Elastic Properties of Femur Bone: A Review

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Abstract- *The aim of present review is to summarise experimental determination of elastic properties of human and bovine femur bone. The study of mechanical properties of bone evaluation is necessary in case of the interaction of metallic joint with bone material and hip joint replacement on bone specimen are performed to know elastic properties i.e. stress, strain, elastic modulus, poison's ratio and yielding point of bone. Such information is extremely important for accurately modelling the failure behaviour of bone, The present study includes description of the structural and the mechanical properties of the cortical and cancellous bone of the human bovine and mammals femur. the experimental methods using silico femoral models from CT scans, Instron Electro Puls E10000 mechanical testing machineto, Velocities of acoustic waves as an input data, ultrasound method 2 and 3-dimensional finite element–based numerical models, electronic speckle pattern-correlation interferometry(ESPI) and strain gauges, compression, tension, bending and torsion test resulting strength analysis of boviden and human femur from the point of view of fracture mechanism.*

Keywords- Femur bone, elastic properties, compression test, poison's ratio, young's modulus

I. INTRODUCTION

The bone composition depends on a number of factors, such as the species, type ofch bone, sample location from which it is taken, and the sex, age, and bone tissue, for example, woven, cortical, cancellous. However, overall composition roughly estimated by volume is 1\3 rd Ap, 1\3 rd collagen, other organic contents, and 1\3 rd H_2O. Roughly amount of Calcium and phosphate is about 65–70% dry weight of a bone. Collagen fibres compile approximately 95% of the extracellular matrix and it is about 25–30% of the bone's dry weight. Amount of water is up to 25% of the total wt. of bone, while 85% of the water to be found in the organic matrix surrounding the ground substance and collagen fibres. The 15% is located in cavities and canals that residence the bone cell

In any long bone, cortical bone is about four times the accumulation of cancellous bone. The basic material of cancellous and compact bone is identical; thus, the difference between the two is the amount of porosity and the organization. The porosity of cancellous bone's ranges from 30 to 90%, while porosity of cortical bone ranges from 5 to 30%. Bone porosity is not permanent and can alter in response to disease, transformed loading and the aging process.

The periosteum is the fibrous outer covering present in all bonesexcept the joint regions, which are enclosed with articular cartilage. There are various terms used to explain the complex design of bone at a higher resolution. Both cancellous and cortical bone may contain two types of vital architecture, lamellar and woven .Bone can also be termed as primary or secondary bone. The term either haversianor laminar is used for regions within cortical bone

II. LITERATURE REVIEW

The Study of elastic properties of femur bones from few mammal species is included in literature survey. In last few decades considerable work has been done to determine elastic properties like compression strain, Young's Modulus, poisson's ratio, shear modulus using of femur bone using different methods. A review of previous work based on determination of elastic properties of femur bone from different mammal species and the comparison of their values determined by different methods is represented.

The mechanical properties of cadaveric pelvis have been compared byTarik Attia13 with the 4th generation composite model. They used Instron Electro Puls E10000 mechanical testing machineto load specimens with orientation, boundary conditions and degrees of freedom that approximated those occurring during the single legged phase of walking, including hip abductor force.[1]

Xinshan Li16 (2015) tried to develop in silico femoral models from CT scans to provide detailed quantitative information regarding the geometry and mechanical response of the femur, with the long term potential of investigating injury mechanisms.[2]

This study deals with the characterisation of mechanical properties of a human femur cortical bone. Compressive and tensile stresses are induced in bone by recurring loading. Tested the assumption that failure bone strength depends on gender and age. Young's modulus for a variety of age groups is obtained for both male and female. The elastic properties of bone subjected to tensile load is demonstrated.Cortical thick femur bones are selected as a experimental source material and collected from cadavers of both male and female. Fifty five samples are prepared of age groups , from 19 to 83 years. Femoral bones are soaked in calcium buffer saline to keep it wet and cool. Coded labelling was used to keep the patient information confidential.Experiments are conducted according to American Society for Testing and Materials International (ASTM) standards. Mechanical tests are performed on an Instron 3366 universal testing machine. The system is fitted with tensile grips and equipped with an extensometer for strain measurements. Bone strength failure analysis is carried out to evaluate the resistance to fracture in both the genders. Mechanical behaviour of bone is gender and age dependent. The results of this study demonstrate age-related degradation in tissue level mechanical properties of human femoral cortical bone. The results show that male bone specimens show higher failure strength and elasticity than compared to female at all age groups.[3]

The structural response of Zirconium and tantalum as implant for fixation have been analyzed byKulkarni10 (2013).They concluded that the Finite Element analysis gives preliminary bone implant response under flexural loads compares the materials used for orthopedic joint orthoplasty.[4]

Mohamed S. Gaith , Imad Al-hayek compared elastic stiffness and the degree of anisotropy for the femur human and bovine bones is presented. Orthotropic symmetry is used to model Bovine and human femurs. The mechanical elastic stiffness can be described by nine independent elastic stiffness coefficients which are function of elastic material parameters, namely, Young’s modulus, shear modulus and Poisson's ratio. The largest value (72 GPa) was noted for bovine plexiform while the human tibia bone has the smallest. The bulk modulus and the overall elastic stiffness have same behaviour for all bones except phalanx. Elastic moduli are important parameter to expose internal anisotropy and its effect on bonding strength. In conclusion they stated that the largest overall elastic stiffness observed for bovine femur plexiform and has the most isotropic (least anisotropic) symmetry also seen in bovine.[5]

The material properties of femur bone in Indian subjects have been studied by Mrudula kulkarni and S.R.Sathe. They carried out series of mechanical tests consisting of tensile testing, compression testing, shear testing to study mechanical properties of cadeveric cancellous distal femur bones of Indian donors. The orthotropic behavior of cancelleous portion of cadeveric femur bone was verified from tests. According to them this property may certainly useful in studies related to total hip joint replacements. They used 100mm length specimen for torsion test.For compression test the specimens were rough cut cubes out of bone with orientation along the axis of long bone. Tensile tests were carried out on “dog bone” shaped specimen. Samples were kept hydrated using saline water during machining. The Lateral strain range was reported between 0.012 to 0.017 while Linear strain was 0.003±0.0005. The Elasticity along the grain orientation direction was 11737 N/mm2 while in direction perpendicular to grain orientation direction it was 8000±500 N/mm2. The Poisson’s ratio was observed in the range 0.21± 0.01.The Modulus of Rigidity along the grain direction and in a perpendicular to grain orientation were 4810 N and 3500± 200 N/mm2. is determining orthotropic behaviour of cancelleous portion of cadaveric femur bone providing comprehensive items of mechanical properties of cadevericcancelleous distal femur, through series of mechanical tests, which comprised of tensile testing, compression testing, shear testing[6]

Du 3et.al. reported broadstudy of distal femur after performing a series of mechanical tests, which comprised of tensile test, compression test, torsion test shear test etc. They revealed that biomechanical properties of the cancellious bone have close relationship with individual difference. The nominal values of compressive strength limits of elasticity, strain, and elastic modulus have been stated for cancellious femur bone.[7]

The methodology of elastic properties of cortical bones by ultrasonic wave inversion have been assessed by T. Goldmann. They considered the bone is considered to be a linear elastic anisotropic continuum. They used Velocities of acoustic waves as an input data into inverse problem and experimentally detected by means of the ultrasonic based pulse-echo immersion technique. [8]

S.P.Kothaa (2005)developedporous composite modelto analyze the tensile mechanical properties of cortical bone. Theyconsidered the effects of microporosity (volksman's canals, osteocyte lacunae) on the mechanical properties of bone tissue .[9]

The geometric and densitometric properties of cortical and trabecular bone at the lower limb and the distal radius have been compared by E. -M. Lochmüller6 with those at the femoral neck. They estimated the ability of these properties to predict mechanical failure loads of the proximal femur.[10]

T. Lee15 (2002) evaluated the method of resonant ultrasonic spectroscopy (RUS) for bovine bone and also compared it with the radiational wave transmission ultrasound method. The resonance structure of a cubic or rectangular specimen is scanned in RUS method.[11]

G.B. McAlister17 (1983)evaluated the ultimate compressive strength and modulus of elasticity of femoral cortical bone from adult geese (Anseranser) by sex and by quadrant by compressing small right circular cylinders.

There is a amazing adaptation in architecture of the human femur,to the mechanical requirements due to the weight on the femur head (Fig.1.2). The sole mechanical structure of the femur formed by various parts taken collectively, wonderfully well adapted for the economical and efficient conduction of the loads from the head to the tibia. Thus the external form and inner structure of human bone are fully modified to the mechanical conditions active at all points in the bone. The internal construction of normal bone is decided by distinct and exact requirements of mechanical and mathematical laws to create a highest of strength with a least of material. The complexity of bone structure is related with it's fundamental mechanical functions (Keaveny and Hayes ,1993).[13]

III. CONCLUSION

Young's modulus of femur bone in axial direction is significantly higher than in transverse direction. Mechanical properties of bone are affected by may aspects of its structure particularly by mineral content. Finite element method gives narrow range of results which are more accurate as compare to other methods.

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