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Effects of progressive and non-progressive threads of immediate loading dental implants on stress and strain

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Abstract:

Immediate loading of dental implants are always be a matter of concern in implant dentistry, however there are no consensus regarding the prerequisites of achieving good results The purpose of the present in vitro study was to assess the stress/strain distribution in the surrounding marginal bone of immediately loaded implants by means of two different designs of threads, progressive and non-progressive threads. A three dimensional model of an adult mandible was developed from a computed tomography scan images. The finite element models of the mandible, which are embedded with two different designs of dental implant, were reconstructed. Each model was put into static vertical load of 100 N to the implant. The min/max von Mises stresses and strains in adjacent cancellous bone for both cases of implants were evaluated. The results showed that the progressive thread design of implant can more uniformly distribute and dissipate the mechanical stress/ strain in the surrounding bone.

Keywords: Dental implants, Immediate loading, Stress, Strain, Finite element analysis

1. INTRODUCTION

In dentistry, missing teeth have to be replaced by an artificial substitute called dental Prosthesis. With the advent of dental implants in the early 80's, this modality shows their power and rationality to being used as an alternative to traditional crown and bridge technique. The logic behind the implant make dentist convinced to use this methodology in their routine practice. Since inception of first commercial dental implant, so many protocols introduced which try to improve the longevity, further increase the degree of osseointegration and reduce the time to function of this great modality. Recently based on patient's bone quality, a protocol called immediate loading has been advocated. It refers to a situation which implants placement and loading take place at the same visit or within 48 hours. Therefore patient will not wait several weeks for healing time [1-2].

The principal function of implants is to support the denture with the jaw bone firmly. Since dental implant transfers loads to surrounding contact area [3-4], dental implants have gradually become one of the most controversial items in dentistry [5-6]. Implant thread configuration is an important objective in biomedical optimization of the dental implants [7]. Previous studies reported that the design of the implant threads directly affects the stress distribution on marginal bone [7-10]. Additionally, there is a high relationship between the stress distribution and the bone loss around the implant. The bone loss can be reduced by controlling the stress concentration and then, success rate of implant can be improved [11].

Nowadays, there are various types of dental implants for clinical use, and designs of the thread shape and taper differ greatly among them [12]. One of them is progressive thread design in which the profile depth of thread is varied along the length of an implant.

In this study, the effects of thread design on stress distribution in the surrounding marginal bone around immediately loaded implants were evaluated. Therefore, two variations of thread design, progressive and non-progressive, were developed to compare the stress distribution in the cancellous bone by utilizing finite element analysis (FEA).

2. MATERIALS AND METHODS

Three dimensional (3D) Computed Tomography (CT) imaging data (image set with slice thickness of 1mm, resolution of 512 x 512 and pixel size of 0.418 mm) of an adult mandible consists of cortical and cancellous bone, was developed. CT scanner (Siemens Somatom Sensation 16, Siemens AG, Germany) was used for data collection.

Using an image processing software package (Mimics, Materialise NV, Leuven, Belgium) and based on the Hounsfield Unit, cortical and cancellous bone were separated and modeled (Fig. 3).

Two commercial dental implants (Institut Straumann AG, Basel, Switzerland) with the same diameter (4.1mm) and length (10 mm) were selected with two different threads: progressive and non-progressive. Geometry of dental implants was measured via a profile projector (Microtechnical LTF, Italy). The accuracy of this method (0.002 mm) made it possible to reconstruct the geometry of implants including the appropriate shape of the threads. Then in a commercially 3D modeling software (SolidWorks 2009, Dassault Systèmes, USA), the implants with none progressive thread (Fig. 1) and progressive thread (Fig. 2) were modeled and inserted into the jaw bone. As it can be seen, in none progressive thread the depth of thread profile is the same dimension along the implant body. In progressive one, the depth of thread profile increases toward the apex part of implant.

Finite element analysis (FEA) method was established by utilizing FEA software (CosmosWorks 2009, Dassault Systèmes, USA). For static analysis of the model, due to no movement of mandible, the models were fully fixed on the outer surface of the mandible. Due to the fact that, initially at immediate loading there is no bone healing, the interfaces between the implant and cancellous bone were assumed to be without any osseointegration. The models were meshed using 0.9 mm parabolic tetrahedral elements with number of 30614 elements and 43318 nodes (Fig. 4).

Materials used in this study were assumed to be isotropic and homogenous. Elastic properties of materials of implants, cortical and cancellous bones were determined from the literature [13] and given in

Table 1. As shown in Fig. 4, a static load of 100 N was applied to implant vertically. The load was distributed on the top surface of implant (Fig. 4).

3. RESULTS

The current study attempted to investigate strain and stress distribution in the adjacent bone to the different types of threads of dental implants. FEA is an applicable means that can be applied to evaluate such these structures which are complicated to be experienced in real world. In this regard, the stress distribution and strain in the cancellous bone for quantifying the models had been considered.

Fig. 5 illustrates the von Mises stress distribution in cancellous bone. It is a section view which was extracted from the model to show the data analysis more clear. There was a significant difference in managing stress in bone between two types of threads. According to Fig. 5(A) which demonstrates non-progressive thread implant, the stress has been concentrated in apical part of implant and within threads (red color). While surface between threads benefited from the lowest amount of stress (blue color). Comparatively, in Fig. 5(B), stress distribution at bone around implant with progressive thread is more uniform. Moreover there was less stress in apical part of progressive thread implant. However, stress concentrated at threads similar to non-progressive.

The max and min von Mises stress in cancellous bone for both designs are listed in Table 2. The von Mises stress in bone around implant with progressive thread varied between 0.16 and 19.1 MPa. In comparison, for non-progressive thread it changed from 0.3 MPa to 32.6 MPa. The magnitude of stress generated in cancellous bone in progressive thread design is much less than

In Table 3, the micro strain in cancellous bone are given. The micro strain in bone around implant with progressive thread varied from minimum 63.8 to maximum 2500. While the minimum and maximum micro strain in cancellous around non-progressive thread were 198 and 15591, respectively.

4. DISCUSSION

The broad use of finite element procedure in analysis of dental implants brings many benefits in over experimental method. Because experimental methods are time consuming and requires sophisticated facilities. In this study mandible of a real patient simulated and 3D FEM was exploited to achieve more precision.

Previous studies reported the implant failures due to the bone loss. The bone loss might be occurred at concentrated stress regions in bone-implant interface [12-14]. Therefore uniform stress distribution at the bone-implant interface will improve osseous fixation.

According the Fig. 5 and Table 2, the stress results indicated that the geometry of implant threads can significantly influence stress distribution and magnitude of resulted stress at cancellous bone. The progressive one can more uniformly dissipate and distribute the stress in the adjacent bone. Managing the stress concentration will considerably increase stable osseointegration between implant threads and the surrounding area which can lead to improvement of the success rate of implant [11]. In addition, the magnitude of stress generated in cancellous bone in progressive thread design is much less than non-progressive thread designs. Hence, bone around non-progressive thread suffers from higher risk of bone-loss due to tolerating higher stress value.

Overall, in immediate loading surgeries, the primary stability of implant is a critical factor that is can affect the implantation results [15]. Hence, in the early period of surgery, implant should be mechanically stable. Based on Table 3, it is obvious that strain in bone for progressive thread of implant was considerably less than the strain in bone around none progressive thread. Therefore, progressive thread can make dental implant much more mechanically stable rather than non-progressive.

5. CONCLUSION

This study showed that there was significant correlation between the geometry of thread of dental implant and its success. It is anticipated that by using implant with progressive thread, the stress concentration and strain had been absolutely decreased, which is postulated to diminish interfacial micro motions and avoid probable implant failure and subsequent bone resorption.

6. ACKNOWLEDGEMENTS

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Table 1. Mechanical Properties of the components used in FEA model [13].

Table 2. Min and max Equivalent stress in cancelous Bone.

Table 3. Min and max Equivalent micro-strain in cancelous Bone.

Fig. 1. Non-progressive thread design of implant.

Fig. 2. Progressive thread design of implant.

Fig. 3. Three dimensional (3D) model.

Fig. 4. Finite Element model.

Fig. 5. Stress distribution in cancellous bone (A) implant with none progressive thread, (B) implant with progressive thread.

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Table 1. Mechanical properties of the components used in FEA model [13].

Material	Elastic Modulus (MPa)	Poisson's Ratio
Cortical Bone	13700	0.3
Cancellous Bone	1370	0.3
Implant	105000	0.37

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Table 2. Min and max Equivalent Stress in cancelous Bone.

Design	Min Equivalent Stress	Max Equivalent Stress
Progressive thread	0.16 MPa	19.1 MPa
None progressive thread	0.3 MPa	32.6 MPa

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Table 3. Min and max Equivalent micro-strain in cancelous Bone.

Design	Min Equivalent Micro-strain	Max Equivalent Micro-strain
Progressive thread	63.8	2500
None progressive thread	198	15591

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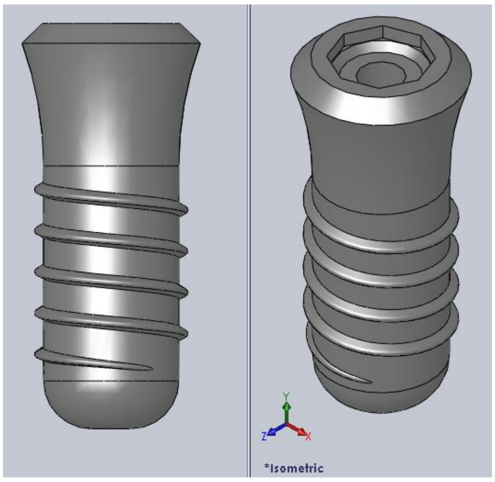

Fig. 1. Non-progressive thread design of implant

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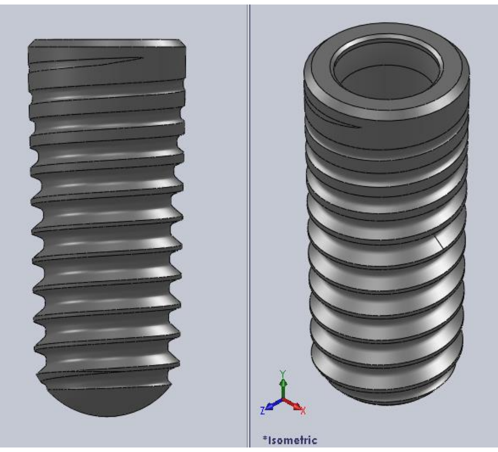

Fig. 2. Progressive thread design of implant

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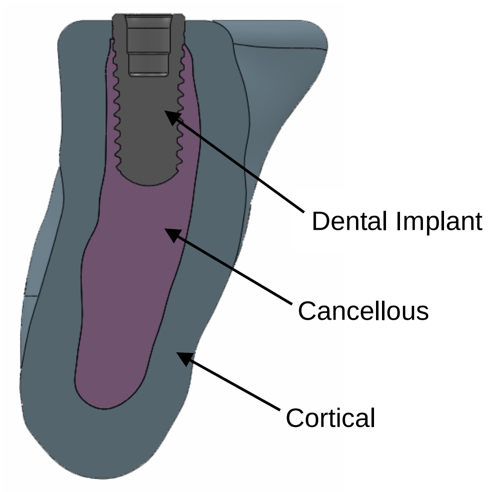

Fig. 3. Three dimensional (3D) model

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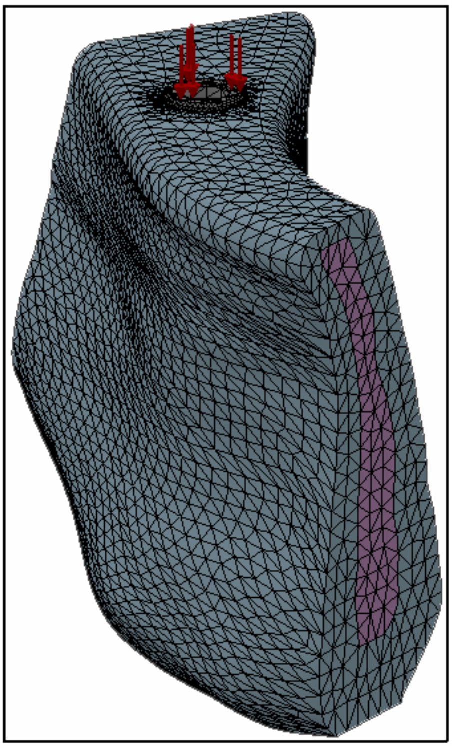

Fig. 4. Finite Element model

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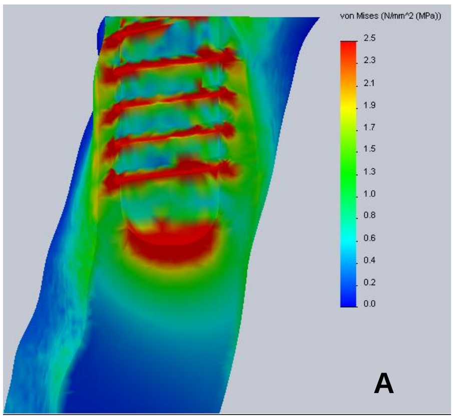

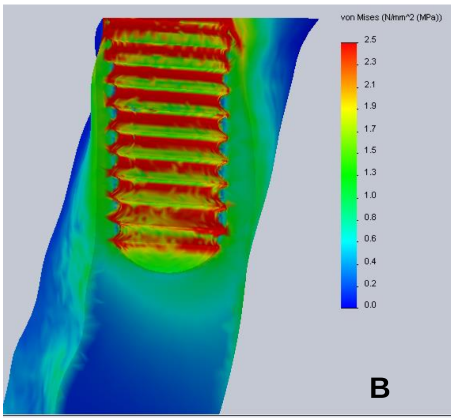

Fig. 5. Stress distribution in cancellous bone (A) implant with none progressive thread, (B) implant with progressive thread