BMD Related Torsional Strength of Human Femur Bone

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Abstract

Radio density of bone is measured in Hounsfield unit (HU) by a technique computed tomography, whereas bone mineral density (BMD) is measured by Dual-Energy X-ray Absortiometry. (DEXA) scan aimed at finding correlation between BMD and HU of human bones for their Torsional strength evaluation. In the paper femur bone undergoing both DEXA scan and CT-scan imaging were evaluated to determine if strength correlated with BMD and T-score. As value of BMD increases, the value of Z-score T-scores decreases and we get best method to find out BMD by error analysis between CT scan and DEXA. Aiming to find Torsional strength of human femur bone, test is carried out with the help of setup having rectangular frame work in which bone is hold by the clamp which is rotated by hydraulic motor.

Keywords: CT-Scan, DEXA, Hounsfield Unit, T- Score, Z-Score

I. Introduction

Biomechanical engineering is a bioengineering sub discipline which applies principles of mechanical engineering to biological systems from the scientific disciplines of biomechanics. The biomechanical evaluation of bone, bone implants, and the bone–implant interface has been carried out for many years. Such investigations nearly always employ the use of mechanical testing systems to generate information on the physical properties of these materials. From simple compression and tension failure testing to fatigue analysis of new total joint prostheses, modern computer-driven machines are commonly used to provide analysis and information. Increased prevalence of debilitating conditions such as degenerative joint disease as well as rising popularity of internal devices for fracture fixation has led to rapid growth of the orthopaedic and biomechanical research communities. Along with this growth has been a commensurate rise in the diversity and production of commercially available testing systems to meet the ever-increasing demand for better and less expensive implants and the specific needs of the modern investigator. Implementation of a materials testing laboratory is neither an easy nor inexpensive endeavour. However, the utility and potential capabilities of even the most basic laboratory can provide the opportunity to perform numerous experiments and far outweigh the initial difficulties or expenses encountered. [2]

II. Objectives

1) To collect data from C.T. Scan and DEXA, like BMD, Z-score, and T-score.
2) Manufacturing of testing set-up to calculate Torsional strength.
3) To generate correlation between BMD and Strength.
4) To generate correlation between HU and Strength.
5) To perform error analysis between C.T. Scan and DEXA and to select best among them.

III. Literature review

[1] Benjamin R. Furman[1], Subrata Saha[2], "Torsional testing of Bone". Torsional testing is a uniquely capable technique for examining the in vitro mechanical properties of a wide variety of bones. Servo hydraulic testing equipment can be a straight forward means to obtain a large amount of Torsional data using different loading modes. [2] Christopher V. Bensen[1], Yuehuei H. An[2], "Basic Facilities and Instruments for Mechanical Testing of Bone". Mechanical testing systems offer the orthopaedic researcher the ability to measure numerous properties of a bone specimen or construct. A large variety of machines are commercially available from several companies; it is up to the individual researcher or team to decide which model is appropriate for the research being carried out in the respective laboratory. [3] J.Y.Rho[1], M.C.Hobatho[1],R.B.Ashman [3], "Relation of mechanical properties to density and CT numbers in Human bone" Mechanical properties of cortical and cancellous bone from eight human subjects were determined using an ultrasonic transmission techniques raw computerized tomography values obtain from scans of the bones in water were corrected to Hounsfield units.

IV. METHODOLOGY

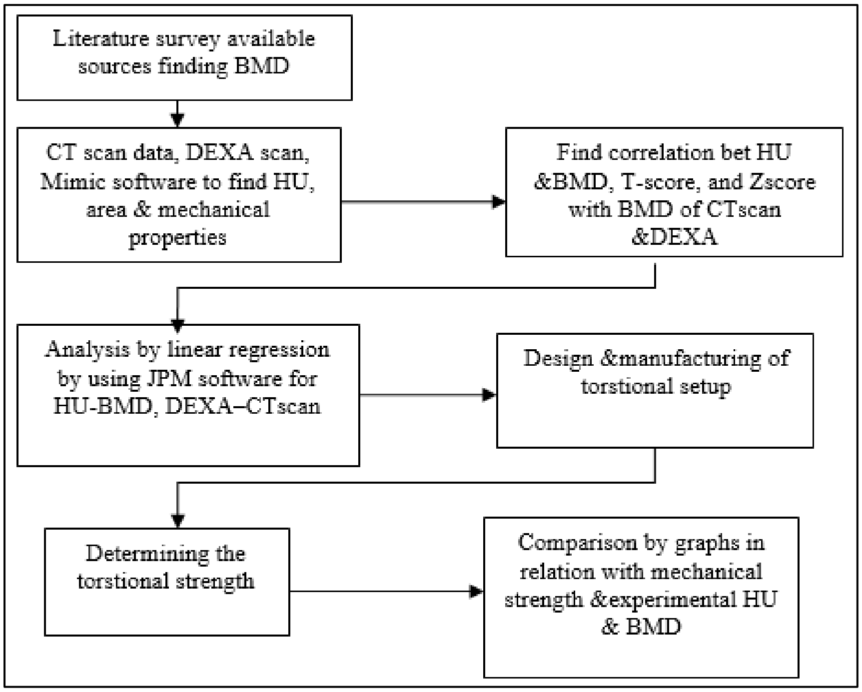

Fig. 1: Flow chart of the process

A. Procedure for finding BMD & HU by MIMICS software

C.T scan data subjected was taken in DICOM format and imported to MIMICS software. MIMICS software automatically stacks the slice in manner of selection. Area and Hounsfield unit of each slice is calculated. Based on this calculation density and modulus of elasticity is calculated for each slice using expression given in user manual of MIMICS software with the help of MS-Excel. The femur length is available up to 130mm. [3]

B. Bone Model in Mimics Software

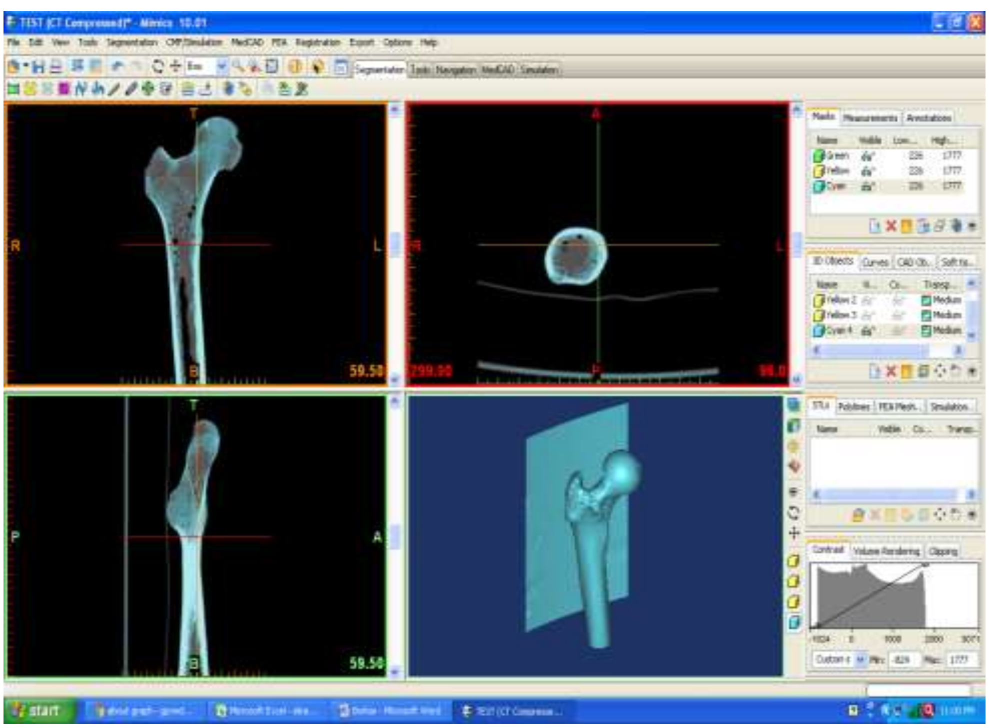

Fig. 2: DBone model

The Mimics software gives HU (Hounsfield number) of bone slice at distance of 1.5mm.

V. WORKING PRINCIPLE

When one end of bone specimen is hold firmly and another end is subjected to measurable torque, the breaking angle of the bone so obtained can be used for calculating the torsional strength of bone.

A. Working Setup

The specimen of human cortical bone is hold firmly by the two clamps. The fixed clamp is welded on the movable bracket which is free to slide over the base plate. As per the specimen length the movable bracket is adjusted and fixed with the help of bolts. The rotating clamp rests on the shaft of gear motor. The clamp is locked on shaft with the help of key. The bone specimen is fixed on the clamp by the bolts, screwed on the clamp radially. After the proper clamping of bone on two respective clamps, the function of hydraulic system comes into picture. The angle Protector is mounted on shaft which rotates along with the same. The instant at which the bone breaks, the motor is stopped. This obtained angle is further used for calculating strength, plotting graph. The torque can be calculated by using the values of pressure obtained using the pressure sensor.[1]

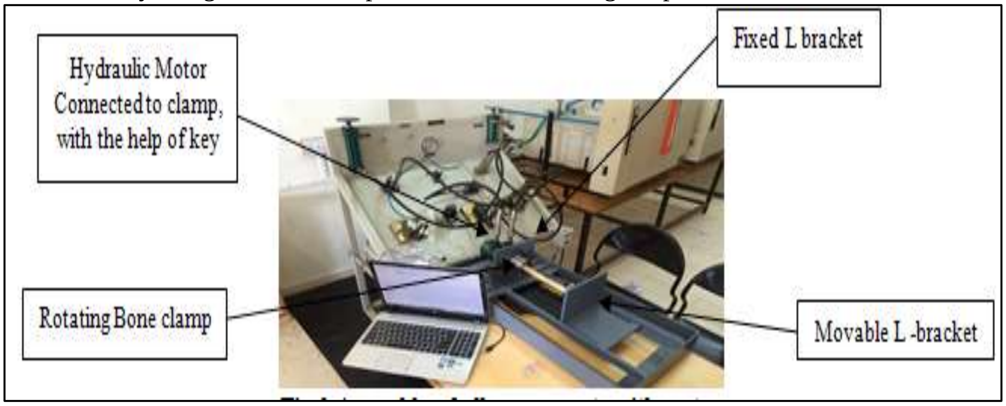

Fig. 3: Assembly of all components with motor

B. Experimental Procedure

For carrying out the experiment, one end of bone specimen is to be hold firmly and another end is to be subjected to torque, the breaking angle of the bone and the respective values of torque so obtained can be used for calculating the torsional strength of bone. The torque can be applied using hydraulic gear motor which was fixed to base plate using bolts. The torque can be varied by controlling pressure and speed can be varied by controlling flow. Observations are to be recorded for the breaking angle and torque. The measured breaking torque and angle were further used for calculating torsional strength of femur bone.[1]

Table - 1
Observation table

Pressure(Kg/cm^2)	*Torque(N.m.)*	*Angle(Ɵ˚)*
1.189	0.271092	2
2.925	0.6669	4
3.997923077	0.911526462	6
4.999077592	1.139789691	8
5.9872301	1.365088463	10
6.988384615	1.593351692	12
7.98953913	1.821614922	14
8.990693645	2.049878151	16
9.978846154	2.278141381	18
10.99300268	2.50640461	20
11.99415719	2.734667839	22
12.99531171	2.962931069	24
14.13191811	3.222661238	26
15.16467262	3.458181091	28
16.19742712	3.693700945	30

C. Calculations

If the cylinder bar with a length of L, the twisting moment can be related to the shear stress as follows

$$\frac{M_T}{J} = \frac{G\theta}{L} = \frac{\tau}{r} \ldots\ldots\ldots\ldots\ldots (1)$$

Where,
J is the Polar Moment of inertia, mm^2
G is the shear modulus, N/mm^2
Ɵ˚ is the degree of rotation, radian

r is the radius of the cylindrical bar, mm or in
L is the length of the cylindrical bar, mm.
Within the elastic range of deformation, the shear stress can be calculated according to equation

$$\tau = \frac{M_\tau r}{J} \ldots\ldots\ldots \quad (2)$$

For a tube specimen, the maximum shear stress at the peripheral of the tube can be calculated from equation,

$$\tau = \frac{16 M_\tau D1}{\pi(D1^4 - D2^4)} \ldots\ldots\ldots (3)$$

Where,
D1 is the outer diameter of the tube
D2 is the inner diameter of the tube
Therefore, if the torque and the degree of rotation are known according to the experimental results, the shear stress and shear strength can be determined from the equation 2&3. [1]

Table - 2
Result Table

Pressure(Kg/cm2)	*Torque(N.m.)*	*Torsional strength(N/m2)*	*Angle(Ө˚)*
1.189	*0.271092*	*40298.2632*	*2*
2.925	*0.6669*	*98569.36819*	*4*
3.997923077	*0.911526462*	*133951.575*	*6*
4.999077592	*1.139789691*	*166527.5338*	*8*
5.9872301	*1.365088463*	*199225.5917*	*10*
6.988384615	*1.593351692*	*232271.9341*	*12*
7.98953913	*1.821614922*	*265241.73*	*14*
8.990693645	*2.049878151*	*298209.6981*	*16*
9.978846154	*2.278141381*	*331333.6616*	*18*
10.99300268	*2.50640461*	*364112.0914*	*20*
11.99415719	*2.734667839*	*397262.5324*	*22*
12.99531171	*2.962931069*	*430378.9095*	*24*
14.13191811	*3.222661238*	*467624.2565*	*26*
15.16467262	*3.458181091*	*501648.1026*	*28*
16.19742712	*3.693700945*	*535355.1449*	*30*

From the calculated strength we find strength and BMD relation using the JMP software so that one can calculate strength if the BMD is known and by Z-Score.

VI. DEXA REPORT


P.H. DIAGNOSTIC CENTRE
Sai Plaza, Chaphekar Chowk, Chinchwad, Pune -33
PH. NO: 020-27356659/7799
ANCILLARY RESULTS: Left Femur

Fig. 4: DEXA Report


P.H. DIAGNOSTIC CENTRE
PATIENT BIOGRAPHICAL
ASSESSMENT
FOLLOW-UP

Fig. 5: DEXA Report

A. Error Analysis

Table -3
Error analysis

BMD			*ERROR*	
Sr. No	*DEXA*	*CT SCAN*	*DEXA AND CT*	*CT AND DEXA*
1	*0.93*	*1.001*	*-0.076344086*	*0.070929071*
2	*0.762*	*0.869*	*-0.140419948*	*0.123130035*
3	*1.018*	*0.589*	*0.421414538*	*-0.728353141*
4	*0.874*	*0.568*	*0.350114416*	*-0.538732394*
5	*0.659*	*0.922*	*-0.39908953*	*0.285249458*
6	*1.003*	*1.586*	*-0.581256231*	*0.367591425*
7	*0.9*	*0.939*	*-0.043333333*	*0.041533546*
Total mean percentage error			*-0.468914173*	*-0.378652001*

VII. VALIDATION OF RESULTS

R^2=0.984715

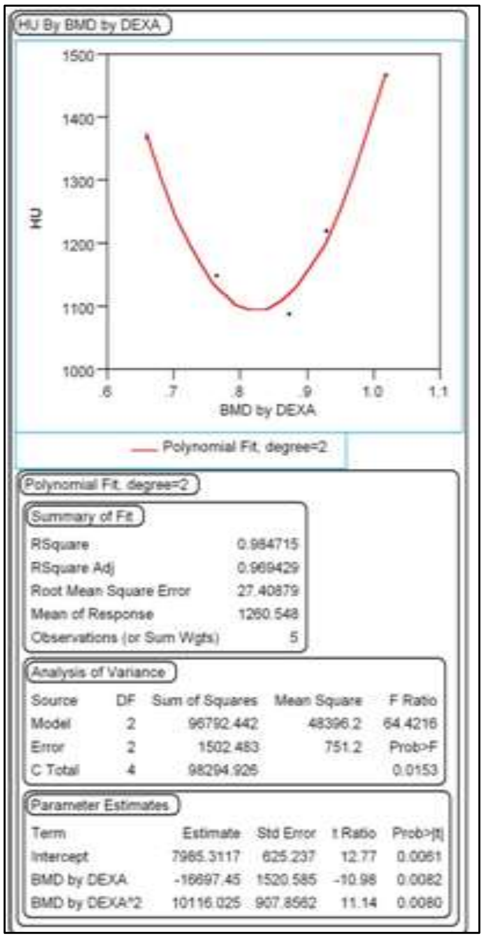

Fig. 6: HU by BMD by DEXA

Y=24780.36X^3-64972.3X^2+55864.13X -14551.6
R^2=0.958271

R^2=0.877835

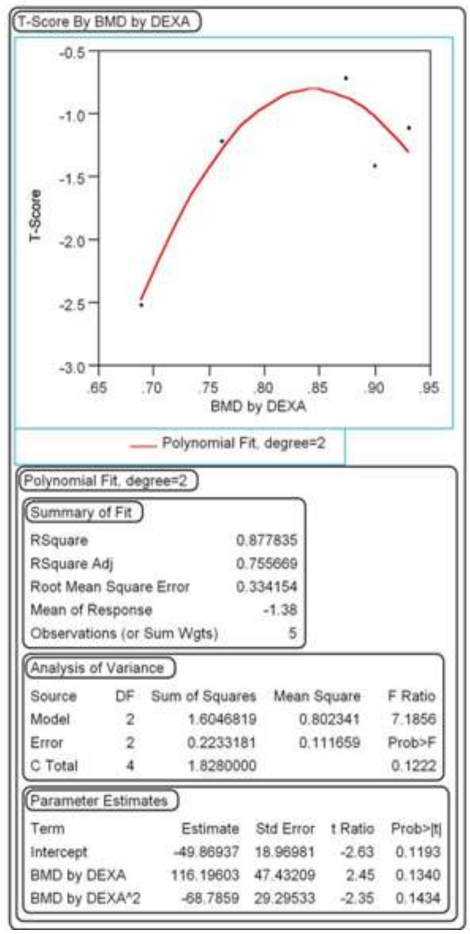

Fig. 7: T score by BMD by DEXA

Y=28.66X^3-44.78X^2+15.22X-0.0016
R^2=0.998098

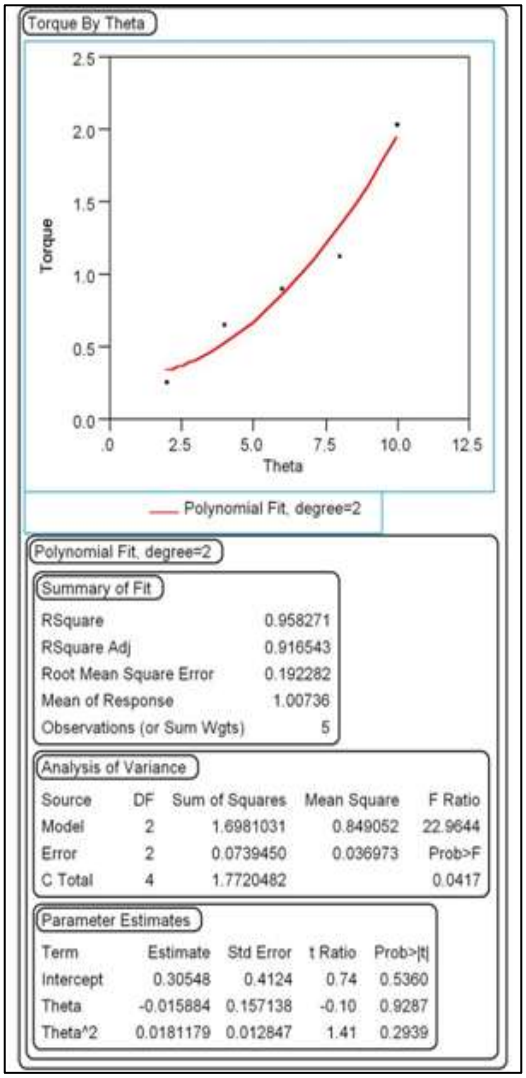

Fig. 8: Torque by Theta

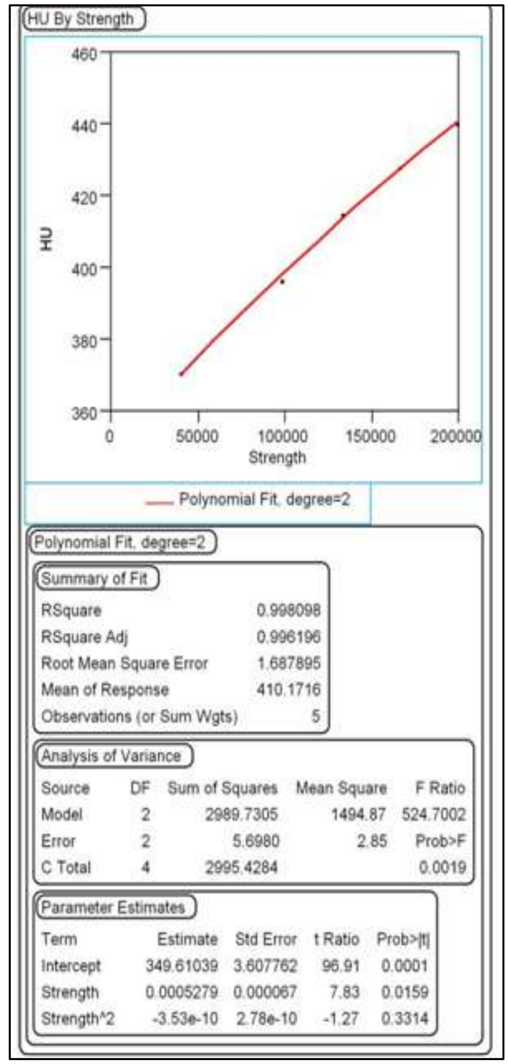

Fig. 9: HU by Strength

Y=-0.0027X^3+0.0496X^2-0.1274X+0.1934

Y= (-1.06e-14) X^3+ (5.557e-9) X^2-0.00022X +374.121

VIII. CORRELATION

A. *Between BMD and strength*

Modified Final Correlation is: BMD= {(1.0190*10^-10 *S^2} + {(-4.1070*10^-5*S} +3.9497

B. *Correlation between HU and Strength*

Modified Final Correlation is:-HU= {(4.5646*S^2} + {(2623.6955)*S}-1520524.244
Where S=Strength

IX. RESULTS & CONCLUSION

1) BMD of bone can be finding by using various methods. E.g. from CT scan data, From DEXA scan.
2) Regression model developed in this investigation could be used for find out correlation between BMD and torsional strength
3) Regression model developed in this investigation could be used for find out the BMD and HU directly by considering the value of torsional strength of bone without using different machines.
4) The investigation used to get the maximum torque required for Break the Femur Bone during torsion test.
5) By using experimental setup we will find different properties of bone, which is also useful in orthopaedic sector for design and manufacturing of implants, research and many other fields.

REFERENCES

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[3] J.Y.Rho1, M.C.Hobatho 2, R.B.Ashman 3, "Relation of mechanical properties to density and CT numbers in Human bone" in mechanical testing of bone and bone implant interface.