Original Article

Finite element evaluation to compare stress pattern in bone surrounding implant with carbon fiber-reinforced poly-ether-ether-ketone and commercially pure titanium implants

ABSTRACT

Background: Titanium allergy is a main reason for failure of dental implant. Hence, newer implant biomaterials have emerged such as zirconia and carbon or glass fiber reinforced poly-ether-ether-ketone (CFR-PEEK)-based materials. The aim of the present study was to compare the stress pattern in bone surrounding implant with CFR-PEEK and commercially pure titanium implant.

Materials and Methods: Three-dimensional formal model of mandibular first molar partsubstituting with implant supported crown was generated. Implant with dimensions of 10 mm length and 4.3 mm diameter was used in this study. Finite element models of CFR-PEEK and commercially pure titanium implant assemblies were generated. A 100 Newton (N) force was implemented along the long axis and obliquely at 30 to the long axis of implant. Von Mises pressures generated in the bone surrounding implant were analyzed using ANSYS workbench 16.0 and other finite element software.

Results: Similar stress distribution was detected in bone surrounding implant with CFR-PEEK implant and commercially pure titanium implant assembly under 100 N force applied vertically and obliquely.

Conclusion: PEEK reinforced with carbon or glass fiber implants can be a viable alternative in individuals who are more of esthetic concern and who demonstrate allergy to metallic implants.

Keywords: Carbon fiber reinforced poly-ether-ether-ketone implant, finite element analysis, stress distribution, titanium implant

INTRODUCTION

Implant-supported prosthesis used to replace missing teeth is the most accepted treatment option in prosthodontics nowadays. There is a continuous research going on to come out with new materials which can be used as implant biomaterials. From the decades, in dental and medical area, titanium is the gold standard material for endosseous implant because of its superior properties.[1]

Although titanium possesses superior properties, few disadvantages of this material such as potential hypersensitivity in susceptible individuals and its darker color which causes dark appearance of the peri-implant mucosa, which has led to

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Syeda Amtul Haseeb, Vinaya K. C., Neha Vijaykumar[1], Anju Sree Durga B., Anju S. Kumar, Sruthi M. K.

Department of Prosthodontics, Sharavathi Dental College and Hospital, [1]Department of Prosthodontics, Subbaiah Institute of Dental Sciences, Shivamoga, Karnataka, India

Address for correspondence: Dr. Syeda Amtul Haseeb, Department of Prosthodontics, Sharavathi Dental College and Hospital, Alkola, T H Road, Shivamoga - 577 205, Karnataka, India.
E-mail: drsyedajaved@yahoo.com

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search for new implant biomaterials. In general, no material can be considered completely biocompatible. According to the literature, titanium allergy is a main reason for failure of dental implant.[1-3]

To overwhelm these limitations and to fulfil the esthetic demands, newer implant biomaterials have emerged in the field of implantology. These novel biomaterials consist of zirconia a high strength ceramic and poly-ether-ether-ketone (PEEK). Zirconia seems to be suitable implant biomaterial due its esthetic appearance, biocompatibility, and superb mechanical properties. According to the literature, zirconia has demonstrated successful osseointegration and stress distribution similar to titanium implants.[4-7]

PEEK is a high temperature thermoplastic polymer, composed of ketone and ether functional groups. Chemical structure of PEEK has stability at high temperatures (exceeding 300°C). PEEK shows resistance to chemical and radiation damage. It can be strengthened with many reinforcing agents such as glass and carbon fibers. Pure PEEK has less modulus of elasticity of 3–4 GPa which is not sufficient to use as dental implant. It can be strengthened with many reinforcing agents such as glass and carbon fibers to increase modulus of elasticity. Surface modification with many materials such as TiO_2 and tricalcium phosphate has resukted in successful osseoin similar to titanium implants. By 1990s, PEEK became popular high-performance polymer for replacing metallic implant in orthopedics. In 1992, PEEK was used in dentistry, first as esthetic abutments and later as implant. PEEK implant has unique characteristics, including biocompatibility, radiolucency on X-ray, magnetic resonance imaging compatibility, adjustable mechanical performance, chemical resistance, and sterilization capability.[8]

A main reason for the failure or success of a dental implant is the manner in which stresses are transmitted to peri-implant bone. Several studies have identified the pattern of stresses in bone-implant interface as well as in cortical bone and trabacular bone with finite element analysis (FEA).[9] FEA is a commonly followed method to determine the biomechanical effects of dental implants. The literature reveals that it has been widely used to model the design and functionality of dental implants. Direction, magnitude, and duration of load on the implant is significant in dissipation of forces from implant assembly into the surrounding bone.[10] Forces during mastication have a cyclic impact on alveolar bone and are applied during a limited period of mastication. Fatigue testing is considered most reliable test to obtain long-term data of clinical importance in the implant dentistry.[11,12] In this study, stresses generated in bone surrounding implant with carbon fiber-reinforced PEEK (CFR-PEEK) and titanium implant assemblies were observed and compared.

MATERIALS AND METHODS

This study was carried out at MIT, Manipal. Methodology consists of geometric modeling and converting it into a mesh model. After obtaining mesh model, material properties were assigned. Boundary condition was determined and load at different angulations was applied. Analysis of stresses and comparison von Mises stresses was done. For ethical clearance was obtained from Sharavathi Dental College and Shivamogga, Institutional Ethical Committee with Ref No. SDC/SMG/2016/246.

Three-dimensional (3D) model of mandibular first molar area with implant-supported crown was created using Tata Technologies Certified Catia V5 R20. Bone section comprising cortical and cancellous bone with 28 mm height and 12 mm width corresponding to tooth number 36 was taken for the study. The bone quality D2 corresponding to the posterior mandible was generated. Design and dimensions of implant were considered according to Nobel Biocare implant system.[13] Dimensions for crown morphology were taken from the standard dental anatomy textbook.[14]

A graphic processing software ANSYS version 16.0, Ansys, Inc.Canonsburg, Pennsylvania, USA was used for creating 3D geometric mesh configuration of section of mandible with implant assembly using 115,250 nodes and 8,045,230 elements, as shown in Figure 1.

Two different finite element models of CFR-PEEK and titanium implant assemblies were studied to compare

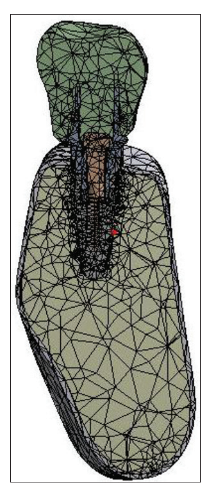

Figure 1: FEM of D2 bone with implant assembly

the stresses in peri-implant bone. Both the models were similar, except for the material properties. All materials used in the models in this FEA study were considered as homogenous, isotropic, and linear elastic. Poisson's ratio and young's modulus of elasticity of materials were incorporated in the models to conduct FEA according to Table 1. A masticatory load of 100 Newton (N) at vertical and oblique at 30° to the long axis of implant were applied on to the occlusal surface of FEA model. Rigid supports were added in the lower and lateral regions of bone to simulate the bonding of the model to the rest of the jaw. Stress analysis was performed, and Von-Mises stresses were compared.

RESULTS

Amount of peak stresses in bone with both implants under vertical and oblique load are shown in Table 2.

Stress pattern with carbon fiber-reinforced poly-ether-ether-ketone implant with vertical and oblique load

Under vertical load, maximum stress of 2.1841 MPa around the apex of implant was observed. A lowest stress of 0.009065 Mpa was observed. Under oblique load, a maximum stress of 5.0280 Mpa around the neck of the implant was observed. A lowest stress value of 0.0064726 Mpa was observed. Stresses were distributed homogeneously over peri-implant bone [Figure 2].

Stress pattern with titanium implant with vertical and oblique load

Under vertical load, maximum stress value of 2.1845 MPa just below the neck of the implant was observed, and minimum stress of 0.009024MPa was observed. Under oblique load, a maximum stress value around the neck of the implant observed was 5.1861 Mpa and minimum stress was 0.0064702 Mpa [Figure 3].

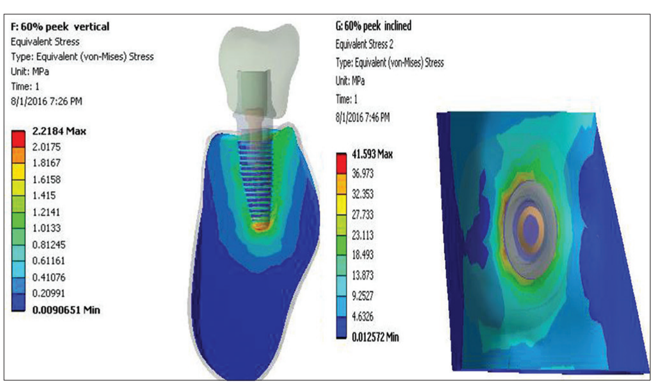

Figure 2: Stress pattern with carbon fiber reinforced poly-ether-ether-ketone implant with vertical and oblique load

It was observed that, the stresses generated by CFR-PEEK and titanium implant assemblies were similar under vertical and oblique load, and stresses were homogenously distributed in peri implant bone.

DISCUSSION

Restoration of missing teeth with implant-supported prosthesis is the most recommended option in edentulous patients. Superior properties and biocompatibility of zirconia and CFR-PEEK could replace titanium in individuals who are allergic to titanium as literature shows titanium allergy is one of the important cause for implant failure. Studies have proved that PEEK reinforced with carbon or glass fibers is biocompatible and possess excellent properties and distributes stress similar to titanium.[8,11,15-18]

PEEK is a thermoplastic polymer and well-known alternative biomaterial to metallic implants in orthopedics and traumatology. Pure PEEK possesses modulus of elasticity of 3–4 Gpa which shows higher deformation. According to the literature, PEEK reinforced with glass and carbon fibers, PEEK with surface modifications has shown osseointegration and stress distribution similar to titanium.[19] Lee *et al*. and Schwitalla *et al*. with their studies demonstrated that PEEK reinforced with glass and carbon fibers is suitable as dental implant biomaterial.[11,15,20] In contrast to the current study, in a study by Sarot *et al*.,[21] 30% CFR-PEEK and titanium was used to compare the stress pattern around implant bone.

Table 1: Properties of materials used in the study

Materials	Modulus of elasticity by young (Gpa)	Poisson's ratio
CFR PEEK (endolgin)	150	0.34
Commercially pure titanium	117	0.34
Chrome-cobalt alloy	216	0.32
Cortical bone	17.2	0.3
Cancellous bone	1.35	0.32

CFR PEEK: Carbon or glass fiber-reinforced poly-ether-ether-ketone

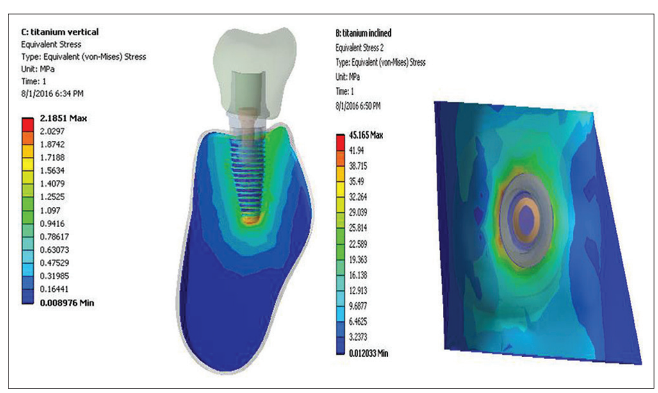

Figure 3: Stress pattern with titanium implant with vertical and oblique load

Table 2: Values of stresses in the bone with carbon or glass fiber reinforced poly-ether-ether-ketone and titanium implant assemblies under vertical and oblique load

Type of load	Maximum von-Mises stress in MPa		Minimum von-Mises stress in MPa	
	CFR PEEK	Titanium	CFR PEEK	Titanium
Vertical load	2.1841	2.1845	0.009065	0.009024
Oblique load	5.0280	5.1861	0.0064726	0.0064702

CFR PEEK: Carbon or glass fiber-reinforced poly-ether-ether-ketone

They determined that under oblique load, CFR-PEEK implant indicated greater stresses at the bone-implant contact because of a greater deformation of PEEK implant than titanium implant.

It was suggested that further strongly reinforced PEEK implant could reduce stresses at bone-implant contact due to the increased modulus of elasticity. Hence, accordingly, PEEK implant reinforced with 60% carbon fibers was considered in the study. According to a literature tapered or screw-shaped implants are of better choice than cylindrical implants.[22]

In the current study, 100 N load was applied in vertical and oblique at 30° direction and stress pattern in the surrounding bone was assessed. 100 N load was used in accordance to previous studies where 100 N vertical and oblique load was applied on occlusal surface, which aims to simulate real function situation of the oral cavity.[20,23,24] It was detected that with vertical load both implant assemblies demonstrated similar stress pattern. Under oblique load, titanium implant assembly has caused slightly more stress compared to and CFR-PEEK implant assembly. Under oblique load, results are similar to studies which has shown that tapered endosseous implant with high modulus of elasticity would be more suitable for implant dentistry.[20,22] Modulus of elasticity and load transfer is an important criterion for the selection of dental implant to achieve homogeneous stress distribution in peri-implant bone.

This FEA study has demonstrated the importance of CFR-PEEK implants which has demonstrated similar von Mises stresses as titanium implant. Hence, CFR-PEEK can be viable alternatives for Titanium, especially for those who show titanium allergy and esthetic concern.

The present study is a computational method of testing the 3D models by crating real oral function. However, further long-term clinical trials are required for evaluating clinical success on long-term basis.

CONCLUSION

Importance of implant biomaterials other than titanium such as CFR-PEEK should be considered. In this study, stress generated by CFR-PEEK implant is compared with titanium. Similar stresses in peri implant bone were observed with both CFR-PEEK and titanium implant biomaterials. Hence, CFR-PEEK implants can be considered an alternative to titanium implants in patients with metallic allergies and also as an esthetic implant biomaterial.

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Conflicts of interest

There are no conflicts of interest.

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