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Article

Effect of Implant Diameter and Cortical Bone Thickness on Biomechanical Performance of Short Dental Implant-Supported Distal Cantilever: A Finite Element Study

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Abstract. The present study aimed to assess the effect of implant diameter and cortical bone thickness on the biomechanical performance of short dental implant-supported distal cantilever placed in posterior atrophic maxilla by finite element method. There were 6 stimulating models in this study, which consisted of a bone block and short dental implant of 7 mm in length, 3 differences of diameter (5.0, 5.5, and 6.0 mm) and 2 variations of cortical bone thickness (thickness of 0.5 and 1.0 mm). All models were applied with 200 N of force with 30° inclination to lingual direction. Von Mises stress and strains were used to evaluate the biomechanical performance of the short dental implant and surrounding bone. Results showed that increasing of implant diameter led to decrease in stress level on neck of dental implants and strains in surrounding cortical bone. However, the implant diameter equal or smaller than 5.0 mm should not be used due to high stress level with could be a cause of implant failure. In addition, clinicians should be aware of placing implant with inadequate bone stock which lead to surrounding bone resorption.

Keywords: Dental implant, biomechanics, distal cantilever, posterior maxilla.

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1. Introduction

Dental implants are predictable treatment procedure for replacement of tooth loss. Their advantages are not only enhancing patient's oral rehabilitation but also increase aesthetics, functions and the quality of life of edentulous patients [1]. Clinically, dental implants had turned out to be a great long-term application with a survival rate over 94% at 10 years follow-up period [2]. Those survival resulted from improvement of dental implant topography, surface modifications, and surgical protocols [3].

After removal of tooth, the alveolar bone is continuously resorbed. The massive resorption will be occurred with aging patients due to their pathologic and physiologic conditions. Moreover, long-term of edentulous ridge leading to more severe atrophy [4]. The posterior maxillary area was commonly poor bone quality (cortical thickness) and quantity (bone height and width) that was limitation of proper implant sizes to be placed [5]. Furthermore, difficulty of clinical procedure is unable to achieve the optimal primary stability. These conditions led to massive decreasing of implant survival rate [6].

There were lots of additional procedures to managed bone defect in the posterior maxilla e.g. guided bone regeneration (GBR), bone block graft and maxillary sinus floor elevation [7-10]. Unfortunately, those surgeries had some adverse events including patients may undergo multiple surgical procedures and longer treatment period, increase patient morbidity and get higher risk of complications, as well as they will get higher costs and may low acceptability [11].

Short dental implant (or short implant) had been introduced to use in case of deficient in bone height instead of standard length of implant (10 mm or more) to avoid additional surgical procedures. Clinical use of short dental implant showed highly predictable result in recent decades and the adaptation of the implant to the existing anatomy by use of short-length implants should be considered as a suitable procedure for alveolar bone deficient cases [12]. However, there is no consensus of definition of short-implant length [13]. Subjectively, some authors stated that the short dental implant is less than 10 mm of length [14], while others stated the intra-bony length of ⩽ 8 mm is the short implant [15]. In this case, the biomechanical performance of short dental implant is a determined factor for long-term survival of dental implant.

Other way to overcome additionally surgical complications is using different prosthetic design. Cantilever extensions are used in dental prosthesis proposing to increase the extension area of the prosthesis part in area of vital structures obstruct the implant bed, or insufficient bone height for implant placement [16]. Cantilever extension exist, nevertheless, related to excessive occlusal-loading force is still controversies. Rodriguez et al. [17] showed the overall success of implants used to support cantilever fixed dental prosthesis. However, the resulting of leverage force might cause the high concentration of stress in the implant system and supported bone [18]. Then, these events could occur and compromising the longevity of implant system [19].

According to abundance of previous studies, finite element analysis is helpful to evaluate the stress and distribution of the implant system and the bone especially in the extremely condition which could not asses in the real-life situation [20, 21]. Therefore, the resulted data allows a crucial analysis of the clinical situation and provides evidence of promising clinical options for achieving the longevity of implant system.

Due to the restriction of implant bone bed, the aimed of this study was to evaluate the effect of implant diameter and cortical bone thickness in the biomechanical performance of short dental implant-supported distal cantilever placed in posterior atrophic maxilla using finite element analysis.

2. Materials and Methods

Three-dimensional (3D) geometry used in this study was created from Computer Aided Design (CAD) software and the FE analyses were perform using FE software.

2.1. Geometric Details of Bone and Implant

Three-dimensional (3D) model consists of maxillary bones, posterior maxilla and suprastructure, they were created using CAD Software (VISI, Vero Software, UK).

The maxillary bone had a block shape which its dimensions were 9 mm in apico-coronal direction, 13 mm in bucco-lingual direction and 25 mm in mesio-distal direction. There were two layers of bone, a thin layer of cortical bone was located outside, surrounding by layer of poor quality of cancellous bone that representing type IV bone according to Lekholm and Zarb classification [22]. The thickness of cortical bone under consideration in this study included 1.0 and 0.5 mm.

Short implants used in this study were referenced from commercial dental implant geometry. All of them had 7.0 mm in length with three difference diameters which were diameter 5.0 mm, 5.5 mm, and 6.0 mm. All implants used in this study were presented in Fig. 1.

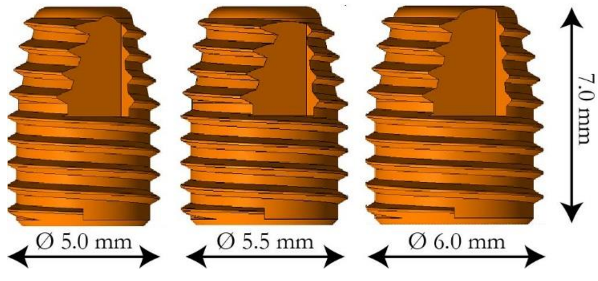

Fig. 1. Short implant used in this study.

Suprastructure (i.e. zirconia crown, and distal cantilever) was aligned and put on top of abutment, and implant system. The implant system was placed in maxillary bone, as shown in Fig. 2.

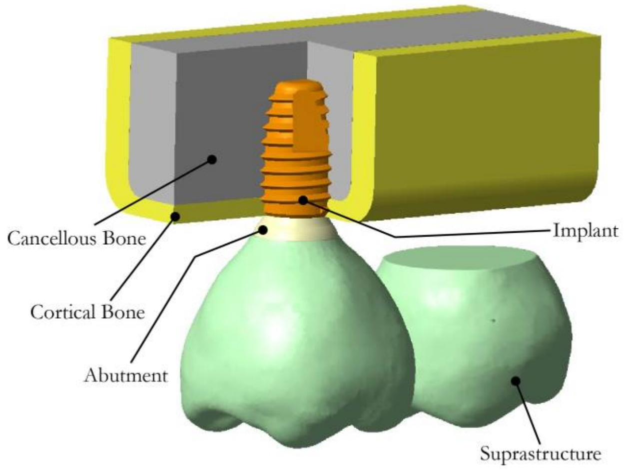

Fig. 2. Short implant and suprastructure placed in bone.

2.2. FE Model

The FE models were derived from CAD models. In this study, two different thickness of cortical bones and three different implant model were under interest. Therefore, the study had six cases in totals.

Element and node of bone structures, suprastructure, and implant system models were created using mesh generation software (MSC Patran, MSC Software, USA). All FE models was built up from four-node tetrahedral elements. Each FE model was controlled the element size, in order to be able to compare the results obtained among studied cases. The element size was 0.3 mm, which was small enough for the FE result to be converged. Total number of elements, and node in the FE models ranged from 377,196 to 499,225.

Two-hundred newton of force with 30° inclination to lingual direction [27] was applied on planes of four palatal cusps. All FE models were fully constrained at the nodes on the most apical of cortical and cancellous bone. Material properties assigned to the FE models were showed in Table 1. All material behavior were assumed isotropic, homogeneous, and linearly elastic.

The implant system was rigidly anchored in the bone models, then the contact condition was defined as no relative displacements. The implant system and the suprastructre, and component inside suprastructre were also clung to another, therefore, relative displacement was not allowed between contacts among these bodies.

All FE analyze was performed in commercial software package (MSC Marc Mentat, MSC Software, USA). Figure 3 shows one of the FE model.

Table 1. Material Properties.

Materials	Elastic Modulus	Possion's ratio	Reference
Titanium (Implant System)	110,000	0.35	[20]
Zirconia Crown	205,000	0.30	[23]
Cortical Bone	13,000	0.30	[24]
Cancellous Bone	1,000	0.35	[25]
Composite Resin	7	0.20	[26]

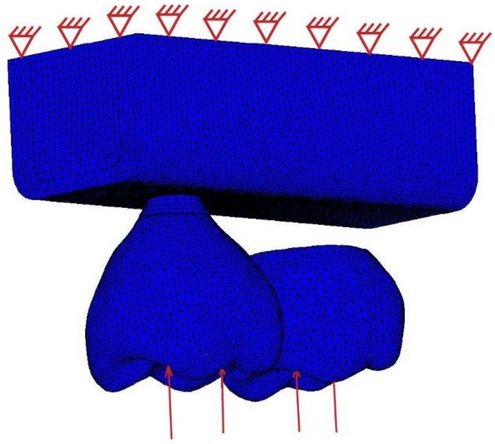

Fig. 3. FE model and boundary conditions.

3. Results

3.1. Stress Distribution in Implant

Under the axial loading, the implant system with greater diameter showed a decrease the maximum Von Mises stress exhibited on the implant. In all FE analysis cases, the maximum stress area was located around the neck of implant. Comparing between implant stresses on the same diameter with different cortical thickness, small variation in magnitudes were found. (Ranging between 1-54 MPa) The maximum Von Mises stress exhibited in each case was shown in Table 2. The stress distribution pattern was presented in Fig. 4.

Table 2. Maximum Von Mises stress on implant.

Case	Cortical Thickness	Implant Diameter	Maximum Von Mises Stress
1	0.5 mm	5.0 mm	920 MPa
2	0.5 mm	5.5 mm	675 MPa
3	0.5 mm	6.0 mm	622 MPa
4	1.0 mm	5.0 mm	972 MPa
5	1.0 mm	5.5 mm	674 MPa
6	1.0 mm	6.0 mm	632 MPa

3.2. Strains Distribution in Cortical Bone

Strains were highly localized in the cortical bone surrounding the neck of implant. Increasing of implant diameter and thicker of cortical bone trended to decrease strains. In the model with 0.5 mm cortical thickness with 6.0 implant diameter, it showed the extremely high value of microstrains. Values of strain shows in Table 3 and the distribution shows in Fig. 5.

Table 3. Elastic strain on cortical bone.

Case	Cortical Thickness	Implant Diameter	Maximum Elastic Strain
1	0.5 mm	5.0 mm	6,415 $\mu\varepsilon$
2	0.5 mm	5.5 mm	5,145 $\mu\varepsilon$
3	0.5 mm	6.0 mm	10,510 $\mu\varepsilon$
4	1.0 mm	5.0 mm	8,602 $\mu\varepsilon$
5	1.0 mm	5.5 mm	4,089 $\mu\varepsilon$
6	1.0 mm	6.0 mm	3,864 $\mu\varepsilon$

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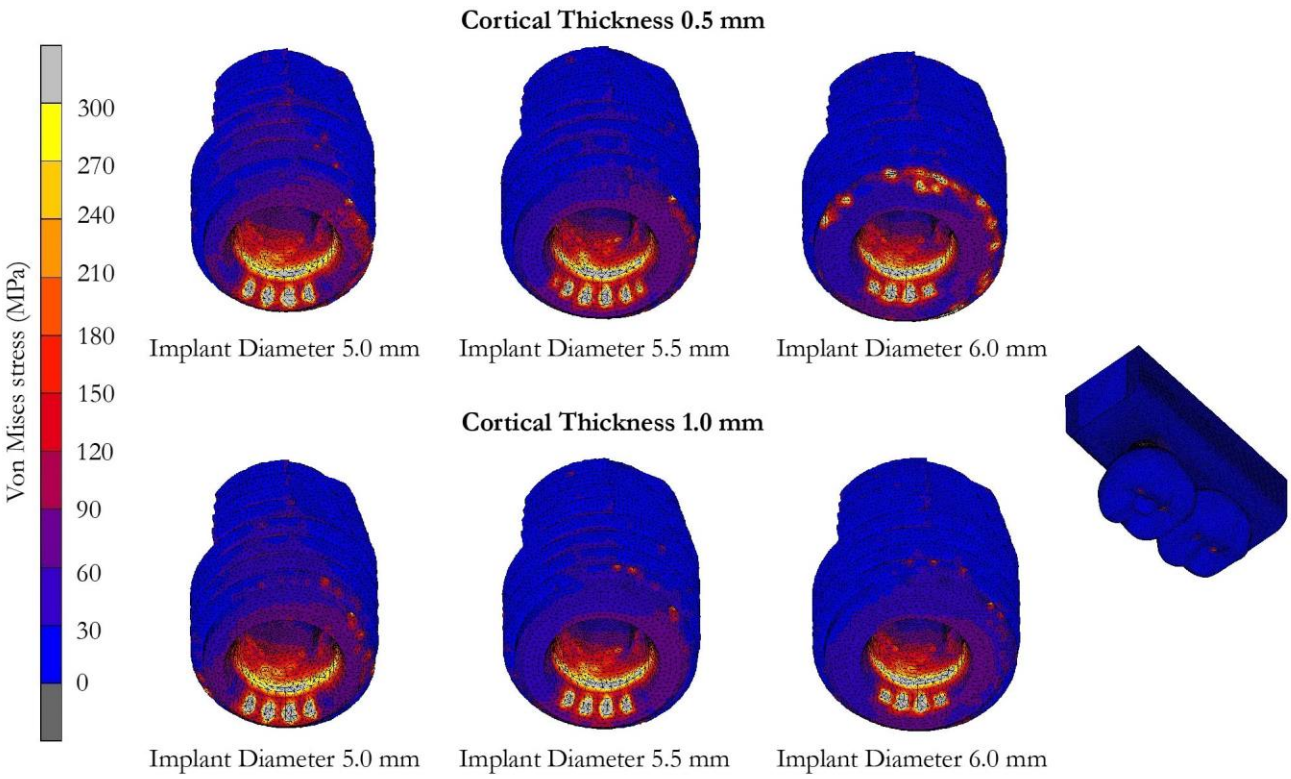

Fig. 4 Stress distribution on implant.

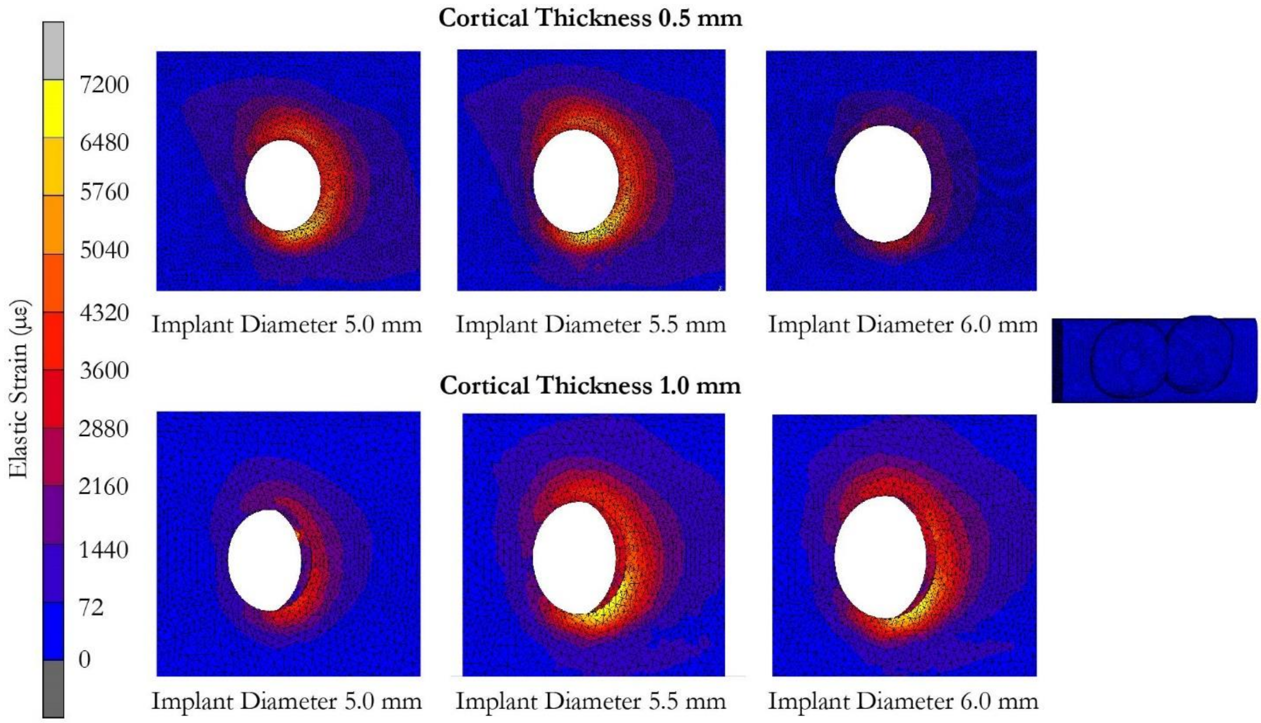

Fig. 5 Strain distribution in surrounding bone.

4. Discussion

This study focused on clinical complication on maxilla based on clinical evidence [4, 10-12] which various previous studies was interested complication in mandible [19, 20, 27]. The short dental implant placement at maxilla is considered to be complicated surgical operation since the maxilla has the limited bone height and lower density compared to other bone regions.

This study revealed that the stress distribution in the implant and the strains distribution in the cortical bone around implant body were influenced by the implant diameter and the bone quality (cortical thickness). Since biomechanical performance of implant system affects the long-term survival rate of dental implants, it would seriously influence implant survival rate due to clinical complications such as implant-surrounded bone resorption.

Placement of short dental implant comparing to the standard implants with additional bone augmentation, reduce time and cost of treatment. It is also less invasive and able to avoid the serious complications. However, previous systematic review and meta-analysis study [28] stated that there was no difference in implant survival rates of short dental implants in comparison to standard length implants in conjunction with maxillary sinus floor elevation.

Conceptually, bone-implant contact (BIC) of short implants would be compensated by increase the implant diameter. A general opinion is implants with diameter of 4 mm or more should be installed in edentulous area [29]. Romanos et al. [30] found that conventional-diameter implants showed greater initial stability compared with narrower implant diameter. It was explained by the increasing of BIC provided by wider implant diameter might influence the treatment outcome. Then, the present study the short dental implant models with wide-diameter (5.0, 5.5, and 6.0 mm) to compensate amount of the short implants BIC.

The result from this study revealed that the maximum Von Mises stress in implant body decreased with greater implant diameter. Smaller implant diameter presented the higher stress due to lesser area for force distribution. High concentrated stress around the implant neck at contact surface with abutment is considered at risk, especially for the cases of short implant diameter of 5.0 mm. In these cases, the maximum Von Mises stress reached over 900 MPa which is over the yield stress of titanium alloy which ranged from 800-900 MPa [31]. This can be a cause of implant failure. As a result, implant diameter equal or smaller than 5.0 mm should not be used.

The maximum strains in the cortical bone was found to be in similar tread. This is except for the model with 0.5 mm cortical thickness with 6.0 mm implant diameter (The greatest diameter implant with the thinnest cortical bone under consideration in this study), which the maximum strains was extremely high. Implants with wide diameter (e.g. diameter of 6.0 mm) placed in poor bone quality is considered as a critical aspect for implant survival, because a limited bone stock around implant is able to cause greater load-transferred strains from the implant body into the surrounded bone. As a result, cortical bone reached excessively high strains. This could be a cause of surrounding bone resorption.

De Carvalho et al. [32], found that the strain were significantly higher in surrounding bone anchored with 5.0 mm implant diameter compared to 3.5 mm implant diameter. This is because surface strains were higher probably because of the wider implants led to more proximity with the outer surface of the bone block whereas the implant diameter of 3.5 mm groups were more distance from the block surface, which led to lower strain values. In addition, Huang et al. [33], also found that the standard implant used in the molar area with wide implant reduced the peak stress in crestal bone by 29–37% for both splinted and non-splinted cases. This supported the authors' finding where the wider implant diameter of 6.0 mm with thin cortical bone thickness of 0.5 mm revealed the poor result.

The bone quality (cortical bone thickness) around dental implant sites varies in different area of jaw. The posterior maxillary area usually has less cortical thickness [34] and this type of bone was classified as type IV bone [22]. Type IV bone is characterized as a thin layer of cortical bone surrounding a core of low-density and poor-strength cancellous bone [35] which might compromise longevity of dental implants.

5. Conclusions

This study presented the effect of various short dental implant diameters used to support distal cantilever to the different bone quality by means of FE analysis. This study paid attention to short dental implant placed on maxilla where is anatomically considered to be challenge for clinician. This is due to limited bone stock height for implant placement. In addition, the bone density at maxilla is considered to be lower than other bone in this region. According to the finding, major factors associated to biomechanics included short implant diameter and cortical bone thickness. Normally, wider short implant diameter with thick cortical bone lead to good implant stability and prevent implant breakage.

Nevertheless, implant with smaller or equal 5.0 mm of diameter should not be used due to the chance of implant failure. In addition, clinician should aware use of wide diameter in narrow cortical bone where cortical bone are thin and bone stock is inadequate.

The finding is beneficial for clinician to select proper short dental implant which can reduce unnecessary operation and simplify surgical procedure. The benefit to patient which could reduce pain from complicated surgery, morbidity, and risk of post-operative complication.

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