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# Effect of Age on the Elastic Modulus of Bone

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**Abstract**

The deterioration of the mechanical properties with aging is the major caused of the fracture of bone in elder population. The elastic modulus (Young's Modulus) deteriorated in aging bones. An understanding is essential to known how elastic modulus degrades in aging bones. In the present study tensile testing experiments on the bovine hip joint bone have been performed in both longitudinal and transvers directions to investigate the effect of age on the elastic modulus on bovine hip joint bone. The samples for testing are taken from the age groups 1-5 years. From these experiments the elastic modulus is determined both in longitudinal and transvers direction. It is found that the elastic modulus deteriorated both in longitudinal and transvers directions with increasing age. It is investigated the deteriorated is higher in transvers direction as compared tolongitudinal direction.

**Keywords:** Hip bone; Elastic modulus; Age effect; Tensile testing; Universal testing machine

## Introduction

Bone is a natural composite anisotropic material, mainly composed of three materials organic, inorganic and water [1]. The Bone primarily contains approximately 70% mineral, mainly hydroxyapatite (HA), and 8% water by weight, 22% proteins (90% type I collagen) [2,3]. Bone performed multi functions in vertebrates including structural support to organisms, protection of internal organs [4,5], and transmission of forces.

Hipbone is the major bone that constitutes pelvis. Embryologically it is made up of three bones ileum (the winged or expanded upper portion) ischium (the lowermost portion) and pubis the front or interior portion as shown in Figure 1. After puberty, all these three bones start fusing forming the hip bone articulates with the sacrum through sacroiliac joint, in between of two hipbones below both sides articulate with the femur to transfer the force of back bone to lower limbs. The joint of femur and hipbone is a ball and socket joint in which femur head serves as a ball and the hipbone acetabulum serve as socket. While sacroiliac joint is a fibrous joint which allow limited movement and is supported by a lot of strong ligaments [6,7].

The mechanical properties of the bone consistently changes with increasing age. In this research paper elastic modulus has been used in order to find and investigate the changes in the mechancial properties of the bone. Literature review shows that elastic modulus and mechanical properties of cortical and fumer bones change with increasing age. Leng et al. investigated the response of mechanical prosperities by considering the age effect of human cortical bone and for collagen phase in different orientations [8]. Micro tensile tests were performed on young, middle and elderly age human bone donor's dematerialized cortical bone and aging effects for the different orientations for the mechanical properties of the collage.

The analysis indicated that the ultimate strength and elastic modulus of the dematerialized bone specimens decreased with aging in both the transverse and longitudinal orientations and there is failure strain has no changes in failure strain in both directions irrespective of aging. Results suggested that collagen strength and stiffness of bone deteriorated with aging for both directions as shown in the Table 1. The failure strain of the collagen phase in both orientations irrespective of aging is not observed and it is concluded that the failure of the collagen phase does not depends upon aging and orientation.

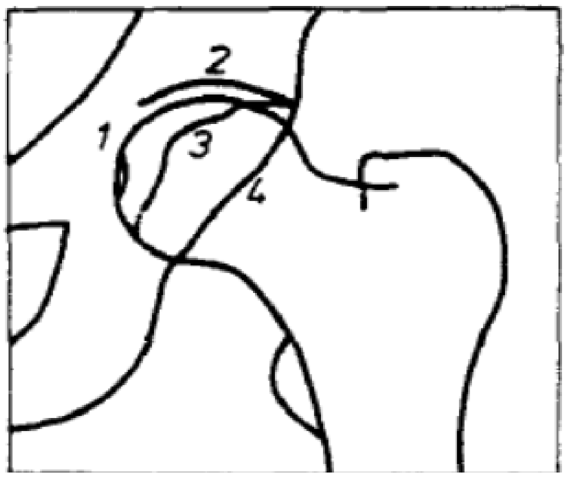


**Figure 1:** Hip joint bone and its parts; 1-femoral head, 2-acetabular cranial contour, 3-aoetabulum ventral rim, 4-acetabulum dorsal rim [6].

Zherrina et al. performed compression and optical microscopy test in the transvers and longitudinal directions for protein portion of bone and mineral portion of bone to investigate the mechanical properties of bovine femur bone of different ages [9]. The optical microscopy test shows that the microstructure of young and mature, the results show that the mature bone is less porous and more stable than the young bone, and found mature bone is more stronger and less tough in both directions longitudinal and transvers for the case of mineral part of bone and protein part of bone. For the protein, part of the mature bone is less strength than young bone. The elasticity of bone is 68% increase

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| Age group | Ultimate stress Transverse (MPa) | Ultimate Stress Longitudinal (MPa) |
|---|---|---|
| Young Age | 4.48 | 19.9 |
| Middle Age | 2.91 | 15.4 |
| Elder Age | 2.31 | 13.2 |

**Table 1:** Mechanical properties of collagen fiber with age [8].

from young age to mature age.

Similarly the Zioupos and Currey carried out the research on the variation in the elastic modulus, stiffness, strength and toughness of human cortical bone in aging bone [1,3,10-12] for the human male age group from 35-92 years, From their experimental investigation they observed that the elastic modulus, stiffness, strength and toughness decreases with increasing age in aging bones (Figure 2).

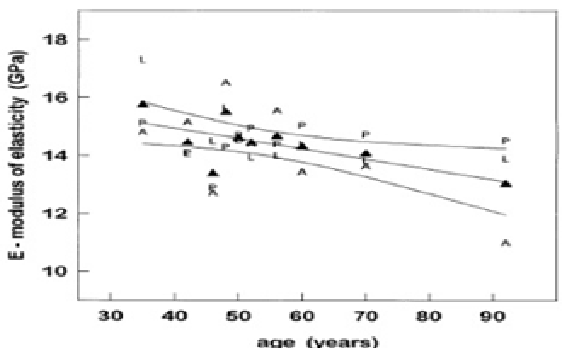


**Figure 2:** Some previous investigation of Young modulus versus the age of the bone [12].

## Materials and Methods

### Materials and specimen preparation

For material and preparation the fresh bones of hip joint were taken within 24 hours from male bovine of different age groups (1-6 years). The bones were kept in freezer at 0°C temperature. Within 48 hours the bones were passed from macining process. The hacksaw was used to cut the required bone samples. These bone samples were shaped using a file. Finaly the 12 samples were shaped and prepared for tensile testing according to ASTM-D3039 standards [13]. Test Matrix of the specimen is given in Table 2. The locations are shown in the figure from where the samples were cut and prepared. The samples were prepapred in two categories one in longitudinal direction and the othere in transvers direction because of the collagen orientation in bone. Two types of tensile test specimens were prepared, longitudinal and transverse. The tensile test specimen is geometry in shown in Figures 3 and 4.

### Test procedure

The test was conducted in universal testing machine (UTM) WDW-E-100 at HITECH University Taxila. WDW-E Series is a new kind of electronic PC control UTM. The loading capacity of this UTM is 1000 KN. We measure and plot the loading force, deformation and crosshead stroke etc. The displacement range of the machine was ± 80 mm. The specimen was bolted in the steel fixture and held in the machine grips. The test setup is illustrated in Figures 5 and 6. The test was performed at normal room temperature and pressure conditions. The load applied by machine at a crosshead speed of 1 mm/minute. During the test, the computer connected to the machine recorded the applied load and corresponding deformation. The Computer records the applied load and corresponding deformation. The test was stopped as the specimen failed.

### Tensile test data analysis

The stress σ was calculated using the equation

$\sigma = F/A$ (1)

In the above equation, F is the load applied and A is the cross sectional area of the specimen.

The strain ε in the specimen was calculated using the equation:

$\varepsilon = \delta/1$ (2)

Where δ is the total deformation of the specimen until failure and l is the initial length of the specimen.

The young modulus E was calculated by the following equation.

$E = \sigma_{max}/\varepsilon_{max}$ (3)

Where $\sigma_{max}$ and $\varepsilon_{max}$ are the maximum stress and maximum strain at failure.

## Results and Discussion

The modulus is lower at the young age of one year, up to three years for both longitudinal and tensile specimens respectively. The modulus after three years decreases gradually. This trend is very rare in the bone and it matches the result of the experimental data of the other species bones like human, bovine for young modulus calculation.

The research done on the variation in the stiffness, strength, and toughness of human cortical bone with Age by Zioupos and Currey, [1,3,12-14] observed in Figure 7 that the age significantly affects the young modulus and ultimate strength of human bone. They determined the fracture toughness, young modulus, and work fracture of human male aged bones between 35-92 years by doing experiments. They found that the all these mechanical properties decreases with age.

## Conclusion

In this research experimental investigatation of the age effect on elastic modulus of bovine's hip bone specimens was carried on. Young modulus was tested using flat specimens using ASTM D-3039 in universal testing machine.

These results show that changes in the young modulus with increasing age are higher for transverse specimens. The higher valuesare attributed to the presence of resisting collagen fibers. The variations in the values of the above properties with respect to age were more sensitive in the case of bovine bones as compared to the human bone behavior. This is due to shorter life span of the bovines than human. On the other hand; the properties of hip bones are similar to the cortical bone properties.

We concluded from our research data the elastic modulus of the hip joint bone decreases in aging bones both for the longitudinal and transver hip bone specimens. The previous research on the variation in the stiffness, strength, and toughness of human cortical bone with Age by Zioupos and Currey, [1,3,12-14] showed that the young modulus and ultimate strength of human bone decreases with increasing age.

### Acknowledgment

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| S.No | Specimen Name | Age | Longitudinal Tensile Test Specimen | Transverse Tensile Test Specimen | Width (mm) | Length (mm) | Thickness (mm) |
|---|---|---|---|---|---|---|---|
| 1 | S1 | 1 | ✓ | | 16.54 | 7.4 | 2.1 |
| 2 | S1 | 1 | | ✓ | 16.22 | 5.91 | 2.18 |
| 3 | S2 | 2 | ✓ | | 16.46 | 6.21 | 2.7 |
| 4 | S2 | 2 | | ✓ | 16.28 | 5.7 | 3 |
| 5 | S3 | 2.5 | ✓ | | 13.26 | 4.07 | 1.91 |
| 6 | S3 | 2.5 | | ✓ | 17.68 | 6.35 | 2 |
| 7 | S4 | 3 | ✓ | | 15.88 | 3.91 | 2.3 |
| 8 | S4 | 3 | | ✓ | 12.32 | 3.3 | 2.03 |
| 9 | S5 | 4 | ✓ | | 16.22 | 5.7 | 2.36 |
| 10 | S5 | 4 | | ✓ | 16.22 | 5.08 | 2.5 |
| 11 | S6 | 5 | ✓ | | 13.3 | 5.08 | 1.91 |
| 12 | S6 | 5 | | ✓ | 16.26 | 5.15 | 2 |

**Table 2:** Test matrix of CT specimens.

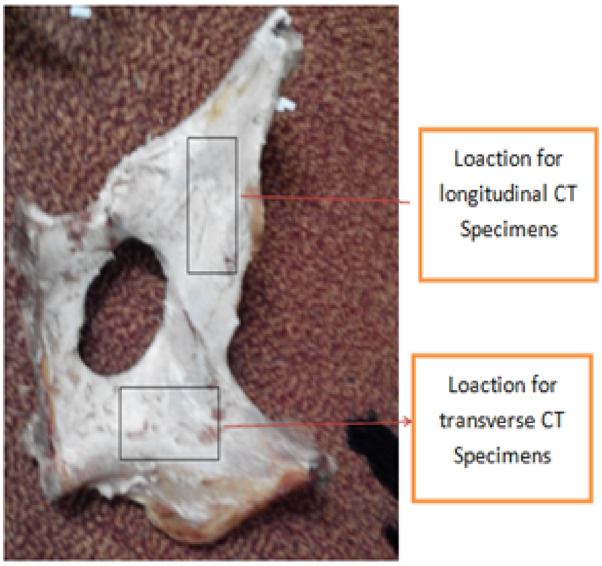


**Figure 3:** Location for tensile test specimens both in longitudinal and transvers direction on the bovine hip joint bone.

**Figure 5:** WDW-E-100, universal testing machine with 1000 KN loads capacity [11].

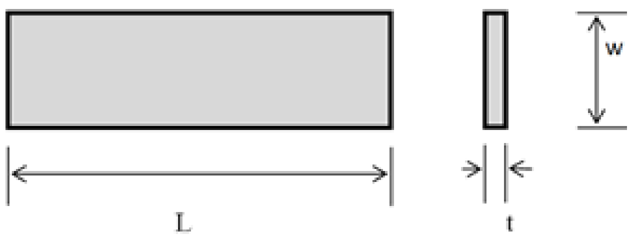


**Figure 4:** Geometry for the tensile test specimen preparation, where L is the length, t is the thickness of the specimen and w is the width of the specimen.

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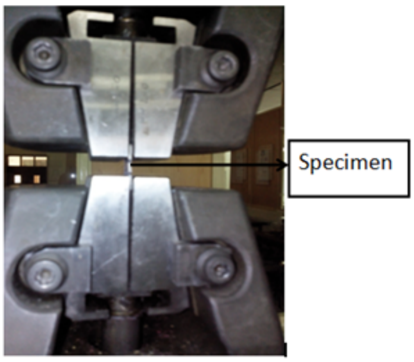


**Figure 6:** Experimental setup for tensile test.

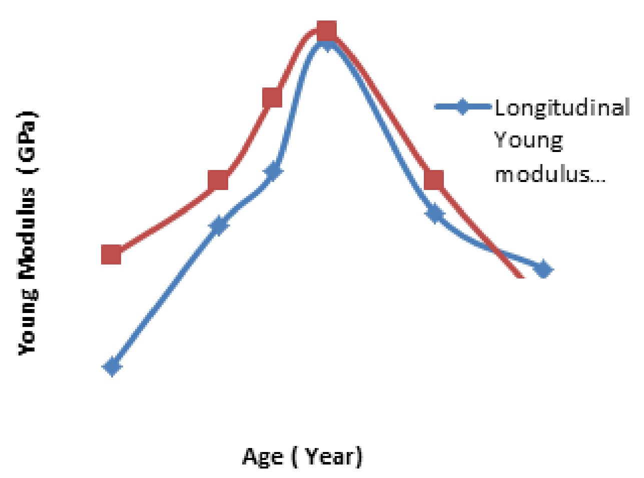


**Figure 7:** Young modulus of hipbone versus age of the bone.


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