Modal Analysis of Femur Bone to Find out the Modal Frequencies of Different Bone Implant Materials

Vaishali Chaudhry, Anubhav Kumar, Shilpa N, Shwetank Avikal, Nithin Kumar K.C.

Abstract: Bio-mechanics is most difficult to carry out on the bone due to the modeling difficulty and complex forces acting on the bones. In this study, we consider human femur bone for modeling analysis. The modal analysis is also important as that of static analysis. We can predict the place at which the fracture occurs. The modal analysis for three different materials is carried out to find the feasible material for bone implants. These materials are Natural bone, AZ31, and Stainless steel 316L. The daily activity such as walking is used as a boundary condition in our study. The femur head is fixed and 750N load is applied at the Knee joint. The results are obtained for these materials. The modal frequencies for Natural Femur bone vary from 0.328Hz to 2.258Hz for Mode1 to Mode 10. The modal frequencies for AZ31 vary from 1.502Hz to 10.292 Hz for Mode1 to Mode 10. The modal frequencies for 316L vary from 3.120Hz to 21.150 Hz for Mode1 to Mode 10. These frequencies are minimal as compared to the natural frequency of the Femur bone. AZ31 is best suited for the fabrication of bone implants because of its lightweight in comparison with 316L material. Also, this is biodegradable in the human body over the period.

Keywords: Femur bone, Modal analysis, fracture, different materials, CT-Scan

I. 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 leg [3]. So we required to understand 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].

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Vaishali Chaudhry, Graphic Era Deemed to be University, Dehradun, India

Anubhav Kumar, Graphic Era Deemed to be University, Dehradun, India

Shilpa N, Department of Medical Electronics, MVJ College of Engineering, Bangalore, India

Shwetank Avikal, Graphic Era Hill University, Dehradun, India

Nithin Kumar K.C., Graphic Era Deemed to be University, Dehradun, India

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].

In this work, we are carrying out the modal analysis of the femur bone for three possible bone implant materials for given boundary conditions. Such that the implant material is selected and modal frequencies are studied.

II. MATERIALS AND METHOD

Following heads, materials, and methods followed in this work are discussed.

1.1. Materials

Natural bone, AZ31, and Stainless steel 316L are selected in this study. These materials are generally used in the manufacturing of bone implants. The mechanical properties of natural bone are Young's modulus 3-20GPa, Poisson's ratio 0.33, and density 1.8-2.1g/cm^3.
The mechanical properties of AZ31 Young's modulus are 45GPa, Poisson's ratio 0.35 and Density 1.81g/cm^3, and For Stainless steel 316L are Young's modulus is 200GPa, Poisson's ratio 0.30 and Density 7.8g/cm^3[11-12].

1.2. Methodology

Fig. 1 shows the method followed in this study.

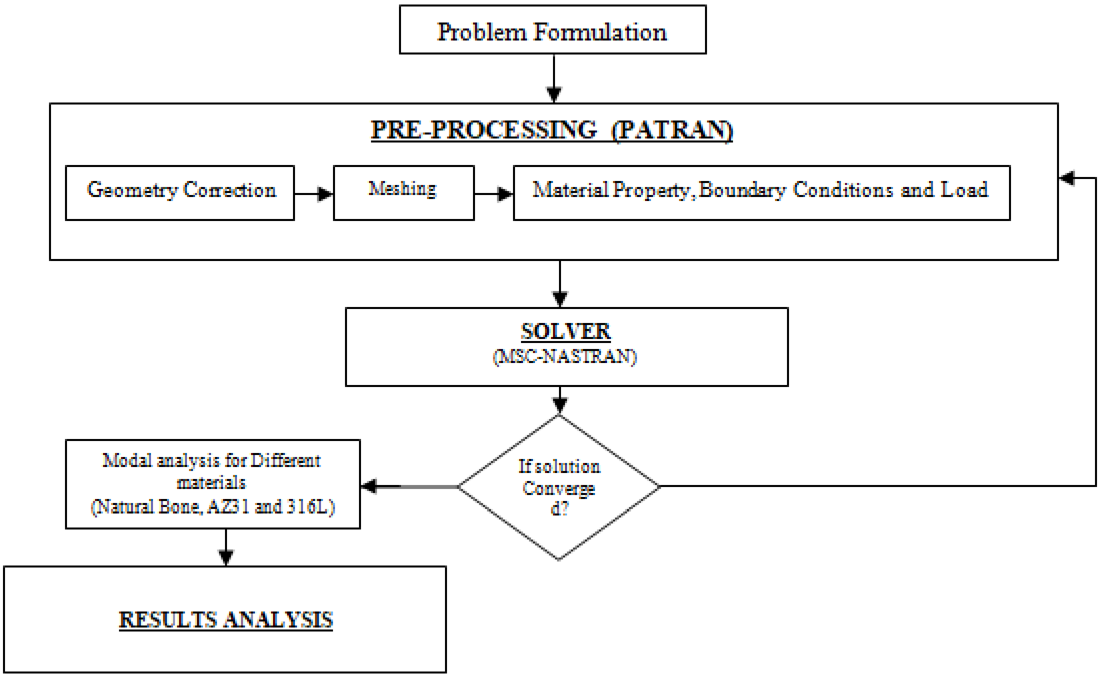


Fig. 1. Methodology

1.3. Modeling and Meshing

The CT-scan grayscale data is used to model femur bone using ITK-SNAp open-source software. The Three-dimensional model is preprocessed using MSC-Patran and we selected CQUID 4 element and it gives accurate results in comparison with the other elements. The element size is decided after applying the convergence criteria. The element size for this study is 2mm.

1.4. Boundary Conditions

The boundary condition selected from the literature. The daily activity such as walking is used in our study [12]. The femur head is fixed and 750N load is applied at the Knee joint.

III. RESULTS

Modal analysis for natural bone, AZ31, and Steel 316L are carried out by meeting all the boundary conditions for femur bone. The results are discussed below.

1.5. Modal frequencies for natural femur bone

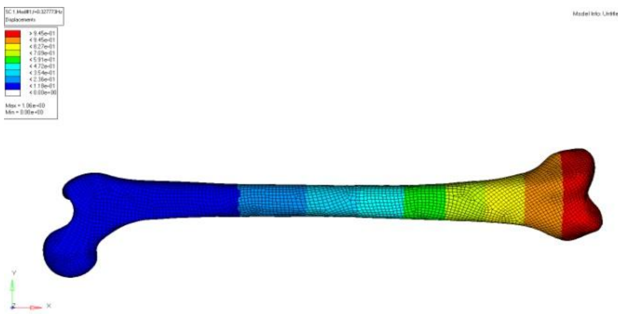


Fig. 2 Mode 1

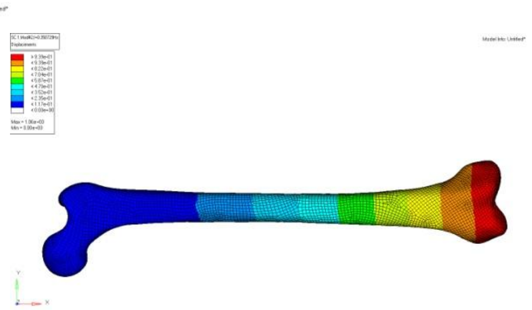
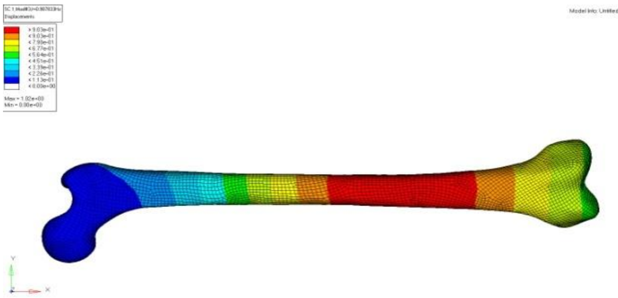


Fig. 3 Mode 2

Fig.2 and Fig. 3 shows the modal frequencies for Mode 1 and Mode 2 for natural bone materials are 0.328Hz and 0.350Hz.



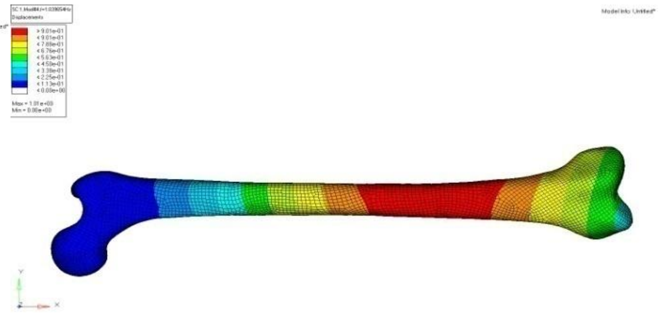
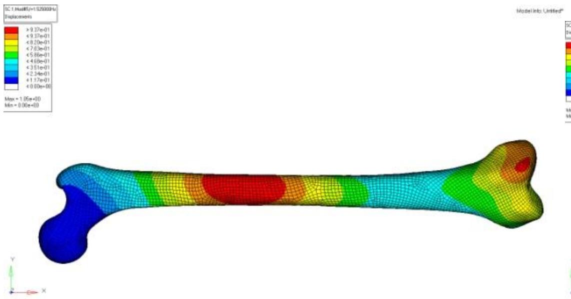


Fig. 4 Mode 3 **Fig. 5 Mode 4**

Fig.4 and Fig. 5 shows the modal frequencies for Mode 3 and Mode 4 for natural bone materials are 0.988Hz and 1.039Hz.



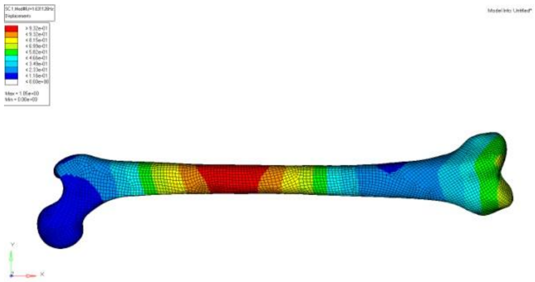
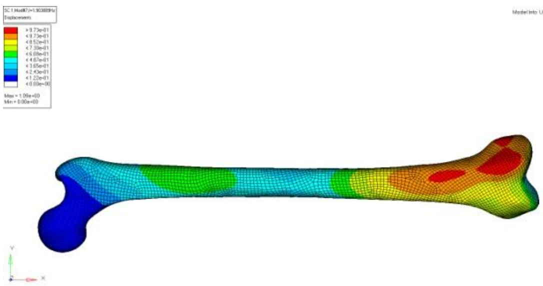


Fig. 6 Mode 5 **Fig. 7 Mode 6**

Fig.6 and Fig. 7 show the modal frequencies for Mode 5 and Mode 6 for natural bone materials are 1.524Hz and 1.631 Hz.



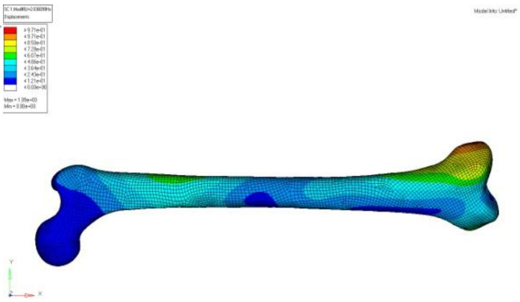


Fig. 8 Mode 7 **Fig. 9 Mode 8**

Fig.8 and Fig. 9 show the modal frequencies for Mode 7 and Mode 8 for natural bone materials of Femur bone are 1.903 Hz and 2.036Hz.

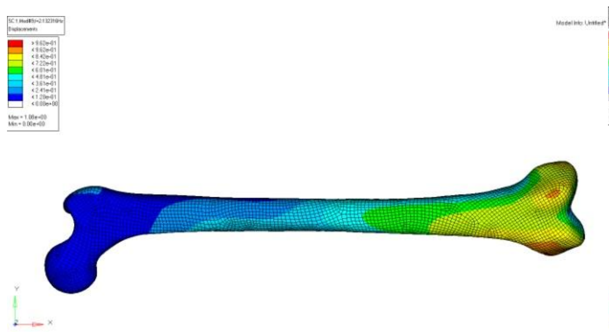


Fig. 10 Mode 9

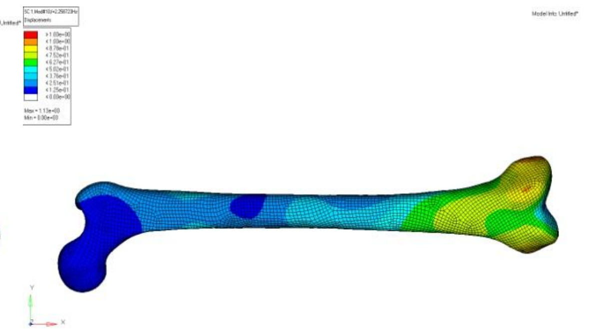


Fig. 11 Mode 10

Fig.10 and Fig. 11 show the modal frequencies for Mode 9 and Mode 10 for natural bone materials of the Femur bone are 2.136Hz and 2.258Hz.

Similarly, the modal analysis for AZ31 and Stainless steel 316L is carried out.

Table 1 Modal frequencies

Modes/ Material	Modal frequency (Hz)		
	Natural bone	AZ31	Stainless Steel 316L
1	0.328	1.502	3.120
2	0.350	1.606	3.338
3	0.988	4.530	9.403
4	1.039	4.759	9.896
5	1.524	6.981	14.516
6	1.631	7.459	15.526
7	1.903	8.395	18.123
8	2.036	9.286	19.381
9	2.132	9.690	20.297
10	2.258	10.292	21.150

The results are shown in Table 1. It is observed that for natural bone modal frequency varies from 0.328Hz to 2.258Hz for different modes. The modal frequency of AZ31 varies from 1.502Hz to 10.292 Hz and whereas 3.120Hz to 21.150 Hz modal frequency for 316L. These modal frequencies are minimal as compared to the natural frequency of the natural bone. If the fracture occurs than it occurs in the femoral shaft.

IV. CONCLUSIONS

Modal analysis of femur bone is carried out meeting all the boundary conditions. The following conclusions were drawn from this study.

- The modal frequencies for Natural Femur bone vary from 0.328Hz to 2.258Hz for Mode1 to Mode 10.
- The modal frequencies for AZ31 vary from 1.502Hz to 10.292 Hz for Mode1 to Mode 10.
- The modal frequencies for 316L vary from 3.120Hz to 21.150 Hz for Mode1 to Mode 10.
- These frequencies must be minimal as compared to the natural frequency of the Femur bone.
- AZ31 is best suited for the fabrication of bone implants because of its lightweight in comparison with 316L material. Also, this is biodegradable in the human body over the period.

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