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An Analysis of Femur Region and Comparison with DXA Standards.

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ABSTRACT

Bone mineral density (BMD) test is used to measure the density of the constituents minerals in bones using a special X-ray or computer tomography (CT) scan. This information is used to estimate the strength of the bones. A decrease in the BMD is commonly called as osteoporosis. This is a type of disease that affects most of the women. It is to a lesser extent also found in men. This disorder may lead fractures. An analysis was undertaken in this work wherein a finite element model of bones was constructed with accurate geometry added with material properties retrieved from CT scan data to determine the mechanical characteristics and behavior of bone structures. The CT images of the femurs of osterioporotic, osteriopenic patients and normal human beings were collected. To analyze the condition of the bone in an accurate way, MIMICS software was used. At the end of the study a correlation of the characteristic of the bone to mineral density in the femoral neck was also arrived at.

Keywords: Osteoporosis, Femur, MIMICS, FEA, DXA.

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INTRODUCTION

The femur is the thigh bone which connects the hip joint to the knee joint. Due to its non uniform and complex shape, it has been a difficult task to build a 3D model of the Femur over the past. Osteoporosis is a multifactorial bone disease concerning a sizeable 4% of the human population[1]. It occurs in bones when a condition occurs in which they lose vital minerals such as calcium and phosphate. The affected patients BMD drastically reduces 2 to 5% per year [2]. The decrease in the BMD influences the properties of bone such as rigidity, compressive strength and elastic modulus. Dual Energy X-ray (DXA) is a special X-ray for detecting the bone loss in a convenient manner than the conventional X-rays do.

MATERIALS AND METHODS

MIMICS is a dedicated software that works on the concept of stacking the two-dimensional images in order to convert it into three - dimensional images. The CT images with 0.5 – 1.0 mm slice thickness of Indian females in three different conditions – normal, osteopinia and osteoporosis stages – were imported in to MIMICS software. The procedure of segmenting the knee joint begins with cropping the CT images in all three views [7] – saggital, coronal, and axial. Cropping operation reduced the chances of segmenting unwanted geometry and fixed the region of interest. Thresh holding operation was performed to cover with a mask that connected all the regions of the same threshold range. The green mask was then created inside the cropped region after the thresh holding operation (fig 1)

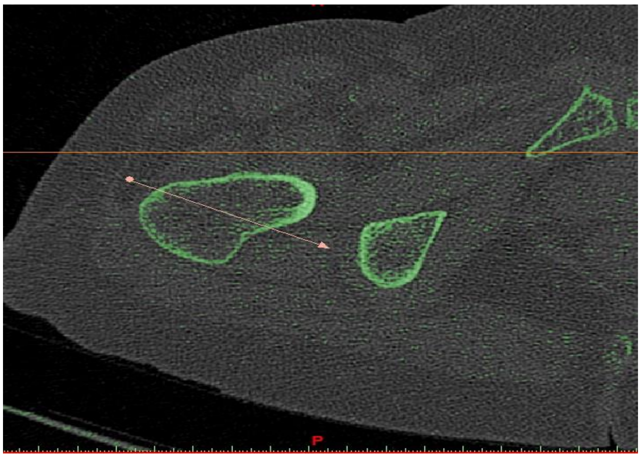

Fig 1: creating a mask using threshold operation

The solid model and the meshed models of the three types of femur bones are shown in fig.2

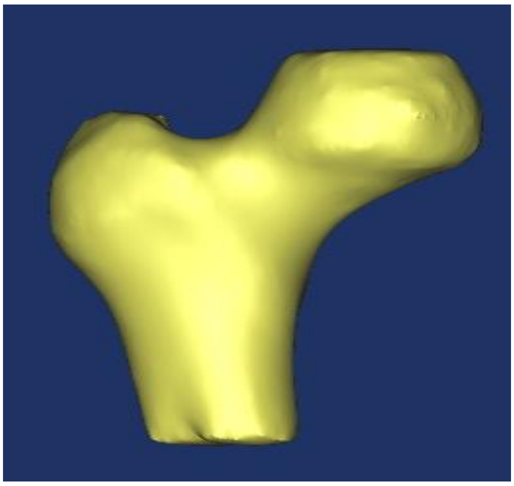

Fig 2 (a) : 3D model of femur

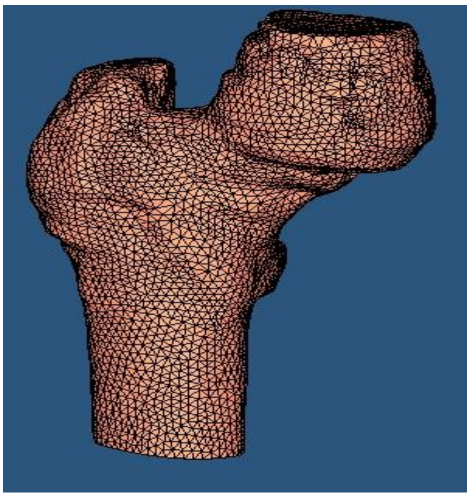

Fig 2 (b) : Mesh of normal femur

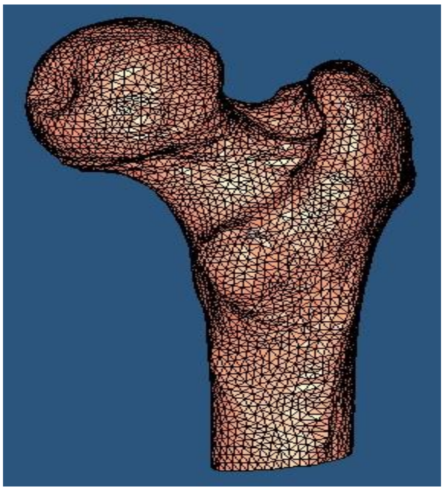

Fig2(c): Mesh of femur with osteopinia condition

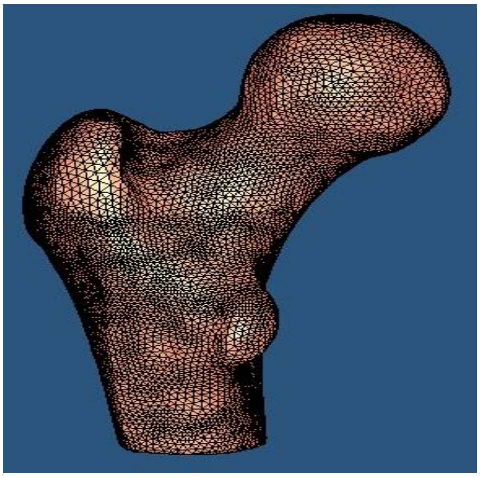

Fig2(d): Mesh of femur with osteoporosis condition

Termination of any connectivity of neighbouring pixels by multi-slice editing function between femur and hip region enables “region growing” operation [4]. While using “region growing” function, termination of all connectivity between femur and hip region part should be followed. The region growing operation is shown in fig.3

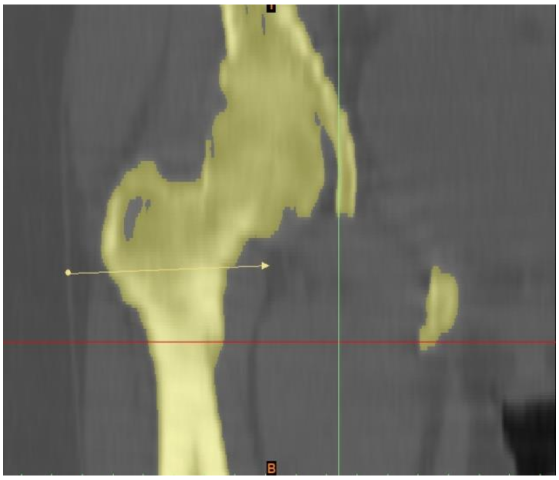

Fig 3: Region growing operation

After modelling and meshing the femur region, “Calculate 3D” function was used to convert the green mask into three-dimensional surface. After obtaining the three-dimensional surface, remeshing was carried out on the selected geometry using the MIMICS remesher. Smoothening operation with the factor of 0.4 was then carried out. Height/base parameter was used to check the qualities of the triangles. Good triangles contained the quality of one and bad triangles contained the quality of zero. The function “edit mesh option” was used to upgrade a triangular elements mesh into a tetrahedral elements mesh in order so that surface mesh is converted into volume mesh.

RESULTS AND DISCUSSION

A 3D model of the normal femur was extracted from the CT image of the patient. Various measurements that were required for the analysis were made using MIMICS tools. The 3D -model was divided into discrete, finite elements. The geometry was defined by points on the elements using the Hyper mesh software. Each element was assigned with required material properties. The analysis was a static-elastic analysis of an isotropic structure.

ANSYS is an engineering simulation software that was employed in this work. Axial load to a magnitude of 1000 N was applied on the femoral head arresting the stem. The loading conditions were imposed in different directions where the angle being 1°, 5°, 10°, 15°, and 20°. Values of Young's modulus were assigned 22000MPa, 20000MPa, 18600MPa in turn and Poisson's ratio was taken as 0.44 with standard boundary conditions.

Von mises stress distribution for three different cases of the femur bone are given in fig.

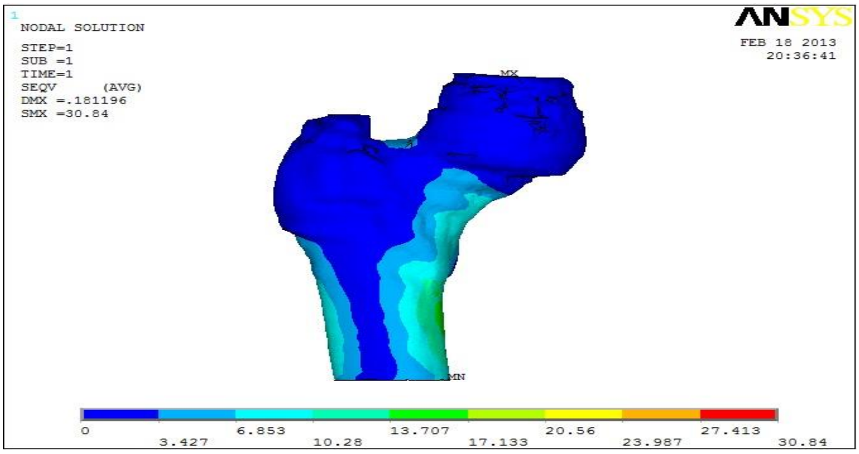

Fig 4 (a) : Von misses stresses distribution of normal femur bone

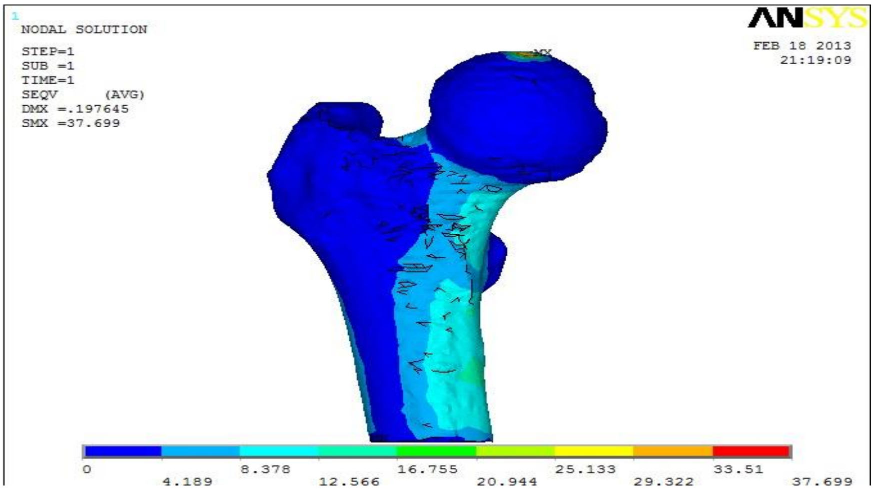

Fig 4 (b) Von misses stresses distribution of Osteopinia femur bone

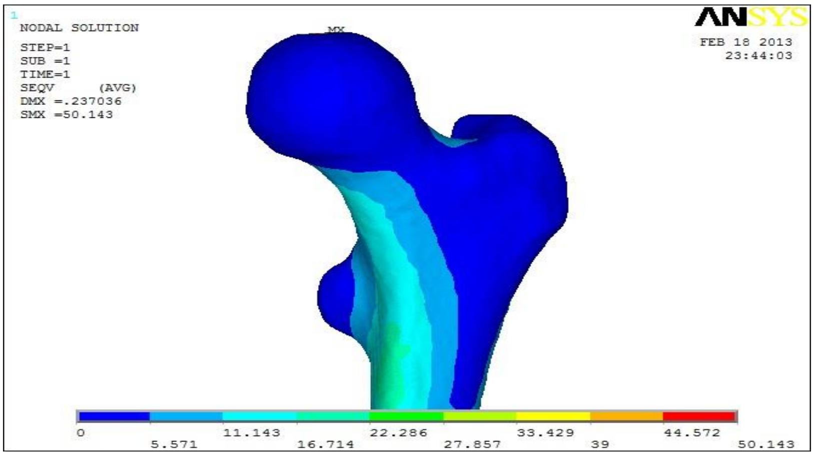

Fig 4 (c) Von misses stresses distribution of Osteoporosis femur bone

The maximum stress and deflection values obtained in the analysis are given in the Table 1.

Table 1: Deflection and stresses at 1000N load

Angle	parameter	Normal	Osteopinia	Osteoporosis
0	Deflection(mm)	0.18119	0.1976	0.2370
	Stress(MPa)	30.84	37.67	50.14
1	Deflection(mm)	0.17253	0.18754	0.22725
	Stress(MPa)	31.162	38.53	48.54
5	Deflection(mm)	0.13031	0.15783	0.19783
	Stress(MPa)	32.45	37.33	51.69
10	Deflection(mm)	0.081819	0.139496	0.180401
	Stress(MPa)	34.05	40.11	53.22
15	Deflection(mm)	0.050401	0.156374	0.204683
	Stress(MPa)	35.59	42.99	54.68
20	Deflection(mm)	0.064201	0.199940	0.244608
	Stress(MPa)	37.039	45.74	56.04

The DXA values are given in Table 2.

Table 2: DXA values

Condition	Neck BDM(kg/m³)	Total BDM(kg/m³)
Normal	14.08	13.7
Osteopinia	12.5	10.4
Osteoporosis	10.12	9.5

CONCLUSION

An analytical work of the BMD was carried out using ANSYS. The results were obtained from the analysis of a femur bone model for a compressive load of 1000N in an axial compression mode. The results were reported and found to be in the expected lines. The areas of high stresses and maximum displacements were shown in the results. These values were compared with DXA standard values. This method gave rise to a faster procedure that resulted in savings of time. The process can be used in different fields of biomechanics, computational stress analysis. Though the verification process required from the biological experiments for the bone structure analysis makes the process a bit difficult yet the advantages this method offers offset the difficulty.

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