

CONTRIBUTION OF BMD AND THREE-DIMENSIONAL TRABECULAR BONE MICROSTRUCTURE OF THE PROXIMAL FEMUR TO ITS MECHANICAL PROPERTIES AS ASSESSED BY MICRO-FINITE ELEMENT ANALYSIS

Wen-Quan Cui^{1*}, Ye-Yeon Won¹, Myong-Hyun Baek¹, Tae-Bong Yun¹, Kwang-Kyun Kim²

¹Department of Orthopaedic Surgery, Ajou University School of Medicine, Korea

²Department of Orthopaedic Surgery, Gong-Ju Medical Center

*San 5, Wonchon-dong, Paldal-gu, Suwon City, Korea, 443-721; Phone: +82-31-219-4536; Fax: +82-31-216-4536; Email: cwq@ajou.ac.kr

Introduction

Osteoporotic hip fracture is the worst complication of osteoporosis, resulting in significant morbidity and mortality. It has been shown that the trabecular microstructure is closely associated with biomechanically determined bone strength, which has a substantial effect on fracture risk¹. Because a substantial heterogeneity of micro-structural properties exists among various skeletal sites, regionally specific three-dimensional architectural measurements made at the site of the highest fracture risk are needed. The goal of this study was to investigate the contribution of bone mineral density (BMD) and the microstructural properties of trabecular bone in predicting its elastic modulus in the intertrochanteric region.

Methods

A total of 15 trabecular bone core specimens were obtained from the proximal femurs of patients undergoing total hip arthroplasty. BMD of all bone cores was measured using PIXImus2 densitometer. All specimens were scanned with a high-resolution μ -CT system (Skyscan 1072, Belgium) at a spatial resolution of 21.31 μ m. From the resulting voxel data, a rectangular volume of interest was selected at a side length of 5mm and height of 10mm, which was matched with the location and size of ROI as measured by BMD. With the μ -CT scanner's built-in software, the following three-dimensional structural parameters, relative bone volume (BV/TV), trabecular number (Tb.N), thickness (Tb.Th) and separation (Tb.Sp), structure model index (SMI), and degree of anisotropy (DOA) were calculated². The segmented reconstructions of the VOI were converted to μ FE models by converting the voxels (size 85 \times 85 \times 85 μ m) that represent bone tissue to equally shaped 8-node brick elements using a hexahedron meshing technique³ (Fig. 1). For all models, the element material properties were considered to be isotropic, linear elastic, and uniform with a tissue Young's modulus of 10 Gpa and a tissue Poisson's ratio of 0.3. The apparent Young's modulus was calculated for the compressive-test model only. The multiple relationships among BMD, microstructural parameters and mechanical indices were assessed using linear regression analyses.

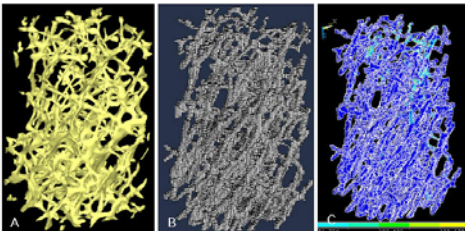


Fig. 1 A-C. (A) 3D reconstruction image. (B) Image-based 3D mesh model. (C) Micro-finite element analysis (FEA)

Results

3D reconstruction images of samples with different age stages from μ CT showed different microstructure patterns, as presented in Fig. 2. The results showed that the BV/TV was the best predictor for Young's modulus ($R^2=0.758$, $p<0.001$), as well as BMD ($R^2=0.752$, $p<0.001$). The structure model index (SMI), Tb.Sp and Tb.N could well explain the variance of Young's modulus by 51%, 42% and 39%, respectively. If BMD is supplemented with any of the examined structural indices there is a clear improvement for predicting Young's modulus. Likewise, the ability to explain variance of Young's modulus is improved by combining the structural indices each other.

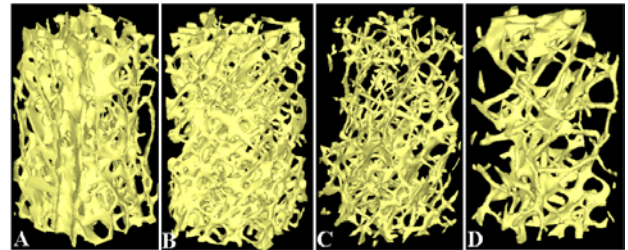


Fig. 2 3D micro-CT reconstruction images of four samples with increasing age. (A) 32 yr. (B) 52yr. (C) 69 yr. (D) 87 yr.

Conclusion

A high-resolution imaging technique in combination with new computer modeling technique based on the finite-element method is a useful tool to provide insight into the structure-function relationship for trabecular bone. A combination of microstructural parameters each other or with bone mineral measurements could provide the best prediction of mechanical property of cancellous bone in the intertrochanteric region. Therefore, as regards detection of osteoporosis and evaluation of the efficacy of drug treatments for osteoporosis, BMD measurement should be supplemented with assessment of bone microarchitecture in vivo.

References

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