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Stress Distribution around Titanium and Biohpp Implant Under Occlusal and Oblique Load: A Three-Dimensional Finite Element Analysis

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Titanium, BioHPP, Implant, Finite Element Analysis

ABSTRACT:

Aim: The aim of this study is to compare the stresses developed around two different implant materials under occlusal and oblique forces when restored with metal ceramic crown with three-dimensional finite element models.

Settings and Design: An in-vitro comparative study.

Materials and Methods: Four three-dimensional Finite Element Models were constructed by the ANSYS software, in which Model 1 depicted titanium implant under occlusal load, model 2 depicted titanium implant under oblique load, whereas model 3 represented BioHPP implant under occlusal load and model 4 illustrated BioHPP implant under oblique load. To evaluate and compare the stress distribution between the bone and implant interface, the occlusal load of 1000 N was applied on to the central fossa and an oblique load of 500 N at 30 degree was applied to the buccal incline of the palatal cusp on the respective models.

Statistical Analysis Used: The results of the simulations obtained were analyzed in terms of Von Mises equivalent stress levels at the bone -implant interface.

Results: The results of occlusal and oblique loading showed that the maximum Von Mises stress was recorded in the titanium implant when compared to BioHPP implant. Among the occlusal and oblique loads, stress recorded under occlusal load was even higher.

Conclusion: This invitro study concludes that BioHPP implant showed better stress distribution when compared to the titanium implant.

Introduction

Due to the promising value of dental implants, they received significant attention from many researchers and providers recently. But because of the complex behaviour of the dental implant, the evaluation of long-terms success is not fully determined yet. Biomechanical factors play an important role in the long-term survival of oral implants. One of the main factors affecting the osseointegration process is the stress at the bone-implant interface. The main factors affecting the stress distribution at the bone-implant interface are type and magnitude of loading, material properties of the implant, implant geometry, surface structure, and implant design quality.[1] The ideal material for the manufacture of dental implants must

have biocompatibility, appropriate hardness, corrosion resistance, wear and fracture strength. Today, most dental implants are made of titanium, because of its characteristics, biocompatibility and long-term clinical success. Despite the popularity of titanium, allergies to this material have been reported (estimated prevalence of 0.06%).[2] The induction of hypersensitivity in sensitive patients was described as a possible etiologic factor for implant failure. The demand for metal-free treatments has grown lately. Recently, a bio high-performance polymer (BioHPP) based on polyetheretherketone (PEEK) has been introduced. Because of its excellent characteristics, including outstanding physical properties, good dental esthetics, low specific weight, low plaque affinity, and high biocompatibility, BioHPP is used in dentistry, including removable prostheses, fixed prostheses, abutments and implant-supported bar.[3] Finite Element Analysis is a powerful design tool. It has been successfully used to assess the design characteristic of highly complex geometries of mechanical assembly. Finite Element Analysis is a method of breaking down a complex geometry into manageable "elements" or simpler geometries whose boundary conditions are known. It allows an analytical evaluation of the distribution of tensional forces through a mathematical virtual model that includes the variables in order to offer directions to the clinician on the most favourable choice.[4]

Material and Methodology

This study aims to evaluate the stress shielding effect on jaw bone with titanium implant and BioHPP implant by using finite element study. The study was conducted by testing models of 2 implants of titanium and BioHPP each for evaluating the stress shielding effects on jaw bone on application of occlusal load of 1000 N and an oblique load of 500 N depending on different forces simulated as per parafunctional loading respectively. The test samples included four models on the basis of different material and forces applied.

MODEL 1 – Titanium implant under occlusal load
MODEL2 – Titanium implant under oblique load
MODEL 3 – BioHPP implant under occlusal load
MODEL 4 - BioHPP implant under oblique load

Modelling

1. Designing Concept of The Bone Model

An edentulous maxilla of a human skull was scanned with a dental volumetric computed tomography device (HDI 100 series 3D Scanner with flex scan software). Using the scanned image, bone structure present in the maxillary right first molar area was modelled where a cortical bone thickness of 1.5 mm surrounding the cancellous bone was made. The proposed design concept is formed on the basis for placement of the dental implant in D_2 type of bone. The D_2 type bone model is prepared as D_2 bone is encountered in most of the cases. D_2 type of bone is present 65% in anterior mandible, 55% in posterior mandible and 25% in anterior maxilla. It has dense to porous cortical and dense trabecular pattern.

2. Designing of Implant Model

In this study basically two types of implants were used - titanium implant and BioHPP implant. Titanium implant with titanium straight abutment and their inner screws were scanned with an optical scanner (HDI 100 series 3D Scanner with flex scan software). The standard tessellation language (STL) data of each component were transferred in to 3D modeling software (ANSYS software). Titanium implant model was made in the same software with diameter of 5mm and the length of 10mm. The same dimensions were selected for the BioHPP implant model. On each model subsequently, the PFM crown was modeled on the abutment. Cobalt chromium coping of 0.5 mm thickness with porcelain thickness of 1 mm in the marginal area and 1.5 mm thick in the occlusal area of the functional cusp was modeled. In all the four models, a dual-polymerized resin cement layer 30 µm in thickness was defined between the abutment and crown to simulate clinical conditions.

Meshing and Material Assignment to the Bone and Implant

In order to do finite element analysis, the prepared model is divided into finite elements to evaluate the stress on applying the force. The model (figure 1) is discretized into finite elements and the triangular meshing is chosen as per the geometry of the model. During the numerical analysis different types of materials were used as mentioned in table 1. The

Young's modulus and Poisson ratio of each material were obtained from the manufacturer and published studies. The components in each model were assumed to be homogenous and isotropic.

Loading of the Implant

An axial load of 1000 N was applied on to the central fossa and an oblique load of 500 N (30 degree) was applied to the buccal incline of the palatal cusp (Figure 2). By using von Mises stress, the distribution of strains in implants and restorative crowns were identified.

Application of Boundary Condition

The D_2 bone was rigidly fixed to the adjacent sides of the same bone. This makes an assembly to simulate the bone (cortical and cancellous) osseo-integrated with the titanium implant and the BioHPP implant. Boundary condition is necessary as the force is applied to the model then it will act as free-floating rigid body which will undergo translatory or rotatory motion. So, to avoid this some degree of restriction must be provided to obtain the correct result.

Results

Using the finite element method, the calculations were performed as per the planned loading protocol. In two models (one titanium and one BioHPP), 1000 N of vertical load was applied to the central fossa and in two models (one titanium and one BioHPP) 500 N of oblique load at 30 degree was applied to the buccal incline of the palatal cusp. The stresses were calculated and noted within the cortical bone, cancellous bone, implant, screw, abutment, cement and crown. The results found in titanium implant under occlusal load and oblique load are mentioned in Table 2 and 3 respectively. The overall stress distribution around the titanium implant is depicted in figure 3 . The results found in BioHPP implant under occlusal load and oblique load are mentioned in Table 4 and 5 respectively. The overall stress distribution around the titanium implant is depicted in figure 4. Under axial and oblique loading, in both BioHPP group and titanium group, the stress generation in bone was seen higher in titanium implants and titanium implant under occlusal load being the highest. The stress was seen lowest in BioHPP implant under oblique load.

Table 1– Mechanical Properties of Different Materials

MATERIAL	Elastic Modulus (Gpa)	Density (kg/m^3)	Poisson's ratio
Cancellous bone	1.37	1300	0.3
Cortical bone	13.7	1300	0.3
Titanium	110	4540	0.35
BioHPP	4	1310	0.36
Resin cement	18.6	2200	0.28
Cobalt-chromium	218	8300	0.33
Porcelain	69	2400	0.3

Table 2- Stress Recorded in Titanium Implant under Occlusal Load

Titanium Implant Under Occlusal Load	
Entity	**Average Stress Mpa (Von mises)**
Overall	14.019
Cortical bone	8.2613
Cancellous bone	3.1164
Crown	27.431
Cement	19.38
Abutment	29.452
Screw	23.257
Implant	21.432

Table 3 – Stress recorded in titanium implant under oblique load

Titanium Implant Under Oblique Load	
Entity	**Average Stress Mpa (Von mises)**
Overall	11.78
Cortical bone	6.0377
Cancellous bone	1.792
Crown	22.158
Cement	24.352
Abutment	19.076
Screw	18.827
Implant	20.496

Table 4 – Stress recorded in BioHPP implant under occlusal load

BioHPP Implant Under Occlusal Load	
Entity	**Average Stress Mpa (Von mises)**
Overall	11.335
Cortical bone	8.5619
Cancellous bone	3.1836
Crown	29.585
Cement	24.747
Abutment	31.243
Screw	48.348
Implant	6.2216

Table 5 – Stress recorded in BioHPP implant under oblique load FIGURES

BioHPP Implant Under Oblique LOAD	
ENTITY	**AVERAGE STRESS Mpa (Von mises)**
Overall	8.2914
Cortical bone	5.7435
Cancellous bone	2.0519
Crown	22.819
Cement	31.408
Abutment	20.986
Screw	31.636
Implant	4.2626

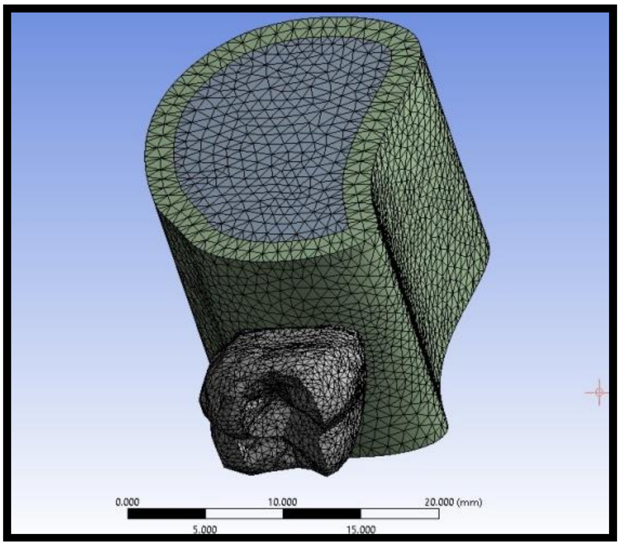

Figure 1- Meshing of the model

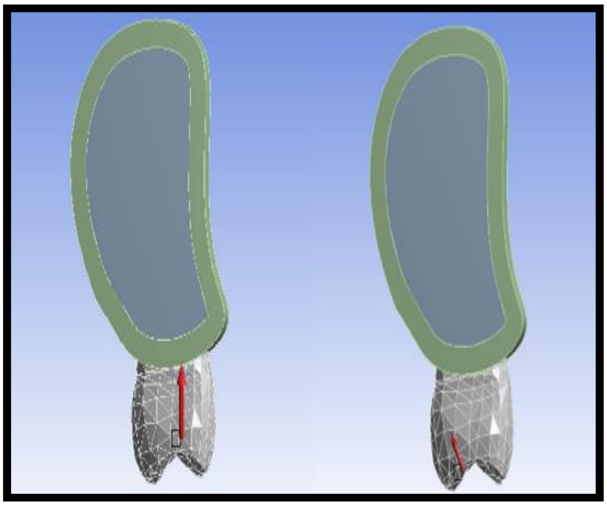

Figure 2-An axial load of 1000 N on the central fossa and an oblique load of 500 N at 30 on the buccal incline of the palatal cusp

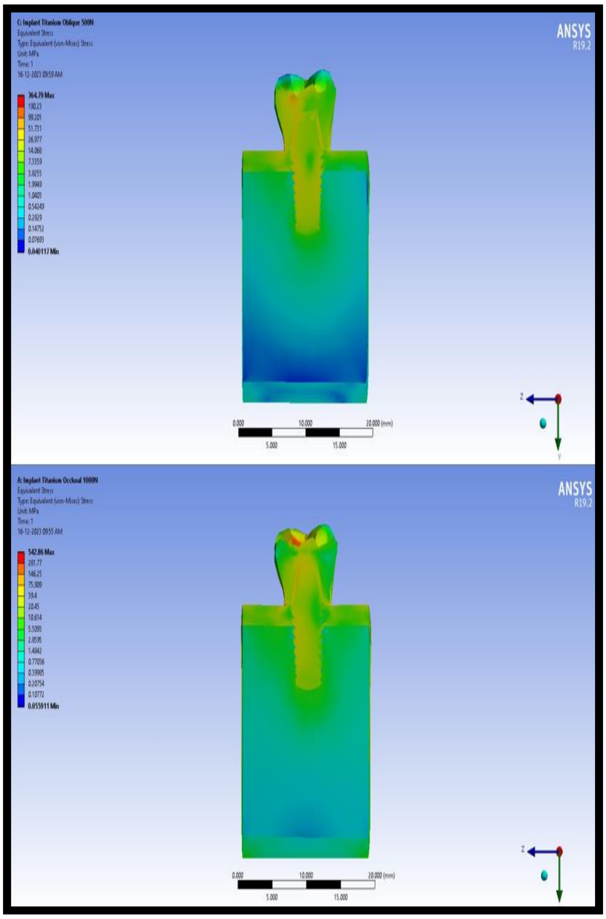

Figure 3 -The overall stress distribution within titanium implant under the occlusal load and oblique load

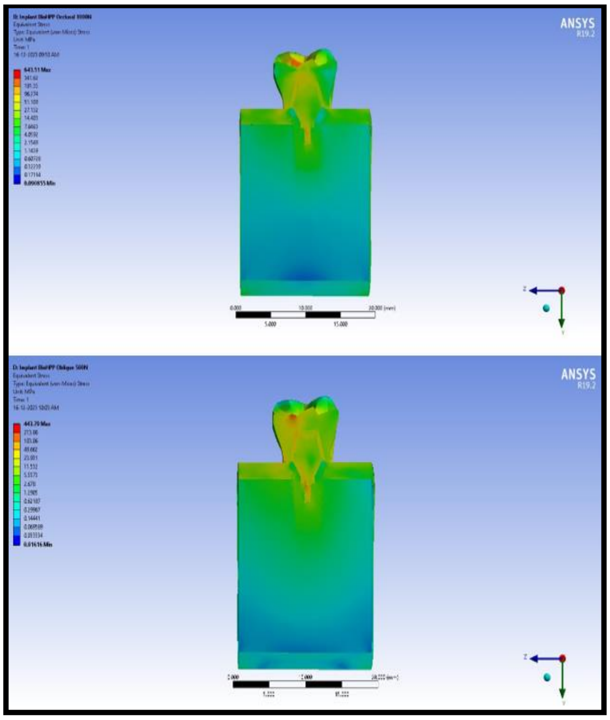

Figure 4 - The overall stress distribution within the BioHPP implant under the occlusal load and oblique load

Discussion

The best material for dental implants is titanium and its alloys because of their notable mechanical qualities, strong corrosion resistance, and great biocompatibility. However, over the years, implant failure has also been reported because of the difference between the implant's and the bone's elastic modulus. Therefore, the success or failure of the implant can be ascertained by the ability of the implant to transfer the generated stress to the surrounding bone. An implant having a lower elastic modulus is thought to have the ability to transfer stress to the nearby bones for long-term stability.[5] Researchers have been working hard to find the alternative of titanium dental implant, such as zirconia which has a high modulus of elasticity and low temperature deterioration. Certain polymeric compounds exist such as PEEK which has low elastic modulus, therefore PEEK is a material that offers few advantages over titanium.[6] However, High Performance Polymer (BioHPP), a high-tech thermoplastic polymer based on polyether-ether-ketone (PEEK) polymer, has been used in surgical procedures for many years due to its exceptional stability. Its strength and mechanical qualities are enhanced by the 20% ceramic filler content. Its small grain size (0.3–0.5 µm) ensures consistent homogeneity, which is crucial for the material's qualities and lays the groundwork for long-term quality.[7] Since BioHPP has a modulus of elasticity of 4 GPa, it is almost as elastic as bone. It's an important characteristic for implant prostheses as this reduces the chance of fracture, balances out torsion caused by the bones, and dissipates any stresses. To prevent implant failures and complications caused by mechanical and technical factors, these factors have to be evaluated in advance.[8] Finite Element Analysis is a numerical stress analysis technique used in implant dentistry. The designed model is discretized into finite elements for the finite element analysis, and the nodes connect these components. The software is updated with the properties of the material that is being utilized in the model. Every element and the nodes in the model experience stresses when a force is applied to it.[9] With the aim of determining the stresses in the dental structures and for the further improvement of their mechanical strength, the stress analysis of these structures has been a main topic of concern in recent years. A study conducted by Rahmitasari et al stated that PEEK may exhibit less stress shielding in the dental implant body than titanium because of its mechanical similarities to bone.[10]Yomna H. Shash et al also stated that PEEK material increased mucosal stress and decreased strains and pressures on bone tissue in comparison to titanium.[11] However, an advanced derivative of PEEK having ceramic fillers,namely BioHPP showed similar properties has been used as a framework material in dentistry. A study conducted by Rodolfo Reda et al stated that, in clinical contexts, BioHPP's characteristics make it suitable for quick loading on implant restorations, endocrowns, small adhesive bridges, and temporary prostheses.[12] The aim of this study was to evaluate the stress shielding effect of bone by replacing the titanium implant by the BioHPP implant. In this study four implant models were designed in the software as titanium implant and BioHPP implant under occlusal and oblique load respectively. An axial load of 1000 N was applied on to the central fossa and an oblique load of 500 N (30 degree) was applied to the buccal incline of the palatal cusp. Finite element analysis was done to observe the von mises stresses appearing in the implant and jaw bone. The titanium implant showed very high stress at

the interface with the jaw bone as compared to the BioHPP implant. Under occlusal load the overall stress evaluated in case of titanium implant was recorded as 14.019(von mises) and in BioHPP stress was 11.335(von mises). However, under oblique load the overall stress evaluated in case of titanium implant was recorded as 11.78(von mises) and in BioHPP it was 8.29(von mises). The same modulus of elasticity between BioHPP and the bone, as noted in earlier researches, may account for the reduced stress in case of BioHPP implant. In the titanium implant model maximum stress was observed on the implant and bone contact point on the top of the implant body and rest of the stress is transferred to all along its body. The modulus of elasticity of the titanium implant is 110 Gpa. The modulus of elasticity of the cancellous and cortical bone 1.37 Gpa and 13.7 Gpa respectively. Due to very high difference between elastic modulus, maximum amount of the stress get absorbed by the implant body only and negligible amount of stress is transferred to the surrounding jaw bone. Due to this phenomenon marginal bone loss may result which may lead to the failure of the implant. In the BioHPP implant model concentration of stress observed at the interface of bone and implant was less as compared to the titanium implant. BioHPP has modulus of elasticity (4 GPa) which is much closer to that of the bone, it's very less stiff as compared to the titanium and due to this reason, it shares more of the stress with the jaw bone and does not absorb it all along the body of the implant.

Conclusion

Within the limitation of the study, it can be concluded that stress concentration is more around the titanium implant as compared to BioHPP implant due to difference in the modulus of elasticity. More similarity between the modulus of elasticity of the materials is present, more stress distribution is observed. The same was observed in this study as well, the stress distribution is maximum seen in BioHPP implant as it's modulus of elasticity is closer to that of the bone.

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