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INFLUENCE OF DIFFERENT THREAD PROFILE DESIGNS ON THE BIOMECHANICAL BEHAVIOUR OF PEEK DENTAL IMPLANT AND THEIR SURROUNDING BONES: A 3D-FEA STUDY

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ABSTRACT

Background: Generally, dental implants helps the people, who losing their teeth partially or completely (EDENTULOUS PATIENTS). The success of the dental implant depends upon various factors, one of the most important factor is implant thread geometry. Because the implant geometry directly contributes the magnitude and distribution of the stress created in the bones and implant, even leads to implant failure when load is applied. **Objective:** Our aim is to find out the most suitable implant thread geometry which minimum stress in the mandibular premolar region among four commonly known thread geometries such as square, V, buttress and reverse buttress. **Materials and Methods:** Four different implants and bone models were designed and assembled using Solidworks 2013.The implants were made up of a biocompatible polymer material *POLYETHERETHERKETONE* (PEEK).Finite element analysis were performed for different assembled implant- bone models by applying a static load to the abutment of the implant using ANSYS 14.5 version.**Results:** Increasing the degree of osseointegration resulted in decreased von-Mises stresses on the implant-cortical transition region, the implant- cancellous transition region, the cortical bone, and the cancellous bone.**Conclusion:** From our study,the implant with square thread profile shows minimum stress when compared to all other thread profiles like v, buttress and reverse buttress.

KEYWORDS:

Three dimensional finite element analysis; osseointegration; PEEK implant; thread profiles.

INTRODUCTION

Implants are artificial medical device used to replace the damaged or missing parts of the body. In such a way that the dental implant supports patients who lost their teeth accidently.Dental implants are widely used and are considered to be one of several treatment options that can be used to replace missing teeth. A number of implant-supported treatment options have been used successfully to replace a single tooth and multiple teeth, as well as a completely edentulous jaw. However, as the number of patients who have dental implants is increasing, dental personnel are more likely to see patients with implant-supported restorations or prosthesis. Nevertheless, dental implants may fail as a result of mechanical complications, such as screw loosening or due to biological causes like peri-implant diseases. This can be overcome in nowadays by using the osseointegrated implants.

Finite element analysis is the computer aided technique used to analyse the stress numerically in all engineering fields in order to avoid the implant failure when load is applied. The four concept used in Finite element modelling are,1.Systemis typically a physical object composed of various material. e.g. solids, liquid, gases or combination of the above. 2.Domain of problem is typically the region of space occupied by the system.

3.Governing equations may be a differential equation, integral equation or a constitutive equation describing the physical properties, & material behaviour.4.Loading conditions are externally originating forces, temperature, etc. that interact with the system causing the state of the system to change. Load acting in the interior of the domain, i.e. interior load appears as part of governing equation. Loads acting on the boundary of the domain i.e. boundary loads appears in separate equation called boundary conditions.

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In this method domain (structure) of the problem is divided into smaller regions called elements. Adjacent elements touch without over lapping and the there are no gaps between the elements. The shape of the elements are intentionally made as simple as possible, such as triangles or quadrilaterals. The entire mosaic like pattern of element is called a Mesh. The Mesh generation is done by **preprocessors**. In each element the governing equations are transformed into algebraic equations, called Element Equations, which are an approximation of the governing equations. Algebraic equations are much easier to work and are relatively easy to solve.
The terms in the element equations are numerically evaluated for each element in the mesh, a process best performed on a computer. The resulting numbers are assembled into a much larger set of algebraic equations called the System equations.
These characterize the response of the entire system so they usually comprise of a very large number of equations, hundreds of thousands. Now the boundary conditions are applied which include the boundary loads. These are imposed by modifying the system equations. This involves adding values to existing terms and or shifting terms from one side of the equations to the other. Both are relatively simple operations.
The system equations are then solved on a computer using conventional numerical analysis techniques that have been popular for many years, having evolved prior to the Finite element analysis. The final operation, called **postprocessing** displays the solution to thesystem equations in tabular, graphical, or pictorial form. Other physically meaningful quantities might be derived from the solution and also displayed.

OBJECTIVES

The main objective of the study is to identify the most suitable implant thread geometry which produces minimum stress in the mandibular premolar region among four commonly known thread geometries such as square, V, buttress and reverse buttress using finite element analysis.

MATERIALS

The most commonly used materials for dental implants are titanium and zirconia. This material may cause allergic reactions in some patients, and also aesthetic problem in it. This can be overcome by a new material **polyetheretherketone (PEEK)** which is a is a polycyclic, aromatic, thermoplastic polymer that is semi-crystalline and has linear structure. This material is obtained as a result of the binding of ketone and ether functional groups between aryl rings and is andelement which is tan-colored in its pure form. This PEEK material is used as a implant material in our project. Mechanical properties of PEEK material are Poisson's ratio:0.3779,Young's modulus:3.76GPa and density:1320kgm^{-3}.

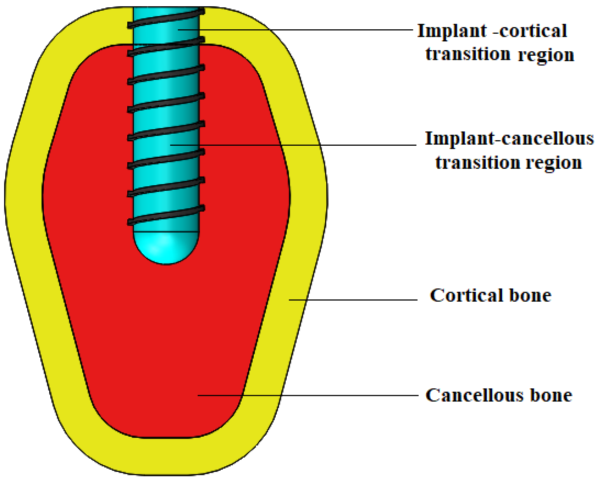

Figure 1. Cross-sectional view of the dental implant,the implant cortical transistion region, cancellous transistion region.cortical bone and cancellous bone

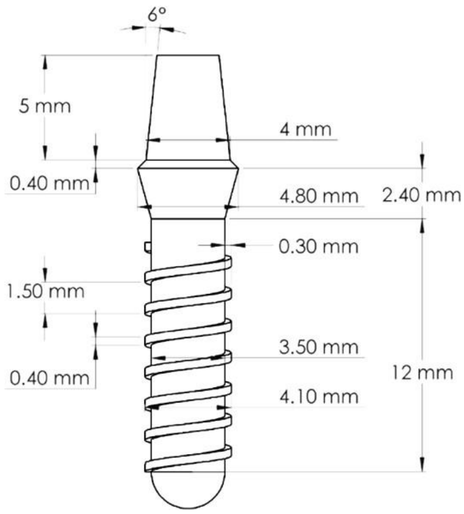

Figure 2. Schematic representation of design parameters used for modeling the dental implant implant and the abutment.

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Table 1. Mechanical properties of cortical and cancellous bone at different degrees of osseointegration.

Mechanical properties	**Cortical bone**			**Cancellous bone**		
	50%	75%	100%	50%	75%	100%
Young's modulus **E** (MPa)	9700	14500	19400	574	861	1148
Poisson's value	0.253	0.253	0.253	0.32	0.32	0.32
Shear modulus **G** (MPa)	2850	4275	5700	217	325.5	434

METHODOLOGY

Finite element modeling is used to find out the stress occurred in premolar mandible region when load is applied. It is described as the representation of the geometric model in terms of a finite number of elements and nodes which are building blocks of the numerical representation of the model. An element which may consist of triangular or quadrilateral shapes is mathematical matrix of the collective interaction among degrees of freedom whose (displacements) and actions (forces) of structure under load are considered to exist.The 3D model of the bone and PEEK implants with different thread profiles were designed by using commercially known Computer Aided design tool called **"SOLIDWORKS-2013"**and it can be analy sed by using **"ANSYS 14.0"** software.

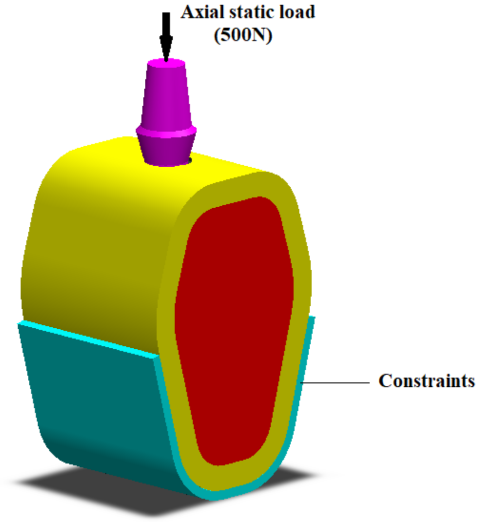

Figure 3.Representation of boundary and loading conditions on 3D finite element dental implant and the surrounding bones.

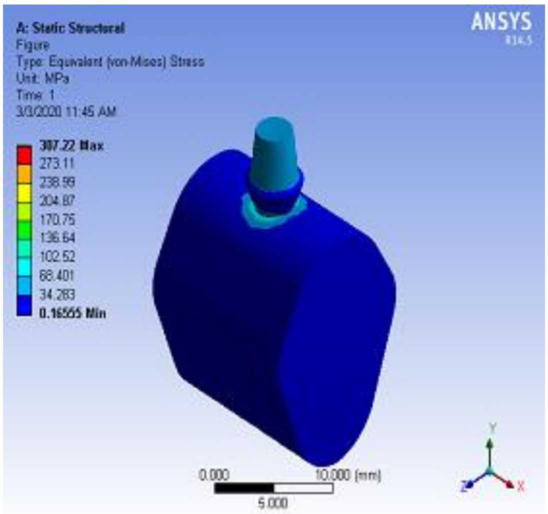

Figure 4. Distribution of von-mises stress on buttress implant at 75% osseointegration.

RESULTS AND DISCUSSION

The successfully treatment for partially or fully edentulous patients is replacing the damaged tooth with a dental prosthesis. Dental implant with suitable thread profile plays a vital role in the success of dental implants. In our

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study, we were using four different commercially available thread profiles were used in implant and compare the contact stresses (von-Mises stresses, shear stresses, and compressive stresses) acting on the surrounding bones of the implant when occlusal load is applied on the abutment surface using three dimensional Finite element stimulations and remaining parameters were kept constant. This may be useful for comparison of dental implants with different thread profiles. The noticeable things of our study were: (1) the cancellous bone close to the cortical region of the implant and the implant experienced peak stress concentration, and (2) decreasing the degree of osseointegration resulted in increased von-Mises stresses on the implant-cortical transition region, the implant-cancellous transition region, the cortical bone, and the cancellous bone.

Thread profile type	**osseointegration**	**Stress developed in bone MPa**	
		Min	**Max**
Buttress	50%	0.18269	351.19
	75%	0.16555	307.22
	100%	0.15614	273.35
Reverse buttress	50%	0.17438	512.17
	75%	0.16236	451.63
	100%	0.15828	403.06
V-Thread	50%	0.1862	449.72
	75%	0.17429	399.78
	100%	0.16418	360.28
Square thread	50%	0.16367	271.23
	75%	0.17909	254.39
	100%	0.17575	241.51

Table 2. Peak von-Mises stresses induced on the implant-cortical transition region, implant-cancellous transition region, cortical bone, and cancellous bone when the dental implant was subjected to an axial static occlusal load of 500 N.

The stress experienced by the surrounding bone of the implant experienced similar in all four different thread profiles. Among four different thread profiles, a dental implant with square thread profile induced lower von-Mises stresses on the transition region and bulk bone. The shear stress distribution is similar to the von-Mises stress distribution, which also have no significant change among four thread profiles. For all four thread profiles, the cancellous bone experienced high values of shear stresses when compared to that in the cortical bone.The compressive stresses were also no change in our model. Decreasing the degree of osseointegration, the compressive stresses were increased in model were shown in Table 10, 11 & 12. High compressive stress were experienced by the cancellous bone than in the cortical bone similar to other contact stresses.The degree of osseointegration is increased from 50% to 100% resulted in 5% to 6% decrease of peak von-Mises stresses induced on the implant-cortical transition region, implant- cancellous transition region, cortical bone, and cancellous bone were shown in Table 4, 5 & 6. From our study, for analyse the dental implant with different

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thread profiles the degree of osseointegration were in the range of 75% to 90% be a suitable consideration [11,12].Among all different thread profiles, the von-Mises stress distribution in the surrounding bone of the implant were almost similar as in the result published byGeng *et al* [1]. They reported that the contact stress on the cortical bone was not sensitive to thread profiles. The way of transferring the stress to bulk bone plays a major role in long term survival of the dental implant [5]. The implant thread profiles should be design to induce less stress in implant contact surface of bone [15]. The density of the bone is increased by the compressive force which results in increasing bone strength, whereas in tensile and shear can decrease the strength of the bone [15].

Thread profile type	osseointegration	Stress developed in bone MPa	
		Min	Max
Buttress	50%	-117.93	96.475
	75%	-97.98	93.004
	100%	-83.031	85.821
Reverse buttress	50%	-82.465	184.57
	75%	-76.631	164.54
	100%	-73.178	147.27
V-Thread	50%	-83.146	183.84
	75%	-72.564	162.63
	100%	-68.488	145.56
Square Thread	50%	-55.868	104.07
	75%	-55.38	83.837
	100%	-57.312	76.308

Table 3. Shear stresses induced on the implant-cortical transition region when the dental implant was subjected to an axial static occlusal load of 500 N.

The dental implant with square thread induced the lowest contact stresses to bone structures at all degrees of osseointegration on the implant-cortical transition region, implant-cancellous transition region, cortical bone, and cancellous bone. This result is in contrast with the findings of Velmurugan *et al* [14]. This result is in line with the findings published by Mosavar *et al* [11] and Misch *et al*[15]. They reported that the dental implant with a square thread induced lowest contact stresses induced on the bone structures at all degrees of osseointegration.The dental implant with a reverse buttress thread and the dental implant with a V-thread induced similar shear stresses on the transition region and the bulk bone at all three degrees of osseointegration were shown in Table 2,3,4.

At all different degree of osseointegration, compressive stresses induced in the surrounding bones of the implant were different were shown in Table 10, 11 & 12. The dental implant with a square thread induced greater values of compressive stress on the transition region and the bulk bone. The bone strength can be increased by increasing the compressive forces in the implant-bone interface by increases the bone density [2]. Therefore, the square thread profile type is considered to be a favourable shape for the dental implant made of the

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biocompatible Polyetheretherketone material. From this study, we find out that the dental implant with square thread profile induced lower values of von-Mises stresses and shear stress and induced higher values of

Thread profile type	osseointegration	Stress developed in bone MPa	
		Min	Max
Buttress	50%	-92.983	283.97
	75%	-82.073	255.31
	100%	-82.658	232.6
Reverse buttress	50%	-140.57	229.13
	75%	-139.67	216.94
	100%	-136.47	206.74
V-Thread	50%	-105.09	251.99
	75%	-80.419	235.53
	100%	-86.888	220
Square thread	50%	-167.96	219.24
	75%	-139.35	237.27
	100%	-129.37	213.6

Table 4. Peak compressive stresses induced on the bone surrounding the implant when subjected to an axial static occlusal load of 500 N.

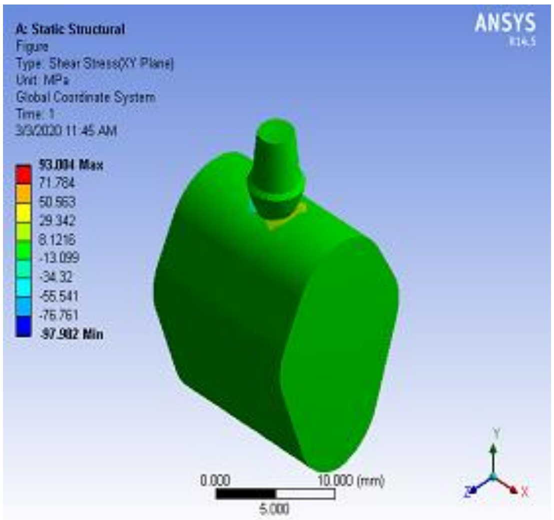

Figure 3.Distribution of shear stress on butress implant at 75% osseointegration

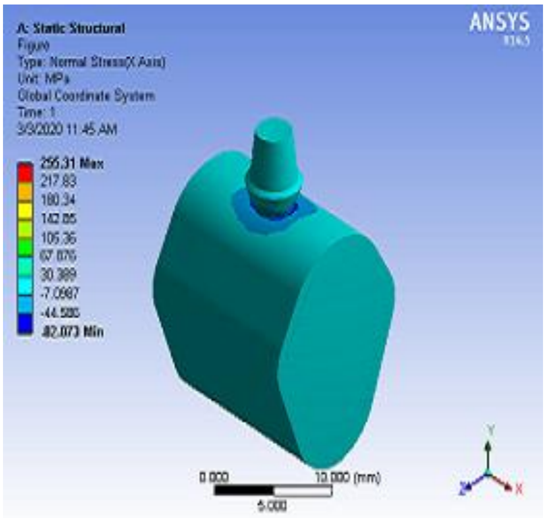

Figure 4. Distribution of normal (compressive) stress on buttress implant at 75%osseointegration.

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compressive stress on the transition region and the bulk bone at all three degrees of osseointegration.

LIMITATIONS

In our study the clinical bone model stimulated using Finite Element analysis, which is based on mathematical calculations and based on simulation of the structure in it environment. But the parameters of living tissues and bones are not in confined i.e. biology is not a computable entity. Another assumption in our study is the bone is assumed as transversely isotropic in nature, but the natural bone may behave as anisotropic in nature. The above limitations are to be consideredwhile interpreting the results of a functioning clinical scenario, and further studies are required.

CONCLUSION

In this study, we have demonstrated that a solid-screw Polyetheretherketone dental implant of **square thread** profile prevents higher magnitude contact stresses within the surrounding bones when compared to dental implants of buttress thread profile, reverse buttress thread profile, and V-thread profile. The contact stresses (von-Mises stresses, shear stresses, and compressive stresses) are occurred due to non-suitable thread profile, type of the dental implant and the degree of osseointegration. Increasing the degree of osseointegration resulted in decreased von-Mises stresses on the implant-cortical transition region, the implant- cancellous transition region, the cortical bone, and the cancellous bone.These results may help to optimizethe design parameters of the dental implants and also to accomplish long-term implant survival and success in the clinical scenario.However further clinical research is required in order to prove it as a reliable and a successful treatment method.

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