# CHAPTER VI JUMPER'S TIBIA ASSESSED ALONG 64 DIRECTIONS CENTERING CENTER OF THE BONE GRAVITY BY PQCT

## VI. A. Purpose

It was reported by Nilsson et. al. (64), who measured the BMD of athletes for the first time, that the distal femoral BMD of athletes was greater than that of controls. Continuously, the positive effect of exercise on human bone mass has also been well documented in many studies comparing athletes with sedentary controls (14,23,29,30,31, 43,47,57,92). These studies were measured by DXA, which is applied to measure aBMD defined as the bone mineral content per projected area ($g/cm^2$), and it was pointed that aBMD is influenced by bone depth and bone size (8,24,30,52). Comparison of aBMD among athletes revealed the importance of weight bearing activity to increase aBMD. It had been demonstrated in many cross-sectional studies (14,23,29,30,31,43, 57,92) that young female athletes who engage in weight bearing activities, such as volleyball and gymnastics, have a greater aBMD at a majority of skeletal sites when compared to athletes in a non-weight bearing activity (swimming) and controls.

On the other hand, pQCT, which is capable of three-dimensional measurement of bone mass, assesses the vBMD i.e. bone mineral content in a unit volume. By using pQCT, the effect of the exercise on vBMD has been confirmed in the following studies assessing side-to-side differences of professional tennis players (1,33), volleyball players (75) as well as triple jumpers (38,69), and comparing mid-tibia of jumpers, swimmers and sedentary controls (51). These studies suggested that the improvement of the mechanical properties of bone in response to long-term physical exercise is related to geometric adaptation and not to vBMD. It means accompanying cortical drift, the increase of periosteal and endocortical radius, cortical thickness increases also adapted to improve the bone strength, such as PMI and SSI (81).

Peripheral QCT is capable to re-construct three dimensional image of bone, analytical procedure of previous studies were however rather poor. For example, geometric parameters of the training bone (cortical thickness, periosteal area, endocortical area) were generally calculated assuming cylindrical configuration of the bone, which does not reflect the true shape of bone. In addition, bone strength indexes (PMI, SM and SSI) are functionally more important than bone mass (81). Since the bone geometry is changed by mechanical loading, it is also considered that the direction of the loading effects the change of bone geometry. To understand the geometric bone adaptation to mechanical loading due to exercise, therefore, these geometric indexes should be evaluated in relation to a direction of mechanical loading correctly. In the present study, by assessing the geometric bone adaptation to mechanical loading, bone geometry and mechanical properties of jumpers and controls' non-dominant tibiae were compared along 64 directions (at intervals of 5.625°) centering center of gravity of the bone on cross-sectional pQCT images.

## VI. B. Materials and methods

### Subjects

A study population comprising jumpers (10 male, 7 female) and controls (7 male, 8 female), aged 18-23 yr, was recruited from the University of Tsukuba, Japan (Table 7). Written, informed consent was obtained before the study, and the project was approved by the University of Tsukuba Human Subjects Institutional Review Board.

### Bone measurement

The non-dominant midtibia was measured by using pQCT (Densiscan 1000, Scanco Medical, Zurich, Switzerland). The leg was positioned in a radiolucent cast anatomically suitable for the subject during computed tomography scanning. The detailed statement of bone measurement had been written before (18; CHAPTER IV. B). Cortical thickness was defined as the distance between the inner and outer edge of the cortical shell, measured along 64 radius' directions (at intervals of 5.625°). The bone strength indexes (PMI and SSI) (81) were measured along 32 diameter's directions. By connecting the gravity of tibia and fibula with the line, which was defined as 0°, and bone geometric properties (periosteal and endocortical radius, cortical thickness), PMI and SSI were calculated along 64 directions at intervals of 5.625° from the 0° line (69) (Figure 9).

The calculated program of bone strength indexes was made by Pascal language using Macintosh computer. The exercise, smoking and alcohol use habits and medical history were obtained through questionnaires.

**Statistical analysis**

Values are presented as means ± SD. Two Factor ANOVA was used to assess the effect on bone geometric properties and bone strength indexes adjusted for the history of training and measure direction. The comparison of jumper and control groups at different direction was assessed by using *t*-test. Statistical significance was taken at the $p < 0.05$ level.

## VI. C. Results

**Physical characteristics of the subjects**

The physical characteristics of the groups are given in Table 7. The female jumpers were heavier than controls, but there were no significant differences in age and height between male or female jumpers and controls groups. The female jumpers had less numbers of menstrual cycles during the past 12 mo than controls, although there was no significant difference in the age of menarche between the two groups. And there was a female jumper who had had fatigue fracture at non-dominant tibia, but the values of this subject were around mean values, neither the highest or lowest value, the values of this subject were not excluded from the whole statistical analysis.

**Bone geometric properties and strength indexes**

The jumpers had significant greater values in bone geometric properties (periosteal and endocortical radius, cortical thickness) and strength indexes (PMI and SSI) than controls. And the values depended on the direction of measurement, cortical thickness had the greatest value along the longitudinal direction (around the connection of 67.5° and 247.5°). PMI and SSI also had the greatest value along the longitudinal direction, it suggests the greatest bending strength along the neutral axis which is vertical to the longitudinal direction. The interaction between history of training and measure direction were significant in the endocortical radius and cortical thickness of female subjects, as well as cortical thickness of male subjects (Table 8, Figure 10-13).

## VI. D. Discussion

Peripheral QCT measures vBMD in grams per cubic centimeter and allows for separate assessment of trabecular and cortical bone of the appendicular skeleton, also can determine bone geometric properties (periosteal and endocortical radius, cortical thickness) and bone strength indexes (PMI and SSI) (1,33,38). The previous studies investigated the effect of exercise on bone (1,38,51,61,75,81), suggesting that the improvement of the mechanical properties of bone in response to long-term physical exercise is related to geometric adaptation and not to vBMD. However, the geometric parameters (periosteal and endocortical radius and cortical thickness) were generally calculated assuming cylindrical configuration of the bone, which does not reflect the true shape of bone. For example, the average cortical thickness of the tibia in male control group was 3.48 ± 0.51mm, but the thickest cortical part was 4.79 ± 0.94 (at 118.125°) and the thinnest part was 2.62 ± 0.29mm (at 315.000°). Furthermore, it is difficult to consider that mechanical loading effecting on bone are similar at every direction. Therefore, while comparing jumpers whose tibiae receive large impact loading during the exercise with sedentary controls, the values were recommended to be analyzed by ANOVA, since the values were possible related with the training history, the measurement direction, or as well as both of them.

Periosteal and endocortical radius, cortical thickness, PMI and SSI were greater in jumpers than controls. The results have also been confirmed by many previous cross-section studies (38,51,61,75,81) and the comparative side-to-side difference study of tennis players' radius (1,33). Periosteal and endocortical radius, cortical thickness, PMI and SSI were measured at different direction by using the gravity of the cross-section image as the center, it was found that the cortical thickness, PMI and SSI had the greatest values along the connection of about 61.875°～67.5° (anterolateral direction) and 241.875°～247.5° (posteromedial direction).

Since the bone geometric properties and bone strength indexes were changed largely along the different directions, it becomes very necessary to compare the pQCT images under the same condition. In this present study, the pQCT images were compared by making the gravity of tibia as the center, and making the connection line of tibia and fibula as the 0° reference line. The significant difference of endocortical radius between jumpers and controls were along about 22.5°～61.875° in female, and 298.125° (-61.875°)～67.5° in male. However, only by these data it is still difficult to assess that the exercise improves the bone resorption of the surface of endocortical bone at the certain direction. On the other hand, since either periosteal and endocortical radius suffered the same effect from the shift of gravity, it seems that the cortical thickness, which is the difference between periosteal and endocortical radius, suffered less effect from the shift of gravity caused by the other change of bone. The difference in cortical thickness between jumpers and controls is most prominent in the direction of 247.5°, on the other words also in control group, cortical thickness, PMI and SSI were significant along this greatest direction. It suggested that besides in control group, bone modeling towards periosteal direction was active adapted to the daily life's loading, which resulted the increase of the cortical drift towards periosteal direction, the similar change was caused by physical training more significantly. It means that jump brings the greater mechanical loading than walking at the same position. The reasons why this position is brought greater mechanical loading are 1) the related position with muscle and tendon, which increase the tension toward periosteal direction. 2) the relation with the shape of tibia, which is explained by that the physical exercise such as jump or walking adds the compressive force especially to the inside and the backward of the tibia, because tibia naturally leads outward and forward direction.

To limit X-ray radiation, pQCT scan has not been applied on whole bone but on selected only one slice, a 66 mm distance from the distal tibia, is analyzed in this study. The results therefore respond to the part and not to the whole bone. In the future study, we expect that some other technical methods excelled in evolution, such as magnetic resonance imaging (MRI), will be applied to investigating the effect of long-term physical exercise on bone geometric architecture and bone strength of whole bone.

In conclusion, difference in the cortical thickness between jumpers and controls was the greatest toward the posteromedial direction. Along this direction, differences in mechanical properties were also the most significant, suggesting that the site-specific adaptation of bone to long-term physical exercise is due to geographical relation of bone to muscle.