

## CREATION 3-D FE MODEL OF AN OSTEOPOROTIC HUMAN FEMUR

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### ABSTRACT

This paper researches the development of a finite element model for a cadaveric human osteoporotic femur. The author is engaged in a study of determining ways of extracting information in *in vitro* from human osteoporotic and intact femur to characterize osteoporosis femur numerically. The finite element model involves stress analysis, and stress reduction through the introduction of auxiliary holes (i.e. Stress Relief Hole theory) in the vicinity of the osteoporotic region with minimal surgical intervention. The model was based on an Osteoporotic 68 year woman femur was derived from quantitative computed topography images CT data. The importance of this research stems from the fact that in United States, osteoporosis leads to more than 300,000 hip fractures annually. The developed finite element model of a cadaver femur neglects the influence of the joints adjacent to the human femur and the surrounding tissue, i.e. skin, muscles, ligaments, and ligaments. The principal stresses around the affected region of the Osteoporotic femur condyles were computed. A stress relief hole has been introduced near posterior-medial condyle, thus the stresses around the defect "Osteoporotic" area have been redistributed to the rest of the femur. Thereby, the Von Mises Stress values in the vicinity of the Osteoporotic region were lowered.

**Keywords:** Osteoporosis, bone, femur, finite and element model.

### INTRODUCTION

In the United States, there are more than 300,000 hip fractures annually. It is estimated that these related fractures cost \$10-12 billion yearly in medical, nursing home, and societal costs. If hip fracture risk is not reduced, experts projected that the number of hip fractures will exceed 600,000 in the United States (AAOS, 1993) and 6.26 million throughout the world by the middle of next century (Cooper *et al.*, 1992). Cortical defects are often present in bone as a result of disease "Osteoporosis" as shown in Figure 1 or are created orthopedic surgeons through biopsies and screw holes. Osteoporosis is a condition characterized by microarchitectural deterioration of bone tissue leading to decreased bone mass and bone fragility. The major processes responsible for osteoporosis are poor bone mass acquisition during adolescence and accelerated bone loss in persons during the sixth decade (the perimenopausal period in women). A cortical penetrating is the outer surface of a body structure, such as bone Screw-plate device are often used for in internal fixation of broken bone. The plate serves as to stabilize the bone until the bone repairs in our research we want to keep this phenomenon or this multiple holes which caused from screw holes to be prepayment on surface the femur bone is a dynamic system by it self; it remodel its geometry and structural "material properties". There is no easy way and straightforward (turn-key) way of converting STL-file into a file format usable by the FEM-software. After researching the market for commercial available solutions, it was found that the best option is to use Geomagic Studio from Raindrop Geomagic by using Geomagic we did edited the Osteoporotic.

### MATERIALS AND METHODS

With today's technology, many researchers in biomedical engineering use numerical analyses to solve many types of problems such as static and dynamic analysis. The Finite Element Method constitutes very attractive numerical method. Moreover, most analysis software requires a finite element model (FEM) to describe geometry in a numerical analysis. The FEM offers numerical solutions to a wide variety of problems. Studies and analyses of biological tissue behavior and response are conducted using an FE approach in conjunction with experimental methods.

### RESULTS AND DISCUSSION

This study concerns the development of a finite element model (FE) of an osteoporotic femur, which is a defect on the cortical and cancellous cortex bone from computer tomography data (CT) Figure 1, and at the same time creates an intact femur by editing the defected surfaces using Raindrop Geomagic Figure 2 and Figure 3. The analysis will provide the stresses and strains in the Intact and Osteoporotic femur and shows the effects of osteoporosis. Furthermore a stress reduction through the introduction of auxiliary holes will be preformed to reduce stress values for elderly patients with minimal surgical intervention were it occurs in the vicinity of the osteoporotic area. A three-dimensional finite element model of a cadaveric fresh human femur is developed with geometrical and mechanical properties derived from quantitative computed topography data. Finite element models of bone segments generated from CT data using automatic mesh generation algorithms are becoming common not only in research but also in clinical applications such as

computer aided orthopaedic surgery. But, creation of the 3D FE models of human bones, such as the human femur is not a easy task. The mesh generation operation requires a description of the geometry of the domain to be meshed. By Starting from CT scans data sets, various methods can be adopted. Manual mesh generation can produce very accurate models such as simple geometric models. In the past few years, automatic mesh generator (AMG) algorithms have become widely available. Table 2 illustrates the number of elements and nodes for each material in the FEMs. These programs can generate FE meshes of an object from its given irregular geometric description automatically, allowing the user to control discretization parameters, such as the average, minimum or maximum element edge lengths. If the mesh does not satisfy the required mesh size and element quality, the process of remeshing is preformed until a satisfactory mesh is generated for both Intact and the Osteoporotic femur as shown Figure 5 and Figure 6 respectively The forgoing figures illustrates a solid view of the mesh generated in I-DEAS for the Intact Model using 'Section Meshing' and Delaunay Method. Parabolic tetrahedral elements were used. The model has a total of 20959 nodes and 13193 elements. The groups of elements defining the cancellous distal and proximal regions bone in the proximal and distal regions for the Intact model are illustrated in Figure 3. In addition, Figure 4 show the solid mesh for the Intact cortical bone and bone marrow, respectively. The axial peak strains on the medial, lateral, medial aspects of the femur for Load case 1 and Load case 2 Table 1 for the Intact model is –3000, 2100, 450, and –420, respectively. For similar Load case 1 the only studied in vitro strain measurements of human cadaveric femur reported by Cristofolini *et al.* (1996), the author reported peak medial, lateral strains of –900 and –450. Cristofolini *et al.* studied the action of 10 muscles experimentally *in vitro* instead of three as in this study. The stress results obtained for the orthotropic models shows lower stress values than the isotropic model as expected. The maximum Von Mises stresses exhibited by the two models are 72.9 MPa for the isotropic 64.8 MPa for the orthotropic model, thus the later model is approximately 12.5 % higher than the isotropic model. In both case the areas of high stresses are located in the cortical shell in the superior-medial head neck and on the superior postero-medial condyle. The cancellous bone stresses for both models are significantly lower. The maximum Von Mises stress in the cancellous bone occur in proximal region, 3.86 MPa for the isotropic model and 1.24 MPa for the orthotropic, respectively. The Von Mises stress of each model had been computed. Thus we carry out finding the stress, first for the isotropic intact femur 72.9 MPa, which is higher than the values reported by Taylor *et al.* (1996) Von Mises stress value as

shown in Figure 7. That's expected because of two rezones first, Taylor model cortex diaphyseal geometry thicker than our model, also to the assumption were been made by Taylor *et al.* regard the distal condyles boundary conditions. Furthermore, as shown in Figure 8 we computed the Von Mises of the Osteoporotic femur model which reveal a value of 110 MPa, which is approximately twice the stresses values which we obtained from the Intact orthotropic model, where the maximum stress occurred in the vicinity of osteoporotic postero-medial condyle, the Osteoporotic medial condyle region, and the superior-posterior condyle. The superio-posterior compressive stress is expected cause the femur will behave like a beam, whereas, the Osteoporotic stress is caused by the influence of osteoporosis. In order to simulate osteoporosis in the cortical bone and cancellous bone at various osteoporosis stages, the orthotropic elastic modules for the osteoporotic region were varied ( $E_{ij}$ )<sub>Osteoporosis</sub>. The osteoporosis site in the medial condyle represented by 34 tetrahedral elements, were varied between 0.06 and 1.0. In this case 1.0 represent the Intact or healthy femur ( $E_{ij}$ )<sub>Intact</sub>. The Von Mises stresses values were calculated for each ( $E_{ij}$ )<sub>Osteoporosis</sub> values. In addition, the ratio between ( $E_{ij}$ )<sub>Osteoporosis</sub> and ( $E_{ij}$ )<sub>Intact</sub> were calculated Figure 9. Figure 10 illustrates the Von Mises stresses for the osteoporotic model by varying the elastic modulus. Given a 50% increase in ( $E_{ij}$ )<sub>Osteoporosis</sub>, a 20% increase in the Von Mises stresses was demonstrated. The theory of the Stress Relief Hole that the maximum tensile/compressive stress can be reduced by placement of holes in the vicinity of the stressed area was based on the idea that the stresses will be relieved or displaced away from the critical area in this study we used or implemented the foregoing theory for the osteoporotic medial femur distal condyle model. This would definitely change the stress distribution in the osteoporotic femur and would most likely transfer more of the stress to the compressive/tensile side of the femur. By changing ( $E_{ij}$ )<sub>Osteoporosis</sub> to small values hereby, introduced or demonstrates the Stress Relief Hole at the vicinity of the osteoporotic cortex region, where the hole placement and size varied in the entire vicinity aspects defected region (i.e.. osteoporotic cortex region) Case 2. Moreover, using the SRH in the anterior-medial distal condyle cortex surface Case 1 revealed minimal stress reduction as illustrated. Thus, Case 2 is chosen. By using the forgoing case, a reduction of 19% was achieved. The Von Mises stress values was lowered from 110 MPa to 81 MPa.

## CONCLUSION

As we mentioned at the beginning of this paper, one of the main objectives of this research was, verify our finite element model analytically by computing the maximum bending stress on the mid-diaphysis cross-section where the maximum bending stress is

located. The combination of the FE analysis and the analytical model, demonstrated that, when the femur is loaded as with Load Case 2, a compression stress will occur on the mid-diaphysis. Furthermore, reveal a 6% discrepancy in bending stress values. FE analyses for three different femur models were carried out. In addition, to demonstrate and study the advantage of existing stress relief hole on an osteoporotic human femur, we conclude that by comparing the Von Mises stress values to an intact model a 19 % reduction on Von Mises stress values were obtained. Complete bone fractures may require fixation plates. After the fracture has healed the fixation device and the screws are removed, but the screw holes remain in the bone. Such hole is presents in the bone shell. As the bone was remodeled following Wolffs law, the existence of the hole intuitively, will attract the stress and will be relief, thereby reduced according to the theory. The

present study furthers these efforts by investigating the effects of holes across the Osteoporotic femur distal extremes.

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**Table 1.** Muscle and joint reaction forces for the wo load cases

Load case number		Applied vectorial forces (N)			Resultant (N)
		X	Y	Z	
1.	Abductors	439	122	-2000	2051.3
	Joint reaction force	307.1	0	828.6	883.7
2.	Joint reaction	-758.6	92	-2000	2140
	Force Abductors	307	0	828.6	883.6
	Ilio-tibial tract	0	0	-857.2	857.2
	Iliopsoas	55.7	-400	375	550

**Table 2.** The number of elements and nodes for each material in the FEMs.

Femur Model	Material	No. of elements	Total no of Elements	No. of Nodes	Total no. of Nodes
Intact	Cortical bone	8379	13582	1150	23100
	Cancellous Proximal bone	2288		4281	
	Cancellous Distal bone	1865		5437	
	Medullary Cavity	1050		1832	
Osteoporotic	Cortical bone	8349	13522	11433	22658
	Cancellous Proximal bone	2288		4281	
	Cancellous Distal bone	1835		5112	
	Medullary Cavity	1050		1832	
OFSRH	Cortical bone	8149	13482	11280	21560
	Cancellous Proximal bone	2288		4281	
	Cancellous Distal bone	1815		4959	
	Medullary Cavity	1050		1832	

Figure 1. Osteoporotic femur condyle

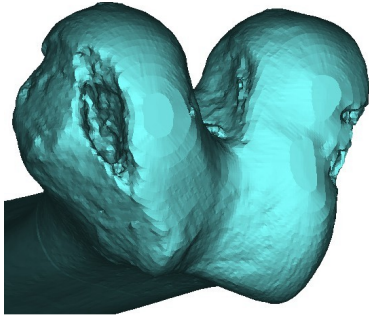


Figure 2. Removing defects and internal holes; a) cortical bone defect; b) medullary cavity filling holes; c) External cancellous bone defect; c) Internal cancellous bone defects.

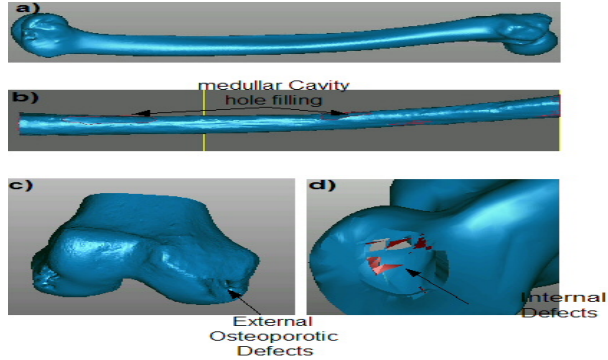


Figure 3. Intact polygon model; a) and b) cortical bone shell, c) and d) cancellous bone and medullary cavity; e) Intact cortical distal bone.

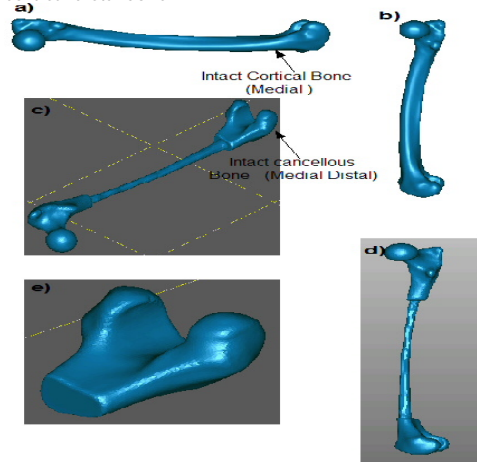


Figure 4. Osteoporotic polygonal geometry; a) and b) osteoporotic cortical bone; c) and d) osteoporotic cancellous bone; e) osteoporotic cancellous distal bone.

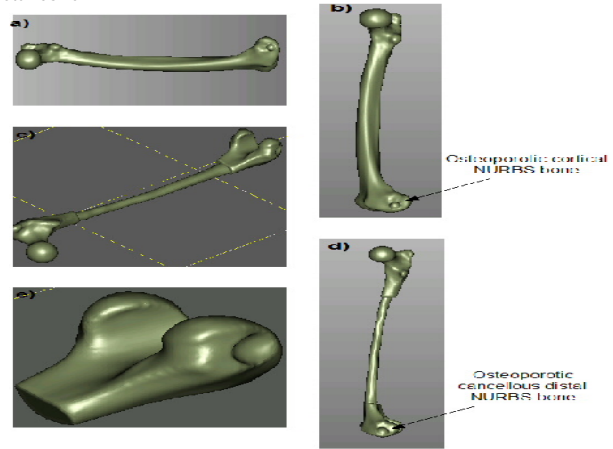


Figure 5. Osteoporotic femur mesh

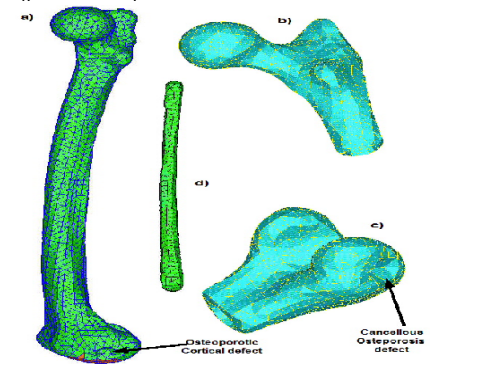


Figure 6. Intact femur

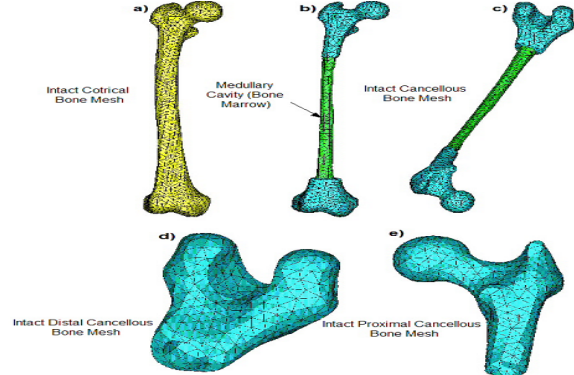


Figure 7. Von Mises Stress : Intact femur model

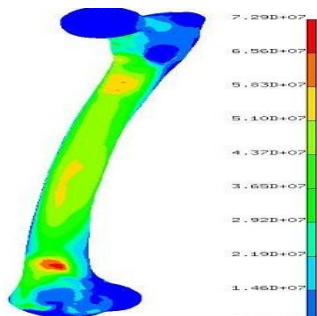


Figure 8. Von Mises Stress : Osteo-porotic femur model

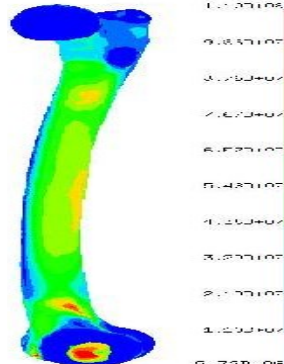
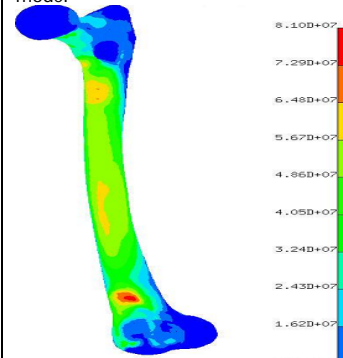


Figure 9. The relieved stress orthotropic model



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