Roxanne Su
HU ID: 406 4626 4
DEAS-Applied Physics

Analysis of Human Body via ABAQUS

Femur Loading and Cracking

I. Abstract

Human body is neat and complicated; stress may cause great irreversible damages to the bones and soft tissues, muscles, for instance. This analysis is a preliminary demonstration on stresses on the femur bone. With a simple 2-dimensional (2-D) model and ABAQUS calculating results, we may predict the initial cracking spots on the bone.

II. Introduction and Paper Survey

Physical stresses may bring us unhappy experiences, like pain and sourness, even worse, the fracture of bones. For instances, tennis elbow is caused by over using the muscles in the same region.

To explore the mimic of our body, finite element analysis (FEA) is widely used in investigating the human body, the bones [1], the joints [2] and the hand [3,4], for instance. Femur bone is a common examined part, where the upper part body weight is loaded [5,6], and is therefore needed to pay more attention to.

III. ABAQUS- model and parameters

- **Model**

Commercial packages provide 3-dimensional (3-D) models for various shapes of objects; among them, medical models are the most expensive ones. The goal in this report is to analyze a simple 2-D model built from a CT picture, as shown in figure 1. ABAQUS results help (1) to make comparisons with the results obtaining from 3-D model and (2) to estimate the place where initial cracking may occur through the stress field distribution.

This report explores two types of bone - homogeneous and inhomogeneous - the latter one introduces the bone relative density factor. The bone was assumed as an elastic material.

- **Parameters**

The relation between elastic modulus (E) and relative bone density (ρ) was used according to the results of Querol *et al.* [6]

$$E = \begin{cases} 60 + 900\rho^2, & \rho < 0.46\left(g/cm^3\right) \\ 2875\rho^3, & otherwise \end{cases} \quad ①$$

For homogeneous model, the relative density value is set as 1. Poisson ratio was set as 0.3. As is shown in figure 2, the upper body weight can be viewed as the point loading on the humeral head. Therefore, the concentrated force was loaded on that spot while the diaphyseal part of bone was maintained fixed.

IV. Results and Discussions

To study the place where crack starts first, relative concentrated stress regions are of more important. Absolute stress values are not emphasized here, as we can change the loading value easily in ABAQUS.

- **Homogeneous Model (HM)**

  In this case, the modulus is uniform, or relative density is identical. That is, ρ is taken as unity in the entire model. ABAQUS result is as shown in figure 3. Higher stress field is built at the neck part of the right fixed end if normal downward stress was loaded. The von Mises stress is relatively low in the middle part of the bone.

- **Inhomogeneous Model (IHM)**

  Because bone density was non-uniform in this case, modulus values were estimated by equation ①. For simplicity, three density values were considered: 1, 0.8, and 0.5. The amount of loading and its direction was remained unchange as in homogeneous model; the result is shown in figure 4. Maximum stresses were built up at the neck part of the fixed end, and was the same as in HM.

- Note that, in both cases, the highest stress appeared in the loading region, followed by the neck part, which may arise from curvture. (However, this was not discussed in the reference papers.) From this 2D model, cracking starts from the above mentioned regime, which is not the same as the resulted shown by Ota *et al.* [5] Figure 5 represents the results done by Ota *et al.*, indicating the stress field built within the femur bone. Experiment confirmed the stress existing in the white circle. The pink circle also suggests that the stress in the model was high, which is the same as was observed in this 2-D result.

- Another noteworthy point is as high relative bone density expands, high stress regime increases, which shows the same trend as presented by Querol *et al.*[6] , as is shown in figure 6. From FEA, the stress field was relatively small as ρ = 0.5 or smaller.

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V. Summary

2D model predicts the stress field trend successfully, but fails to explain the correct cracking position. However, the high stress field regime is consistent with what was found in both Ota *et al.* and Querol *et al.* It locates at the right part of the neck at the fixed end. Also, the figures reveal that von Mises stress is highly, proportionally dependent on bone relative density. 2D model is therefore reliable on studying stress field in femur bone.

References

[1] D.C. Newitt *et al.*, Osteoporosis international, **13** 6 2002.
[2] F. Eckstein *et al.*, Anatomy and embryology, **189** 545 1994.
[3] J. Z. Wu *et al.*, Annals of biomedical Engineering **31** 867 2003.
[4] A. A. Zadpoor, Int. J. Sci. Res., **15** 1 2005.
[5] T. Ota *et. al.,* J. Bone Miner. Metab., **17** 108 1999.
[6] L. B. Querol *et. al.,* J. Biomedical 405 2006.

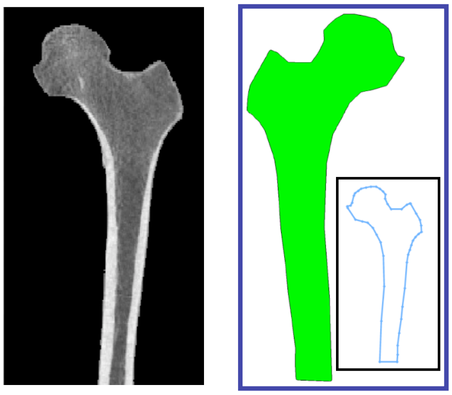

Figure 1. (Left) CT picture and (right) bone model used in ABAQUS.
The inset was directly sketched from CT picture.

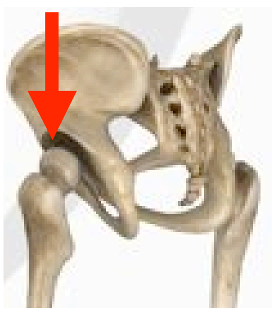

Figure 2. The arrow points to the place where the body weight is loaded.

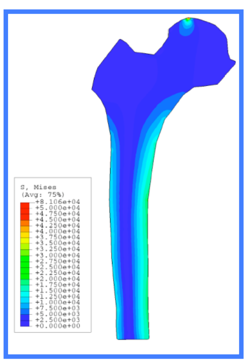

Figure 3. ABAQUS results for homogeneous bone model.

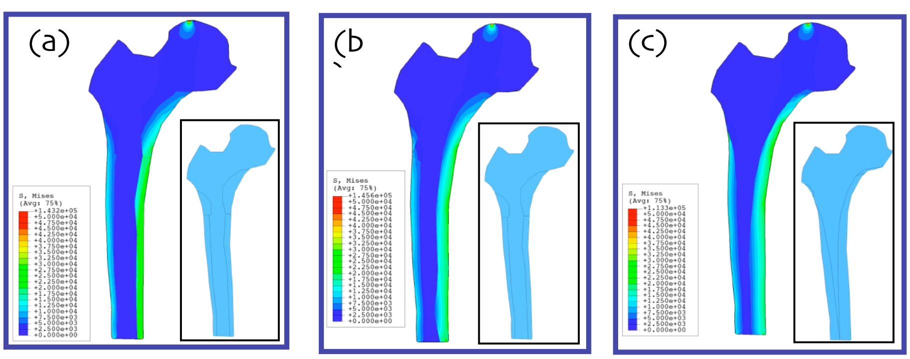

Figure 4. Results of finite element analysis under three different ways of partition, as is shown in 4(a), 4(b) and 4(c). Inset is the partition.

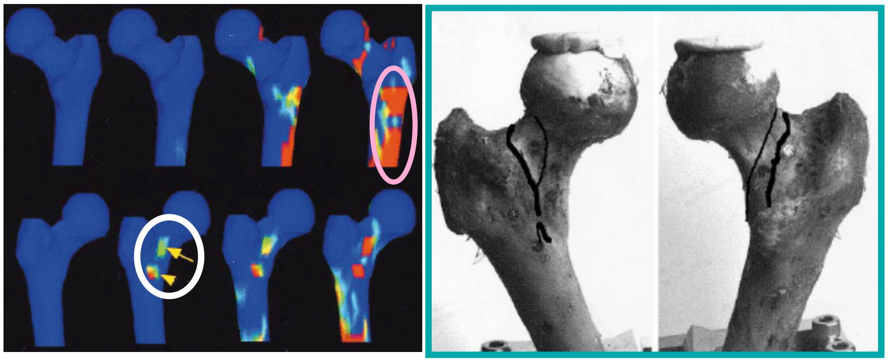

Figure 5. Femur cracking: ABAQUS results (left) and experiment picture (right)

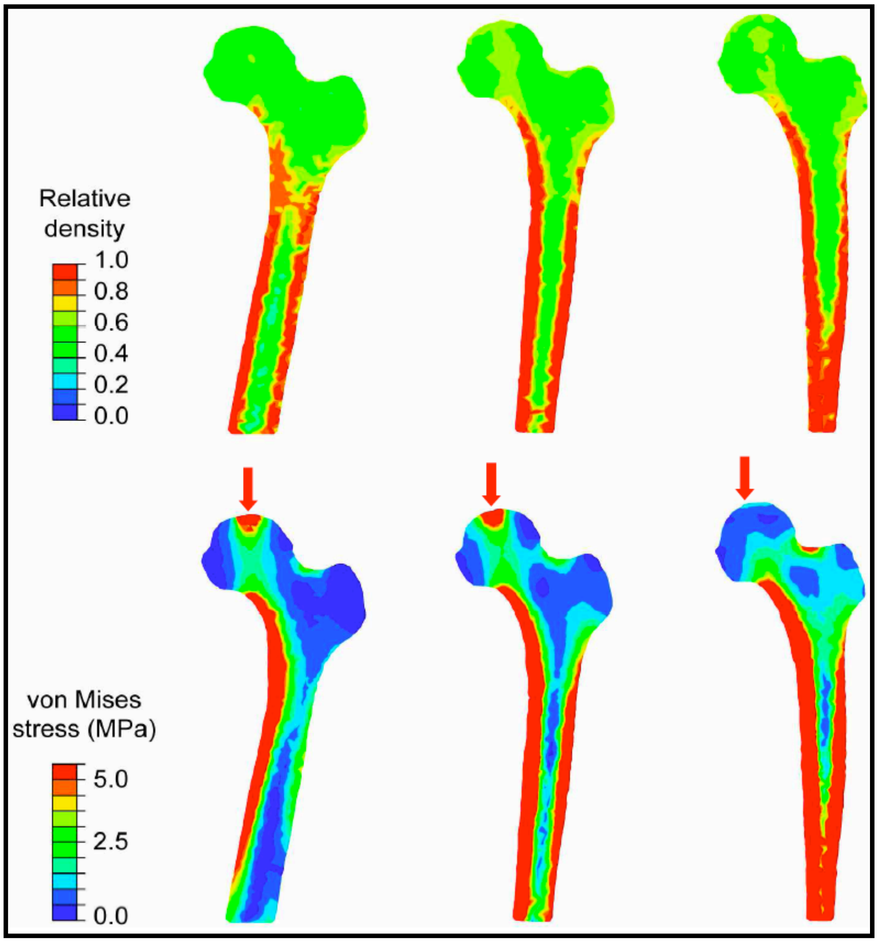

Figure 6. Effect of bone density on von Mises stress