# LARGE-SCALE FINITE ELEMENT ANALYSIS BASED ON CT IMAGES CONSIDRING INHOMOGENEOUSNESS OF BONE

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## INTRODUCTION

Range of mechanical property variation of a bone depends on individual, and it influences on the total stiffness and stress condition of the bone. Therefore, mechanical analysis considering inhomogeneous property of bone is necessary for patients oriented evaluation of bone in clinic. If the finite element method is used, mechanical analysis considering the bone inhomogenity is possible by giving a material property to an element one by one. So that, extreme fine meshing of finite elements is required for precise analysis of bone with inhomogeneous property. Handling of material property data, element by element, is impracticable by general finite-element codes and their pre-processors. In this study, we used "ADVENTURE system" [1] which was developed as a large-scale finite element analysis system operated on the PC cluster with parallel processing. Program sources of the system are open for free and it can be developed on the Linux operating system. We improved the ADVENTURE system to be applicable to stress analysis of inhomogeneous bone problems. We applied the improved program to a composite beam model with graded material property and ensured its validity by comparing between the theoretical and numerical results. Furthermore, the improved program was applied to stress analysis of proximal femur based on CT images and its efficiency was discussed.

## METHOD

ADVENTURE system developed by Japan Society Promotion Science (JSPS) enables to solve more than a few million degree of freedom problems on the PC cluster with parallel processing. The system consists of plural modules for pre-processor, solver, and post-processor. We improved pre-processor and solver of the system to be able to give a material property to an element one by one using element-property table. Therefore, if Young's modulus of each element is obtained from X-ray CT images, the ADVENTURE system can be applicable to stress analysis of inhomogeneous bone problems. The Young's modulus of elements can be given by relationship with CT data provided by Carter [2], Keyak [3] and so on. Flow of bone analysis using ADVENTURE system shows figure 1. Under the PC circumstances, we used MSC/Patran software for meshing pre-process. FE data related with nodes and elements are converted from MSC/Patran to ADVENTURE system. Main-process and post-process are operated on the ADVENTURE system.

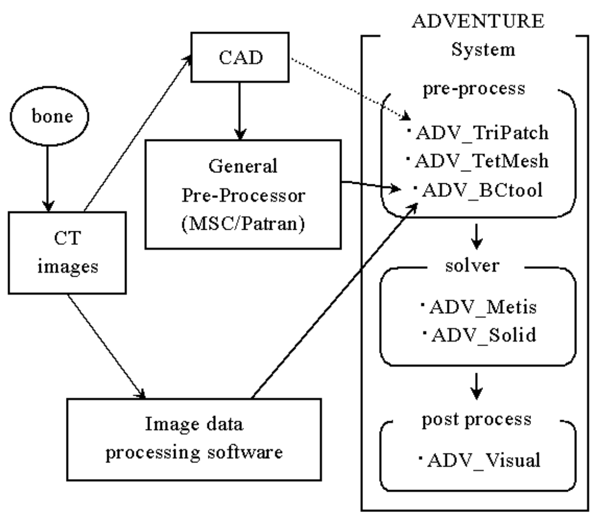


**Figure 1. Process flow of bone analysis using the ADVENTURE system**

## RESULT

We applied improved program to a composite beam model with graded material property and compared between the theoretical and numerical results. Boundary condition and material property distribution of the beam model is shown in figure 2. Origin of coordinates of the model was set the center of fixed end and z-axis was set in the longitudinal direction. Distributed load of 5 N/mm was added at the edge of the beam. Distribution of Young's modulus is depended on only y direction and Poisson's ratio is constant. In FE analysis, Young's modulus is constant in an element, and it is calculated from CT data at a center of element. FE model by hexahedral meshes of the beam and Mises stress of the beam model are shown in figure 3. Axial stress distribution at x=0 mm and z=15.1 mm along y direction is shown in figure 4. Good correspondence between both results was found, so efficiency of improved program was confirmed. Furthermore, improved ADVENTURE system was applied to stress analysis of a femur as an example of clinical problem. We prepared CAD model of 24-year-old male femur from based on CT images at 2mm intervals. Its boundary condition was assumed as standing still by one leg: hip joint force of 1500 N was applied to the femoral head with an angle 13 degree relative to the femoral axis, the greater trochanter was loaded with 1000 N, the angle of 20 degree with the femoral axis, and distal edge face of the model was fixed. Femur CAD model and its boundary condition and FE model meshing (element length is 10mm, 5mm, or 3mm) by tetrahedral elements are shown in figure 5. Mises stress of whole model and cross-section at the neck of caput of three models are shown in figure 6.

## DISCUSSION

It was noticed Mises stress distribution became clearer as FE mesh of the model was finer in the figure 6. Stress concentration was found wider at the region between greater trochanter and third trochanter, and neck region of femur especially in fine mesh model. Bone fracture of stumbling down in advanced age occurs at a neck region of femur continually. The improved ADVENTURE system can solve the problem with very fine mesh, so it is effective to evaluate the bone fracture analysis more precisely.

## CONCLUSION

The efficiency of improved ADVENTURE system was confirmed by analysis of the composite beam model having gradient material property, and FE analysis of the proximal femur was suggested availability of the system on a clinical analysis.

## REFERENCES


1. http://adventure.q.t.u-tokyo.ac.jp/jp/
2. Dennis R.Carter, Wilson C.Hayes, The Compressive Behavior of Bone as a Two-Phase Porous Structure, Journal of bone and joint surgery, 59A No.7, October, pp.954-962, 1977
3. Joyce H.Keyak, Stephen A.Rossi, Kimberly A.Jones, Harry B.Skinner, Prediction of femoral fracture load using automated finite element modeling, Journal of Biomechanics 31, pp.125-133, 1988


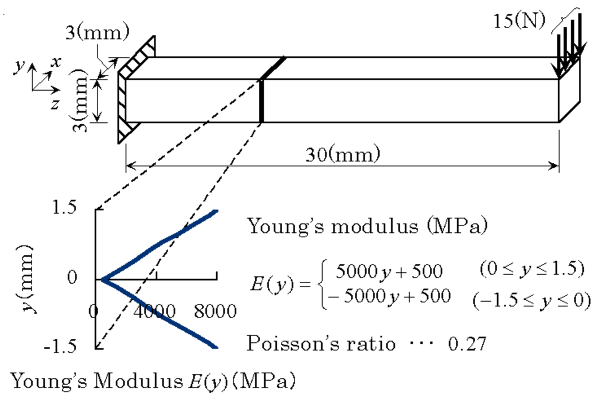


**Figure 2. A beam model and its material properties**

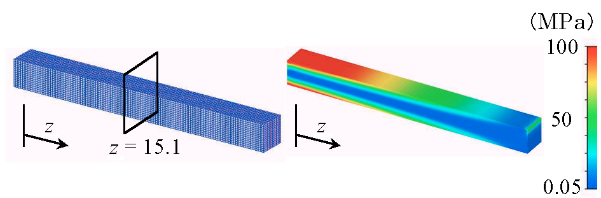


**Figure 3. FE model and Mises stress of the beam**

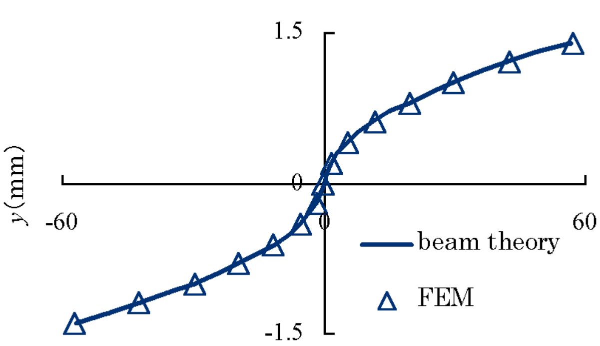


**Figure 4. Axial stress distribution at x=0 mm and z=15.1 mm along y direction**

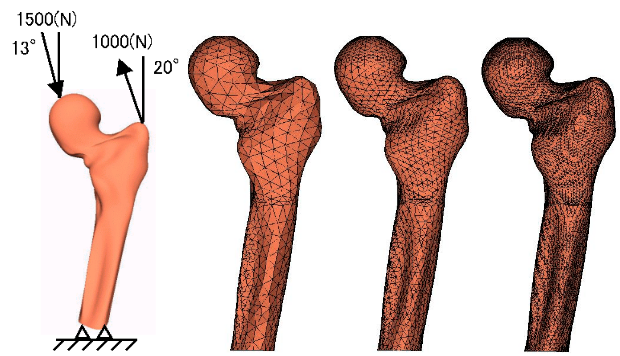


**Figure 5. Femur CAD model with boundary condition and FE model meshing by tetrahedral elements (length of element is 10mm:left, 5mm:middle, and 3mm:right)**

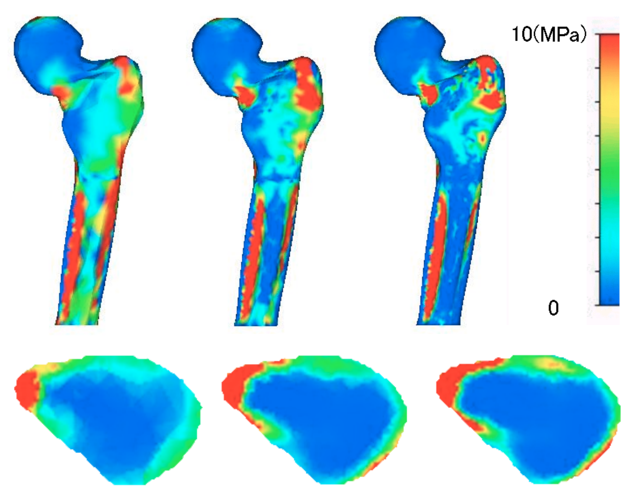


**Figure 6. Mises stress contour of the whole model and the cross-section at the neck of caput of three models (length of element is 10mm:left, 5mm:middle, and 3mm:right)**