11th. World Congress on Computational Mechanics (WCCM XI)
5th. European Conference on Computational Mechanics (ECCM V)
6th. European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

REMODELING SIMULATION FOR PREDICTION OF MORPHOLOGICAL CHANGES IN BONE CYSTS IN CANCELLOUS BONE OF OSTEOARTHRITIS OF THE HIP

Daisuke Tawara[1], Hiroyuki Kogita[1], Ken Nagura[2], Tetsuya Tsujikami[1], Hiroyuki Ike[3] and Yutaka Inaba[3]

[1] Department of Mechanical and Systems Engineering, Ryukoku University,
1-5 Yokotani, Seta, Otsu, Shiga 520-2194, Japan, datawara@rins.ryukoku.ac.jp
[2] Graduate School of Mechanical and Systems Engineering, Ryukoku University, Japan
[3] Department of Orthopaedic Surgery, Yokohama City University, Japan

Key Words: *Biomechanics, Bone cyst, Stress analysis, Remodeling, Osteoarthritis.*

INTRODUCTION

Osteoarthritis arises from an abnormality in the shape of a joint and the ensuing wear and tear. During the progression of osteoarthritis, a fluid-filled hole, referred to as a “bone cyst”, appears and enlarges, which often leads to fracture of the surrounding tissue. Because osteoarthritis closely relates to the mechanical condition of the tissue in the hip [1], it is also expected that growth of the cyst is connected to mechanical stimulation during trabecular bone remodeling in that region. Mechanical elucidation of the processes mediating cyst growth is thus desired to understand the mechanism of osteoarthritis for its treatment. In this study, we first sought to perform a stress analysis around a cyst in the coxal bone using CT image-based modeling of the osteoarthritis in macro-scale. Second, we estimated changes in the trabecular morphology around the cyst using our bone remodeling simulation method in micro-scale. Here, we present the results and discuss the efficiency of our simulation methods in gaining an understanding of the mechanism of the cyst growth.

METHODS

First, to evaluate the effects of a cyst on stress distribution, we performed a stress analysis on osteoarthritis patients who presented with (an osteoarthritis model) or without (a normal model) a cyst using CT image-based coxal bone models. The finite element model of the coxal bone with the cyst applied the boundary conditions, and the material properties are shown (Fig. 1). The heterogeneous Young’s modulus distribution of the bone is also reflected [2]. Second, to estimate the change in trabecular morphology around the cyst, remodeling simulation of a simplified model with/without cyst was performed using our remodeling simulation where we defined the driving forces of remodeling and nonuniformity of stress. Bone formation and resorption depend on the magnitude of nonuniformity, but they progress only after nonuniformity exceeds the threshold values. The simplified whole model, having 31,935 voxels, applied a compressive stress, and its material properties are shown (Fig. 2). We allocated 280 voxels-cysts in the model and assessed the morphological changes.

RESULTS AND DISCUSSION

The principal stress distribution of a transverse section around the cyst in the cyst/normal models is shown (Fig. 3). Overall, we found differences in the stress distributions between the osteoarthritis and normal models. High stress occurred around the cyst, suggesting that the bone around the cyst is load-supporting because of the low stiffness in the cyst. The difference in the stress distribution between both models implies that the change in stress distribution affects the balance of remodeling and leads to cyst growth. Whole and cross-sections of the remodeled morphologies with stress distribution in the tissue with or without cyst are shown (Fig. 4). Bone resorption at the area proximal to the cyst was observed, indicating cyst growth. We also demonstrated that the total volume in the cyst model increases even though bone resorption occurs around the cyst, which corresponds to the clinical findings that a bone spicule is formed and that bone volume around the cyst increases. These results suggest that cyst growth is significantly related to the change in stress distribution in bone and our simulation models can predict the growth of the cyst.

REFERENCES

[1] L.G.E. Cox, M.W. Lagemaat, et al., The role of pressurized fluid in subchondral bone cyst growth, *Bone*, Vol. **49**, pp. 762–768, 2011.

[2] J.H. Keyak, S.A. Rossi, et al., Prediction of femoral fracture load using automated finite element modeling, *Journal of Biomechanics*, Vol. **31**, pp. 125–133, 1998.

[3] T. Adachi, M. Tanaka, et al., Uniform stress state in bone structures with residual stress, *Journal of Biomechanical Engineering*, Vol. **120**, pp. 342–348, 1998.

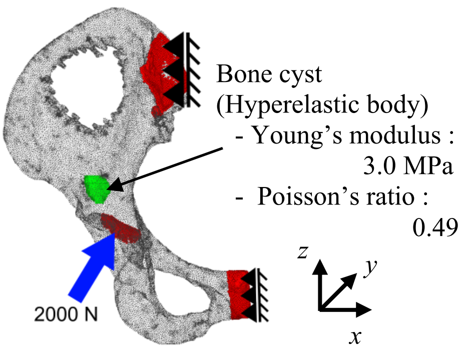

Fig. 1 Coxal bone model with the bone cyst and its boundary conditions.

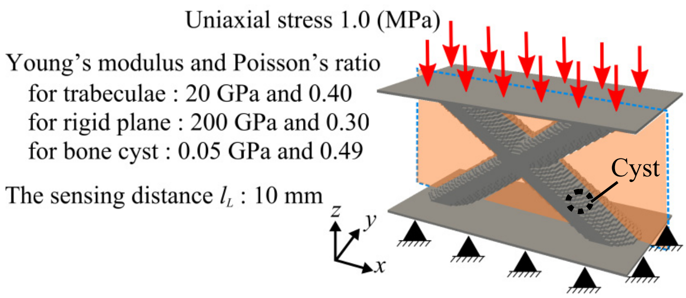

Fig. 2 Simple trabecular model and position of the bone cyst for remodeling simulation.

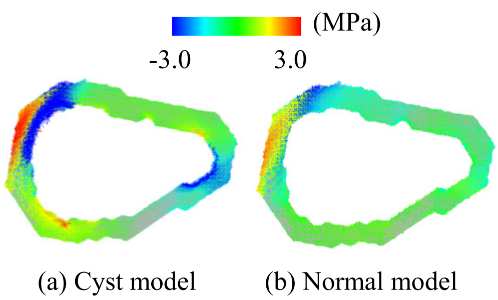

Fig. 3 Principal stress distribution of the transverse section around the cyst.

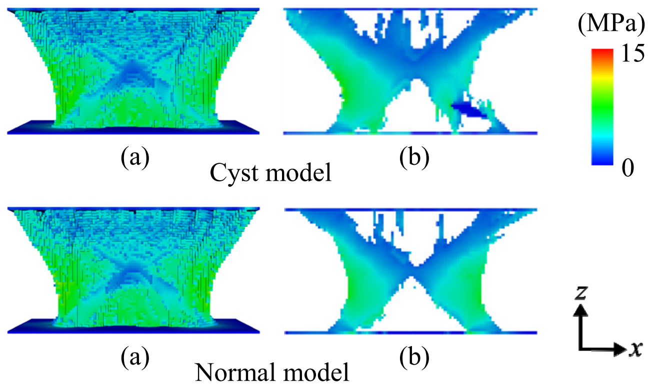

Fig. 4 Remodeled morphology with its von Mises stress distribution of the whole model (a) and the cross-section (b) of the cyst and the normal models.