EXPERIMENTAL ANALYSIS OF STRESSES IN REAL (PRESERVED) INTACT PROXIMAL HUMAN FEMUR (THIGH) BONE UNDER STATIC LOAD

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ABSTRACT

The objective of this study is to carry out experimental analysis to decide the high stress concentration areas of the femur bone which are extremely responsible for fractures and damages. Here, behavior of femur bone is analyzed by experimental work under physiological load conditions. We carried out strong literature review for using mechanical properties of the bone because the mechanical analysis with heterogeneous material property is varying with individual person. In the present work Electronics Universal Testing machine is used to apply Quasi-Static Load (considered as static load).Also selection of proper electrical resistance strain gauge and mountings of it on bone's irregular surface area was a challenging job. Hence, this field is at beginning level and still immature as compared to other areas. These obstacles include the greater bone complexity in terms of geometry, difficult to decide the material properties, handling and availability of bone. The said problem and obstacles are handled through this work. The results of this analysis will be helpful for orthopedic surgeons for clinical and experimental purpose. Also the results of this analysis will helpful to design an implant, which is called hip prosthesis, to replace the failed femur part. Overall, we concluded that in the proximal area of the real human femur bone had tensile as well as compressive stresses and the femur neck area had more stress concentration.

***Keywords*: Biomechanics, Embalmment, Proximal femur, Prosthesis, Strain Gauge, Total Hip Arthroplasty**

I. INTRODUCTION

Nowadays the T.H.A. (Total Hip Arthroplasty i.e. Total Hip Replacement-T.H.R.) is a common practice of reconstruction used when the natural function of the hip articulation and the leg is damaged. Different problems are associated with the T.H.A. and some of them are because of the design or the applied materials. Among the principal problems associated to the T.H.A. are the fatigue fracture of the implants, the dislocation or loosing of the implant and stress shielding. In Biomechanics there is study of how tissues, cells, muscles, bones, organs and the motion of them and how their form and function are regulated by basic mechanical properties. The femur is responsible for bearing the largest percentage of body weight during normal weight-bearing activities. The femur is also known as thigh bone. It is not a completely solid part. It consists of cortical (which is the outer bone and is also known as compact bone), cancellous (which is the inner bone and is also known as spongy bone), bone marrow, etc. The structure itself is complex. This leads to the complexity of bone's properties. A femur fracture happens due to either a large force or something is wrong with the bone. In patients, the most common causes of femur fractures include: Car accidents and falls from a height. Patients may also have bone that is weakened by osteoporosis, tumor, or with some infection. These conditions can lead to a so-called pathologic femur fracture. The following four proximal femur fractures are commonly referred to as hip fractures: 1.Femoral head fracture 2. Femoral neck fracture 3.Inter-trochanteric fracture 4.Sub-trochanteric fracture. The following fig. clears the terminology of bone which related to proximal portion. Proximal femur means upper third of the human femur bone, which includes the femoral head, femoral neck, greater trochanter, and upper portion of the femoral stem. The femoral neck is the narrowed region directly below the femoral head. Cortical bone is the outer (hard) shell of a bone having higher material density. Trabecular bone is the relatively soft, sponge-like bone residing inside the hard cortical shell.

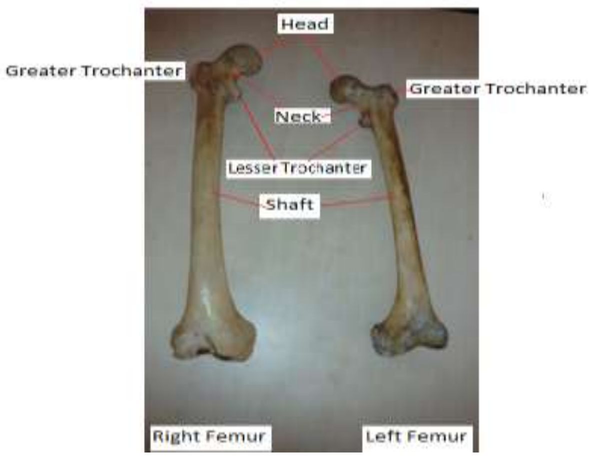

Fig.1: Actual Photo of Femurs

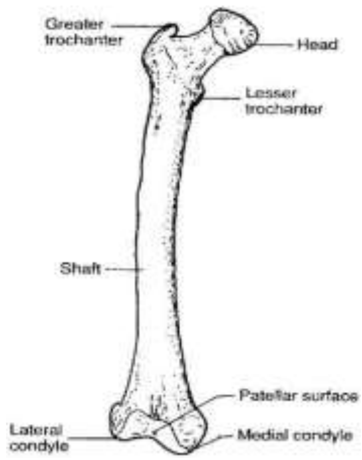

Fig.2: Terminology of Femur Bone

Also, following fig. clears the actual position of the bone and gauges which are used to find the strains in this experiment: 1- Neck inferior; 2- Neck superior; 3- Shaft lateral; 4- Shaft medial.

Fig.3: Positions Of Strain Gauges

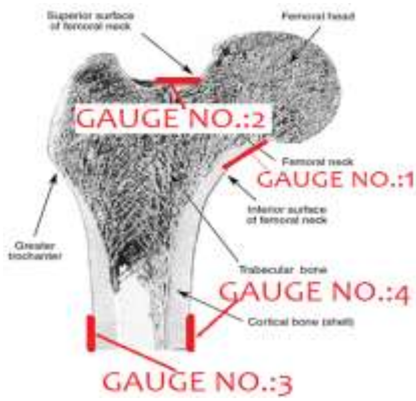

Fig.4: Proximal Femur with Gauge Positions

II. METHODOLOGY

To carry out the experimental work the condition of femur is important. Due to the fact that the bone sample is taken from Yashwant Ayurvedic College, Kodoli, Tal.-Panhala, Dist-Kolhapur, (M.S.), the specimen went through an embalmment process. This is a common method of preserving human bone specimens. In this process the bone is chemically fixed with formaldehyde to prevent decomposition of the bone structure. In summary, the embalmment process is an insignificant effect on the mechanical properties of human bone. The different researchers show that after embalmment the Elastic modulus increases, the UTS increases, Elongation carrying decreases. The detailed discussion of our methodology is as follows:

2.1 Assignment of Mechanical Properties

After carried out detailed literature survey, we found the following mechanical properties:

2.1.1 Femur Materials

Human bone is highly heterogeneous and non-linear in nature, so it is difficult to assign the material properties. The proper assignment of material properties on the other hand, is *still under active research* because of the inherent inhomogeneous and anisotropic nature of bone's tissue. Most past studies assumed the bone to be inhomogeneous isotropic due to simplicity and the limited knowledge of the anisotropic behavior. Thus, the bone is known to be anisotropic and inhomogeneous, most studies simplify these difficulties by considering an isotropic inhomogeneous material so we have also considered same (i.e. Isotropic In-Homogeneous) femur bone material in our study.

2.1.2 Density (ϱ)

The proximal femur consists of cortical (dense) and trabecular (cellular) tissues. Hence, density values are different at the different area of the throughout femur which is found by different researchers. Also different researchers used different values. Thus, from reputed international journal we found that 2080 Kg/m^3.

2.1.3 Young's Modulus (E)

The Young's modulus for cortical bone is evaluated according to the functional representation of the density. Hence, different researchers found out different Young's modulus values. Also different researchers used different values for their study. Thus, we used 14200 MPa value of 'E' from reputed international Journal.

2.1.4 Poisson's Ratio (ν)

As the material is non-linear and heterogeneous the Poisson's ratio is also having different values for different researchers. The values of this ratio are 0.2 and 0.5, etc. for cortical bone but mostly used value is 0.3 by the different researchers which is mean value of 0.2 & 0.5.After carried out detailed literature survey we come to know that there is a wide variation in values of mechanical properties of femur, which is found by different researchers. In summary we referred the following data:

Table 1. Mechanical Properties of Human Femur Bone

Sr. No.	Test Specimen	Test Specimen	Mechanical Properties of Bone	Value	Unit
1.	Preserved Human Femur Bone	Isotropic In-Homogeneous	Density(ϱ)	2080	Kg/m^3
2.			Young's Modulus/Modulus of Elasticity (E)	14200	MPa
3.			Poisson's Ratio (ν)	0.3	Dimensionless
			Yield strength:		

5.			Ultimate Compressive Longitudinal Strength	270	MPa
6.			Ultimate Compressive Transverse Strength	131	MPa
7.			Ultimate Tensile Longitudinal Strength	135	MPa
8.			Ultimate Tensile Transverse Strength	53	MPa
9.			Ultimate Shear Strength	65-71	MPa
10.			Shear Modulus/Modulus of Rigidity	8-40	MPa

2.2 Design and Fabrication of Box Type Femur Bone Fixture

It is very difficult to develop femur holding fixture which is into femur's biological condition. Hence, to carry out our experimental work we have developed the following box type holder. This avoids complexity of experimental work. By taking considerations of design parameters for work holding devices, we have restricted maximum Degrees of Freedom (D.O.F.) of bone through this fixture.

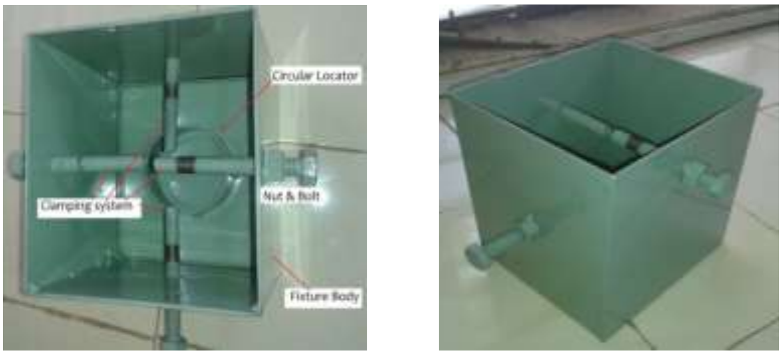

Fig.5: Actual Photos of Box Type Femur Bone Fixture

2.3 Selection & Mountings of Electrical Resistance Strain Gauge

There are mainly two techniques of stress measuring such as photo-elasticity & strain gauges method. But because of the irregular and unique shape, it is very difficult to make the photo –elastic model of femur. So, we preferred strain gauge method to find out the stresses of the femur. It is very convenient and reliable method for femur. The specifications of selected strain gauge are as follows:

Table 2.Specifications of selected strain gauge

Strain Gauge Type	**Gauge Length**	**Resistance**	**Adhesive Type**
Composite Type	3/5 mm	350 Ω	Methyl Methacrylate

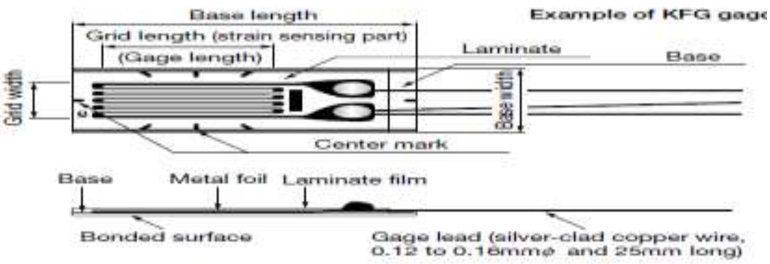

Fig.6: Construction of Wire Type Electrical Resistance Strain Gauge

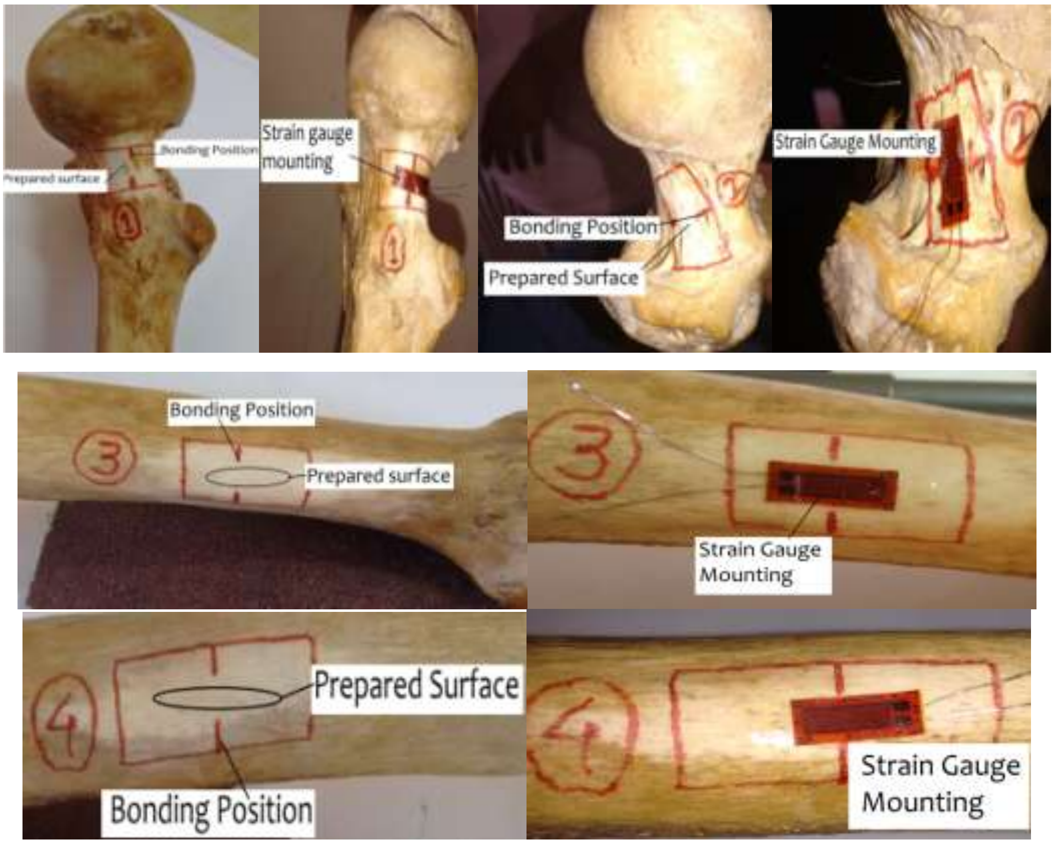

Fig.7: Actual Photo of Mountings of Strain Gauges On Femur

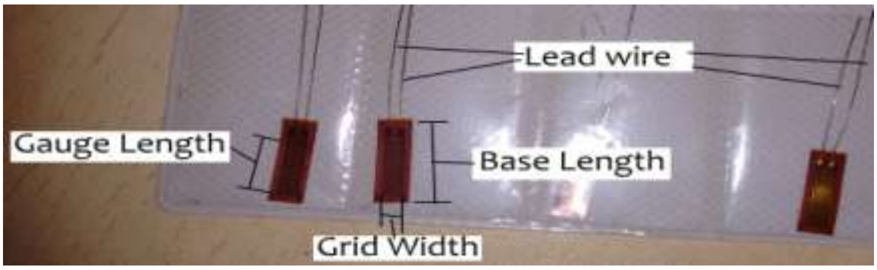

Fig.8: Actual Photo of Composite Type Strain Gauge

Fig. 9: Test Specimen (Right Femur Bone)

III.STRAIN INDICATOR (WHEATSTONE METER BRIDGE CIRCUIT)

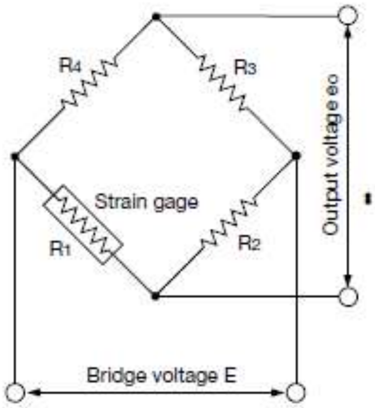

Fig.10: Wheatstone bridge

Fig.11: Actual Photo of Strain Measuring System

3.1 Strain-Gauge Wiring Systems:

With the 1-gauge system, a strain gauge is connected to a side of the bridge and a fixed resistor is inserted into each of the other 3 sides. This system can easily be configured, and thus it is widely used for general stress/strain measurement. A strain-gauge Wheatstone bridge is configured with 1, 2 or 4 gauges according to the measuring purpose. The output voltage that is proportional to a change in resistance, i.e. a change in strain. This microscopic output voltage is amplified for analog recording or digital indication of the strain.

IV. ELECTRONIC UNIVERSAL TESTING MACHINE (U.T.M.)

Electronic ranges of universal testing machines are fast, accurate, & simple to operate. In these machines load and displacement are displayed on the digital display system in their respective engineering units. The machine is capable of performing the following tests:- a) Tension b) Compression c) Transverse d) Bending e) Shear f) Hardness**.** There are three main units: - a) Loading Frame b) Hydraulic Pumping System c) Electronic Control Panel.

4.1 Load Cell

To suit the testing range, load cells of different capacities are supplied. All the load cells are strain gauge based type with full wheat-stone bridge configuration. Structure of the load cell is such that it can be loaded both in tension and compression.

Table 3. Specifications of Electronic Universal Testing Machine

Max.Capacity: 0.10 kN – 100 kN (As per requirement)	Measuring Range: 0-100 kN
Load Resolution: 5N	Max. Test Speed (mm/min)**:**500
Usable temperature range 0-50^{o}C	Min. Test Speed (mm/min.):0.01

Fig.12: Actual Photo of UTM **Fig. 13: Experimental Set-Up**

V. CALCULATIONS OF STRESSES

Hooke's Law states that when a material is loaded within elastic limit, the stress is proportional to the strain produced by the stress. This means the ratio of the stress to the corresponding strain is constant within the elastic limit. This constant is known as Modulus of Elasticity or Modulus of Rigidity or Elastic Modulii.The ratio of compressive stress to the corresponding strain is a constant. This ratio is known as Young's Modulus or Modulus of Elasticity and is denoted by 'E'.

Therefore, $$E = \frac{\text{Compressive Stress}}{\text{Compressive Strain}} = \frac{\sigma}{\varepsilon}$$

VI. RESULTS & DISCUSSION

It is important to realize that the tests represent a very simple loading condition. The simple loading condition is due to experimental constraints and for reducing the complexity of the mechanical response.

Table 4. Results

Sr.No	Strain Gauge Positions On Femur	Load (N)	Strain	Stress (N/mm^2)
		Reading No.:1		
01.	1- Neck inferior	50 Kg*9.8=490 N	0.015	213
02.	2- Neck superior	490	0.015	213
03.	3- Shaft lateral	490	0.013	184.6
04.	4- Shaft medial	490	0.013	184.6
		Reading No.:2		
05.	1	55Kg*9.8=540 N	0.015	213
06.	2	540	0.016	227.2
07.	3	540	0.013	184.6

08.	4	540	0.014	198.8
Reading No.:3				
09.	1	60Kg*9.8=588N	0.016	227.2
10.	2	588	0.017	241.4
11.	3	588	0.014	198.8
12.	4	588	0.014	198.8
Reading No.:4				
13.	1	65Kg*9.8=640N	0.017	241.4
14.	2	640	0.018	255.6
15.	3	640	0.015	213
16.	4	640	0.015	213

VII. CONCLUDING REMARK

The following conclusions can be drawn from this study:

1. Successful application of the proposed technique to find out stresses in real femur bone.
2. These results are useful for surgeon in femur surgeries and bone prosthesis.
3. We observed that the neck side of the femur is subject to high strains.
4. The results show that higher weight provides higher total displacement.

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