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Experimental and FEA Analysis of Goat Femur Bone With Different Age Group

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ABSTRACT

Clinicians and Engineers have long been interested in assessing the mechanical properties of human whole bones and implant devices , to address a vast array of orthopedic pathological conditions and traumatic injury patterns. Finite element (FE) models of the implant system is used to identify areas of high stress, strain, and to facilitate implant redesign . Experimental methods and computational techniques have been employed over the years, separately and in combination to assess the performance of femoral orthopedic implants and biomechanical testing . Generally mechanical properties like axial stiffness and torsional stiffness which are most important parameters , are using to characterize any biological system. Due to vast similarity between Goat and human femur bone , a fresh-frozen Goat femur was scanned by computed tomography. CT scans data used to generate a high-order FE bone model (By using mimic software) , then distinct cortical and trabecular regions are used for finding axial stiffness .Properties find out through experimental results by using strain gauges validated by Finite element analysis . Different age groups of male Goat femur was preferred for the analysis and experimental result shows that with increasing the age both axial stiffness increases significantly.

Keywords— Biomechanics, Finite Element Analysis, cadaveric femur, Axial stiffness.

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I. Introduction

Biomechanics is the theory of how tissues, cells, muscles, bones and the motion of them and how their form and function are regulated by basic mechanical properties Strength and stiffness are typically used to define the "health" of a bone, but they are not as clearly related to risk of fracture as is the amount of energy required to cause fracture. Trauma transfers energy into the bone and, if that energy exceeds what the bone can absorb, the bone will break. A bone that is highly mineralized is also stiff and brittle and will require much less energy to fracture (the area under the curve) than a bone that is more compliant. Irrespective of its biological function, bone is one of the most interesting materials known in terms of structure–property relationships. Bone exhibits electro mech- anical effects, presumed to be due to streaming potentials, both in vivo and in vitro when wet. In the dry state, bone exhibits piezoelectric properties. Because of the complexity of the structure–property relationships in bone, it is necessary to concentrate on one aspect of the mechanics. Currey [1984] states unequivocally that he thinks, "the most important feature of bone material is its stiffness." This is, of course, the premiere consideration for the weight-bearing long bones. Thus, We will concentrate on the elastic properties of compact cortical bone . When load is converted to stress and deformation converted to strain by engineering formulas, the relationship between stress and strain in bone follows a curve

called the stress–strain curve. The slope of the stress–strain curve within the elastic region is called the elastic or Young's modulus (E). The Young's modulus is a measure of the intrinsic stiffness of the material. The area under the stress–strain curve is a measure of the amount of energy needed to cause material failure. This property of a material is called energy absorption or modulus of toughness or just toughness.

Objective of biomechanics is to help medical field to develop treatment for the diseases which are difficult to cure. Aim of biomechanics is to develop data of properties related to different parts of bone. so that this properties will helpful in developing treatments. Biomechanics deals with development of biocompatible materials. A proper understanding of the biomechanical situation of the lower extremity is essential to better elucidate the relationship between its form, ultrastructure and function. In many aspects, the mechanical environment in bones is considered a major factor influencing biological processes and therefore vital for surgical procedures, healing processes as well as therapeutic regimens. Although an organic material, bone can often be considered in the same way as man-made engineering materials.

More recent advances in computer hardware, computed tomography (CT) scanning devices, and computer aided design (CAD), have allowed for the generation of more representative geometries and material properties of whole bones . Human cadaveric whole bone specimens have been mechanically characterized by investigators for well over a century. Gross parameters such as stiffness and load-to-failure have been measured under various loading modalities, the most common being three-point bending, four-point bending, lateral bending, torsion, and axial compression .

It is also of interest to determine whether FE models of synthetic bones, with appropriate adjustments in input material properties or geometric size, could be Experimental Analysis to obtain the Relative values of first, second and third modal natural frequencies, by performing the laboratory experiment for beam. used to simulate the mechanical behavior of a wider range of bone quality and size. To shed light on these questions, the axial and torsional stiffness of cadaveric femurs have to find.

II. OBJECTIVE

In the present research, a number of papers published thus far have surveyed, reviewed and analyzed. Most of the researchers studied stress, strain and toughness of femur bone. In younger people with good bone quality, i.e. normal bone properties, femur fractures usually require high-energy events such as the 6.5 million automobile accidents that occur annually in the U.S. alone . In elderly people with poor bone quality, i.e. osteoporosis or osteopenia, low-energy impact from falls is the most frequent cause of femoral neck fracture. Moreover, in the U.S. alone, about 231,000 hip replacement and 542,000 knee replacement surgeries are done annually due to femoral diseases like osteoarthritis and bone cancer.

The main portions of femur bone are ,

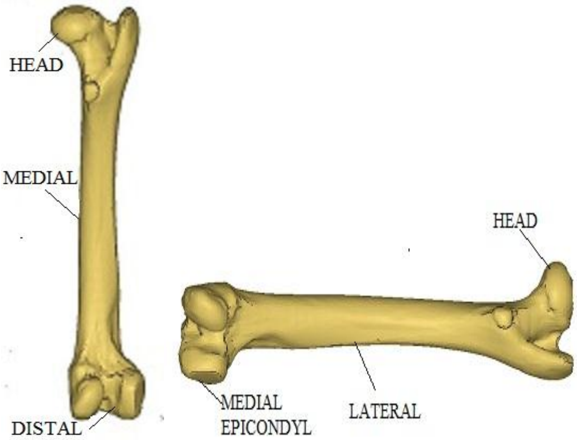

Fig.1: Femur Bone of Goat (Age of 10 moths)

main focus is on the neck portion of the femur bone because the most of femur fracture are in the femur neck region. Thus have selected femur portion of body for study the reasons behind this are:

- Implant Design:

For implant design of femur bone we have developed data of properties related to stiffness.

- Diseases & Accidents .

Furthermore, because of the use of these standardized long bone geometries in FE studies of bone/implant systems, it is also of interest to determine whether the FE models could be used to simulate a wider range of bone qualities by adjustment of input material properties or a simple change in bone size (i.e., without changing the bone's geometry) To shed light on these questions, the axial (note that an axial load applied to a femur head causes axial compression) a sample was found by using compression test .

Mechanical properties are very important parameters which are used to characterize any biological system and its interactions with biomedical devices. These parameters will allow the optimization of the performance in different topics like in clinical procedures, surgeries and rehabilitation. Analysis of trabecular femur and it's neck plays very important role in study related to hip-pelvis joints. Also Femur analysis is mostly important in case of osteoporosis which we find in old humans especially in old women. this mechanical properties are very important in the implant design. The implant is nothing but a dummy organ that is placed on replacement of original bone. While designing this implant the mechanical properties are very important because the implant must behave like original organ for what it is replaced.

The objective of finite element analysis is to validate the result that obtained in experiments. The main objective is to obtain the stiffness of goat femur bone of varying ages .this values will be important in the in determining the nature of variation in stiffness according to the age. This trend of the graph for the goat bone can be correlated with humans of similar age groups. so the result of the age groups can be used design the implants for the people of different age.

So the objectives can be summarized in the following way,

- To find out the axial stiffness of goat femur bone in axial gradually applied loading of different ages.
- This value of the stiffness is very important in the design of implant which can be use in place of original organ.
- To find out bio-compatible material of equal strength that will prove useful for design of implants.
- The analysis is to be done on the goats of different ages, the data of which can prove useful for the future researchers.
- To correlate the results that are obtained through analysis of goat femur bone with human femur bone which can prove useful in the medical surgeries and while selecting the material for implant design.

III. METHODOLOGY

Samples of femur of domestic goats breed Osmanabadi that is commonly found in the Deccan region of India, will be collected from the local butcher shop within 5 hours of death of the animal .The femurs will stored at 22℃ in HBSS (Hanks' Balanced Salt Solution) soaked gauze and keep to room temperature. Samples are selected from Different ages 3 to 13 months .Male samples were collected for experiment.

With reference with previous research lot of data is available on the femur bone only so by taking the help of that data and proceeded for work on femur bone analysis. The FEA analysis and validated the results of axial stiffness be experimental setup. For FEA analysis, Model need to CT scan the goat femur bone and take the soft copy of that that image. Then the same image need to be processed and the final outcome will be the model of bone. This model need to be analyzed in the software to get the numerical result .

The detail procedure of obtaining the final result can be classified in the subsystems named experimental and finite element analysis .Then the FEA may be detailed with steps like CT scan of model ,it's image processing by using MIMIC software and conversion to 3D model and it's analysis in the ANSYS software. Experiment consist as bone preservation, bone surface preparation and mounting of strain gauges on the surface of bone, preparing the strain gauge alignment circuit with help of strain indicator and finally place the bone on the set-up and take the readings.

IV. EXPERIMENTATION

A. Set Up Description

The set up that used for experimentation was very simple which consist of a base plate, two vertical C-channels and a plate to cover the top. The two channels where welded to the base plate and top plate to channel as well. The role of this structure is to just support the other important components. To the base plate, mechanical screw jack welded. Screw jack has main function of applying the load. The capacity of screw jack that used is 3000 kg. from the papers came to know that the maximum load that a bone can withstand is up to maximum 500 kg so that using the screw jack of 3000 kg is feasible. The reason, why used the mechanical screw jack is due to its rigidness and to apply the constant load. The main drawback of hydraulic screw jack is that it cannot keep the load constant due to change in pressure of oil as the well as the mechanical screw jack can be easily welded to the base plate.

The top of toggle jack was provided with a jaw like fixture which is used to hold the load cell tightly. Head end of the femur bone was held in the jaw which is manufacture specially. The jaw was provided with internal tapered hole, during the experiment the head end of the bone just held in that hole which do not allow the bone to move laterally. this jaw is fixed to the load cell point. The load cell was used to measure the load that was being applied on the bone. the load cell can measure the load up to 300kg which is sufficient as per requirement. When we compress the bone against the top plate the load cell senses the load and displays the reading digitally.

Fig.2: Lower Jaw

The strain gauge used is have gauge factor of two which is fair enough to detect the strain induced in the bone. While deciding the geometrical parameter of set up we have consider the lift of screw jack, length of jaws used and maximum length of bone. The material used for making set up is taken as per availability as well as thickness of material selected is also by random on availability. The reason of not paying attention on the design is that it is not having that much importance other than having only robust construction with heavy weight to support the experiment without having the any deflection. To apply the load the screw jack lever is rotated this causes the jack to get lifted and bone is compressed in between the both the jaws.

The distal end of the femur bone is cut to make the surface parallel to upper plate and to have ease of holding. the distal end is not fixed in the jaw. The end is only held at position by resting it on plate. The reason not making the fixture is that each of the femur bone has different shape.

So that the end must be adjusted in such that there should not be direct bending of bone.

Fig.3 Set-up Diagram

B. Bone Preservation

It is important stage in the project because the availability bone is not periodic. Sometimes we got bone in bulk so it the just be kept somewhere in such way that the mechanical properties of the bone should not change with respect to the time. So as per data available the procedure for bone preservation is as follows;

- Bring the bone from market and the bone as maximum as possible in the shop itself without any damage to the bone.
- Then clean the bone again with the delicate surgical instruments like BP blade, BP handle mayoscissor to remove all the meat on the surface bone where we have to mount the strain gauges.
- Then take the ethanol and phenolformeldehyde and the solution in such that the ethanol is 96% and phenolform-eldehyde 4%.
- Take two towels and sink that towels in the solution. Wound the bones in the wet towels and keep them in close compartment in absence of sunlight.

C. Bone Surface Preparation and Mounting

- Make sure that all the meat is from the location where the strain gauge has to be mounted.
- Rub the surface gently with emery paper to make rough.
- Then apply the m-prep neutralizer 5a solution on the surface to clean it. Repeat this step for 3-4 times to ensure the proper cleaning.
- Again use another cleaning solution M-Coat a air Drying Polyurethane Coating to ensure final cleaning.
- Apply the 200catalyst-c for protection purpose of strain gauge.
- Hold the strain gauge with cello tape for the purpose of handling.
- Apply the flex-kwik solution on bone surface and paste the gauge on it. Wait for drying of solution. Remove the cello tape from the strain gauge.
- Now wound the single layer of cello tape on the surface of strain gauge and it is ready for taking reading.

D. Experimental Procedure

Take the bone with strain gauge mounted on it and fix it on set-up. Ensure that the head end was held at lower jaw and upper end is parallel to the surface of frame. Take the wires out of frame and make connection with the strain indicator as per mentioned earlier. Start the computer and connect the strain indicator with it. Start the P3 Software. Now start the channel to which the connection of strain gauge is made. Select the type of bridge you want to make and balance the circuit to set the initially induced resistance to zero. Now apply the load gradually on the bone without breaking it. Let the load be stable at some value. Now note down the reading by observing the value of load and respective deflection value on the strain indicator. Start the recording of deflection in the software after fix interval of time. Remove the bone from set-up and put another for testing. Follow the same procedure for each specimen. Analyze the reading and note down the result as per required.

E. Calculation

Axial Stiffness = $load/deflection$

$=m\times g/10^{-6}\times e\times l$

Where,

m= load applied in kg.

e=strain induced.

L=length of bone.

g=Acceleration due to gravity

=9.81 m/$sec2$.

Sample Calculation:-

1) For 3 month bone:

Length of the bone: 118 mm

Load applied: 120 kg

Strain induced: 5680

Therefore,

Axial Stiffness = $load/deflection$

$= m\times g/10^{-6}\times e\times l$

=120×9.8110−6×5680×118

=1756.23 N/mm

Similarly calculated the stiffness of all goat femur bone for each load applied on it.

V. RESULT AND DISCUSSION

For finding Axial stiffness and comparing it with the different ages , the number of readings were analyzed as follows ,

A. AGE: 3 months length-118mm

TABLE I
RESULT FOR AGE OF 3 MONTHS.

Sr.no.	Load(kg)	Strain	Stiffness(N/mm)
1	120	5680	1756.23
2	115	5460	1751.024
3	110	5366	1704.23
4	105	5212	1674.83
5	100	5038	1650.17
6	95	4852	1627.75
7	90	4685	1597.05
8	85	4534	1558.56
9	80	4373	1520.88
10	75	4200	1484.56
	Average		1632.52

B. AGE- 4.5 months length-133mm

TABLE II
RESULT FOR AGE OF 4.5 MONTHS.

Sr.no	Load(kg)	Strain	Stiffness(N/mm)
1	120	3590	2465.50
2	115.5	3478	2449.46
3	110.2	3380	2404.82
4	105	3275	2364.8
5	100.8	3165	2349.12
6	95	3071	2281.2
7	90.4	2938	2269.52
8	85.7	2798	2259.18
9	84.8	2747	2276.96
10	81.8	2665	2263.98
11	80	2634	2240.23
	Average		2329.6

C. AGE- 5 months length-114mm

TABLE III
RESULT FOR AGE OF 5 MONTHS.

Sr.no.	Load(kg)	Strain	Stiffness(N/mm)
1	120	4050	2549.70
2	115	3940	2511.68
3	110	3818	2479.25
4	105	3690	2448.65
5	100	3555	2420.6
6	95	3404	2401.58
7	90	3270	2368.42
8	85	3120	2344.38
9	80	2961	2324.9
10	75	2811	2291.88
	Average		2414.11

D. AGE- 6 months length-114mm

TABLE IV
RESULT FOR AGE OF 6 MONTHS.

Sr.no.	Load(kg)	Strain	Stiffness(N/mm)
1	120	3684	2685.24
2	115	3550	2670.51
3	110	3397	2669.43
4	105	3234	2676.52
5	100	3070	2685.24
6	95	2950	2654.75
7	90	2758	2690.11
8	85	2640	2654.22
9	80	2458	2683.05
10	75	2315	2670.74
	Average		2673.98

E. AGE- 6.5 months length-114mm

TABLE V
RESULT FOR AGE OF 6.5 MONTHS

Sr.no.	Load(kg)	Strain	Stiffness(N/mm)
1	120	2741	3940.16
2	115	2672	3873.5
3	110	2611	3791.65
4	105	2540	3720.47
5	100	2478	3631.9
6	95	2399	3564
7	90	2287	3541.75
8	85	2167	3530.22
9	80	2065	3486.7
10	75	1957	3449.15
	Average		3652.956

Similarly calculated the stiffness of all goat femur bone for ages 8 months,9 months,10 months,11.5 months,12 months &13 months for each load applied on it.

F. Age and Avg. Stiffness

TABLE VI
AGE AND AVG. STIFFNESS

Sr.no	Age	Average Stiffness
1	3	1632.5284
2	4.5	2329.6
3	5	2414.11
4	6	2673.98
5	6.5	3652.956
6	8	18167.01
7	9	32603.791
8	10	25058.65
9	11.5	12252.243
10	12	6129.93
11	13	1603.15
12	13	1231.83

G. Age (months) v/s Average stiffness (N/mm)

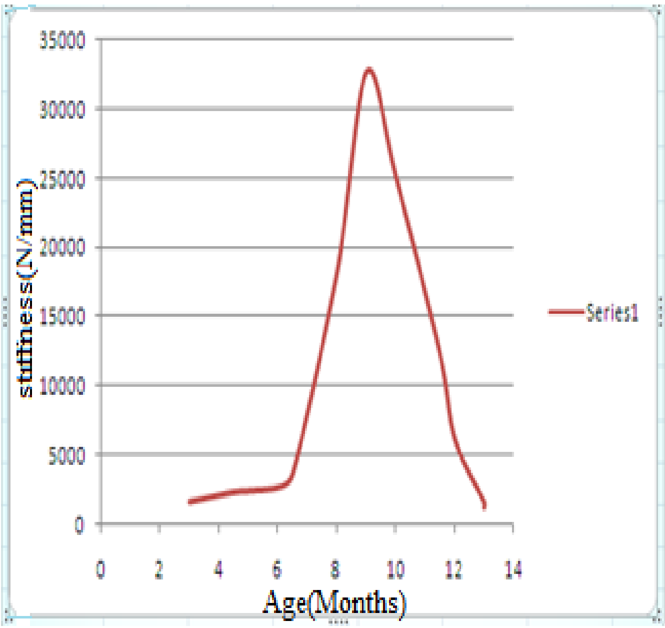

Fig.4 Age (months) v/s Average stiffness (N/mm)

Above graph indicates that as increase of age of goat femur ,the stiffness also increases . It is found that on the age of 10 months stiffness has its max value.

H. Age and Average Strain.

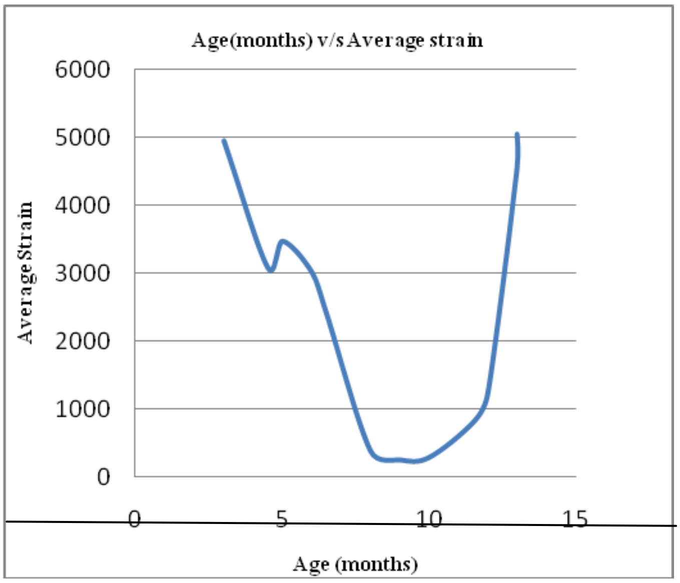

Fig.5 Age v/s Avg.deflection

From above graph it can be conclude that as age of goat bone increases the value of strain decreases up to certain age i.e. 10 month and again it increases.

I. Age = 6 months

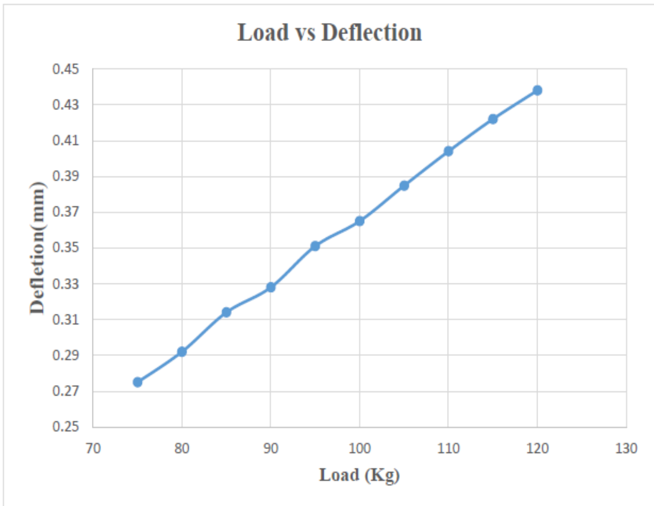

Fig. 6 Load vs Deflection

Moreover experimental results of 6 month bone shows linear variation of deflection with respect to load .

VI. FINITE ELEMENT ANALYSIS

For FE analysis of femur bone, firstly the three dimensional model of femur was developed. This work used goat femur bone which was reconstructed from CT scan images(DICOM). This study used one sample from Different ages. The model was received as (.cdb) file then it was imported to (ANSYS R14.5). then the model was divided into two parts, the upper part which includes the head and neck and the lower part which includes the body of the femur and the condyles, the process of creating two parts is to consider the upper part as cortical bone and the lower part as trabecular bone the process of dividing the femur bone is as follows, after importing the three dimensional model in to the geometry window, a new plane has been created on the head of the femur the axes of the new plane has been rotated 90 in order to make the direction of the cut in X-Y plane and the Z axes is pointed toward the longitudinal axes of the femur bone.

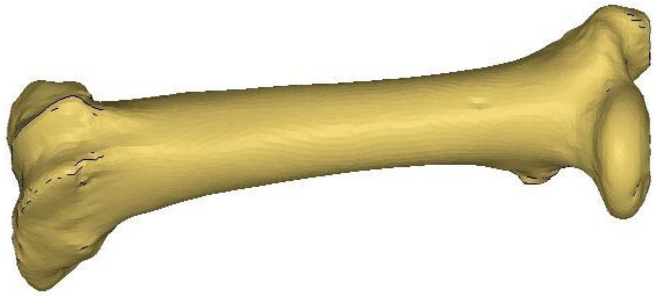

Fig .7 Bone Model

A. Mesh Preparation

Mesh is a very important step required for Finite Element Analysis of the femur model, an optimized mesh has been developed using model wizard in Hyper mesh 11.0 software, a solid 187 quadrilateral element was selected for analysis. Proper setting and values have been executed in order to use smaller elements on proximities and curvatures for the model.

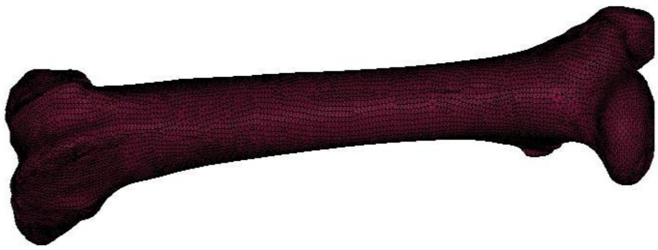

Fig.8 Meshed Bone

Fig.9 Section of Meshed Bone

B. FEA Results

For FEA analysis 10 months femur bone has been taken for validation of experimental result. The stepwise procedure of FEA analysis is given below, CT scan of bone(1.5 Tesla m/c, Giriraj hospital, Baramati).
- 2-D and 3-D images in DICOM format.(200-300 images)
- Conversion of images into 3-D model by using MIMIC software.
- Conversion of .stl file into .igs by using solid works.
- Correction of geometry missing data by using Hypermesh.
- Meshing of bone using Hypermesh 11.0.
- Import geometry into ANSYS R14.5
- Applying material properties and boundary conditions.
- Getting deflection values for different loads.

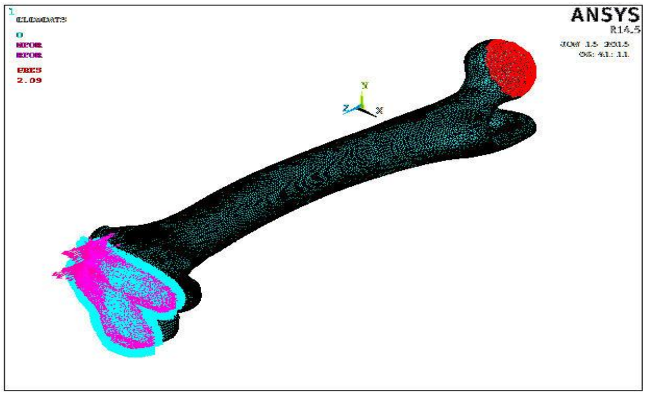

Fig.10 Applying Boundary Conditions

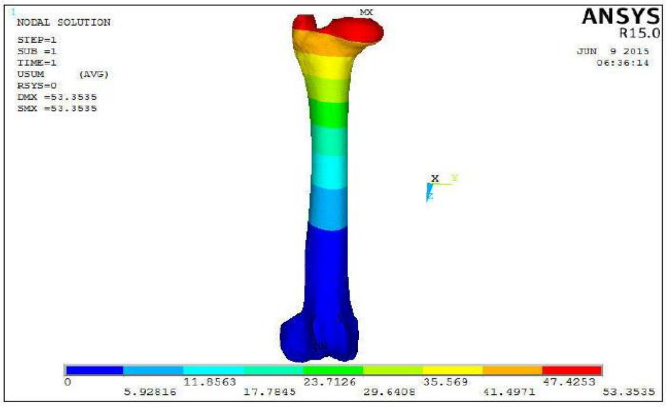

Fig.11 load of 110 Kg

TABLE V
RESULT TABLE OF 10 MONTHS BONE

Sr.no	Load(Kg)	Strain	Deflection(mm)	stiffness(N/mm)
1	75	203.39	0.0242037	30398.24
2	80	212.8	0.02508	31282.51
3	85	230	0.02736	30476.19
4	90	244.07	0.029044	30398.11
5	110	299.12	0.03556	30338.21

providing me guidance throughout the research but also expands my academic vision.

VIII. CONCLUSION

The mechanical properties of bone is vital in prediction of effects of aging and disease on mechanical behavior of bone. In this study the axial stiffness of goat femur bone was determined and validated through FEA result . The finding of this study is as follows ,

1. It is experimentally prove that axial stiffness of goat femur varies with age in which axial stiffness of femur increases up to 9 months from beginning and subsequently decrease according to the age.
2. On comparing results obtained from experimental analysis and finite element analysis it is cleared that the deflection, stiffness, strain at neck portion of femur bone are almost similar.
3. The mechanical properties that is axial stiffness obtained from above analysis will be helpful for Implant design purpose. Axial stiffness gives significance of strength and flexibility.
4. This study will be helpful to implant design for implantation.

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