Selection of Optimum Thread Type in Implants to Achieve Optimal Biomechanical Properties by Using 3D Finite Element Method

Zeinab Arsalanloo, Reza Telchi, and Kambiz Ghaemi Osgouie

Abstract*—Using osseointegrated dental implants allows restoration of completely or partially edentulous patients and success of this technique is linked to the connection between living bone and surface of load-bearing artificial structure, generally titanium-based. Many factors affect load transfer at the bone implant interface such as the type of loading, material properties of the implant and prosthesis, implant geometry, surface structure, implant design quality and quantity of surrounding bone, and nature of bone implant interface. The bone has the best resistance upon compressive loads, and lower resistance against tensile and shear loads. On the other hand, implants are subjected to various kinds of loads. Recently, to eliminate failures, caused by the threaded root-form implants have been introduced. In this paper, it is aimed to investigate how thread types can affect the amount, type of load and biomechanical responses induced in mandible/maxilla and implant–abutment complex by a finite element method. This problem signifies due to the usage of different kinds of thread forms made by different implant manufactures. Solid models have been developed for missing upper/lower lateral incisor dental position and 26 fixture models of 5-implant systems are made in to carry out analysis of lateral Incisor tooth of human by using FEA. The results of this paper will help in understanding the way in which stresses are distributed in dental structures. Consequently, static, dynamic and fatigue behaviors of implants are investigated.

***Index Terms*—Dental implant, kinds of threads, kinds of loads, finite element method, lateral incisor position.**

I. Introduction

A dental implant is a biocompatible device and usually made of titanium, surgically placed into mandibular or maxillary bone for supporting a prosthetic tooth crown, and thus allowing the replace of the teeth lost due to caries, periodontal disease, injuries, or other reasons. Dental implant is being allowed bone tissue to interlock with the implant and maintain its stability when mastication forces are applied. [1]-[3]

The regenerative physiologic phenomenon, that allows the fixation of the implants to the patient bone, is denominated bone integration. It was discovered and defined by Branemark in the sixties, when using titanium cameras for live studies. The bone integration, from a biomechanics point of view, is defined as the absence of progressive and relative movement among the implants and the surrounding bony structure facing physiologic loads or any other load that can emerge during the patient life. According to previous reports, the success rate of dental implants in the mandible and maxilla are almost 95% that it has led to its widespread clinical application. If implants are properly designed and manufactured, and if they are inserted in a bone segment characterized by good quality and quantity [1]–[3] the success of implants are being high.

In the other hand, the clinical success of dental implants depends largely on initial stability and long-term osseointegration with optimal stress distribution that provides lasting incorporation with bone and also on implant design features such as materials, geometry. To accelerate osseointegration and to control the stresses in the bone, the most common approach is alteration of dental implant designs such as macro-design and micro-design (surface alterations) [4]-[7]. In this respect, it is a widely accepted fact that the thread geometry has a significant effect on implant biomechanics. [8], [9]. There are many advantages associated with threaded implants; so implants with extended threads are highly recommended in implant dentistry today to enhance initial stability, enlarge surface contact area, favor dissipation of interfacial stress, and reduce micro movements of the implant during post insertion healing period until the stable osseointegration is established. This characteristic is more importance in the regions of low bone density and in the submerged placement modality of implant. In the situations of poor integration, or in the regions of large tensile stress, the separation of bone and the implant might occur.

There are different types of externally threaded implants available in the market, which vary in shape, thread pitch, thread depth, thread thickness, thread face angle, and thread helix angle that determine the functional thread surface and affect the biomechanical load distribution of the implant [10], [11]. As well as, using threads on implant body with some micro scale roughness provides a favorable situation for osseointegration. When a favorable osseointegration is achieved, the stress is spread over a wide area and at a lower level; so, improves stress distribution as the integration between bone and implant improves.

Primary implant stability is considered to play a fundamental role in obtaining successful osseointegration [12]. Major contributors to initial implant stability have been suggested to be implant length, diameter, surface texture, and thread configuration. In a finite element study, Siegele and Soltesz [13] evaluated the load transfer in the case of several different implant forms (cylindrical, conical, with shoulder, screwtype). They found a high failure rate in the hollow

Manuscript received January 13, 2014; revised March 19, 2014.

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DOI: 10.7763/IJBBB.2014.V4.336

cylindrical implants due to low primary stability and high infection of the bone in the hollow cylinder. Moreover, Riedmuller and Slotesz [14] found that the conical or shoulder-type implants distributed high stress level at the bone interface. Rounding of the corners of the implant was found to have a significant effect in reducing the stress. Therefore, today, screw-type implants with rounded screw threads are highly recommended. Another finite element study by Moser and Nentwig [15] was observed that using screw threads with an apically increasing screw thread depth reduces tension in the cervical area when implant was apically loaded. In a study by Skalak *et al*. [16], stress transfer at the implant interface was evaluated. Their study showed that using screw threads on the implant body helps to transmit stresses any direction without any gross sliding due the presence of threads. Inclined faces of threads allow normal stress to carry perpendicular to the interface. Hansson [17] concluded that the threaded collar implant design transfer lower interfacial shear stresses compared to the smooth collar design. Chun *et al*. [18] conducted a finite element study to evaluate the stress distribution using different thread design implants under a 100N applied 15 degree off axis. They observed that the maximum effective stress in the cortical bone was higher in the plateau design compared to the triangular or square designs. In addition, they found out that screw pitch has a significant effect on stress distribution. In another study carried out by Patra *et al*. [19], tapered thread design implant were found to distribute higher stress levels in bone rather than the parallel profile thread.

This paper is aimed to investigate some biomechanical aspects and advantages relevant to the effect of the type of thread effect and types of loads on biomechanical responses induced in mandible/maxilla and implant–abutment complex by a finite element method. In this study, solid models have been developed for missing upper/lower lateral incisor dental position and 26 fixture models of 5-implant systems to carry out analysis of lateral incisor tooth of human by using Finite Element Analysis (FEA). The results of this paper will help in understanding the distribution of stresses in dental structures. In this study, static dynamic and fatigue behaviors of the implant are investigated.

II. Methods and Materials

The study was realized using the three dimensional finite element techniques, for achieve the optimum conditions in lateral incisor position. In this paper, implant systems studied comprised two types of Nobel (Nobel Biocare Management AG Switzerland), one type of Neo CMI Implant (NeoBiotech, Seoul, Korea), a kind of Implantium system (Implantium, Dentium, UK Ltd.) and a Biodenta Endosteal implant (Biodenta Swiss AG, Berneck, Switzerland). DIO implant system (DIO, Haeundae-gu, Korea) also is being used with two types of DIO-ProTem Series that consisted of mini-implants series.

The 26 different implant designs of these 7 implants categories, used in this study cover the diameter range from 2 to 3.5 mm that these series of diameters called Narrow Platform series and some other with diameters smaller than 3 are called mini-implants. On the other wise, among these different implants, length range varies from 8 to 16.0 mm for upper/lower lateral incisor situation. Mandible section geometries in lateral incisor tooth position are 88.461 mm height, 48.514 mm width, and 10 mm thickness. In this position, the geometries of maxilla are 99.258 mm height, 60.495 mm width, and 10 mm thickness. Mandible and maxilla are involve cortical and cancelious. The cortical bone is outer layer of jaw. According to CBCT scans reports the thickness of this layer varies among the jaw bone that in lateral incisor teeth position, the most thickness in mandible is 22.39 mm and the less is 4.36mm. In this condition for maxilla the most thickness of cortical is 9.25 mm and the less is 1.085 mm. Nevertheless, the average thickness of this layer in maxilla and mandible respectively is 7.02mm and 10.31mm.

After modeling implant-abutment complex and bone, we apply different kinds of loads. To simulate the average masticator force in a natural loading on the implant, forces of 17.1 N, 114.6 N, and 23.4 N were applied respectively in lingual, axial, and mesiodistal directions [20]. In general, torque was generated by using two equal forces in magnitude, opposite in direction, applied to two opposite points on the diameter of the implant head. Therefore, in this paper, due to masticator forces and loads that caused by foods moving and also bruxism and clenching para-functional habits, we assume four components of torque that applied in teeth and implants. Values of torques components [11] are:

TABLE I: Torques in Different Directions

Direction	Min Value	Ave Value	Max Value
Axial	50 N.cm	—	100 N.cm
Lingual	100 N.cm	—	200 N.cm
Distal	100 N.cm	200 N.cm	300 N.cm
Occulasal (Cronal)	200 N.cm	400 N.cm	600 N.cm

These loads were applied on the top middle node of each implant-abutment assembly in the studied models but in different directions. These estimations about forces and torques were based on the assumption that an individual has three episodes of chewing per day, each 15 min in duration at a chewing rate of 60 cycles per minute (1 Hz). This is equivalent to 2700 chewing cycles per day. Due to the foods and liquids a thermal load is being applied to teeth and implants that it`s range is between 60 C as hot temperature and 15 C as cold temperature [20]. Another thermal load that been applied to teeth and implants caused by drilling process. In this period must be careful that the bone temperature not exceed to 47 C because upper temperature of 47 C endamage to the living bone tissue. The pre-load that every time is imposed to jaw bone is cause by human skull that it`s approximate weight is 16N. In addition, the swallowing pressure is applied to implants and teeth in cyclic form that values are:

TABLE II: Swallowing Pressure Cyclic Loads

	Each swallowing	Per hour	Total Pres
16 hr-awaking	5 Pascal	25 time	2000 Pa
8 hr-sleeping		10 time	400 Pa

Other kinds of loads are relative to implants preparation and installation processes that involve drilling and tightening loads. These loads are being defined according to different implants systems surgical catalogs. Following the modeling and loading, working steps in post processing consist of: 1) Analysis 2) Interpretation of results both numerically and by color-coding. In this paper, a nonlinear and complex static, dynamic, thermal and fatigue analysis was perfumed. The implant-abutment configurations were analyzed by using the Finite Element Method. After FE analysis, stress distribution in the FE model comes in numerical values and in color-coding.

Material property as an effective parameter in FEA, greatly influence the stress and strain distribution in a structure. In this research, we assume that materials are linear elastic isotropic for Titanium alloys and isotropic for Cobult-Chrome alloys. The implant, abutment, and abutment screw were all designed to be Titanium, Titanium-Aluminum-Vanadium (Ti-6Al-4V) and/or cobalt-chrome alloy that are changed among the different implant systems. The Segregated properties of different components are illustrated in Table III.

TABLE III: MATERIAL OF DIFFERENT COMPONENTS OF IMPLANTS SYSTEMS

	CMI	Implantium	Biodenta	Nobel	DIO
Fixture	Ti	Ti-6Al-4V	Ti Gr. 4	Ti Gr. 4	Ti-C
Abutment	Ti	Ti-6Al-4V	Ti-6Al-4V	Ti Gr. 4	Ti-C
Screw	Ti	Ti	Ti-6Al-4V	Ti Gr. 4	-

For bone because of the porous structure, we used nonlinear isotropic properties. Two types of bone density were modeled by varying the elastic modulus of compact bone and cancellous bone (with high and low densities) to account for the effect of the bone behavior on the implant accurately. The fragmental mechanical properties of materials that been used in this study are listed in below Table IV.

TABLE IV: MECHANICAL PROPERTIES OF IMPLANTS AND BONE

Material	Elastic Modulus	Shear Modulus	Tensile Strength	Density	Poisson Ratio
	(MPa)			(kg/m^3)	N/A
Ti Gr. 4	105000	45000	550	4510	0.37
Ti Gr. 4	105800	41023	827.37	4428.78	0.31
Ti	105000	45000	440	4500	0.37
Co-Cr	190000		1200	8290	0.3
Cortical	14000		7.82	1720	0.3
Cancellous	1370				0.3

After material properties were applied, a mesh 3D finite element model was constructed. For meshing, be used different finite elements softwares. The element in meshing all three-dimensional models is eight nodes Brick element (SOLID45), which has three degrees of freedom (translations in the global directions). The interface between implant and bone was modeled as an immovable and rigidly junction, which simulated the condition of the optimal implant osseointegration. For this purpose, ‘‘Fixed Geometry’’ option in the software was chosen. The bone and implants simulated models were meshed tetrahedron elements. Another relevant parameter in meshing is been mesh density. In this paper, a finer mesh was generated around the implant.

Next in this research, we peruse different implants of five implant systems that are chosen. Until a few years ago implants were used in several forms such as cylindrical, tapered, netted, etc., but many studies determined that implants with threated and combinations of the former forms are better. Reasons of using threaded implants relate to load shifting property. The threaded implants can change the direction of loads. Manner of this change, related to several parameters such as pitch, depth, angle and shape of threads. In this study, we classify mentioned parameters among the different selected implants to achieve the best values of each parameter that stress on implant been minimum. The selected implants have variable parameters that shown in below Table V.

TABLE V: THREAD PROPERTIES IN TERM OF IMPLANTS

Implants	Pitch (mm)	Depth (mm)
Biodenta	0.7	0.397
CMI	0.7	0.497
IMPLANTIUM	0.5	0.265
Nobel Speedy	0.5	0.251
Nobel Replaced	0.52	0.286

The objective of these analyses is been studied the effects of parameters such as pitch, depth and angle in success of implantation and finally proposing values to achieve the optimum value that minimize stresses on implants in lateral incisor position in maxilla and mandible. Therefore, in this study, it is investigated the implants with different properties in lateral incisor position, with different bone qualities according to lekholm and zarb classification to investigate the effect of above factors in success of bone integration process. According the lekholm and zarb classification four different qualities are assumed. In this study, after the analyzing implants, we interpret of results both numerically and by color-coding.

III. RESULTS AND DISCUSSION

The aim of this study was to find the pure effect upon the stresses of variations of the thread shapes. For this purpose, at first, we collect information about threads parameters. The comparison between these parameters, help us to achieve the optimum conditions about threads. In our study, because of using real models, the threads parameters are real, so, the results can show accurate analysis between the various threads parameters such as shape, depth, pitch, and angle of threads.

Previous studies had shown some advantages of threaded implants. One of these studies showed that threaded implants had higher remodeling rates and less mineralized bone formation when loaded with axial force than the non-threaded implants. Moreover, these responses were triggered by tissue micro damage as a direct consequence of the applied loads [21]. In other study of retrieved dental implants, it was found that bone defects tended to be located at the thread tops. This study showed that a square thread design (as opposed to the standard V-shaped or buttress thread) was suggested to reduce the shear component of force by taking the axial load of the prosthesis and transferring a more axial load along the implant body to compress the bone [22], [23]. Another study showed that modified square thread, looking like reverse buttress, imparted 10 times less destructive stresses at the implant-bone interface than conventional v-thread designs, while maximizing compressive load transfer, and providing excellent primary stability [18].

Based on the result of this study, stress distribution on surface of implants does not seem to be greatly differed. Almost in all models, the edge of threads is being in safe, but the most stress transferred to the inner portions on thread. If the implant has self-tapping, it's seems that due to the lower hole diameter ratio to implantation in respect to without self-tapping case, the nearest threads to this part have been exposed to more stress. So, it suggested that stress distribution in self-tapping site, is not influenced by thread shape under the similar condition.

On the other hand, due to the variable shapes of threads in selected implants, the values of stresses on each type of threads are been different, according to the finite element results. Samples implants models have conical threads that called "V-shaped" thread. According the previous studies, the classic forms of V-shaped, square and buttress threads do not have acceptable results, so in today`s modern threaded implants has been tried to use a combination of various shapes for thread. The shapes of threads in selected implants are being shown in below Fig. 1.

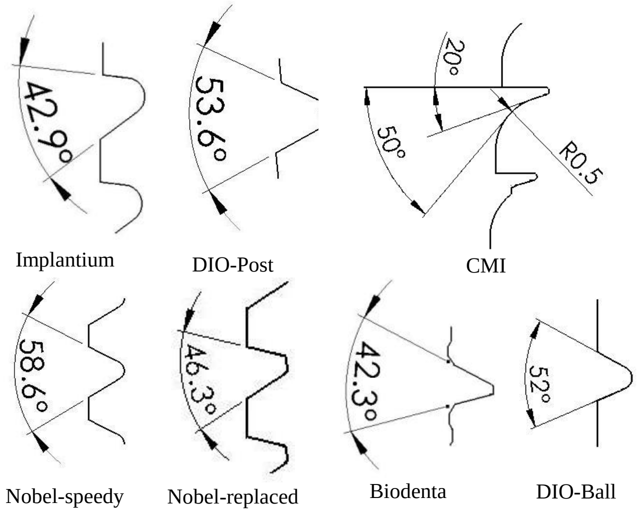

Fig. 1. Thread types in selected implants.

Pitch of the thread is one other parameter that influenced in thread. Pitch is the distance from one thread groove to the next, measured from crest to crest. According to the pitch concept, if the pitch value is being increased, the numbers of thread on implant is being decreased which this phenomenon reduce the amount of stress on threads. Stress reduction on threads, causes the lake of initial stability of implants. In relative with the thread shape, can noted to angle of thread. The angle included between the sides of the thread measured in an axial plane. The angle (included) of thread describes the threads type. According to the angle of threads in selected implants systems, threads are a combination of V shape, Whit worth, Pipe, Acme, Buttress and German Buttress (Fig. 2 a)).

Depth of thread is another factor that effect in amount of stress on threads. Depth is the distance between the top and bottom of the thread. Increase or decrease in depth can change the amount of the stress but in previous studies was not investigate the effect of depth value on threads, so in this study, it is considered different depth amounts of different threads, for achieve the optimum depth value (Fig. 2 b)).

According to results, the maximum stress value on threads in CMI implant threads is 6830MPa that these values related to the depth portion of thread. In Implantium system, the value of stress in depth of the thread is 11951MPa. In comparison of these two values, with considering the pitches and depths amounts, we can result that in CMI implant because of the larger value of pitch, the number of threads on the implant length is lower, and so, amount of stress is lower.

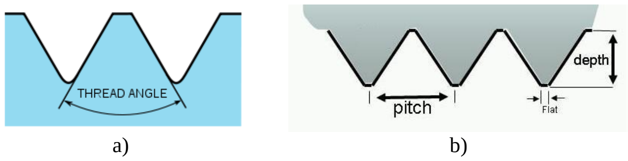

Fig. 2. Thread parameters.

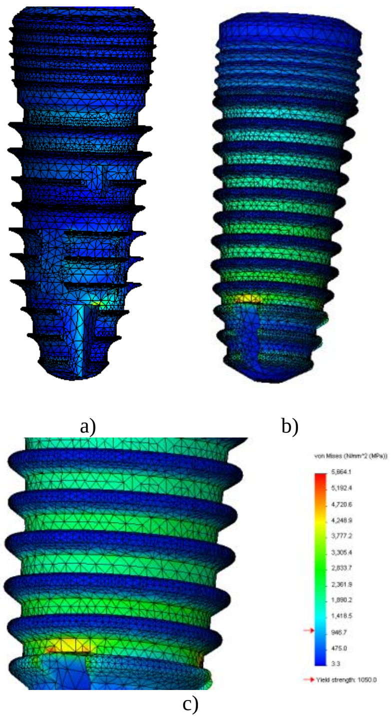

Fig. 3. The stress distribution in FE models, a) CMI, b) Implantium.

In other comparison, it is considered the results of Implantium and Nobel-replaced systems that their pitch amounts are so near to each other. In this case, the maximum stress in the depth of the thread for Nobel-replaced is 1060.3MPa. By comparing the results, it can be concluded, that by increasing the depth, the stress value on thread is decreased. In other case, by assuming the almost constant depth and comparing the results between Implantium (11951MPa) and Nobel-Speedy (5277.6MPa), we conclude that in implantium because of the shape of the thread, the stress is been higher than Nobel-speedy implant. An interesting issue about the thread is that Biodenta implant system, despite having a larger pitch and thread depth provides more efficient results.

In this study, we assume the important parameters of thread for investigate effects of each parameter on the stress distribution to achieve the best values and shapes for implant. According the results, von mises stress distribution and equivalent strain in the different areas studied. Some of results are shown in fig-3 and 4.

Except experimental articles that due to having enough time to passionately convey the planting process according to the physician faced with a variety of jaw bone of the patient and the physician in selecting the types of implants, in most conditions, theoretical papers have some restrictions that this issue cause to obtain various assumptions during FEA in various studies with quite different results. We tried to resolve these discrepancies. Therefore, we have some innovations in this article. At first, it is noteworthy that checking out of lateral incisor issue of dental implants has been lacking so far in the debates. Our other innovations are:

1) Evaluation of the theoretical results is conformity with clinical studies.
2) Neglecting hundred percent osseointegration and imposed the micro-gap.
3) In most previous papers just have been considered occlusal force, but in fact, other various loads are being affected on the implant that in this paper have been considered.
4) Because of the geometry complexities of the jaw in some papers, is not chosen the suitable elements for analysis, nevertheless, in this paper, the number of elements and nodes is selected according to the optimum results.

and some others.

IV. Conclusions

In this paper, based on the results from numerical analyses, the following conclusions are obtained from the effects of thread parameters:

1) Using the threads with more depth, enhances the stress distribution Decreasing the pitch of the thread, cause to reduce the number of threads that it is a bad occupation for the implant initial stability.
2) Decreasing the pitch of the thread leads to reduction of the number of threads that adversely affects the implant initial stability.
3) Shape of the thread is influenced by the angle, in either positive or negative way.
4) In Biodenta implant in spite of the higher pitch and depth we expect to highest stress on thread, but according to the modern design, and despite micro-thread between the main threads on implant surface, and using variable pitch and angle for main threads, will cause lower stresses in the implant.

Acknowledgment

The authors wishes to express their deepest gratitude to Dr H.Mehdizade, Decedent Dr. H. Hamidi, Mr. D. Porafshar, Dr. Zeratiyan, Eng. Kazempour, Eng. Asakere, , Eng. Fathi and some others for their great helps and efforts.

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