Journal of
Periodontology
&
Implant Dentistry

Research Article

Comparative stability analysis of two types of CpTi and Zr-2.5% Nb implants after maxillofacial surgery

Adel Pirjamalineisiani • Mohsen Sarafbidabad*

Department of Biomedical Engineering, Faculty of Engineering, University of Isfahan, Isfahan, Iran
*Corresponding Author; E-mail: moh_sarraf@yahoo.com

Received: 26 July 2016; Accepted: 20 November 2016
J Periodontal Implant Dent 2016;8(2):49–54 | doi:10.15171/jpid.2016.009
This article is available from: http://dentistry.tbzmed.ac.ir/jpid

Abstract

Background. Improving the implantation conditions in order to reduce the failure is always desirable for researchers. The aim of this study was to compare two different types of dental implant materials from biomechnical viewpoint in order to introduce a novel simulation method to select suitable materials for dental implants.

Methods. In this research, drilling process was performed in the cortical bone of the mandible by finite element analysis simulation. Then, a 3D model of the produced hole in the drilled site was derived and a dental implant model by ITI design was inserted into the cavity. The space remaining between the implant and cavity was considered as a newly formed cortical bone area. Implant loading was performed on two dental implants with different types of material. The change in the volume of the cortical bone around each implant was considered a criterion for evaluating bone damage. Additionally, the micromotion of dental implant in the mandible after implantation was used for investigating dental implant stability.

Results. After implant loading, the volume changes in newly formed cortical bone around Ti and Zr-2.5%Nb dental implants were measured at 0.010809 and 0.010996 mm^3, respectively. Furthermore, micromotion of Ti and Zr-2.5%Nb dental implants were measured at 0.00514 and 0.00538 mm, respectively.

Conclusion. This study showed that Ti dental implant creates better conditions than Zr-2.5%Nb dental implant in the maxillofacial region.

Key words: **Dental implant, mandible, finite element analysis, drilling operation.**

Introduction

Development of a desirable alternative for lost teeth has been an essential goal for dentists for many centuries.[1] After many years, implants became a suitable replacement for original teeth.[2] Although implantation helps patients live normally, some drawbacks exist during and after implantation process for some biological and physicochemical reasons.[3] The failure cases such as bone degradation occur due to surgical trauma or bacterial invasion or high stresses on implant–bone interface.[4] Failures in implantation indicate that further information is needed on stress–strain distribution in the adjacent bone and also implant stability.[5] Osseointegration is a mechanism in which an implant is accepted by the host bone tissue biomechanically.[1] As shown in many clinical researches, implants can fail because of bone attenuation or decay around the implants.[6] Mechanical loading on implants is transferred to the newly formed bone around the implants, producing stress and strain in this region, which results in bone structure deformation.[7] Some effective parameters of implants, prosthesis material, implant surface structure and property of bone–implant interfaces have significant roles in the transfer of force to implant–bone interfaces.[8] Different materials like metals, ceramics and polymers are used to manufacture implants. Titanium is one of the metals used vastly for the manufacture of implants due to its stability, biocompatibility and mechanical properties.[9,10] Additionally, some metallic alloys such as stainless steel, Co-Cr alloys, gold and tantalum alloys are metals used to this end.[10] In this research, the effect oftwo types of implant made of pure titanium and zirconium-2.5 niobium on reconstructed area of cortical bone in the mandible was investigated by a practical test and calculation of percentage of bone formation after six weeks. After that, the effect of each implant on the general stability in newly grown cortical bone after 6 weeks was studied by finite element analysis.

Methods

This research consisted ofone practical and two simulation sections. In the practical section, Young's modulus of newly grown cortical bone around two different implants was calculated after 6 weeks based on the percentage of bone formation. The simulation section consisted of two stages. The first stage was drilling of the cortical bone of the jaw to achieve cavity geometry and second was implantation and loading on it, followed by investigation of the parameters applied in this process.

The first section

Young's modulus calculation for newly formed cortical bone around Ti and Zr-2.5%Nb implants after 6 weeks

An in vivo animal model was used for measuring the density of the newly formed bone. The animal model was a 2-year-old hybrid dog. Six weeks after implantation, the samples were separated from the sacrificed dog's jaw, and the percentages of the newly grown bone around the implants were determined by histomorphometry. The percentages of newly formed bone around Ti and Zr-2.5%Nb implants were estimated at 39.5% and 38.5%, respectively. In the second part of this research it was supposed that the percentage of newly grown bone density around implants relative to 100% formed bone is equivalent to thevalues in the first part. The 100% formed cortical bone density was 2.1 g/cm^3[3,11] and its Young's modulus was 13.7 GPa.[1] The relation between the density and Young's modulus is shown in Equation 1.[12]

$\mathbf{E \sim \rho^3}$ Equation 1

By supposing 39.5% bone formation around Ti implant and 38.5% around of Zr-2.5%Nb implant, newly formed cortical bone density around them were 0.8295 and 0.8085 g/cm^3, respectively. By using equation1and making a relation between the density values and Young's modulus of 100% bone formation, Young's modulus of the newly grown bone around Ti and Zr-2.5%Nb implants were 0.844 and 0.781 GPa, respectively.

The second section

The first stage: Bone drilling

Modeling: At first, a 3D-model from the cortical bone of the mandible was designed by Catia software and then the desirable model was imported into Deform 3D software. The thickness of the cortical bone of the mandible in this model was supposed to be 2 mm, which has been measured for the end part of the mandible in a previous research.[13] For modeling of the drill bit, Deform 3D part design was used. The diameter of the designed drill bit for this simulation is 3.5 mm, the rotation speed is 400 rpm and the feed rate is 60 mm/min.

Determination of cortical bone material for drilling: For cortical bone drilling, the stress–strain curve of human cortical bone in various strain rates wasrequired. According to Figure 1, the relevant data[14] were imported to Deform-3D software. In order to simulate drilling, the state of cortical bone and drill bit model were supposed to be elasto-plastic[15] and rigid, respectively. The number of elements relating to cortical bone model was 22316 and the number of nodes was 14431. In this model the size of meshes in drilled area was supposed to be 0.2 $\leq$ mm. The fix boundary condition was supposed for outer surfaces of jawbone model except for the upper surface on which the drill bit was placed. After drilling the cortical bone of the jaw model, the 3D design of the created hole was derived by Boolean operation in Deform-3D software to be used in the second stage of the research (Figure 2).

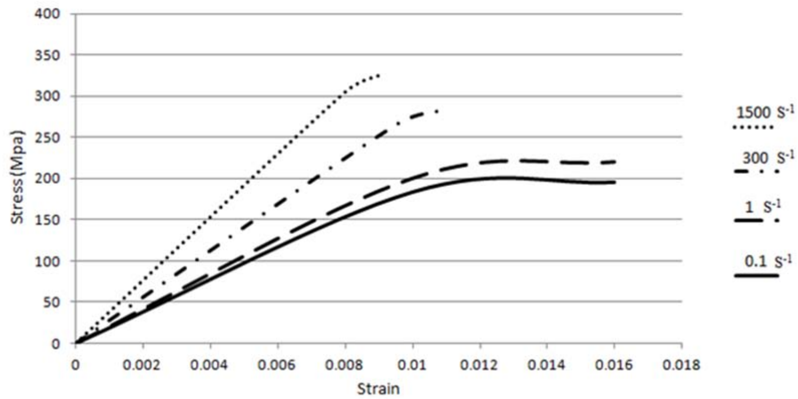

Figure 1. The stress–strain diagram of human's cortical bone in different strain rates.

The second stage: Implantation in the jawbone and applying load on implant

Modeling: The modelsused in this part consisted of drilled cortical bone model, the geometrically derived models from the inside of the hole, obtained from the first part of simulation, acancellous part of the jawbone model and a standard implant model. The model of cancellous jawbone in maxilla was drawn by Catia software and placed withinthe jaw cortical bone. An ITI standard implant (Institute Straumann AG, Waldenburg, Switzerland) with a diameter of 3.3 mm was designed by Catia software using data from a previous research.[6] The designed implant model was placed within the jawbone. Using Boolean operation in Deform-3D software the place of the implant and its treated surface were cut within the cancellous bone and also the geometric model was derived from the interior cavity form (Figure 3). Figure 3 (C) indicates the model of newly grown cortical bone around the implant. The diameter of the implant designed in this research was 3.3 mm, whereas the diameter of the cavity drilled in first part was 3.5 mm. In fact, the aim of this design was to achieve a model of newly grown cortical bone around implant with a minimum thickness of 0.1 mm. In other words, the thickness of the newly formed bone around the thread tip of the implant was about 0.1 mm and between the threads it was about 0.3 mm.

Material determination: For implant loading simulation, each model was supposed to be elastic and implant materials were Ti and Zr-2.5%Nb. Young's modulus and Poisson's ratio relating to each modelused in this part are presented in Table 1. The size of elements in areas adjacent to implant and bone is approximately 0.1 mm which is smaller than other areas. The total numbers of elements for implant, drilled cortical bone, cancellous bone and newly grown cortical bone model were 46916, 18827, 61253 and 14652, respectively, and the numbers of nodes were 11016, 4608, 1354 and 37950, respectively. After placing the models in proper places,

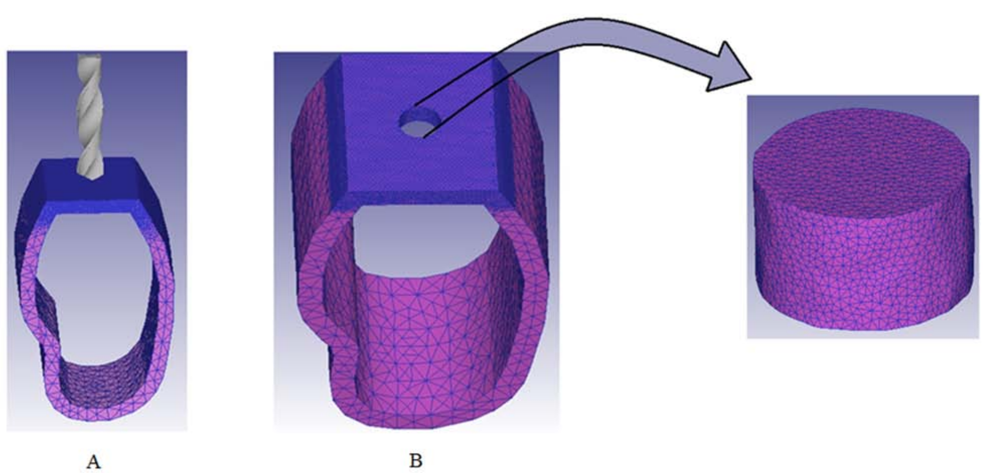

Figure 2. A) Insertion of drill bit on the cortical bone of the jaw; B) The cavity created on the cortical bone of the jaw and extracting the 3D geometry of the cavity by Boolean operation.

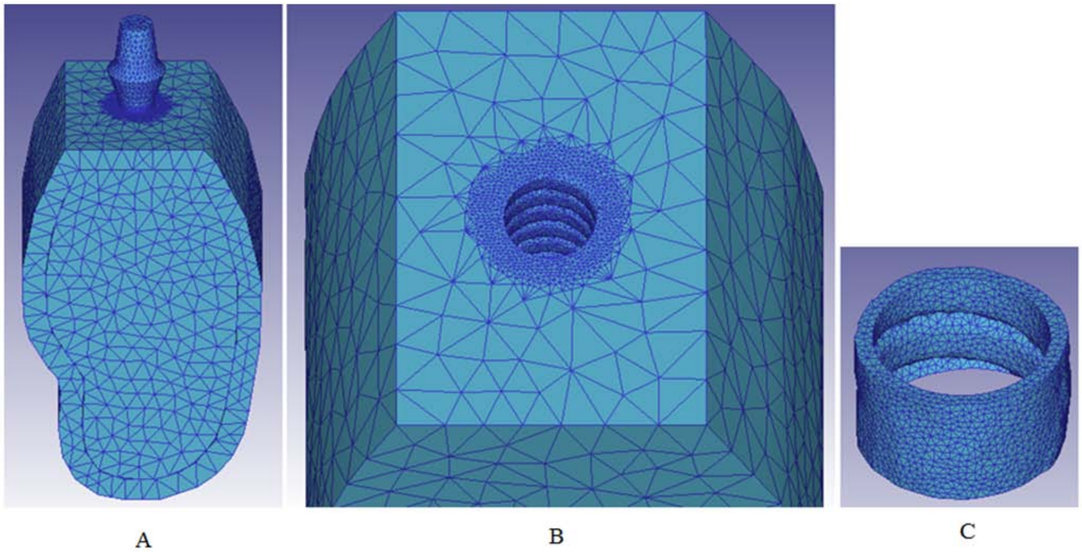

Figure 3. A) ITI implant model inserted into the jawbone; B) Extraction ofimplant geometry from the cancellous bone of the jaw by Boolean operation; C) Extraction of implant geometry from the 3D cavity created on the cortical bone of the jaw by Boolean operation.

meshing them and specifying the suitable material for each one, the stick boundary condition was supposed for adjacent models. A 100-N vertical loading was applied on the upper surface of implants. All the models entered into the Deform-3D software were in the STL format and all these simulations were performed in a system with 8192 MB RAM, Intel® Core™ i7-3770 CPU.

Results

After these simulations the volume change in newly formed cortical bone model around each implant was achieved as a criterion to compare the bone defect around the implants. Displacement of each implant was measured as a criterion for stability of each implant in the jawbone. In relation to volume change in the bone model around each implant, the first volume of newly grown cortical bone was measured at 4.537818 mm^3. After application of 100-N vertical loading over two different implants, the volume of newly formed cortical bone around Ti and Zr-2.5%Nb implants reached 4.527009 and 4.526822 mm^3, respectively. Therefore, the volume changesafter loading for new cortical bone around Ti and Zr-2.5%Nb implants were 0.010809 and 0.010996 mm^3, respectively. Furthermore, the maximum amount of displacement for Ti and Zr-2.5%Nb implants were 0.00514 and 0.00538 mm, respectively (Figure 4).

Discussion

Several studies have been performed on different parameters related to implantation and their effect on the bone surrounding implants after loading. A study in this field evaluated the effect of cortical bone density and its thickness on emerged stress in cortical bone after loading the implant. In that study, Guan et al[1] proved that increasing Young's modulus increases stresses in bone. Different studies have shown that decreasing the cortical bone thickness increases stress in the cortical bone.[1,17] The relation between bone density and Young's modulus has been studied in various researches.[1,18] The results have shown that an increase in bone density, increases Young's modulus. Additionally, different studies have shown that a decreasein bone density will increase the strain in bone.[5] In the current study, two different types of materials were used for dental implants in order to investigate mechanical properties of implants and newly grown cortical bone around them. The results of the practical test 6 weeks after implantation

Table 1. Mechanical properties of materials related to each modelin the second simulation part

Material	Young's modulus (Gpa)	Poisson's ratio	Reference
Pure titanium	114	0.34	[6]
Zr-2.5%Nb	97.9	0.33	[16]
Cortical bone	13.7	0.3	[6]
Cancellous bone	1	0.3	[6]
Newly-formed cortical bone around Ti implant	0.844	0.3	Examined
Newly-formed cortical bone around Zr-2.5%Nb implant	0.781	0.3	Examined

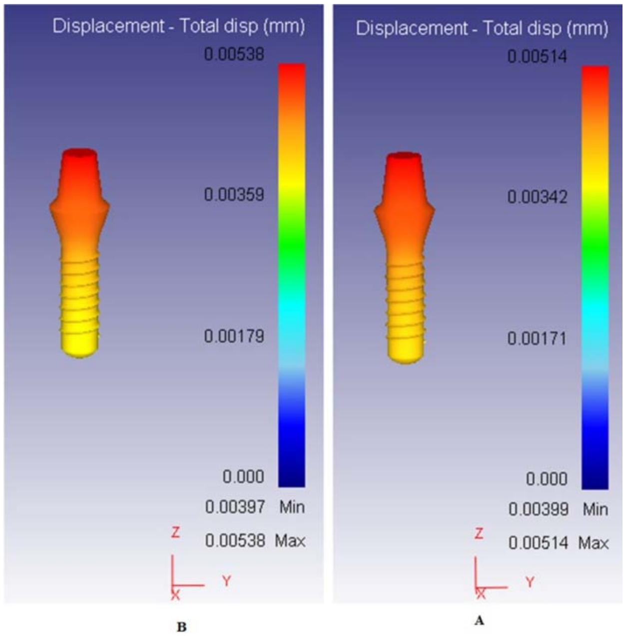

Figure 4. The schematic distribution of displacement in: A) Ti implant, B) Zr-2.5%Nb implant.

showed that the cortical bone density around Ti implant was higher than that around Zr-2.5%Nb. In other words, the rate of bone formation around the implant made of Ti is more than that formed around Zr-2.5%Nb. In the next stage, the simulation of implant loading process was performed 6 weeks after implantation. The volume change in the surrounding bone was considered as a criterion to compare bone damage that each implant inflicted on its surrounding bone. The results showed that Ti implants resulted in less volume changesin the newly formed cortical bone around it in comparison with the Zr-2.5%Nb implants. In addition, the displacement of each implant in the jawbone after loading was measured to investigate the stability of each implant in the bone.

Conclusions

The results of the current study showed that using Ti dental implants not only inflicted less damage onthe newly formed cortical bone but also resulted in higher stability in the surrounding bone tissue under loading compared to Zr-2.5%Nb dental implants. The results of this study can help dentists select dental implantswith suitable materials. In addition, this research provided a novel simulation method to predict the behavior of dental implants from biomechanical aspects for each material of dental implants.

Acknowledgments

The authors would like to acknowledge the Faculty of Engineering staff members and technicians in the University of Isfahan for scientific consultation and assistance.

References

1. Guan H, Van Staden R, Loo Y-C, Johnson N, Ivanovski S, Meredith N. Influence of bone and dental implant parameters on stress distribution in the mandible: a finite element study. Int J Oral Maxillofac Implants2008;24:866-876. doi: 10.1007/s00707-010-0409-3
2. Lee C-C, Lin S-C, Kang M-J, Wu S-W, Fu P-Y. Effects of implant threads on the contact area and stress distribution of marginal bone. J Dent Sci2010;5:156-165. doi: 10.1016/s1991-7902(10)60023-2
3. VerriFR, de Souza Batista VE, Santiago JF, de Faria Almeida DA, Pellizzer EP. Effect of crown-to-implant ratio on peri-implant stress: A finite element analysis. Mat SciEngC2014;45:234-240. doi: 10.1016/j.msec.2014.09.005
4. Baggi L, Cappelloni I, Di Girolamo M, Maceri F, Vairo G. The influence of implant diameter and length on stress distribution of osseointegrated implants related to crestal bone geometry: a three-dimensional finite element analysis. J Prosthet Dent2008;100:422-431. doi: 10.1016/s0022-3913(08)60259-0
5. Marcián P, Borák L, Valášek J, Kaiser J, Florian Z, Wolff J. Finite element analysis of dental implant loading on atrophic and non-atrophic cancellous and cortical mandibular bone–a feasibility study. J Biomech2014;47:3830-3836. doi: 10.1016/j.jbiomech.2014.10.019
6. Baggi L, Cappelloni I, Maceri F, Vairo G. Stress-based performance evaluation of osseointegrated dental implants by finite-element simulation. Simul Model PractTh2008;16:971-987. doi: 10.1016/j.simpat.2008.05.009
7. Himmlova L , DostálováTj, Kácovský A , Konvičková S. Influence of implant length and diameter on stress distribution: a finite element analysis. J Prosthet Dent2004;91:20-25. doi: 10.1016/j.prosdent.2003.08.008
8. Rismanchian M, Birang R, Shahmoradi M, Talebi H, Zare RJ. Developing a new dental implant design and comparing its biomechanical features with four designs. Dent Res J2010;7:70. doi: 10.4103/1735-3327.92961
9. Chang CL, Chen CS, Huang CH, Hsu ML. Finite element analysis of the dental implant using a topology optimization method. Med Eng Phys2012;34:999-1008. doi: 10.1016/j.medengphy.2012.06.004
10. Osman RB, Swain MV. A critical review of dental implant materials with an emphasis on titanium versus zirconia. Materials2015;8:932-958. doi: 10.3390/ma8030932
11. Li T, Hu K, Cheng L, et al. Optimum selection of the dental implant diameter and length in the posterior mandible with poor bone quality–A 3D finite element analysis. Appl Math Model2011;35:446-456. doi: 10.1016/j.apm.2010.07.008
12. Natali AN. Dental biomechanics: CRC Press; 2003. doi: 10.1201/9780203514849
13. Schwartz-Dabney CL, Dechow PC. Edentulation Alters Material Properties of Cortical Bone in the Human Mandible. J Dent Res2002;81:613-617. doi: 10.1177/154405910208100907
14. Johnson T, Socrate S, Boyce M. A viscoelastic, viscoplastic model of cortical bone valid at low and high strain rates. Actabiomaterialia2010;6:4073-4080. doi: 10.1016/j.actbio.2010.04.017
15. Lughmani WA, Bouazza-Marouf K, Ashcroft I. Finite element modeling and experimentation of bone drilling forces.

Paper presented at: J Phys: Conference Series2013. doi: 10.1088/1742-6596/451/1/012034

16. Webster RT, Albany TWC. Properties and Selection: Non-ferrous Alloys and Special- Purpose Materials. ASM Handbook. Vol 2: ASM International; 1990:9. doi: 10.1016/0142-1123(91)90190-a
17. Okumura N, Stegaroiu R, Kitamura E, Kurokawa K, Nomura S. Influence of maxillary cortical bone thickness, implant design and implant diameter on stress around implants: a three-dimensional finite element analysis. J Prosthodont Res2010; 54:133-142. doi: 10.1016/j.jpor.2009.12.004
18. Natali C, Ingle P, Dowell J. Orthopaedic bone drills-can they be improved? Temperature changes near the drilling face. J Bone Joint Surg Br 1996;78:357-362. doi: 10.2106/jbjs.ses.l.00545