Biomechanical comparison of different materials (commercial pure Titanium versus Titanium-Zirconium alloy) of dental implants

Aaron Yu-Jen Wu
Department of Dentistry, Chang Gung Memorial Hospital, Chang Gung University College of Medicine, 123, Ta-Pei Road, Niao-Sung, Kaohsiung 83305, Taiwan.
aaronyujen.wu@gmail.com

Yun-Te Lin
School of Dentistry, China Medical University. No.91 Hsueh-Shih Road, Taichung 40402, Taiwan
a7989929@yahoo.com.tw

Jui-Ting Hsu
School of Dentistry, China Medical University. No.91 Hsueh-Shih Road, Taichung 40402, Taiwan
jthsu@mail.cmu.edu.tw

Heng-Li Huang
School of Dentistry, China Medical University. No.91 Hsueh-Shih Road, Taichung 40402, Taiwan
henleyh@hotmail.com.tw

The corresponding author: Heng-Li Huang

Abstract

Recently Titanium-Zirconium (Ti–Zr) implant has been recommended for the use of dental implants; however, until now no study has analyzed the biomechanical effects of this new implant. In this research, the bone strains around the Ti–Zr implants have been evaluated as compared to those of pure Ti implants. By finite element analysis (FEA) and in-vitro experimental strain gauge test, two implant materials (Ti–Zr alloy and pure Ti) were tested to measure the peri-implant bone strain as the important index related to the possibility of overloading bone loss. For loading conditions both the force of 130 N applied vertically were tested at FEA and *in-vitro* experimental test. The statistically analysis were also used to evaluate the results of *in-vitro* test. The results of the strain gauge test show that the principle strain values of the Ti–Zr model are 18.11% and 5.12% less than that of the titanium model, For FEA, the maximum/minimum principle strain, and the equivalent stress values of the Ti–Zr model are 4.37%, 1.46%, and 0.88% less than that of the Ti model respectively. The conclusion can be drawn that Ti–Zr dental implants decrease strains at bone more than Ti implant at both vertical loading and lateral loading conditions.

Keyword: Titanium zirconium alloy dental implant, finite element analysis, *in-vitro* test, strain gauge, bone strain/stress

Introduction

Titanium zirconium (Ti–Zr) alloys are a new choice for dental implants. Some studies showed that Ti–Zr dental implants have better adaptation than Ti implants have. For example, Ti–Zr implants have higher stability, similar osteoconductive properties, and more bone areas with in the chamber than Ti implants do, as indicated from a study in mini pigs [1]. Some studies describe properties about Ti–Zr alloys. A Ti–Zr alloy, which is harder than pure titanium, could provide a base material for a new biomedical alloy [2]. In addition, Ti–Zr alloys with HA/TiO2 coatings display excellent bone-like apatite-forming ability when soaked in simulated body fluid [3]. Although these studies provide a rough view of Ti–Zr alloys, case reports and research about Ti–Zr dental implants are still limited. Therefore, the purpose of this study is to investigate the biomechanical effect of Ti–Zr dental implants especially focusing on the bone stress/strain values.

Materials and Methods

Both experimental methods—finite element simulation and in-vitro strain gauge test are conducted in this study. For the strain gauge test, there are three experimental bone models used for each material. For the numerical finite element simulation, models with different material properties (Ti–Zr and Ti) of implants were applied. The study checks the data from both the in-vitro and FE tests to see if the results reach a good agreement. Biomechanical effects of Ti–Zr and Ti on bone stress/strain are also compared so that the difference between these two materials may be observed. Based on the result, the study is trying to prove the hypothesis: Ti–Zr dental implants have good biomechanical properties.

The strain gauge test

Preparation for experimental models:

A few of experimental artificial jawbone models (Sawbones Pacific Research Laboratory Inc., WA, USA) are bought for the studies, and these models contain a cortical part (4*2.5*0.25 cm, Sawbones, model 3401-1) and a trabecular part(4*2.5*3.75 cm, Sawbones, model 1522-05). The mechanical properties of artificial jawbones are similar to human mandibles although their configurations are different. 5*13 mm of the commercially available Ti (SLActive, Institut Straumann AG, Basel, Switzerland) and Ti–Zr (Roxolid, Institut Straumann AG, Basel, Switzerland) implants were placed at the level of the crest cortical bone. With the help of a dentist, all the bone models were drilled appropriately and the implants were inserted and the abutments were used for the connection to the implant.

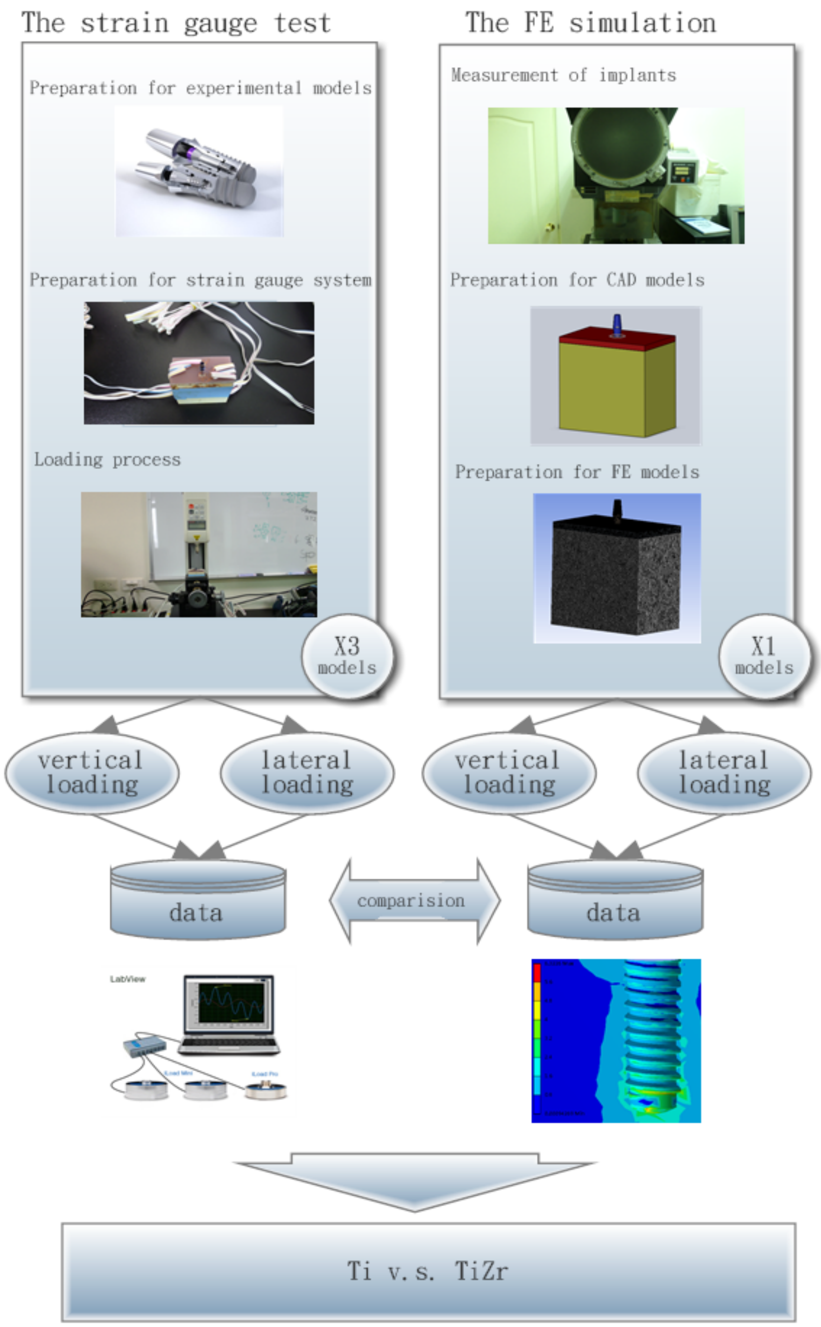

Fig1. The flowchart of this study.

Preparation for strain gauge system:

Strain gauge signal process related to the three independent strains εa, εb, εc measured by the three gauges comprising the rosette strain gauge were sent to the data acquisition system (Compack Daq, National Instrument, TX, USA) and analysed by the associated software (LabView SignalExpress, National Instruments). Each measurement was repeated three times. The maximum (εmax) and minimum (εmin) principle strains were obtained [4]

The rosette strain gauges (KFG-1-120-D17-11L3M3S, Kyowa, Tokyo, Japan) (1mm in length and 1.5 mm in width) were attached to the buccal and lingual sides of the crestal region of cortical shell around the implant by using cyanoacrylate cement (CC-33A, Kyowa). Strains around the cortical bone will be recorded after the loading process.

Loading process:

Each loading procedure involved applying a force of 190N to the abutment using a universal testing machine (JSV-H1000, Japan Instrumentation System, Nara, Japan) with a head speed of 1mm/min. A vertical force were applied in the experiments, so each model has two kinds of test.

Finite element analysis

Preparation for FE models and convergence analysis:

This study uses computer-aided design software (SolidWorks 2007, SolidWorks Corporation, MA, USA) to construct a model of a bone block and a implant. After obtaining all of the models by applying Boolean operations to the variables, the corresponding solid models were exported from the CAD software to the commercial FE software ANSYS workbench 10.0 (Swanson Analysis Inc., Huston, PA, USA) to generate FE models. The interfacial condition between the implant and the cortical part of a bone block was set with a frictional coefficient of 0.45 for the cortical part, and 0.83 for the trabecular part. The contact areas among the implant, abutment, and screw were set with a frictional coefficient of 0.3. The implants and bone blocks were applied with homogeneous and isotropic elastic properties. The bottom of the bone block was fixed as the boundary conditions. The loading condition was applied on the top surface of the abutment. A vertical force of 190-N was applied as well. The element size was 0.4 mm for the implant and its components and the cortical part of a bone block while the element size for the trabecular part was 0.8 mm. Young's modulus and Poisson's ratio for all the materials [5, 6] are listed in Table 1.

Table 1. The Young's modulus and Poisson's ratio of the materials.

Materials	Young's Modulus (MPa)	Poisson's ratio
cp grade IV Ti	104100	0.3
TiZr	125000	0.3
Cortical bone	16700	0.3
Trabecular bone	759	0.3

Results

The strain gauge test

The maximum principle and minimum principle strains were measured at both buccal and lingual side of the cortical surface of a bone block. This test has three models for each material. Furthermore, each model was tested three times, so each parameter (Ti–Zr or Ti) has nine values which were averaged and rounded off to the second decimal place.

The peak values (Fig. 2) of bone near Ti or Ti–Zr implants occurred at buccal and lingual side. In addition, the bone strain near a Ti implant is higher than that near a TiZr implant (Ti: 682.36/627.69 , Ti–Zr: 558.78/595.52). The peak strain value of bone near a TiZr implant is 18.11% lower than that near a Ti implant at buccal side and 5.12% lower at lingual side.

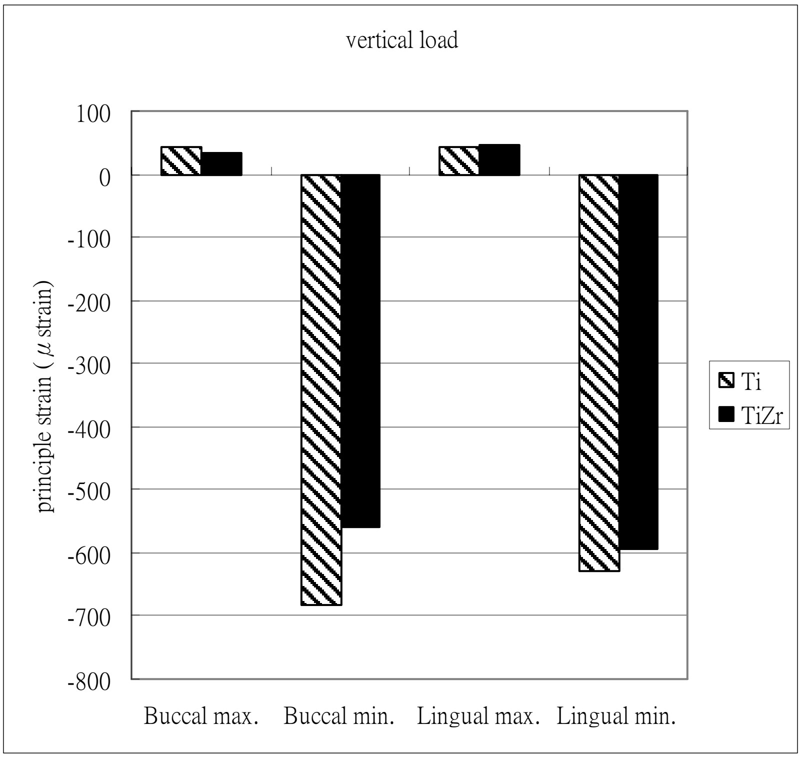

Fig. 2. The peak value of bone strain (unit: micro strain) near the implant in vertical or lateral loading modes.

Finite element analysis

All the peak stress/strain values of bone (Table 3, Fig. 3) around a Ti implant is higher than those around a Ti–Zr implant. The bone strain value of a Ti–Zr model is 4.37% lower for the maximum principle strain, and is 1.46% lower for the minimum principle strain, and is 0.88% lower for the maximum equivalent stress. The strain/stress distributions of bone around the two implant models are similar but the strain/stress concentration area of a Ti implant is slightly larger, as indicated in Fig. 4.

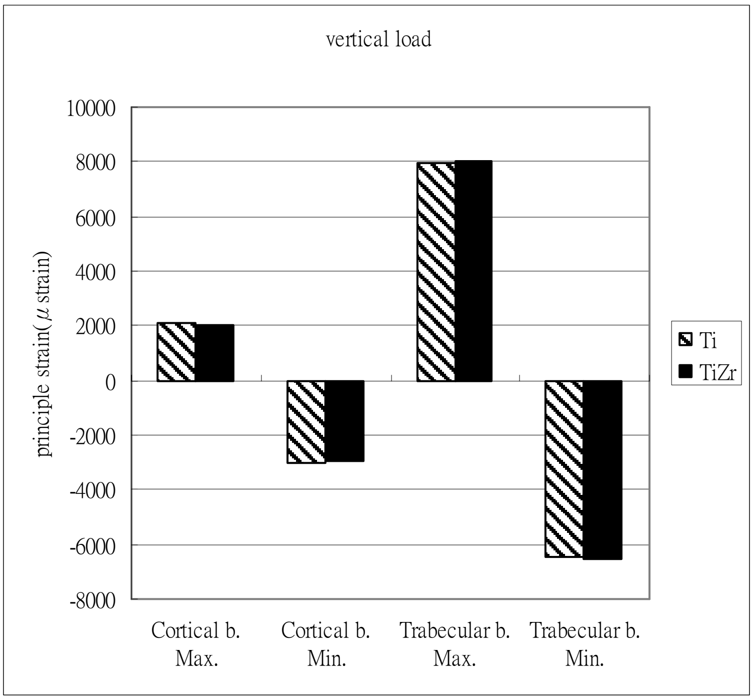

Fig. 3. The peak value of bone strain (unit: micro strain) near Ti and Ti–Zr implants.

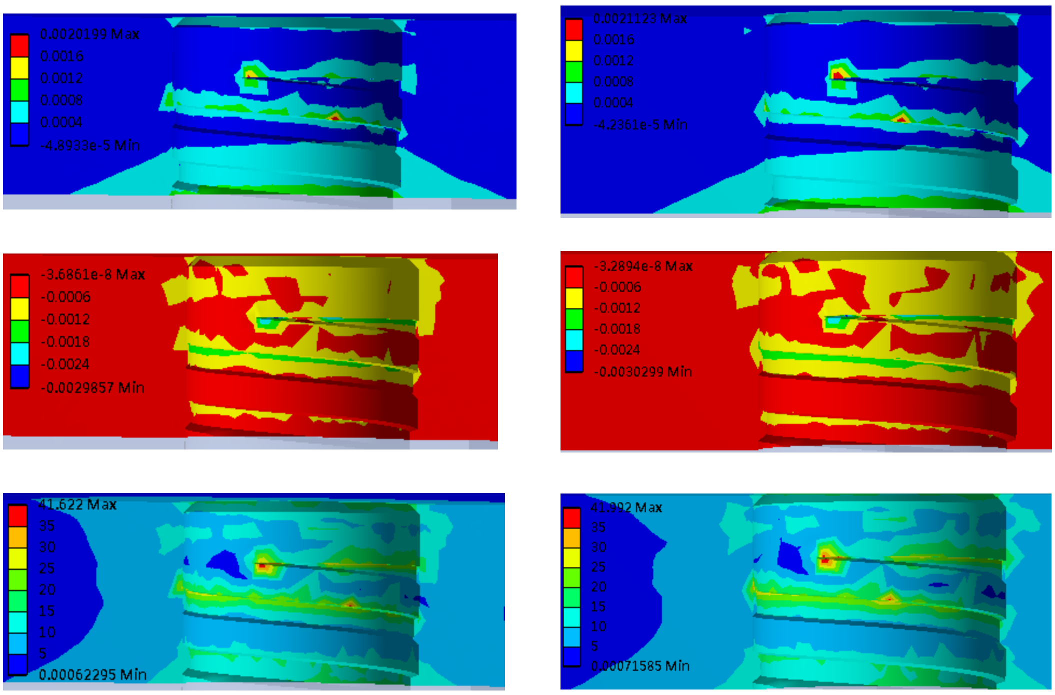

Fig. 4. The maximum/minimum principle strain (top, middle) and maximum equivalent stress (bottom) in cortical bones of Ti–Zr (left) and Ti (right) implants.

Conclusions

A TiZr dental implant is able to reduce the peak strain value around the cortical region of the bone, therefore decrease the possibility of the bone loss due to overloading and indirectly reduce the risk of failure in an dental implant surgery.

Acknowledgement

This study was supported by a grant (NSC 101-2314-B-039-022-MY3) (NSC 100-2815-C-039-032-B) from the National Science Council, Taiwan, and partly, by a research project (CMRPG8A0761) from Chang Gung Memorial Hospital, Taiwan.

References

[1] Gottlow J, Dard M, Kjellson F, Obrecht M, Sennerby L. Evaluation of a New Titanium-Zirconium Dental Implant: A Biomechanical and Histological Comparative Study in the Mini Pig. *Clin. Implant Dent. Relat. Res.*, 2010. [Epub ahead of print]

[2] Kobayashi E, Matsumoto S, Doi H, Yoneyama T, Hamanaka H. Mechanical properties of the binary titanium-zirconium alloys and their potential for biomedical materials. *J. Biomed. Mater. Res.*, 1995, 29(8):943-950.

[3] Wen C E, Xu W, Hu W Y, Hodgson P D. Hydroxyapatite/titania sol–gel coatings on titanium–zirconium alloy for biomedical applications. *Acta Biomater.*, 2007., 3(3):403–410.

[4] Huang H L, Hsu J T, Fuh L J, Lin D J, Chen MYC. Biomechanical simulation of various surface roughnesses and geometric designs on an immediately loaded dental implant. 2010, Comput. Biol. Med., 40(5):525-532.

[5] Niinomi M. Mechanical properties of biomedical titanium alloys. *Mater. Sci. Eng. A*, 1998, 243(1-2): 231-236.

[6] Ho W F, Chen W K, Wu S C, Hsu H C. Structure, mechanical properties, and grindability of dental Ti–Zr alloys. *J. Mater. Sci. Mater. Med.*, 2008, 19(10):3179–3186.