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Review Article

A 3D Finite Element Analysis to Compare Stress Distribution and Deformation in Bone using Titanium, Zirconia and PEEK Implant Biomaterials

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AIM

To compare stress distribution and deformation in bone surrounding implant using three different implant biomaterials Titanium, Zirconia & PEEK composites.

MATERIALS & METHODS

A 3D geometric model of left mandibular area with missing first molar and replacing it with implant supported crown was generated. Implant of 10mm length & 4.3mm diameter was used in study. FEM of implant assemblies of three materials Titanium, zirconia & 60% CFR PEEK were generated. Force of 100 N was applied vertically and obliquely at 30 degree to the long axis of implant. Von Mises stresses and deformation were analyzed using ANSYS workbench 16.0 and finite element software.Results of the imitations attained were assessed in terms of Von Mises equivalent stress levels at bone–implant interface.

RESULTS

All 3 implant assemblies under vertical load demonstrated similar stresses and deformation in bone. Under oblique load, titanium implant assembly has demonstrated slightly higher stress and deformation compare to zirconia and PEEK composite implant assemblies.

CONCLUSION

It was concluded that Zirconia and PEEK implants can be used as an alternative implant biomaterial to titanium in individuals who are more of esthetic concern & who shows allergy to titanium.

Keywords: Finite Element Analysis; PEEK Implant; Stress distribution; Titanium implant; Zirconia implant

INTRODUCTION

Restoration of lost teeth with implant supported prosthesis has become most accepted treatment modality in prosthodontics. Titanium is considered as material of choice as endosseous implant in medical and dental field because of its superior mechanical properties and biocompatibility [1].

Despite of various advantages, few disadvantages of this material have led to search new materials which replace titanium as implant biomaterial. Among these disadvantages of titanium most important is potential hypersensitivity in susceptible individuals and esthetic concern due to its dark grayish colour and lack of light transmission which can provoke dark shimmer of the peri-implant soft tissue. It should be noted that no material can be deliberated generally biocompatible and this does include titanium. It has been suggested that titanium hypersensitivity may be a factor responsible for implant failure [1, 2].

To overcome these limitations, new materials for implants have emerged as alternative to titanium. These novel materials include Yttrium – Partially Stabilized Zirconia (Y- PSZ) a high strength ceramic and poly-ether-ether-ketone (PEEK) composites. In recent years, zirconia ceramics have become most popular as biomaterials for dental implants. Zirconia seems to be a suitable material for dental implants because of their tooth-like colour, excellent mechanical properties and biocompatibility. Studies have proved the osseointegration of zirconia through histomorphometric & ultra-structural techniques like SEM observation [3-6].

PEEK is a comparatively new family of high temperature thermoplastic polymers, containing of an aromatic backbone molecular chain, interconnected by ketone and ether functional groups. Chemical structure of polyaromatic ketones confers stability at high temperatures (exceeding 300°C), resistance to chemical and radiation damage, compatibility with many reinforcing agents (glass and carbon fibers). In 1992, PEEK was used for dental applications, first in the form of esthetic

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abutments and later as implant. PEEK implant has unique characteristics including biocompatibility, radiolucency on X-ray, MRI compatibility, adjustable mechanical performance, chemical resistance, sterilization capability [7].

A major factor for the success or failure of a dental implant is the means in which stresses are transferred to the surrounding bone. Researchers can predict stress distributions in the contact area of an implant in cortical bone and around the apex of an implant in trabecular bone with FEA Finite Element Analysis (FEA) has proved to be effective tool to evaluate the biomechanical properties of dental implants [8]. The magnitude, direction and duration of load employed on the implant plays an important role in the dissipation of forces from the restoration, abutment, screw, fixture unit into the surrounding bone [9]. Bite forces during masticatory function have a cyclic impact on the bone and are only applied during a limited period. Hence, fatigue testing is considered as most reliable test to produce long-term data of clinical relevance in dentistry [10].

It is believed that 3D models are more realistic and represent the biomechanical interactions of the human anatomy, restorations and implant components as a complex and are more superior to 2D models. Some norms impact the exactness of the FEA results significantly. These incude detailed geometry of the bone and implant to be modeled, material properties, boundary conditions and interface between bone and implant [11]. In this study, an attempt is made to investigate the stress patterns and deformation in bone surrounding titanium, zirconia and PEEK implant assembly separately.

MATERIALS AND METHODS

This 3D finite element analysis was done in the department of Prosthodontics after obtaining the ethical approval from institutional ethics committee. Methodology was categorized as: Geometric modeling, meshing of model, assigning material properties, Application of boundary condition, Application of different load, Analysis of stresses and comparing Von Mises stress components

GEOMETRIC MODELLING

3D geometric model of a left mandibular region with missing first molar and replacing it with implant supported crown was generated in CATIA V5 R 20. Bone section of 27.5 mm height and 12.3 mm width portion of cancellous bone and cortical bone corresponding to tooth number 36 was considered as shown in Figure-1.

Fig 1: 3D CAD Model and FEM of D2 bone with implant assembly

The bone quality D2 was generated. Design and dimensions of implant assembly were considered as given in Table-1[12]. Dimensions for crown morphology were considered from standard dental anatomy textbook [13].

MESHING OF MODEL

A graphic processing software ANSYS version 16.0 was used for creating 3D geometric mesh configuration of section of mandible with implant and crown in the left first molar region using 1,15,250 nodes and 80,45,230 elements. An implant with prosthetic components surrounded by cortical and cancellous bone were modeled as shown in Figure-2.

Fig 2: 3D CAD Model and FEM of D2 bone with implant assembly

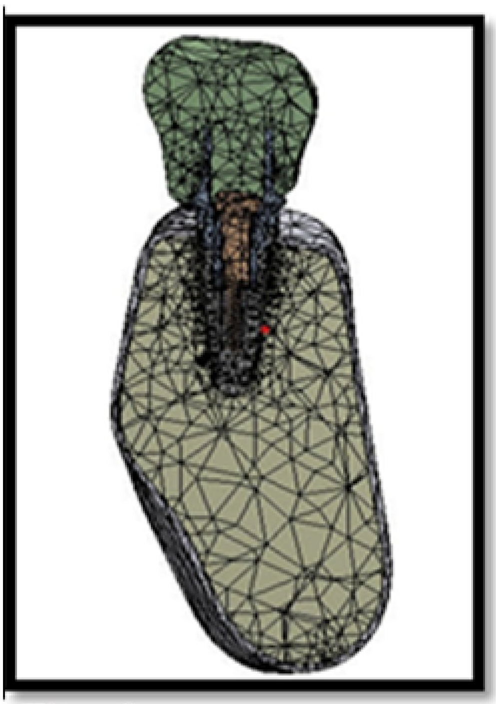

Fig : 2

ANALYSIS

Three different models (titanium, zirconia and PEEK) were investigated in this study to compare the stresses and deformation in surrounding bone of implant. All the models are identical, except for the properties of the used materials. All material used in the models were considered as homogenous, isotropic and linear elastic. Poisson's ratio and young's modulus of elasticity of materials were incorporated in the models as shown in Table-2. All contacts among the structures were considered perfectly bonded. A masticatory load of 100N at vertical and oblique at 30 degrees were applied on to the occlusal surface of FEA model. Rigid supports were incorporated in the lower and lateral regions of bone to mimic the bonding of the model to the rest of the jaw. Stress analysis was performed by comparing the compression stress and Von-Mises stress components. An analysis of the model's deformation degree was also performed in the same simulation using the same software.

RESULTS

Table 1: indicates various implants details

Implant dimension	**4.2 mm Diameter** **12 mm length**
Collar height	1.4 mm
Collar diameter	4.2 mm
Apex diameter	2.5 mm
Thread depth (major dia – minor dia)	4.2-3.5= 0.5 mm
Thread width	0.5 mm

Table 2: indicates material properties of various implant type

Materials	**Modulus of elasticity(Mpa)**	**Poisson's ratio**
Gold Alloys	101,000	0.32
Zirconia (y-szp)	208,000	0.23
Cobalt Chromium (Co-Cr-Mo) alloy	212,000	0.31
Cortical bone	16400	0.2
Cancellous bone	1310	0.33

Table 3: Deformation in bone and stress using different alloys under oblique and vertical load

Type of load	**Maximum von-Mises Stress in MPa**			**Minimum von-Mises Stress in MPa**		
	Gold Alloys	**Zirconia**	**PEEK**	**Gold Alloys**	**Zirconia**	**PEEK**
Stress under vertical load	2.1642	2.2467	2.2138	0.008358	0.0091356	0.0090347
Deformation under vertical load	0.0035302	0.0032679	0.003357	0.00032005	0.0004245	0.0004346
Stress under oblique load	5.1457	3.6359	4.275	0.0063360	0.0065324	0.0064213
Deformation under oblique load	0.0072142	0.006524	0.0069463	0.0065647	0.0007235	0.0006456

Peak stress and deformation in bone generated by three implant assemblies were as shown in the figures 3-8 and explained separately as follows.

STRESS AND DEFORMATION IN BONE WITH TITANIUM IMPLANT ASSEMBLY

Fig 3A and Fig 3B: shows stress and deformation with vertical load respectively.

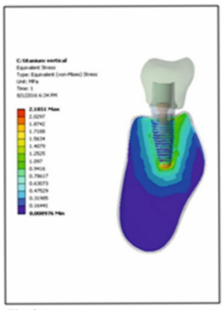

Fig: 3 A

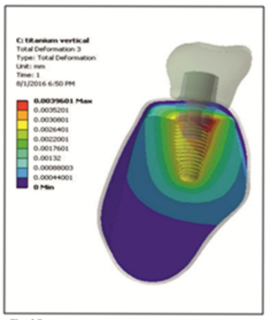

Fig: 3 B

Under vertical load, maximum stress of 2.1642MPa and minimum stress of 0.008358MPa was observed. Maximum deformation of bone values observed was 0.0032679mm and minimum deformation was 0.0004245mm.

Fig 4A and 4B: shows stress and deformation with oblique load respectively.

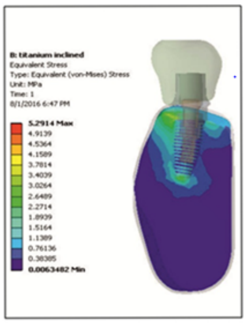

Fig: 4 A

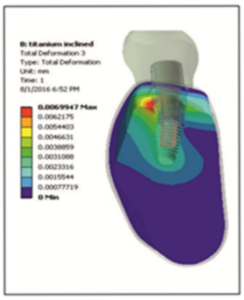

Fig: 4 B

A maximum stress of 5.1457 MPa and a minimum stress of 0.0063360 MPa was observed. Maximum deformation of 0.0072142 mm and minimum deformation of 0.0069463mm in bone was observed.

STRESS AND DEFORMATION IN BONE WITH ZIRCONIA IMPLANT ASSEMBLY

Fig 5A and 5B: shows the stress and deformation with vertical load respectively.

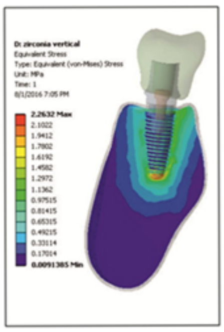

Fig: 5 A

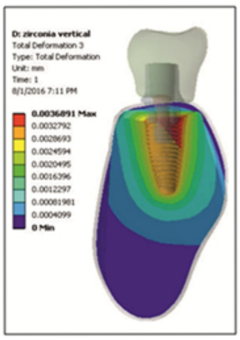

Fig: 5 B

A maximum stress of 2.2467 MPa and a minimum stress of 0.0091356 Mpa was observed. Maximum deformation of 0.0032679 mm and minimum deformation of 0.0004245 mm in the bone was observed.

Fig 6A and 6B: shows stress and deformation pattern during oblique loading.

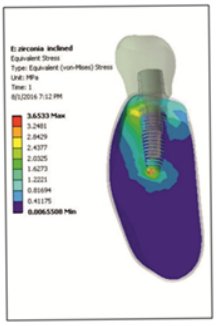

Fig: 6 A

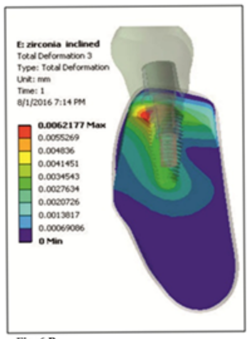

Fig: 6 B

A maximum stress of 3.6359 MPa and a minimum stress of 0.0063360 MPa was observed. Maximum and minimum deformation values observed was 0.0064213mm 0.0072142 mm respectively.

DISCUSSION

Nowadays, restoration of missing teeth with implant supported prosthesis is the most recommended treatment plan in completely and partially edentulous patients. Satisfactory mechanical properties and biocompatibility of Zirconia (Y-PSZ) and 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. Several studies have proved that zirconia (Y-PSZ) and PEEK are biocompatible and have excellent mechanical properties and distributes stress similar to titanium [7, 10, 14-19]. PEEK is a high performance thermoplastic polymer. Today it is well known as an alternative biomaterial to metallic implant materials in the field of orthopedics and traumatology. Pure PEEK possess modulous of elasticity of 3-4 Gpa which shows higher deformation. In a study of FEA, 30% CFR-PEEK (carbon fibre reinforced PEEK) and Titanium was used to evaluate the stress distribution during load transfer of dental implant. It was determined that under an oblique loading condition CFR-PEEK dental implant displays higher stress peaks at the bone-implant interface due to a higher deformation, whereas the titanium implant shows a more homogenous stress distribution [20]. It was suggested that further stronger reinforced PEEK dental implant could show reduced stress peaks at the bone-implant interface due to a reduced elastic deformation. So accordingly PEEK containing 60% parallel oriented endless carbon fibers implant was considered in the study. According to a literature tapered or screw shaped implants are of better choice than cylindrical implants [14, 21].

Load of 100 N was applied in two different directions vertical and oblique at 30 degree and stress distribution in surrounding bone was analyzed. In previous studies 100 N vertical and oblique load was applied on occlusal surface, which aims to simulate the real function situation [22, 23]. It was observed that under vertical load all three implant assemblies have similar stress pattern.Under oblique load titanium implant assembly has caused slightly more stress compared to zirconia and PEEK implant assemblies. Under oblique load, results are similar to studies which has shown that tapered endosseous implant with high modulous of elasticity would be most suitable for implant dentistry [24,25]. Rieger, et al concludes that tapered zirconia implant with high modulous of elasticity is the reason for low stresses observed in the bone under oblique loading [21]. Caglar et al found that under oblique loading, low stress values were obtained for zirconia implants versus titanium implants [24].

The difference between the deformations in bone generated by the different implant assemblies is insignificant under vertical load. Slightly more deformation was associated with titanium compared to zirconia and PEEK implant assembly under oblique load. This increase in deformation could be due to the difference in the modulus of elasticity where less deformation was associated with high modulus of elasticity of implant biomaterial.

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

CONCLUSION

Importance of implant biomaterials other than titanium such as zirconia and PEEK should be considered. In this study, stress and deformation generated by zirconia and PEEK implant is compared with that of titanium. Similar stress & deformation pattern in bone were observed with all three implant biomaterials. Hence, Zirconia (Y-PSZ) and PEEK implants can be considered as an alternative in individuals who shows allergy to titanium and as an esthetic implant biomaterial.

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