

Effect of Implant Diameter And Alloy on Peri-Implant Strain: An In Vitro Quantitative Strain Analysis

ABSTRACT

This study aimed to evaluate the impact of implant diameter and alloy on peri-implant strains. Three implant types were investigated: regular commercially pure titanium (RcpTi), narrow commercially pure titanium (NcpTi) and narrow titanium-zirconium alloy (NTi-Zr) implants. Strain gauge models were fabricated from epoxy resin. All the implants were loaded in identical fashion. The greatest peri-implant strains were recorded around NTi-Zr implants, followed by NcpTi implants. The RcpTi implants were associated with the least strain values. The difference between the implant types was significant. Therefore, it can be concluded that the implant diameter and material can influence the peri-implant strain magnitude.

INTRODUCTION

Implant placement can be restricted by anatomical boundaries such as reduced bone volume and proximity of adjacent teeth roots. In such situations, narrow diameter implant may become a viable option.¹⁻⁵ However, narrow diameter implants can be associated with some disadvantages. In comparison to regular implant diameter, the narrow implant has less total area of osseointegration which will result in greater stresses within the peri-implant bone during function. It is thought that increased stress and strain levels beyond the physiological limits can evoke bone resorption. In vitro investigations using finite element analysis (FEA) models have suggested that crestal stress distribution is less favorable for narrow diameter implants,⁶⁻¹⁰ which may induce biological complications. In addition, the reduced implant dimensions may result in a greater risk of technical failures above that seen clinically with regular diameter implants. Given that commercially pure titanium (cpTi) has low modulus of elasticity and tensile strength,¹¹ the narrow implants may be more prone to mechanical complications.

To overcome material limitations, titanium was alloyed with different elements such as aluminum and vanadium. Although the implant mechanical properties were improved, there have been some biological concerns about the toxicity of the released ions.^{12,13} Alternatively, titanium was recently alloyed with zirconium which has been shown to improve the mechanical strength yet without compromising the biocompatibility and osseointegration abilities.¹⁴ Preclinical studies using titanium-zirconium (Ti-Zr) alloy of 13-17% of zirconium showed superior biocompatibility and mechanical properties, such as increased tensile and fatigue strength, and higher elastic modulus over commercially pure titanium.^{11,14,15}

Keywords

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Therefore, Ti-Zr alloy was used by an implant manufacturer (Straumann) to produce narrow diameter implant. However, the biomechanical effects of Ti-Zr implants relative to cpTi implants on the surrounding bone remain to be determined. For example, since Ti-Zr alloy implants are more rigid than cpTi implant, they will experience less strain during function. As a consequence, Ti-Zr implants may be associated with greater strains and stresses transmission to the surrounding bone.^{16,17} Early clinical reports on Ti-Zr implants have indicated that the new alloy appear to be as acceptable as commercially pure titanium.^{1,3,4,18}

To date, the biomechanical features of Ti-Zr implants have been minimally investigated in the literature.^{19,20} This study aims to evaluate the effect of implant diameter and implant alloy on peri-implant strain under static loading. Regular and narrow diameter cpTi implant will be compared against narrow diameter TiZr implants. The null hypothesis is neither the implant diameter nor the implant material have an impact on peri-implant strains.

MATERIALS AND METHODS

SPECIMENS' PREPARATION

Three bone level implant types from the same manufacturer (Straumann) were included in the study: (1) regular commercially pure titanium implant (RcpTi), (2) narrow commercially pure titanium implant (NcpTi), and (3) narrow titanium-zirconium alloy (Roxolid) implant (NTi-Zr). The regular and narrow implants had diameter of 4.1 mm and 3.3 mm respectively, and all of them had length of 10 mm. For each group, a total of 6 implants were investigated.

Each implant was embedded in a block of modified epoxy resin (Masterflow 622) block (Figure 1). The exact resin block dimensions were ensured by using single polyethylene mould. The resin block had a cylindrical shape (diameter of 10.4 mm) with one flat surface (width of 8 mm). The elastic modulus of the epoxy resin material was 15 GPa. Vertically, the implant platform was set slightly coronal to the resin surface. As per manufacturer recommendation, only the rough surface of the implant was embedded within the resin. To simulate clinical situation, the implant was centered in the resin block and the distance between external surface of the implant and the flat surface of the resin block was 1 mm.^{21,22} A dental surveyor was used to mount the implants and facilitate accurate implant positioning.

Identical titanium direct-to-implant crowns were fabricated for all the implants. The crown contour resembled maxillary lateral incisor tooth shape with 16.0 mm height and 6.5 mm width. To ensure similar crowns were produced for all the implants, the titanium crowns were produced by CAD/CAM according to a single virtual crown contour. After receiving the crowns from the manufacturer, all of them were fitted on their respective implants and the retaining screw was torqued to 35 Ncm.

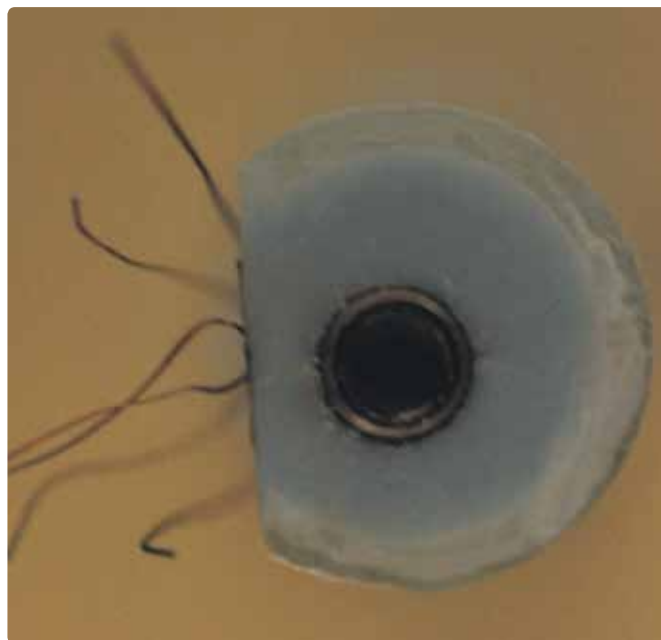


Figure 1: Implant embedded in resin block. 1 mm resin thickness is maintained between strain gauge and implant surface.

STRAIN QUANTIFICATION

On each specimen, a 45° stacked miniature rosette strain gauge (Vishay Micromeritics) was bonded on the centre of the resin flat surface near the crestal edge of the model (Figure 2). This location was selected due to the likelihood of maximal strain development.⁶ Accurate placement was confirmed by a digital vernier. The strain gauges were bonded using M-Bond 200 cyanoacrylate (Vishay Micromeritics).

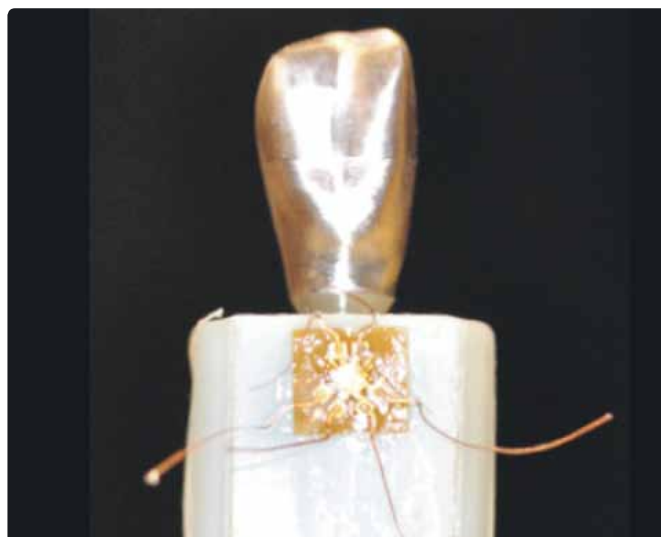


Figure 2: Rosette strain gauge is attached on center of resin flat surface. A lateral incisor titanium crown is fitted on implant.

The strain gauges were individually connected to a data capture system via Wheatstone bridge electrical circuit. Strain development was observed by data acquisition software (Labview). The strain data were recorded in microstrain ($\mu\epsilon$).

The specimen was secured in a customized metal jig that tilts the implant 30° from the direction of vertical forces. The crowns were loaded on the palatal aspects just above the cingulum area (Figure 3). The load was applied in a gradual protocol, starting from zero to a maximal force of 200 N using a universal testing machine (Instron 5544) at a displacement rate of 1mm/min. This load was selected as it closely resembles the forces applied on incisor implant physiologically.²³ Before loading, the strain gauges were zeroed to standardize all the readings. The principle maximum peri-implant strain magnitudes were computed with the strain-transformation mathematical formulae and the Mohr's circle of strain.

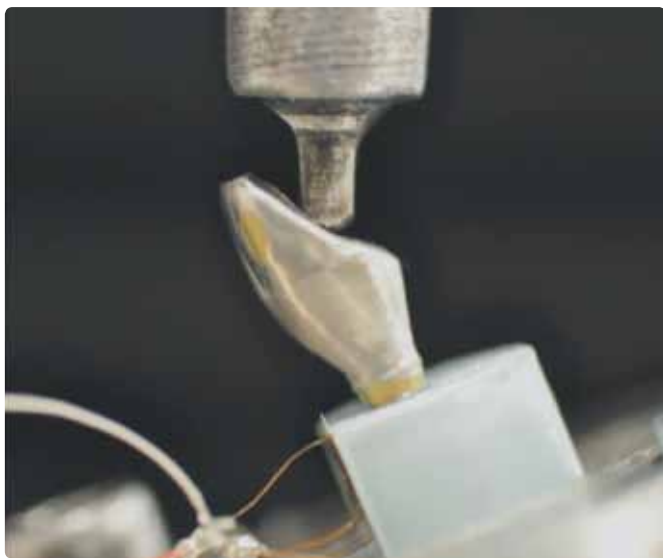


Figure 3: Implant tilting by 30° and crown loading by steel indenter.

STATISTICAL ANALYSIS

For each implant, the mean strain was calculated and the Kruskal-Wallis H test was implemented to verify the effect of the different implants ($p = 0.05$). The statistical analysis was conducted by software package (SPSS).

RESULTS

Table 1 summarizes the generated strain values from each implant system. The NTi-Zr implants were associated with the greatest peri-implant strain development, followed by NcpTi implants. The RcpTi implants had the least amount of peri-implant strain. The results indicated that under 30° angle loading the peri-implant strain can be influenced by implant diameter and implant alloy. However, the effect of the implant diameter is more prominent (Figure 4). In addition, the NTi-Zr implants were associated with more variation in the generated strains. The difference between the NTi-Zr and NcpTi implants was statistically

significant ($p < 0.05$). Likewise, the RcpTi implants had significantly less strain than NTi-Zr ($p < 0.05$) and NcpTi implants ($P < 0.05$).

Table 1. Generated strain values from each implant system

Implant system	RcpTi	NcpTi	NTi-Zr
Minimal strain ($\mu\epsilon$)	389	959	1027
Maximal strain ($\mu\epsilon$)	469	1009	1261
Average ($\mu\epsilon$)	423.3	990.8	1147.0
Standard deviation ($\mu\epsilon$)	26.3	19.6	88.0

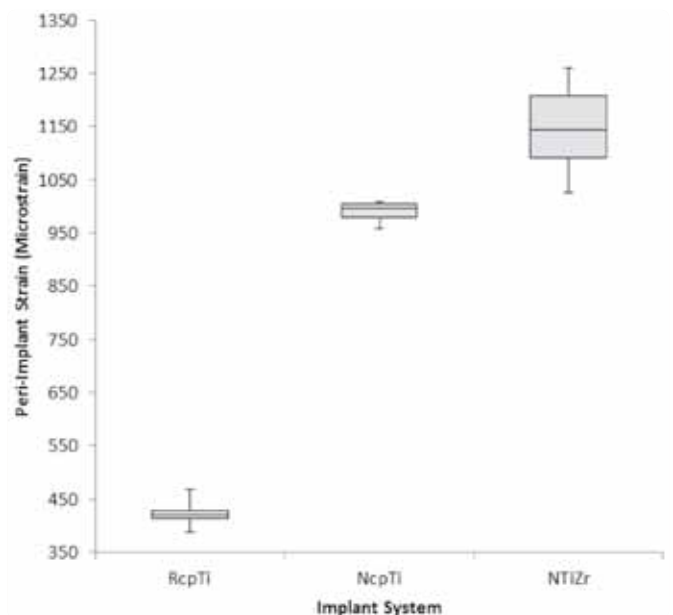


Figure 4: Box plot diagram of the peri-implant strain values around RcpTi, NcpTi and NTi-Zr implants.

DISCUSSION

Overall, this study indicated that the implant diameter and the implant material can influence the peri-implant strains. The peri-implant strains appear to increase with decreasing the implant diameter and increasing the stiffness. However, the impact of implant diameter is more significant. These observations could be attributed to the alterations in the mechanical environment after altering the diameter and the material properties. Therefore, the hypothesis that the implant material and diameter do not influence the peri-implant strain was rejected. In earlier investigations, Ti-Zr alloy for dental implants has been investigated for biocompatibility, osseointegration potential and stability in the biological environment.^{11,14,15} Nevertheless,

studies on mechanical performance in *in vitro* and *in vivo* situations are limited. Whilst alloying of zirconium with titanium has yielded superior mechanical properties over cpTi, it appears that increasing the stiffness of the implant is associated with increasing peri-implant strains.

The observed reduction in peri-implant strains (by more than half) after increasing the implant diameter is in agreement with several strain gauge and FEA studies.^{7-9,24} Increasing implant diameter was found to be one of the most effective approaches in reducing peri-implant stresses.^{7,8,24} Similarly, Kheiralla and Younis, in a strain gauge study, found that mini-implants had the greatest strain values in comparison to standard implants, and wide and short implants.¹⁰ In accordance with this study, Castro *et al* had shown that 5.0 mm diameter implants had half the strain magnitude in comparison with 3.5 mm diameter implants under similar compressive loading conditions.²⁴ It is presumed that as the implant diameter increases, the implant-bone surface area will increase as well. Thus, the applied stresses will be dissipated to a wider area and the strain experienced at any given point (e.g. at the crest) will be less than with a smaller diameter under a given load.^{6,7,24} In addition, wider diameter implants also undergo less flexure during loading, which will eventually cause less strain at the fulcrum point that occurs on the crest.⁹ On the contrary to the wider implant, narrower implant will concentrate the forces to less peri-implant area which will eventually increase the strain at the crestal region. Further, the narrower implant is vulnerable to greater bending which will transfer higher stresses to the peri-implant bone. This explains the higher strains recorded around the narrower implants. However, the clinical relevance of the observed differences in peri-implant strains between regular and narrow implant is yet to be determined. Although increasing the implant diameter clearly reduces the peri-implant strains, an *in vivo* study had found that wide implants had less bone density than narrower implants.² The authors attributed their findings to the reduced peri-implant stress transferred from the wide implant. It may be speculated that the denser bone around narrower implant can offset the problems of the increased peri-implant bone strain. Nevertheless, from the clinical perspective, it is yet to be determined if narrow implant within strained alveolar bone will perform more favorably than regular implant within thin or grafted crestal bone.¹

Although the narrow implants tested in this study had similar geometry, the NTi-Zr implants were associated with greater peri-implant strains than NcpTi implants when loaded in an identical protocol. As the NTi-Zr implant has a higher reported elastic modulus and tensile strength than the NcpTi implant, it is expected that the implant body will experience less strains.^{16,17} However, this did not translate to less peri-implant strain. It appears that since the stiffer NTi-Zr implant body will exhibit less deformation than the NcpTi implant under the same load, greater stresses will be transferred to the surrounding structure.^{16,17} Despite the statistical significant difference between the two narrow implants, the actual difference in the peri-implant strain is minimal and may not have significant clinical effect. Such observation is in accordance with several previous laboratory studies. Mobilio *et al* evaluated the differences in

peri-implant strains between acrylic embedded zirconia implant and titanium implant.¹⁷ They found the stiffer zirconia implant induced slightly more peri-implant strain than titanium implant, when the implants were loaded in similar condition to the present study. However, when the same design was converted to a FEA model using simulated cortical and cancellous bone rather than acrylic, they found the zirconia implant produced slightly less strains. Another FEA investigation had found Ti-Zr implants and cpTi implants exhibited similar biomechanical performance.²⁰ In a strain gauge study, Wu *et al* had compared the mobility and the peri-implant strains of NTi-Zr and NcpTi implants in synthetic bone.¹⁹ The two implants had revealed similar mobility and peri-implant strain. The differences between the present study and the other studies could be related to differences in the experimental set-up. The slight variation between the previous studies and the present study can be attributed to the inevitable variation in the experimental set-up and assumptions. Still, the clinical impact of this difference is better answered by the clinical trials.

Currently, there insufficient evidence to support that the alterations in the peri-implant strains after using stiffer implants will cause any negative effect. In relation to Ti-Zr alloy implant, an animal study had shown even superior osseointegration than cpTi implant, which could overcome the potential problems of altered peri-implant strains.¹⁵ In addition, at least in the short-to-medium term, early clinical studies had revealed NTi-Zr implants are reliable for supporting fixed and removable prostheses.^{1,3,4,18}

In this study, the clinical recommendations were adhered to as much as possible in the mounting of the implants within the resin block. A thickness of resin material over each implant of 1.0 mm was implemented.²¹ Since the bone thickness can influence the crestal strains measured,²² reproducible implant positioning was ensured by dental surveyor. Also with the loading protocol, it should be noted that the results obtained from this study only used a single load of up to 200 N. A great variation of vertical loads/forces have been reported for patients with endosseous implants (means range: 91–284 N), and the loads appear to be related to the location of the implant, as well as to food consistency.²³

In order to represent a clinical scenario, the implants were embedded in epoxy resin material that has similar elastic modulus to the cortical bone.¹⁷ Nevertheless, the results of this research need to be interpreted with some caution since bone is an anisotropic material and may behave differently clinically. In addition, through the experimental design, complete osseointegration and isotropic peri-implant bone conditions are assumed. Therefore, although this study provides an input on the mechanical behavior of NTi-Zr implants, it suffers from some limitations that prevent extrapolation clinically. A definitive conclusion should be drawn from clinical studies.

CONCLUSIONS

Within the limitations of this study, it can be concluded that the implant diameter and implant material can influence the magnitude of peri-implant crestal strain. The implant diameter has

greater effect on peri-implant strains than the implant stiffness. The regular diameter implant showed much lower peri-implant crestal strains than both the narrow diameter implants. NTi-Zr implants were associated with the greatest peri-implant crestal strains.

MANUFACTURERS' DETAILS

- Digital venier, 150 mm digital venier caliper K11100, Kincome, Victoria, Australia
- Instron 5544, Instron Corporation., Canton, MA, USA
- Labview, Data Logger, CPE Systems, Victoria, Australia
- Masterflow 622, Degussa, NSW, Australia
- SPSS statistics software, SPSS for Windows, version 23, SPSS Inc., Chicago, IL, USA
- Straumann AG, Basel, Switzerland.
- Vishay Micromeritics, Vishay Precision Group Inc., Raleigh, NC, USA

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