MODAL ANALYSIS OF FEMUR BONE TO FIND OUT THE SUITABLE BIO COMPOSITE BONE IMPLANT MATERIALS

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ABSTRACT

The materials selected for the bone implants are most important and while selecting the materials care must be taken like biocompatibility, cost and feasibility and so on. Three different materials viz natural bone, PMMA/HaP, Nylon 6/HaP, and Poly-lactic acid/HaP are selected for the modal analysis. A three-dimension model of the femur bone is prepared from the CT scan image using ITK-SNAP code. MSC- Patran-2017 is used as a pre and post processor and Nastran-2017 as the solver. From this analysis, we found that the probable fracture of bone occurs near the femoral head and knee joint, but the modal frequency of any of these materials is not exceeding natural femur bone frequency. PMMA/HaP is best suited for bone implants because its modal frequencies are optimal and also it had an optimum weight in comparison with Nylon 6/HaP, and Poly-lactic acid/HaP composite materials.

Keywords: Femur Bone, Modal analysis, PMMA/HaP, Bone, Nylon/HaP,Poly-lactic acid/HaP.


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1. INTRODUCTION
The biomechanical study deals with the understanding of the mechanical behavior of biological objects such as bones [1]. The recent development in the field of computational made the analysis of complicated systems easier and less time-consuming [2]. In the human body, the femur bone is the most important and longest, it is important because it supports the body and the whole body weight is transferred to the legs [3]. So we required understanding the behavior of this bone and at the same time, we required to find the feasible implant materials through finite element analysis [4].

Femur bone fractures generally occur due to the trauma caused by accidents [5]. The modal analysis is one of the criteria to analyze the frequencies for different materials such that we can predict whether the modal frequency exceeding the natural frequency [6]. If the modal frequency exceeds the natural frequency the bone is going to fail [7]. Many studies are conducted to predict the modal frequencies of the femur bone, but only a few can develop/model the proximal femur bone for the analysis purpose [8-9]. In the design of femur bone implants stress analysis and modal analysis plays an important role and finding the critical places where the fracture occurs will help us to design the implants properly [10].

1.1. Anatomy of Femur bone
A femur bone is the longest bone in the human body which carries the weight of the body. This bone consists of three major parts and is Hip joint, Knee joint, and Femur Shaft. The hip joint connects the pelvic bone at the femoral head. Near the femoral head, tensile and compressive forces will act. Whereas the knee joint connects the lower portion of the leg and the femur shaft lies between Hip joint and Knee joint. Fig. 1 shows parts of the femur bone [11].

Figure 1 Femur Bone Main Parts

2. THREE-DIMENSIONAL MODELING, MESHING AND BOUNDARY CONDITION
The three-dimensional modeling of the femur bone is one of the most difficult. But in this study, we prepared three-dimensional models from CT-Scan image using ITK-SNAP open-source code. This converts the grayscale image into three-dimensional models. We used manual segmentation to get the 3-dimensional models. The meshing is carried out using the CQUAD4 element and we used convergence criteria to optimize mesh size and the mesh size we selected is 4. These CQUAD4 elements will give accurate results as compared to the CTRIA element and also these elements are best suited for static stress analysis. The meshed model is shown in Fig. 2.
Modal analysis of femur bone to find out the suitable bio composite bone implant materials

![Meshed model](image)

**Figure 2 Meshed model**

### 2.1. Materials Properties

The composite materials are widely used in many applications and their application is not limited. The usage of Composite materials in the Field of Bioengineering started from the past twenty years [12]. As technology grows the different manufacturing and testing methods are improved. These materials are used most of the field because of their lightweight and high strength and also they can be tailored as required. In this study, we selected three different Composite biomaterials and are biodegradable. The mechanical properties of these materials are shown in Table 1 [13-14]. The mechanical properties of natural bone are Young’s Modulus 3-20 GPa, Density is 1.8-2.1 g/cm³ and Poisson’s ratio is 0.33 [15-16].

<table>
<thead>
<tr>
<th>Material</th>
<th>Young’s Modulus E (GPa)</th>
<th>Poisson’s ratio(ϒ)</th>
<th>Density( ρ ) (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMMA/HaP</td>
<td>220</td>
<td>0.2</td>
<td>1.18</td>
</tr>
<tr>
<td>Nylon6/HaP</td>
<td>300</td>
<td>0.21</td>
<td>3.72</td>
</tr>
<tr>
<td>Poly-lactic acid/Hap</td>
<td>3.80</td>
<td>0.38</td>
<td>1.21</td>
</tr>
</tbody>
</table>

### 2.2. Boundary conditions

The boundary condition was selected from the literature. We selected fixed and free boundary conditions. The knee joint is fixed [14].

### 3. RESULTS AND DISCUSSION

The modal analysis was carried out by meeting all the design constraints such as materials properties and boundary conditions. The results are compared with literature and are discussed below.

#### 3.1. Results for PMMA/HaP materials

From the modal analysis for Mode 1 and Mode 2, we obtained a modal frequency of 6.377 Hz and 7.309 Hz respectively. The mode shapes are seen near the femoral head and are compared with the literature [10-13]. The results are optimum and are shown in Fig.3 and Fig. 4.

![Mode 1 for PMMA/HaP](image)

**Figure 3 Mode 1 for PMMA/HaP**

![Mode 2 for PMMA/HaP](image)

**Figure 4 Mode 2 for PMMA/HaP**
From the modal analysis for Mode 3 and Mode 4, we obtained a modal frequency of 7.790 Hz and 7.823 Hz respectively. The mode shapes are seen near the femoral head and are compared with the literature [10-13]. The results are optimum and are shown in Fig.5 and Fig. 6.

![Mode 3 for PMMA/HaP](image1)

![Mode 4 for PMMA/HaP](image2)

**Figure 5** Mode3 for PMMA/HaP  
**Figure 6** Mode 4 for PMMA/HaP

From the modal analysis for Mode 5 and Mode 6, we obtained a modal frequency of 8.019 Hz and 8.032 Hz respectively. The mode shapes are seen near the femoral head and are compared with the literature [10-13]. The results are optimum and are shown in Fig.7 and Fig. 8.

![Mode 5 for PMMA/HaP](image3)

![Mode 6 for PMMA/HaP](image4)

**Figure 7** Mode5 for PMMA/HaP  
**Figure 8** Mode 6 for PMMA/HaP

From the modal analysis for Mode 7 and Mode 8, we obtained a modal frequency of 8.056 Hz and 8.064 Hz respectively. The mode shapes are seen near the femoral head and are compared with the literature [10-13]. The results are optimum and are shown in Fig.9 and Fig. 10.

![Mode 7 for PMMA/HaP](image5)

![Mode 8 for PMMA/HaP](image6)

**Figure 9** Mode7 for PMMA/HaP  
**Figure 10** Mode 8 for PMMA/HaP

From the modal analysis for Mode 9 and Mode 10, we obtained a modal frequency of 8.188 Hz and 8.212 Hz respectively. The mode shapes are seen near the femoral head and are compared with the literature [10-13]. The results are optimum and are shown in Fig.11 and Fig. 12.

![Mode 9 for PMMA/HaP](image7)

![Mode 10 for PMMA/HaP](image8)

**Figure 9** Mode7 for PMMA/HaP  
**Figure 10** Mode 8 for PMMA/HaP
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Similarly, the mode shapes for Bone, Nylon6/HaP, and Poly-lactic acid/HaP were obtained.

<table>
<thead>
<tr>
<th>Modes</th>
<th>Modal frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bone</td>
</tr>
<tr>
<td>1</td>
<td>1.620</td>
</tr>
<tr>
<td>2</td>
<td>1.876</td>
</tr>
<tr>
<td>3</td>
<td>2.050</td>
</tr>
<tr>
<td>4</td>
<td>2.059</td>
</tr>
<tr>
<td>5</td>
<td>2.110</td>
</tr>
<tr>
<td>6</td>
<td>2.111</td>
</tr>
<tr>
<td>7</td>
<td>2.119</td>
</tr>
<tr>
<td>8</td>
<td>2.119</td>
</tr>
<tr>
<td>9</td>
<td>2.153</td>
</tr>
<tr>
<td>10</td>
<td>2.157</td>
</tr>
</tbody>
</table>

The results are shown in Table 2 and PMMA/HaP material is best suited for bone implants. Because the modal frequencies are optimal in comparison with the remaining materials and the literature. Also as per weight saving is concerned it is best suited to manufacture bone implants.

4. CONCLUSIONS
The modal analysis for Natural bone, PMMA/HaP, Nylon 6/HaP, and PLA/HaP were carried out. The following conclusions were drawn from this study

- The modal frequency of Natural bone materials for Mod 1 to Mod 10 is 1.620-2.157 Hz respectively. When we compared with literature these frequencies are optimum [10-13].
- The modal frequency of PMMA/HaP materials for Mod 1 to Mod 10 is 16.377-8.212 Hz respectively. When we compared with literature these frequencies are optimum [10-13].
- The modal frequency of Nylon6/HaP materials for Mod 1 to Mod 10 is 7.430-9.591 Hz respectively. When we compared with literature these frequencies are optimum [10-13].
- The modal frequency of PLA/HaP materials for Mod 1 to Mod 10 is 0.873-1.091 Hz respectively. When we compared with literature these frequencies are optimum [10-13].
- PMMA/HaP material is best suited for bone implants. Because the modal frequencies are optimal in comparison with the remaining materials and the literature.
- Also as per weight saving is concerned PMMA/HaP is best suited compared to Nylon 6/HaP to manufacture bone implants.
REFERENCES


