RELATIONSHIP BETWEEN STRUCTURAL ANISOTROPY AND BONE MINERAL DENSITY IN THE HUMAN VERTEBRAL BODY

*Hagiwara, H; **Inoue, N; *Matsuzaki, H; **Cohen, D; **Kostuk, J P.; **Chao, E Y.S.
*Department of Orthopaedic Surgery, Nihon University School of Medicine, Tokyo, Japan. **Orthopaedic Biomechanics Laboratory, Johns Hopkins University, Baltimore, MD. Ross Research Building, 720 Rutland Avenue, Room 235, Baltimore, MD 21205; 410-502-6416, Fax: 410-502-6414, eychao@eagle.gsh.jhu.edu

INTRODUCTION: Osteoporosis is characterized by not only a reduction in bone mass but also alteration in the architecture of cancellous bone. Changes in bone mineral density (BMD) have long been considered the most important factor in the diagnosis of osteoporosis and in predicting the risk of fractures caused by osteoporosis. However, recent studies have demonstrated that similar BMD values have been associated with different osteoporosis-induced fracture outcomes. Changes in the trabecular architecture of the osteoporotic vertebral body are well known, but quantitative analysis of trabecular structure and its correlation with BMD have not been well studied. The purpose of this study, therefore, was to investigate relationship between structural anisotropy and BMD in human vertebral bodies.

MATERIALS AND METHODS: Thirty-nine vertebral bodies from 11 human cadavers were used for this study. BMD was measured using dual energy x-ray absorptiometry (DEXA, QDR-4500, Hologic) in lateral projection. After measuring BMD, a 5 mm thick sagittal section was taken from the midline of each vertebral body using a fine band saw. A soft x-ray was taken with an aluminum step wedge. The x-ray image of the vertebral body was digitized and a 3 by 3 square grid was superimposed (Fig. 1). The bone density of each region was measured using the x-ray image. The intensity of trabecular orientation in both the vertical and horizontal directions was analyzed for each region using 2 dimensional Fast Fourier Transforms (Fig. 1) (1). The trabecular ratio was defined as the ratio of the intensity of vertical trabecular orientation to the intensity of horizontal trabecular orientation (vertical/horizontal) for each region. Anisotropy of the entire vertebral body was defined as the ratio of the sum of the nine regional intensity values for vertically oriented trabeculae to the sum of the nine regional intensity values for horizontally oriented trabeculae. Distribution of bone density measured by x-ray image and the intensity of trabecular orientation in all nine regions were analyzed using one-way analysis of variance with a post-hoc test. The relationship between the intensity of trabecular orientation of the entire vertebral body and BMD measured by DEXA was analyzed using regression analysis.

RESULTS: BMD measured by DEXA ranged from 0.255 g/cm^2 to 1.046 g/cm^2 (0.678±0.317 g/cm^2, mean ± SD). Regional bone density measured from x-ray images in the anterior regions showed lower densities than the other areas in their respective rows (p<0.01) (Fig. 3). In these same regions, a higher trabecular ratio than the other regions in each row was observed (p=0.0001) (Fig. 2). The trabecular ratio of the entire vertebral body and BMD measured with DEXA showed a strong non-linear correlation (r^2=0.626, p<0.0001, Fig. 3). This new knowledge of the non-linear relationship between the microstructure and BMD of osteoporotic bone. This may be another approach for evaluating the changes in the microstructure of the osteoporotic bone as a function of BMD besides analyzing the microstructure of the bone directly. The current study analyzed only the structural anisotropy of cancellous bone. Changes in bone microstructure due to osteoporosis include other parameters such as connectivity and thickness of the trabeculae. The relationship between these parameters and BMD also needs to be investigated.

DISCUSSION: The current study showed significantly lower BMD and higher vertical trabecular orientation in the anterior one third of the vertebral body. Oda and co-workers demonstrated similar findings in a semiquantitative manner and postulated that this macroscopic inhomogeneity caused the wedge-shaped vertebral deformity (2). There is an increasing number of studies indicating that, in addition to BMD, trabecular microstructure is an important factor in the assessment of osteoporosis. The prediction of fracture risk in osteoporotic bone based on BMD measurement alone has recently been reported to be insufficient. Several attempts to evaluate the microstructure of bone using high resolution CT and MRI have been reported. However, the practical application of these methods is unknown. The question of whether microstructure is independent of BMD still remains. If there is no relationship, both the microstructure and BMD need to be measured for better assessment of osteoporosis. The current study, however, demonstrated a high correlation between the anisotropy of the trabeculae and BMD. The non-linear relationship between BMD and the mechanical properties of cancellous bone is well known (3). This phenomenon may be a result of the non-linear relationship between BMD and the microstructure of cancellous bone currently observed. The prediction of fracture risk using BMD measurement could be improved by incorporating this new knowledge of the non-linear relationship between the microstructure and BMD of osteoporotic bone.