4	0.37

After assigned material properties for each geometry, suitable mesh structure and size were determined for geometry. The quadrilateral dominant element type assigned for each geometry. While the element size is determined, attention paid to ensure that the results are independent of the mesh structure. Ti/bone samples meshed with element body size of 0.1 mm element size. All of the surfaces on implant-bone interface meshed with a 0.035 mm by using local element size, since there were many sharp discontinuities that could induce an unrealistically high-stress concentration. Using the aspect ratio and element quality checks, all elements were within acceptable limits, thus increasing the accuracy of the results. An average number of elements and nodes was 19677 and 60539 respectively (Fig. 2). Type of finite element structure, a number of elements boundary conditions kept constant for increasing accuracy of results.





(a)

(b)

Fig. 2. FEA model of Ti/bone sample (a) V shaped (b) squared shaped.

Deformation of Ti rod at Z axis was applied in the FEA model, which is the experimental displacement of Ti rod break from the bone in the direction normal to the Ti rod top surface (Fig. 3). Von-Misses stress also referred to equivalent tensile stress, is used to check whether the design will withstand a given load condition. Only Z directional displacement allowed for the micro-grooved titanium implant. Bounded contact was defined by bone and implant. The interface between the implant and bone was also set as contact, with frictional coefficients for the surface contacts of the rough implant surface with the adjoing bone for the prediction of frictional coefficient [10]. This study used maximum equivalent Von-Misses strain in order to evaluate the effect of microgrooves profile on stress shielding to the bone due to the fact that bone density in the pressure exposed side of the bone is higher than the tensile exposed side of bone [11]. This situation is compatible with the strain distribution which was taken in the adjacent bone with the first groove region.

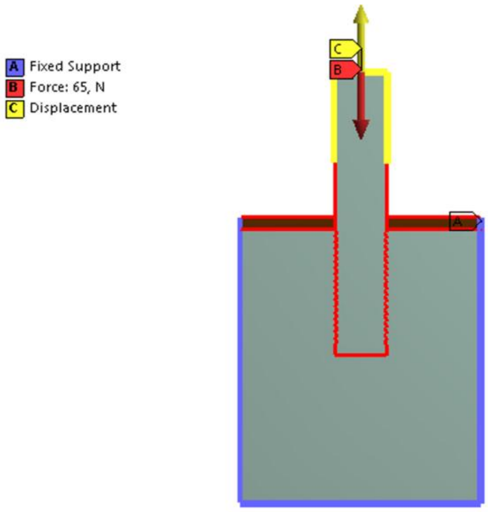


Fig. 3. Boundary conditions of the FEA model.

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III. Results and Discussions

According to FEA results, a significant increase in stress value is observed along the length of the implant-bone interface. The stress values around the implant can be explained by the contact between the two different material surfaces. Higher equivalent Von-Misses stress was observed along the edges of the microgrooves.

It was proved that high-stress concentration region occurs in the first thread of all screw design. This was consistent with most clinical failures in which the screw was broken. In this study, it was observed that increasing of equivalent stress concentration on the first groove under the pullout boundary condition. In this region, the value of 103.97 MPa as maximum equivalent stress was obtained in square profile. This value of V-shaped implant is 107.72 MPa in the first groove.

As shown Fig. 4 and Fig. 5, implant contains higher stress concentration than surrounding bone of implant. This proves the existence of stress shielding. However, stress distribution in the surrounding bone varies depending on the change of the microgroove profile. In addition, variation of local strain distributions around the adjacent bone of the first groove was observed for square type and V-shaped microgrooves on the implant (Fig. 6).

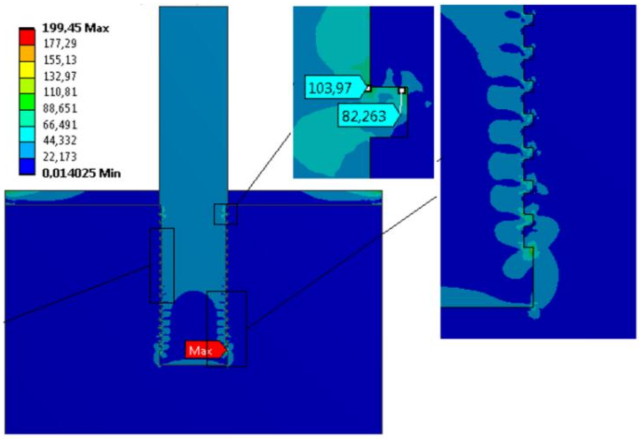

Fig. 4. Stress distributions at the implant/bone interface and local stress distribution around first thread for square type of the microgroove.

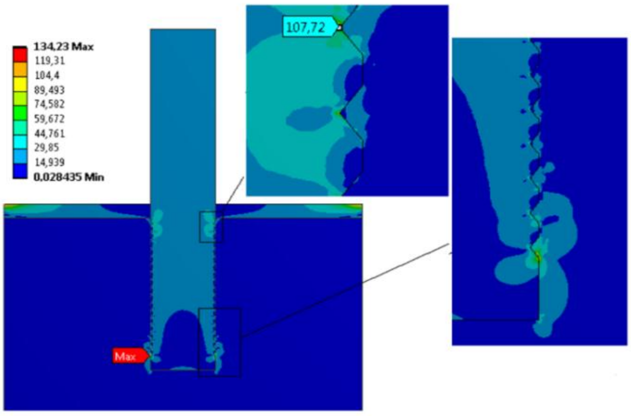

Fig. 5. Stress distributions at the implant/bone interface and local stress distribution around first thread for V-shaped type of the microgroove.

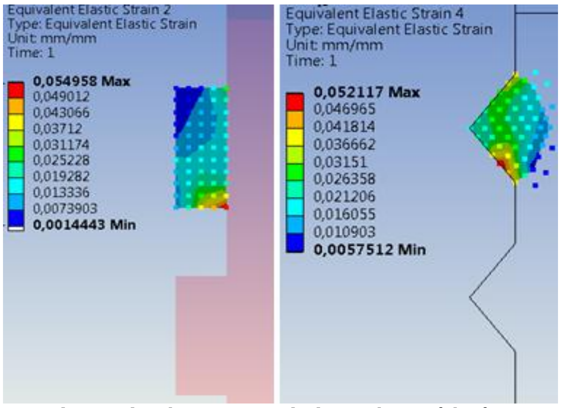

Fig. 6. Local strain distributions around adjacent bone of the first groove for square type and V-shaped of the microgroove.

IV. Conclusion

This study evaluated numerically the effect of surface modification for the V-shaped and square type of the microgrooves on a titanium implant to the load transfer characteristics from the implant to the bone for examining Von-Misses stress distribution. In the first groove region, an implant with V-shaped microgroove profile has 3.5% higher maximum equivalent stress value than an implant with the square groove profile (Fig. 7).

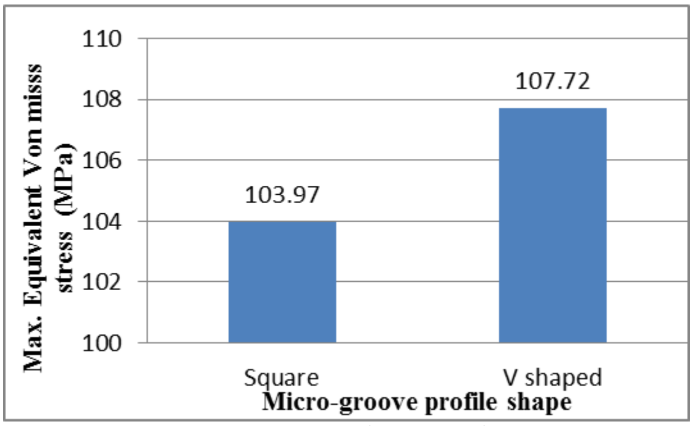

Fig. 7. Maximum equivalent stress in the first groove of V-shaped and square micro groove profiles.

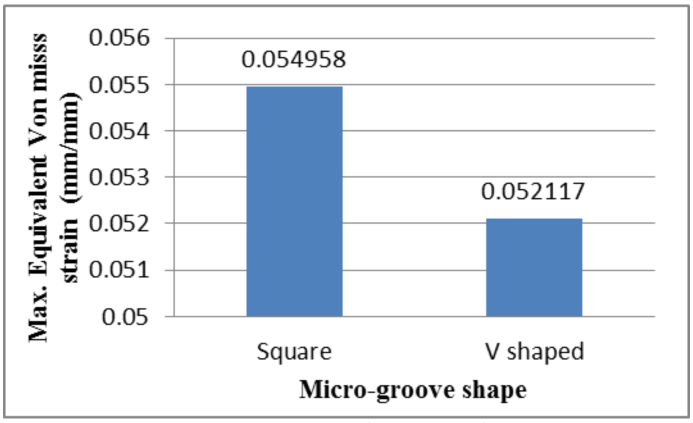

Fig. 8. Maximum equivalent strain in the first groove of V-shaped and square micro groove profiles.

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When maximum equivalent stress value in the bone as mechanical stimuli for predicting bone remodeling and effect of stress shielding used, square profile 5.6 % decreased the effect of stress shielding according to V-shaped profile in the first thread. In the other word, square profile allow more strain transfer to the surrounding bone (Fig. 8).

Implant with square profile allows obtaining less maximum equivalent Von-Misses stress and more strain transfer to the surrounding bone in order to fix microdamage than V profile on the first groove region. In conclusion, the square profile shows better performance than a V-shaped implant.

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