Investigation of Strain and deformation analysis of Biomaterial in Dental Implant: A 3D FEA Study

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Abstract. In this study, the deformation and strain values in the periimplant bone were assessed in order to examine the impacts of three different dental implant thread pitch settings. In this work, the diameter, length, material, and elastic modulus impacts on the biomechanical behaviour of a new dental implant were predicted using the finite element method. Both a three-dimensional dental implant model and a mandibular segment model that matched the premolar region were acquired. Loads that are axially applied. The dental implant models were built using Solidworks 2021, and the simulations were carried out using Ansys / CAE.

In this work, FEA was used to analyse how the bioactive material (30% CFR PEEK) and implant thread design influenced strain and distortion in the implantation. According to the study's hypotheses, the 30% CFR PEEK implant system will be made of an isotropic, homogeneous, and linearly elastic material. Using the modelling software tools Solidworks and Ansys Workbench, strain and deformation at the implant and implant-cortical bone contact are examined and evaluated.

1 Introduction

For the restoration of edentulous arches, dental implants are preferred because to their aesthetics, usability, and survival rate. The choice of design is essential for maintaining...
Osseointegration. Implant success is impacted by implant material biocompatibility, design, bone quality, and applied load circumstances.[1,2,3]

The implant thread serves as a cautious element to expand the engaging zone and stress distribution. The implant's design, pitch, and material are what primarily define its stability and longevity. Titanium alloy are advised because of their exceptional mechanical strength, capacity to tolerate fracture, and biocompatibility.[4-8]

According to study, hydroxyapatite (HA)-coated screw implants should be used to treat anterior and posterior maxillas with a 10mm bone depth and a thinner cortical layer. For narrow posterior maxillae, the use of cylindrical implants with HA covering is indicated. However, there is cause for worry given the bacterial susceptibility and likely failure of HA-coated implants due to coating-substrate fracture.[9,10]

Implant biocompatibility with jawbones has been enhanced by the use of more recent bioactive materials in dental applications, such as CFR PEEK. These substances strengthen bonds, encourage bone tissue regeneration, and have antimicrobial characteristics. Studies have also concentrated on changing geometric patterns such thread pitch, helix angle, depth, and breadth in order to vary implant design. By changing surface area, the pitch considerably affects stability.[11,12]

Finite element analysis, which gives three-dimensional insight into 2D axial symmetric models and accurately evaluates bone-implant biomechanical behaviour and stress concentration, enables the clinical and in vitro evaluation of bone-implant interface phenomena. [5,10]

In the current research, the impact of the thread design and bioactive materials (30% CFR PEEK) on strain, and deformation in the dental implant structure is assessed with three-dimensional (3D) FEA. General dental implant system is shown in Fig 1.

![Fig 1. Dental implant system](Source: sandiegoinvisaligndentist.org)

<table>
<thead>
<tr>
<th>Materials</th>
<th>Young’s Modulus (GPa)</th>
<th>Poisson ratio</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortical bone</td>
<td>13.7</td>
<td>0.3</td>
<td>[16, 17]</td>
</tr>
<tr>
<td>Dense cancellous bone</td>
<td>1.37</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>Type II, Type III</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low-dense cancellous bone</td>
<td>0.231</td>
<td>0.3</td>
<td></td>
</tr>
</tbody>
</table>
Table 1. Material Properties for analysis

<table>
<thead>
<tr>
<th>Material</th>
<th>Young's Modulus (GPa)</th>
<th>Poisson's Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEEK</td>
<td>4.1</td>
<td>0.4</td>
</tr>
<tr>
<td>CFR-PEEK</td>
<td>12</td>
<td>0.4</td>
</tr>
<tr>
<td>30% CFR PEEK</td>
<td>18</td>
<td>0.39</td>
</tr>
</tbody>
</table>

2 Materials and methods

2.1 3D Design and Model Generation

The research looks at the factors that affect the correctness of FE analysis values, including material attributes, model design, and FE model creation. It takes into account 100 percent osseointegration and a 2 mm cortical bone layer, modelling bones and tissues as homogenous, isotropic, and linearly elastic. Dental implant components' mechanical characteristics were taken from published sources.

Poly-aromatic polymers are increasingly being used in hip prostheses and fracture fixation plates with similar stiffness to bone. These chemical components may be modified to form a structure that is nearly identical to cortical bone (18 GPa) using materials like carbon fibre (CFR-PEEK). This biocompatible material offers a variety of possibilities for implant construction and buccal concealing components because of its biomechanical behavior. [13,14,15]. 3D model of implant system given away in fig 2:

![Fig 2. Implant system model](image)

2.2 Numerical analysis

In a dental implant system, ideal osseointegration entails a flawless connection between the implant and bones,. Modelling software is employed, and axial loads are applied to the implant's occlusal surface. Mesh the specified model with tetrahedral components, each of which has three degrees of freedom, and conduct a convergence analysis. For strain and deformation at the cortical and cancellous bone under vertical loading circumstances, results are evaluated. Meshed 3D model shown in fig 3
Fig 3. Meshed 3D model

Fig 4. Total deformation for 0.8mm pitch for 150N

Fig 5. Deformation at bone for 0.8mm pitch for 150N
3 Results and discussion

The implant material, bone type, implant thread pitch, and implant thread patterns all have a major impact on the bone's stress and strain ranges as well as its deformation.

The results of simulation performed to assess the pertinent aspects are given in Tables 3-5 for the dental implant arrangement. The von Mises strain and implant distortion for the
functionalized implant employing CFR PEEK biomaterial are shown in table 2 and table 3 and Figures 2 and 3, respectively.

The software that was used was ANSYS Workbench. Geometric models of the implantation, cortical and cancellous bone component were determined to be imported. Three-dimensional models of the implant, which has a 14mm diameter and a 13mm height, were imported and evaluated.

The PEEK material characteristics for the implant portion were used in the FEA software. To build a 3D model, the compressed model was meshes using a 5 mm meshing spacing. The boundary conditions for each of the components were resolved. Observations show that the strain increases as the load increases. Analysis data are given in Fig 4, Fig 5, Fig 6.

The strain and deformation are in the (7.9e-5-1.95e-4) and (5.9e-4-1.25e-3 mm) ranges, respectively. Details are given in Table 2 and Table 3.

### 4 Conclusion

Dental implantology has evolved significantly since its introduction over 40 years ago, with research focusing on developing ideal implants. Today, dental implant technology offers unparalleled effectiveness, convenience, and affordability. However, understanding the correlation between biomaterials, biomechanical behavior, implant geometry, patient condition, and bone quality is crucial for long-term success. Further study on materials, design elements, surface treatment, and analytical techniques are necessary to advance.

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