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Biodynamic Response of Femur Bone

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Abstract: ***The main objective of this paper is to study the development of research work performed for femur bone. A broad literature survey from 1980 to 2019 was studied. It was observed that researcher had performed modal analysis, strength analysis and fracture study of femur bone in previous study. The natural frequencies were determined and different mode shapes were studied. The bone materials and different boundary conditions of previous study were noted and future research problems was identified. In conclusion from previous studies it was noted that there is lot of scope to perform study on femur bone. These studies will be related to fracture identification, healing of femur bone and advanced strength analysis for varying bone size using different boundary conditions. For surgical implants few new materials are identified that can be used for future study.***

Keywords: ***Femur Bone, FEA, Strength, Fracture, Natural Frequency, Mode shape***

I. INTRODUCTION

Primary structural element of the human body is known as Bone. Bone protects the important internal organs of human body and made many linkages that enhances force produced by contraction of skeletal muscle which transform them into different body motions. In stressed condition bone can change its properties and repaired by itself. Bone also consists of different types of ions i.e. calcium, phosphate, and other ions [1]. These ions play an important role in maintaining homeostasis in body fluids by storing and releasing of ions. The modelling is the process in which bone is shaped and customised. For repairing and fine tuning of bone is done by remodelling process. Bone consists of cells and organic matrix (known as osteoid). Cells are made up of collagen and other proteins while organic matrix is fibrous in nature and cell are embedded in matrix [2]. Approximately 50 % of bone volume is made up of the organic matrix. Mineral phase of bone provides the strength and rigidity. So, the remaining 50 % volume of bone are made up of the mineral phase. It has been observed that bone have different types of bone cells which constitutes of 10% by weight [3].

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A. Anatomy of Hip or Pelvic Joint

The hip joint is also known as ball and socket joint. This joint is made up by joining of the spherical head of the femur and the concave acetabulum of the pelvis. Hip or Pelvic joint forms the connection between the lower limbs and upper part of Skelton. The primary function of this joint is to wear weight of whole body and also provides the support in static as well as in dynamic posture condition [4]. A layer of cartilage is surrounded by both the femur and acetabulum which facilitates the smooth movement and damping. To prevent dislocation of femur from acetabulum and to enhance the range of motion the hip joint is surrounded by a fibrous, flexible capsule.

B. Location and Anatomy of Femur Bone

The femur bone is also known for the longest as well as strongest bone in the human skeleton. Femur bone have a head and a neck, a shaft (also known as diaphysis) and two condyles. The shaft of femur is a simple, cylindrical in nature, while the proximal femur is irregular in shape, having of a spherical head, neck and lateral bony projections termed the greater and lesser trochanters [5]. The trochanters play role in muscular linking.

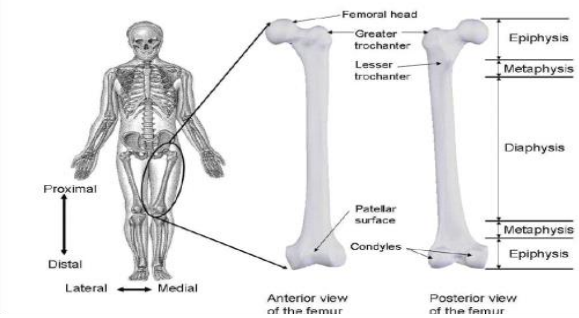

Fig 1. Location and Anatomy of Femur Bone

C. Failure of Femur (Hip) Bone

There are many reasons of failure of the femur bone which are as follows:

- **Accidents:** Road accidents are very common due to improved road conditions and increased speed of private as well as public transport systems. Industrial accidents are also impact on femur bone fracture.
- **Diseases:** In elderly human beings' different type of diseases related to femur bone occurs due to low energy levels. Some of the diseases are discussed below [6].
- **Osteolysis:** In this disease the loss of local bone tissue takes place due to loss of calcium or it may be due to infectious, congenital and movement problems.

- **Osteoarthritis (OA):** In this disease the patient feels severe pain due to breakdown of joint's cartilage cause friction between ball and socket of hip. Cartilage is an important part of pelvic joint which provides cushions ends for smooth movement of the mating bones.
- **Avascular Necrosis**: In this disease blood supply in bone is reduced leads to bone death. In this pain gradually starts with mild pain and increases as the time passes.
- **Developmental Dysplasia**: In this disease the ball has abnormal relationship with socket (acetabulum) which leads to dislocation of hips or instability in pelvic joint.

Paget's disease: This disease mostly affects elderly people. In this disease irregular bone tissues formation takes place. It is the responsibility of bone cells to dissolve old ones and replace with new one [7]. All submitted paper should be cutting edge, result oriented, original paper and under the scope of the journal that should belong to the engineering and technology area. In the paper title, there should not be word 'Overview/brief/ Introduction, Review, Case study/ Study, Survey, Approach, Comparative, Analysis, Comparative Investigation, Investigation'.

II. REVIEW CRITERIA

A literature survey is an essential part of performing any investigation. A lot of research articles and papers have been published in the field of vibration and structural analysis of femur bone and different method of healing of fractured femur bone among which some of important literature survey discussed below:

Paddan et al. [1] have studied the transmission of seat vibration to the head and analyze the adverse effects of whole-body vibration. They have also considered the mechanical, psychological and physiological aspects of whole-body vibration. It is difficult to measure glove transmissibility using knuckle vibration at low frequencies due to low transmissibility to knuckle. In order to measure glove transmissibility palm adapter is used which measures the uneven pressure distributions on the glove due to vibration to knuckle.

Holmlund et al. [2] have studied the mechanical impedance of the human body in sitting posture and vertical direction was measured by different experimental conditions. This has been found that the mechanical impedance increases as the frequency up to a peak at about 5 Hz. After that impedance decreases inappropriate manner which have two different peaks. First additional peak ranges from 8Hz to 12 Hz and second are relatively high ranges from 50Hz to 80 Hz.

Tiemessen et al. [3] have worked towards reduction method of whole-body vibration. They have identified important factor of whole-body vibration such as design consideration, posture, amplitude of vibration and the time duration of vibration exposure. They have also found that whole body vibration and lower back pain are inter related to each other.

Ingólfsson et al. [4] have perform a literature review for Pedestrian-induced lateral vibrations of footbridges and explore the various factors for footbridges design to reduce the retrofit cost because of vibration. The main study of this research is about the phenomenon known as Synchronous Lateral Excitation (SLE).

Lings et al. [5] studied the literature survey (1992-1999) for whole body vibration and lower back pain. It has been found that lower back pain and whole-body vibration are related to each other. They also provided the methods by which whole body vibration and lower back pain can be reduced. It has been seen that quality of most of the papers and articles related to WBV and LBP are low.

Valentini et al. [6] have simulated the human spine vibration. A new innovative numerical dynamic model has been used. The modeling approach is based on the use of the dynamic spline formalism in order to achieve a condensed description requiring a smaller set of variables but maintaining the nonlinear characteristic and the accuracy of a fully multibody dynamic model. The simulation result has been compared with literature result.

Hight et al. [7] have performed vibration analysis of human tibia using beam type finite element model and satisfied the result with analytical and experiment results. Natural frequencies are greatly affected by boundary conditions of model and the position of particular tibia also plays important role.

Pelker et al. [8] have studied the dynamic loading of femur bone with stress wave. They studied the travelling wave phenomenon for a single compressive pulse in fresh bone. Due to longitudinal impact of steel ball at one end of bone generated stress wave which is got monitored by bonded strain gauges.

Huiskes et al. [9] performed computer simulation to study bio mechanics of femur bone. Finite element analysis (FEA) tool used to study and analysis of complicated structured geometry. In this paper Finite element analysis is used to find mode shapes and natural frequencies of femur bone by Modal analysis.

K**halil** et al. [10] studied the femur bone by two different methods. By analytical method mode shape and natural frequencies of femur bone studied by analysis software. For experimental measurements they did Fourier analysis of transfer function. Transfer matrix method was employed to find analytical solution of mathematical model of 59 elements. First 20 natural frequencies of femur bone vary from 25 to 7300 Hz.

Pu-Pin Yu et al. [11] have studied the knee joint having hard tissues as well as soft tissues. For Analysis 3-D model need to be imported in ANSYS software. This results in finding the fundamental mode shapes, natural frequencies. Stress analysis can also be performed for different theories of failure at each component of knee joint.

Priyadarshi et al. [12] studied the detection of crack in femur bone and also found the places where maximum stress induced during loading. It has been seen that femur bone experienced maximum load when person walks or in standing position. With the help of analysis software mode shapes and natural frequencies has been derived. Stress analysis of femur bone tells about potential failure regions where crack can occur during loading.

Vijayakumar et al. [13] studied the potential reasons of femur bone fracture and how it affects the physical as well as mechanical properties of bone. Mechanical aspect of femur bone studied by varying material properties.

The von mises stress theory applied to study the deformation in femur bone at different boundary conditions for specific material. Different body weights are also varied to find deformation and stresses at different locations of femur bone. Modal analysis done to find natural frequency of vibration and different mode shapes.

Chandramohan et al. [14] explained the effect of natural frequency, different boundary condition and geometry of humeral bone shaft. For this they reduced the ggeometry of the humeral shaft bone to a cylinder and two spheres mounted to its two ends. It has been studied that natural frequency of vibration can be increased by constraining the bone shaft.

Wirtz et al. [15] have studied the physical and mechanical properties of real femur bone experimentally such as: Young's modulus, tensile, compressive and torsional strengths, Poisson's ratio, the shear modulus and the viscoelasticity. This experiment was done at room temperature in moist environment with real untreated human femur bone which is freshly removed.

Chethan et al. [16] have studied the femur bone for static structural analysis using varying loading conditions from 1000N to 8000N. The von mises stresses and total deformation were captured for performance analysis. The long femur bone performs well in comparison to short femur bone. In order to generate 3D models of femur bones drawing data has been picked from MIMICS from the CT scans.

Sharma et al. [17] have analysed the cup radius variation of humerus bone and noted the bio-dynamic response. FEA technique were adopted for evaluation of model frequencies and fracture locations. They also compared the FEA simulation results with experimental results which is available in literature review.

Jia et al. [18] have focused weight reduction of bone supporting plate. The plate was remodelled for light weight having 40% weight reduction in comparison to conventional supporting plate. By use of lattice plates, the average stress of the Skelton by 4 %. The dot matrix formation has been used for weight reduction without compromising the strength. Also studied the effect of different types of implants material and their effect on strength, stress shielding and weight reduction.

Rajapakse et al. [19] have used MRI guided FEA technique for hip fracture strength analysis. The technique has vast future application in managing hip fracture risk analysis. Hip bone became more fragile due to bone disease known as Osteoporosis. To assess the bone quality and to diagnoses the osteoporosis disease, Dual-energy X-ray absorptiometry (DXA) of areal bone mineral density (BMD) is carried out which determines the fracture risk to hip joint.

Esmaeili et al. [20] have modelled femur bone using PLA-HA nanocomposite materials. The three loading conditions: centralized loading, full scale and partial loading were applied. The remodelled femur bone can be used for replacement having proper strength and mechanical stability. The strength analysis has been performed by analysing stress-strain curve. 3D printing machine used to model the middle part of the hip using polylactic acid–hydroxyapatite (PLA–HA) nanocomposite, and ceramic nanoparticle.

Ong et al. [21] have suggested a new technique SHM with existing technique for monitoring of femur bone healing. They performed FEA first on fixated femur bone and found the response of this in its fractured state as well as in healed state. SHM mechanism is employed to monitor and assess the state of fracture healing after implant has been fixed.

Reina-Romo et al. [22] have highlighted the importance of mechanical vibration study of femur bone. They have calculated different mode shapes and natural frequencies at varying boundary conditions. They found that bone tissue adapts and provides better mechanical loading. It has been found that some bone regeneration therapies related to vibration of bone tissue.

Satapathy et al. [23] have studied the fractured bone. A new material FGM (functionally graded material) has been used for supporting bone plates. It was made of different layers of homogenous material. Use of FGM bone plate deformation decreases by 15% in torsional loading conditions. It provided better results in comparison to commercially available bone plate materials.

Adachia et al. [24] have studied new bone formation. The mechanical simulation method was applied for study of bone formation and scaffold surfaces. They studied that rate of scaffold degradation due to hydrolysis also affects the mechanical properties. It is the water content diffused from the surface to the bulk material. Bone regeneration process in the bone–scaffold system found by computer simulation using a voxel finite element method.

Kim et al. [25] studied various types of healing method used for long bone fracture conditions. For fractured bone structure stabilization bone plates were used with fastening screws. For plates and screws non-corrosive metals such as stainless steel and Titanium alloy were used. In order to increase the stress shielding effect composite bone plates were recommended. The effect of composite bone plates is that they helped in remodelling of bones, results in early bone union.

Fanisam et al. [26] studied the reason of femur bone fracture and the different type of methods for healing and replacement of bone implants. As the femur bone plays important role in human body. It connects the lower limbs to upper skeletal part. Most of the body weight carried by this bone during different activities of humanin day to day life.

Masood et al. [27] studied that when pressure was applied on the upper side of femur bone while epicondyle was restrained then the maximum deformations occur on the upper side of femur bone and minimum deformation occurs on lower side of femur bone. The maximum stresses were on the lower end of femur bone.

Gupta et al. [28] studied the natural frequencies and mode shapes for femur bone using the analysis software Abaqus for fixed-fixed boundary condition. They performed modal analysis for first 20 modes and found out that frequency of vibration varies from 722 Hz to 8480 Hz. They also compared the analytical results with the experimental results.

Nareliya et al. [29] studied the biomechanical analysis of femur bone under physiological conditions. As most of the body weight taken by femur bone during normal weight bearing activities. They used CT scan data for 3D model generation for more realistic results from analysis.
Analysis results depends upon the accuracy of Model and meshing used for analysis (automatic meshing used) and used analysis software as ABAQUS6.10.
A. Gupta et al. [30] studied that mode shapes are essential to find the behaviour of any structure which have external exposure. Analysis of femur bone carried out using Elmer software. They also identified the natural frequency and mode shapes for fixed-fixed boundary conditions. Analytical results were compared with the experimental results in literature survey.
Francis et al. [31] studied the patient-specific model generation from CT scan data. By making such FE model gave mare realistic results for medical treatment purposes. Major area of concern was cortical and trabecular subdomains of bone which had different material properties makes the femur bone FE model reliable enough for clinical applications.

III. HUMAN BODY VIBRATION

Different type of vibration associated with Human body during working is known as human vibration. The reason behind the study of human body vibration is to minimize the risks related to health and improve the comfort level of human beings. The classification of human vibrations are of mainly two types: Hand-Arm vibrations (HAV) and Whole-body vibrations (WBV) [8,33]. When Hand is exposed to vibration then it is called Hand-Arm Vibrations which results to problems related to joints and muscles and diseases related to circulatory disorders. When persons feet and back is exposed to any vibration during working is known as Whole-Body Vibrations, which results the harmful effect on spinal column and diseases related to spine. As we know that in human body every organ having its own natural frequencies. When the frequency of external excitation matches with natural frequency of organ then resonance takes place which leads to harmful effect on the body and its related organs. The bone which forms bridge between the lower limbs and upper body is known as femur bone. It is one of the longest as well as strongest bone of the human skeletal. At the Hip joint, joining of upper end of femur bone into a socket in the pelvis. The femur bone consists of head which is connected to the bone shaft through projected neck of the femur. In the femur bone, projected neck is weakest part of femur due to its structure so leading to chance of fracture. The knee joint formation takes place with the help of lower end of the femur and the shinbone which forms hinged joint. Our objective is to do femur bone vibration analysis [9].
It has been found that many researchers and authors studied the Human body vibration and contributed a lot in this filed for more than 50 years. As we know that the whole human body weight is taken by knee joint through femur bone. So, the possibility of fracture in femur can occur by two ways: Across its neck and Across the shaft. If the fracture occurs across its neck, results to Broken Hip. This condition mostly happens with elderly people when they fall down. In order to heal this problem replacement of hip is done. When the femur bone experienced to severe load and pressure then fracture occurs across the shaft. This fracture is mostly occurring during road accident or due to continuous exposure to vibration. As all body weight is supported by femur bone so in case of fracture or failure it causes more travel in motion, walking and jumping. As we know that Femur bone have very complex structure so it is not easy to perform the complete 3D mechanical analysis of the femur bone in actual form. For analysis we have considered the simple geometry and mathematical techniques to get the desire result [10,11,12,34].

IV. FEMUR BONE FRACTURE

A fractured bone should be kept stable (restriction of movement) and supported until the bone is not healed to wear the body weight. In order to support and stability the doctors used casts and splints from outside. Now a day's physicians have started surgical procedures allowing them to set the bones at designated place (repositioning) and stabilize the bone internally for fractured bones. In surgical procedure doctors used to reposition or properly aligned the fractured bone and then held them with special implants such as support plates and screws, Nails ad wires.
The main advantage of surgical procedure of internal fixation is to heal the fractured bone faster and also reduced the risk of improper healing. It also reduces the chance of healing of fractured bone in improper positions (Malunion). The selection of implants should be in such a way that they should be compatible with body i.e. should not have any allergic reaction with body. Now a days no. of different implant materials is successfully used for internal fixation of broken bones such as: stainless steel and titanium [35,36]. In replacement of joint mostly cobalt and chrome implants are used. Plates are used for fixation of internal fractured bone to hold the broken parts of bone together for faster healing with the help of screws. These plates may be kept intact after healing or can be removed in some cases depending upon location and type of fracture. Screws are simple type of internal implants used to hold the broken bone together. They are used alone as well as with combination with nails, rods and plates. Different size and design of screws are used in internal fixation depends upon the type of bone fracture. These screws are also kept in place or in some cases removed from their location after healing the fracture. In the case of long bone fracture the effective method of holding the broken bone together by inserting of rod implants in the centre of bone which is hollow and mostly contains the marrow. Screws provided at the ends of rod in such a way that it keeps the fracture from shortening or in some cases rotating. Rod kept intact till the fractured bone is healed. This method is mainly used in fracture related to femur bone (also called thighbone) and tibia (also known as shinbone). Wires type of implants are mostly used for fractured bone where the pieces of broken bones are too small to hold together by other methods. They are used for treatment of small bones of body such as in hand of foot. They are removed after healing the fractured bone in some cases it may be kept forever.

In an external fixator bar is used from outside of body and the metals pins or screws are used in to the bone through small incisions into the skin. By this way the broken bone is held together until the bones are not healed properly to wear the load static and dynamic. It is very different from casts and splints which is purely external support.

V. IMPLANT MATERIAL AND BOUNDARY CONDITION

In human body different type of implant materials are used to replace the fractured human bone depending upon suitability of material and application [37, 38].

- **Metals:** Due to good load bearing capacity of metals because of good strength and stiffness it is widely used in implantation of fractured bone.
- **Metallic Biomaterials:** In the areas where high cyclic stress application is required, we use metallic biomaterials. The human activities like lifting, bending or running requires to transfer stress to implants so, metallic biomaterials are best suited for these applications.
- **Ceramic Materials:** In the application where wear and tear are primary focus then ceramic materials are used as replacement surgery.
- **Polymeric Materials:** Polymeric material provides the flexibility, stability along with controlled porosity. Polymeric materials implants also change itself mechanically as well as chemically to its immediate neighborhood. Due to this property these implants are used in replacement surgery.

Boundary conditions

The Femur Bone Structure has been designed using solid works. Biomechanical analysis of Femur Bone has been done using Ansys based on Finite Element Analysis (FEA). Femur Bone design is a complex procedure having bone shaft, neck and tissues. For simplification only bone shaft and neck has been considered in designing. FEA is based on Nodes and Elements. For bone properties young's modulus, poison ratio and bone density were considered. These are the critical parameters that governs the FEA results. The mechanical properties of Femur bone Young's modulus: 7.585 GPA, Poison ratio: 0.35, Bone density: 866 kg/m^3 (D.C. Wirtz, 2000)

For modal analysis two boundary conditions will be applied i.e. Free-Free and Fixed- Fixed boundary conditions. The modal analysis of femur bone will be performed using Ansys to evaluate natural frequencies and mode shapes. First ten natural frequency and corresponding mode shapes will be considered for result analysis. Free-Free boundary conditions shows natural frequency of femur bone. In natural form femur bone is constraint between Pelvis and Tivia. So Fixed-Fixed boundary condition is most suited which provides frequency of constraint femur bone. The issue of femur bone fracture arises due to aging. As age increases, the bone mass decreases which adversely affect the health of femur bone. However, the low mass density is not the only reason of failure. Sudden loading, high vibration excitation and road accidents are few reasons for femur bone fracture. The most favorable location of femur bone fracture is across the shaft and bone neck of femur. The fracture analysis of femur bone using FEA is possible with the observation of mode shapes available of FEA results [22, 24].

VI. RESEARCH METHODOLOGY /ALGORITHM

For the study of femur bone structural and vibrational analysis the following methodology been adapted:

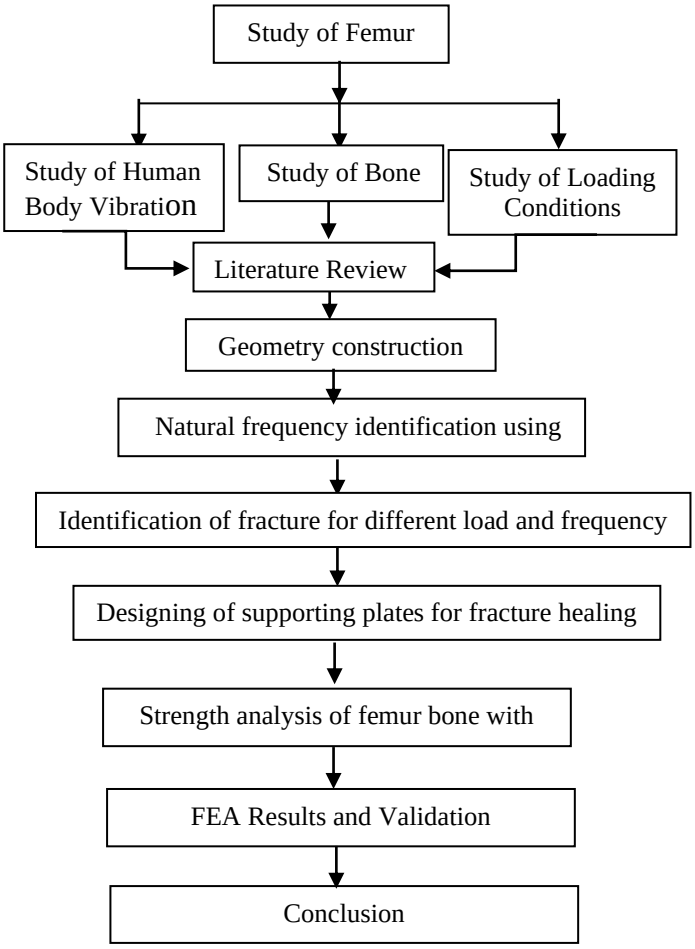

Fig 2. Methodology adapted for study of femur bone analysis

The layout of this thesis is broadly divided into five chapters. The thesis is organized as follows:

Chapter 1: This chapter serves as a brief introduction about femur bone, human body vibration, important literature review and research methodology. After literature survey we start with geometry construction of femur bone using Solid works 2017.

Chapter 2: This chapter contains details about finite element analysis (FEA), femur bone geometry, material properties and boundary conditions applied. Using ANSYS Software natural frequency of femur bone will be identified using modal analysis for varying boundary conditions and for varying load conditions from mode 1 to 10.

Chapter 3: This chapter presents a detailed description of the Modal analysis for natural frequency identification. After detailed analysis, the strength analysis of femur bone will be done this identifies the fracture at different boundary conditions and different loading conditions.

Chapter 4: This chapter deals with fracture study of Femur bone with supporting plate design and analysis. Analysis will be done for different support plate material i.e. stainless steel, titanium material, cobalt chromium alloy and FGM material.
Chapter 5: This chapter summarizes the important conclusions and future scope of present research work. Different material support plates will be used and after assembly of these support plates with model further strength analysis will be performed and best possible material will be found for fracture healing purpose.

VII. RESULT AND DISCUSSION

Femur bone analysis using FEA predict the natural frequency of bone. Using different boundary conditions and loading methods fracture locations will be identified. In case of accidental fracture of bone shaft supporting plates, method will be used for healing. The bone strength of femur bone will be examined for different loads under structural analysis and stress variation pattern will be evaluated. Frequency and stress variation graphs will be plotted for strength analysis [35, 38].

VIII. CONCLUSION

The vast literature survey of bio-dynamic response study will provide plot for detailed study of femur bone. Different boundary conditions were observed to conduct further study on femur bone. Modal Analysis, structural strength analysis will be performed for future work on femur bone. The following study will be conducted on femur bone for detail investigation:

- Natural frequency will be different for different boundary conditions.
- At different loading condition the stress analysis will be different for short femur bone and long femur bone.
- Different methods of fracture healing may be used for type of fracture and location of fracture in femur bone.
- Bone density and the associated mass (As per the health condition and age group of patients) different methods can be used/ employed for fracture healing and different type of support plate design and material can be used.

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