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Correlation between BMD and Radio intensity of Human Bones for Strength Evaluation

S. N. Khan[1], R. M. Warkhedkar[2], A. Shyam[3], B. R. Patil[4]
[1](*Department of Mechanical Engineering, Rajarshi Shahu College of Engineering, Pune, India)*
[2](*Department of Mechanical Engineering, Government College of Engineering, Karad, India)*
[3](*Chief Researcher, Sancheti Hospital Pune, India)*
[4](*Department of Mechanical Engineering L. T. College of Engineering, Koparkhairane, India)*

ABSTRACT : *Bone mineral density [BMD] generally correlates with bone strength. BMD testing is used to assess bone density and diagnose osteoporosis. The HU scale is a linear transformation of the original linear attenuation coefficient measurement in to one in which the radio-density of distilled water at standard pressure and temperature is defined as Zero Hounsfield Unit while the radio-density of air at STP is defined -1000HU. The correlation between CT numbers and mechanical property estimated from cortical bone were found to be low (r2<0.2) and cancellous bone were found to be higher (r2>0.6). The specific relationship depending on the types of bone, that predict elastic module from density and CT numbers were suggested for human cortical and cancellous bone. CT numbers of HU measures X-ray linear attenuation of tissue inside the voxel.*

Keywords - *BMD, Radio-density, Osteotheropy, Strength evaluation*

I. INTRODUCTION

The correspondence of bone strength to functional need is a significant part of the adaptation of a species to its environment. For survival, bones must be strong enough to survive normal activities but not so oversized that to build and carry them is in itself a risk .The aim of the current study was to extend this line of research and to determine how well bone stiffness predicts yield strength, yield strain, ultimate stress, and ultimate strain for both cortical and cancellous tissue. As will be demonstrated, the mechanical properties of human vertebral cancellous bone in compression and cortical bone in tension are related in similar ways; yield strength and ultimate strength are highly correlated to bone stiffness by a relationship that is the same for both vertebral cancellous and habitually loaded cortical bone.

Bone density is defined as means value expressed in Hounsfield units in each pixel. Bone material presents a complex behavior involving heterogeneous and anisotropic Mechanical properties. Moreover, one it is a living issue, therefore its microstructure and mechanical properties evolve with time, in a process called remodeling. This phenomenon has been studied from a long time, and there are many numerical models that have been formulated in the sense to predict the density distribution in various bones, mainly in the femur. A femur, tibia and mandible (all human) were scanned and the image stored in a DICOM format. DICOM images are imported in MIMICS software & different properties like BMD with Hounsfield units (HU) for 50 different materials were assigned to relate the bone mass density.

II. AIM & OBJECTIVES

1. The aim of the research is that to find the correlation between Bone mineral density (BMD) and radio intensity for human bones.
2. HU scale will vary according to the scanner used.
3. Sky scan CT Analyzer software provides for an integrated calibration of data sets in to these two density scales HU and BMD.
4. Both require scans and measurements.
5. Different HU value was computed for each element of the mesh performing numerical integration over the elements volume of the HU field as derived from the CT data sets.

III. PROBLEM DEFINITION

Problem Definition: The stages of the research are as per follows.

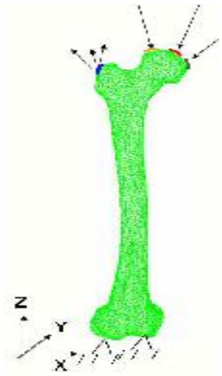

Fig.1 Finite Element models of each type of bone: (a) Femur

Stage1. Preparation of the 3D model of proximal femur [Fig.1]

Then they were imported in MIMICS again, and different material properties were assigned relating the bone mineral density with the Hounsfield Units (HU) (50 materials were considered). Simultaneously, loads and boundary conditions were applied specifically for each type of bone using I-DEAS preprocessor (Figure 1). Then, the bone remodeling analysis was performed using ABAQUS for the femur, tibia and mandible, where the bone material properties were assigned through a user routine that contains the numerical model previously presented. Starting from an arbitrary initial situation (uniform density = 0.5gr/cm^3 and isotropic behaviour), and applying the corresponding walking loads (femur and tibia) and mastication loads (mandible), the changes in the bone density distribution was computed.

Stage2. Formulation of Loads and boundary conditions

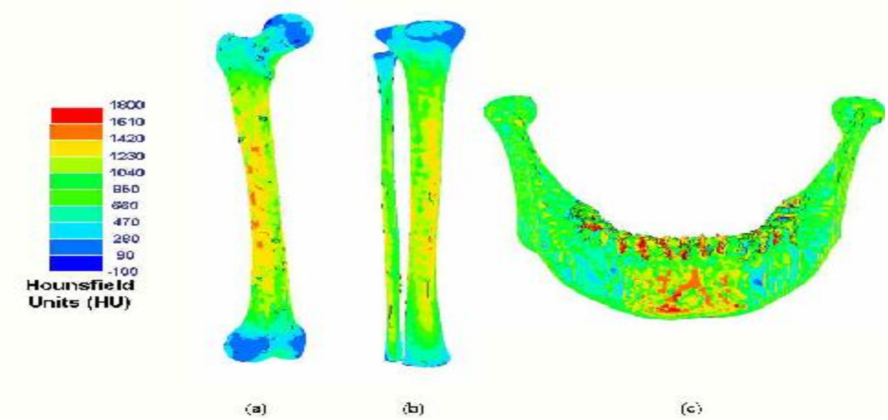

Fig.2. Hounsfield Units (HU) obtained from the CT scanning for (a) femur (b) tibia and (c) mandible.

The range of HU obtained from the CT scanning for the different bone types were as follows: -79 to 1616 HU (femur), -994 to 1893 HU (tibia) and -662 to 2610 HU (mandible). The discretization for the HU computed by MIMICS have been represented in Fig.3. High HU values were found for the cortex of the femur and the tibia, and in the case of the mandible, high HU were located in the chin. The bone density prediction from the bone remodeling analysis performed over the different bone types . The bone remodeling model predicts the cortical region of the femur and its corresponding trabecular bone at HU values (Figure 3) for the different bone types and the error between the bone remodeling model and the HU relationship was computed and represented for each integration point in Fig. 3. Regions with low differences between approaches (bone remodeling vs. CT data) are located where the cortical bone is found. This is observed for the femur, tibia and mandible.

Stage3. As per the above modeling the next will become the validation of the FEA modeling

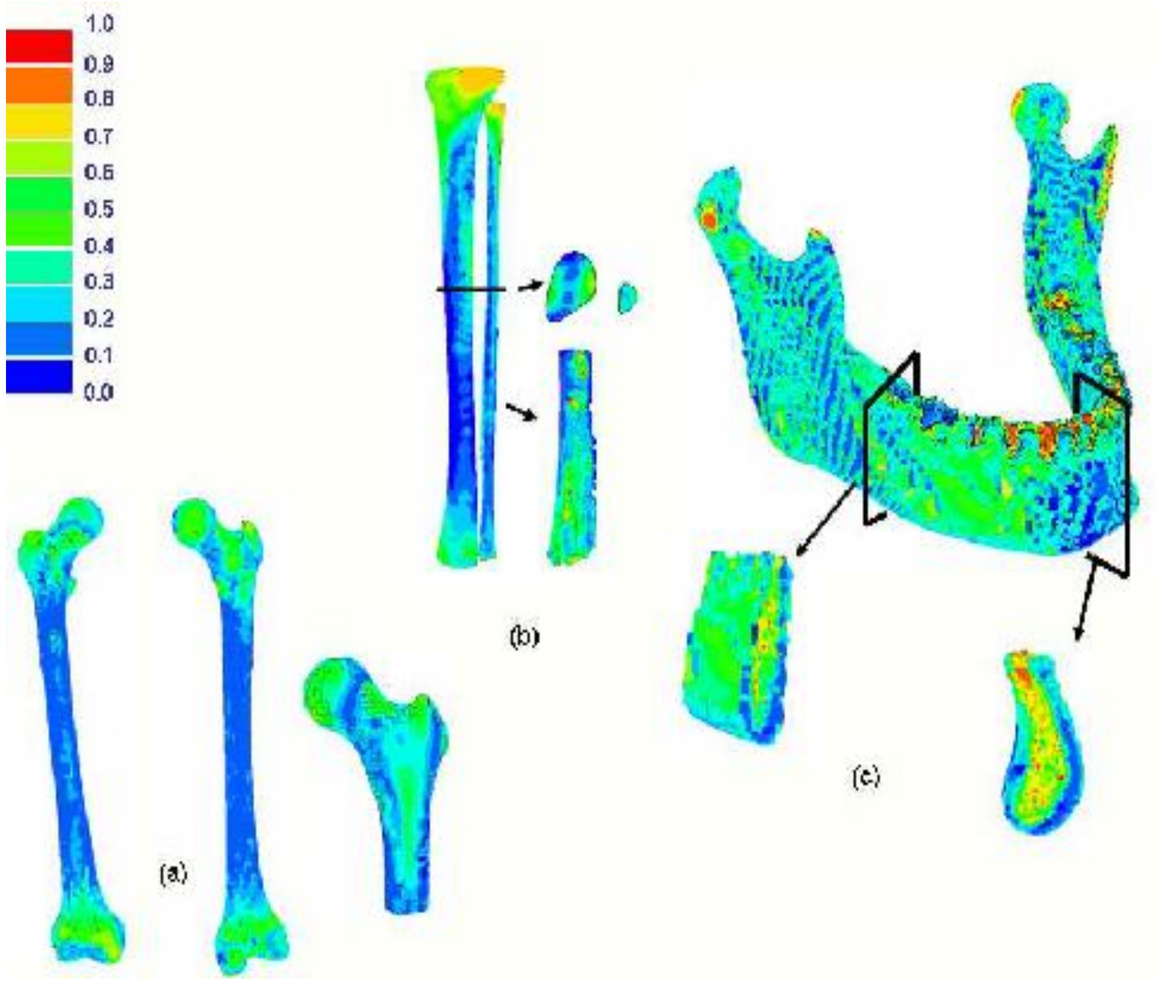

Fig.3 Error computed between the HU information from the CT data and the prediction of the bone remodeling model for (a) femur, (b) tibia and (c) mandible

IV. MANUFACTURING OF MECHANICALLY SIMILAR BONES

Haversian bone can be considered to be transverse orthotropic. The mechanical modelling of bones proposed by researchers is in laminate structure. These basic characteristics of bones are identical to those of the FDM prototypes as analyzed in Section 2. The elastic moduli of compact bones are listed in Table 1. The numbers in the table, 1, 2, and 3, refer to the radial, tangential, and longitudinal orientations in a long bone. Compact bone is solid with spaces only for osteocytes, canaliculi, capillaries, and erosion sites. In the cancellous bones there are large spaces.

Table 1: Table showing Elastic Moduli for Compact Bone

Property	Direction	Value
Young's Modulus *(Gpa)*	3	21.5
	2	14.4
	1	13.0
Shear Modulus *(Gpa)*	23	6.6
	13	5.8
	12	4.7
Poisson's Ratio	31	0.40
	32	0.33
	21	0.42

The FDM prototype for this example. Solid free-form fabrication techniques enable design and fabrication of anatomically shaped scaffolds with varying internal architectures, thereby allowing precise control over pore size, porosity, permeability, and stiffness. Control over these characteristics may enhance cell infiltration and mass transport of nutrients and metabolic waste throughout the scaffold. SFF also allows for the fabrication of biphasic scaffolds that incorporate multiple geometries into a single scaffold, allowing for in-growth of multiple tissues into a single scaffold structure. Several authors have reviewed the advantages of SFF techniques currently in use. (FDM3)[3].

V. CASE STUDY

The following data obtained from Sancheti Hospital is as follows.

TABLE 2

Normative Data on Hounsfield Units Obtained from Lumbar CT scans, Stratified by Sex and Decade of Life n

Hounsfield Units						
Female				Male		
AGE in Yrs.	**Std. Deviation**	**Min**	**Max**	**Std. Deviation**	**Min**	**Max**
10 to 19	253.5 ± 29.6	214.0	314.3	256.7 ± 41.8	208.0	338.7
20 to 29	248.1 ± 52.1	157	322	240.2 ± 43.2	196	356
30 to 39	188.9 ± 35.3	125	242	201.2 ± 29.2	155	261
40 to 49	192.8 ± 15.5	164	211	181.9 ± 32.8	127	231
50 to 59	186.7 ± 40.7	116	240	159.0 ± 30.6	105	202
60 to 69	105.8 ± 36.8	49	156	152.1 ± 31.8	96	213
70 to 79	74.5 ± 29.6	31	118	97.6 ± 44.2	43	188
80 to 89	67.3 ± 41.2	13	119	90.0 ± 25.5	55	145

Hounsfield Units Obtained, Stratified by Sex and Decade of Life*

Our hypothesis is that the HU value may serve as a surrogate marker for bone mineral density and may be of value for estimating regional bone density. Normative data were obtained from computed tomography examinations performed for trauma patients who were stratified for age and sex. In order to further assess the correlation between material densities, the HU value, and mechanical strength, compression tests and computed tomography were performed on polyurethane foam of various densities.

I by Sex

5.1 Advantages

- The specific relationship depending on the types of bone, that predict elastic modulus from density and CT numbers were suggested for human cortical and cancellous bones [3].
- Porosity is one of the important parameters to predict particle bone strength [7].

- In females the cBMD SD in all sub regions of interest increase significantly with advancing age [6].
- In males cBMD SD was not significantly correlated with age [6].
- In males cortical thickness did not decrease significantly with advancing age [4].
- cBMD measurement can be used in the proximal part of the femur [6].
- Bone Remodeling models are necessary to simulate the complexity of bone behavior.

5.2 Disadvantages

- A disadvantage of this method is that the significant anisotropy of bone is detectable in this app. [7]

VI. CONCLUSION

- The Range of HU obtained from the CT scanning for the different bone types were -79 to 1616HU [1]
- The two BMD phantoms had the following HU density values 1205.86243& 3643.45005 for 0.25 & 0.75 g/cm3.[1]
- Mean HU for 25 subjects was 107.1, Mean T score was -1.42, BMD 1.104
- As age goes on increasing the value of the standard deviation for both male & Female goes on decreasing.[1]

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