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Regional Variations in Trabecular Morphological Features of Femoral Head of Patients with Proximal Femoral Fractures

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Abstract

The regional microstructural variations in femoral head from proximal femoral fracture patients were investigated. Micro-CT scanning was performed on seven femoral heads from proximal femoral fracture patients. Each femoral head was divided into three regions according to the trabecular orientation from the fovea of femoral head to the femoral neck. Eight three-dimensional trabecular cube models were reconstructed from each region. A total of 154 trabecular cubic models were reconstructed because the corresponding areas for 14 cubic models were damaged during the surgeries. Eight trabecular morphological parameters were measured and analyzed, namely, trabecular thickness (Tb.Th), trabecular separation (Tb.Sp), specific bone surface (BS/BV), bone volume fraction (BV/TV), structural model index (SMI), degree of anisotropy (DA), trabecular pattern factor (Tb.Pf), and trabecular number (Tb.N). Bivariate correlation analyses were performed for all morphological parameters. One-way ANOVA tests were performed to analyze the differences of each parameter among three regions. Post-hoc multiple comparisons (Student-Newman-Keuls method) were performed to analyze the morphological difference between two regions. Trabecular bone of proximal femoral fracture patients significantly degenerated in all regions of femoral heads. BV/TV was statistically correlated with Tb.Th, Tb.Sp, BS/BV, Tb.Pf, and Tb.N ($p < 0.05$). Statistical differences in morphological parameters were observed between regions ($p < 0.05$). The trabecular strength in the middle regions was significantly higher than that in other regions because of the relationships between morphological parameters and mechanical parameters. Trabeculae in the medial region were more uniform and stable along each direction than those in the lateral region. Most trabeculae in the lateral region only grew along the weight-bearing direction, and those along the other directions degenerated significantly. This study provides detailed trabecular morphological information on fractured femoral heads, as well as references for the prevention of high fracture risk in the elderly.

Keywords: femoral head, trabeculae, proximal femur fracture, morphological parameter, micro-CT

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1 Introduction

In many countries, the frequency of hip fracture increases with adult development and aging[1]. A survey estimated that the hip fracture rate in Asia will rise to 37% in 2025 and 45% in 2050[2]. The general clinical manifestation of fracture risk is usually caused by osteoporosis[3]. The World Health Organization defines osteoporosis as Bone Mineral Density (BMD) of more than 2.5 standard deviations below the mean of a young healthy reference population of the same gender. However, BMD is only a moderate predictor of fracture risk[4], and may only account for 30% of reduction in fracture risk following therapy[5–8]. Some fracture patients have normal BMD[9,10]. Microstructural features of trabeculae are also another important factor contributing to mechanical properties[6,11]. A previous study on fractured femoral heads, which were from patients with a particular form of coxarthrosis and those that underwent fragility fractures, showed that Young's modulus and ultimate stress are positively correlated with bone volume fraction (BV/TV, Bone Volume divided by Tissue

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Volume) and trabecular number (Tb.N), and negatively correlated with trabecular separation (Tb.Sp)[12]. BV and TV were defined as trabecular bone volume and cancellous bone tissue volume, respectively. The subjects comprised males and females, including 11 proximal fractured patients (mean age 81 years old) and 20 coxarthrosis patients (mean age 81 years old)[12]. Using a combination of BMD and microstructural measurements, 94% of the overall strength of trabecular bone was explained in comparison with 64% if BMD was used alone[13].

Bone quality can be measured using Dual-energy X-ray Absorptiometry (DXA), Quantitative Computed Tomography (QCT), or quantitative ultrasound[14]. DXA cannot account for three-dimensional (3D) bone morphology. Evaluation of *in vivo* BMD and 3D bone morphology in QCT is more useful than areal density assessment by DXA. However, QCT can only measure the macro areas, such as femoral head, femoral neck, or greater trochanter, because of low resolution. The nature of fracture involves the accumulation of trabecular micro-damage[15–17]. Thus, trabecular morphology at the tissue level can directly reflect the state of bone quality. The micro-CT images of trabecular bone at the tissue level can be easily obtained and reconstructed into 3D models nondestructively without any sample preparation[12,18, 19]. The voxel size of general micro-CT devices is about tens of microns. The pores and trabecular structures of cancellous bone can be distinguished clearly[20]. Morphological parameters of trabecular bone can be measured and analyzed accurately on the reconstructed models with this level of precision[21–23].

Some studies on the analysis of trabecular morphological parameters of proximal femur have been published. Previous studies analyzed the correlations and regional differences of trabecular morphological parameters of proximal femur[24,25]. These studies observed significant differences in BV/TV, trabecular thickness (Tb.Th), Tb.Sp, Tb.N, and Degree of Anisotropy (DA) between superior and inferior necks, as well as between superior and inferior great trochanter[24]. The donors in these investigations were Asian male cadavers (mean age 61.8 years old) without macroscopic pathological changes in musculoskeletal disease. Studies on the effect of age on trabecular morphological parameters showed that the reduction in BV/TV is significantly associated with the decrease in structural model index (SMI), decrease in Tb.Th, and increase in Tb.Sp at most sites of proximal femur (femoral head, femoral neck, and femoral trochanter) with aging[25]. Samples for these studies were from human cadavers with ages ranging from 52 years old to 99 years old without any musculoskeletal disorders.

Femoral neck fracture has been extensively studied, but femoral head fracture is also a common disease[26–29]. However, most studies on femoral heads mainly focused on trabecular microstructural features as a whole. The trabecular bone bearing the weight and daily gait load directly maintains high density, and that bearing the load indirectly degenerates, which results in regional inhomogeneity of BMD[30–33]. The features that trabeculae grow along the main load directions result in the anisotropy of trabecular microstructures. Micro-CT images showed that trabeculae grew along approximately two cantilever structures from shaft to femoral head, which indicated that they work together to resist the principal compressive loads and cantilever-bending moments[30,34]. This phenomenon reveals the regional inhomogeneity of Tb.N and anisotropy of trabecular orientation. The strength and stability of bone at macroscopic level are affected by the microstructural features of trabecular bone. Thus, the fracture risk can be affected. However, few studies on the regional differences of trabecular morphological parameters exist. The mechanism underlying aging fragility fracture can be elucidated by investigating trabecular microstructures of elderly patients and those of healthy elderly individuals.

The objective of this study was to refine regional morphological differences of femoral heads of patients with proximal femoral fractures. Trabecular morphological parameters of femoral heads were measured regionally on 3D bone models reconstructed from micro-CT images. Trabecular microstructure of fracture patients degenerated severely to cause fractures. These microstructures were significantly different from those of healthy individuals. According to the effect of trabecular morphologies on the strength, we attempted to analyze trabecular morphological features and correlations between trabecular morphological parameters of femoral heads from elderly proximal femoral fracture patients, which would help clarify the mechanism of femoral head fracture and improve prevention and treatment strategies in clinics.