

**CHAPTER V EFFECTS OF DIFFERENT PHYSICAL TRAINING
ON CORTICAL BONE AT MIDTHIBIA ASSESSED
BY PQCT**

V. A. Purpose

Physical exercise has been proposed as one strategy for improving or maintaining the structural competence of bone (19). High levels of physical exercise should produce high levels of mechanical force on bone, such as jumping. This mechanical force should therefore increase bone strength. It is generally assumed that a high level of physical exercise corresponds to a high level of mechanical loading with the exception of a few non-weight bearing activities, such as swimming. One of the early studies of adolescent athletes using DXA reported enhanced aBMD of distal femur (64) and whole body in athletes (23,92). Further, comparison of aBMD among athletes using DXA revealed the importance of weight bearing activities to increase aBMD. 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. The sports with multiple sites of impact and higher intensity activities such as volleyball and gymnastics are associated with greater

amounts of both weight-bearing activity and strength training, whereas swimmers engaged in large amounts of muscle pull activity (12,23,57,92).

In addition, the classic example of the positive effects of activity on bone in humans are studies demonstrating greater mineral deposition in the dominant playing arm versus the non-dominant arm of tennis players across different age groups in DXA studies (29,30,31). On the other hand, the study of tennis players' radii using pQCT, which measure vBMD, revealed that an improvement of the mechanical properties of young adult bone in response to long-term unilateral use in exercise is related more to geometric adaptation than to changes in vBMD. Measurements of bone areas at mid-radius using pQCT showed that average cortical thickness of the playing arm increased, accompanied by periosteal mineral apposition and endosteal bone resorption, leading the center of the cortex to be further away from the neutral axis (cortical drift). Together with an increase in cortical thickness, cortical drift toward periosteal direction resulted in a significant improvement of the mechanical characteristics of the players' dominant radius (1). The preceding observations have been confirmed in a later study of professional tennis players by Haapasalo et al (33).

Since adaptation of bone to physical exercise depends on the nature of the exercise, the following questions remain: 1) Does exercise involving non-weight bearing but less

impact, such as swimming, also induce changes in bone geometric properties? 2) Does extremely high impact exercise increase vBMD? The purpose of the study was to evaluate the effect of long-term exercise on vBMD, geometric properties and the bone strength index of jumpers as a weight bearing activity group, and swimmers as a non-weight bearing activity and active loading group, compared to non-athletic controls using pQCT.

V. B. Materials and methods

Subjects

A study population comprising 43 female adults (13 jumpers, 15 swimmers and 15 controls) and 37 male adults (12 jumpers, 15 swimmers and 10 controls), aged 18 – 23, was recruited from the University of Tsukuba, Japan. The jumpers including long jump, high jump, triple jump and pole jump athletes, and the swimmers including backstroke, breaststroke, butterfly stroke and freestyle swimming athletes, were active, top-level and had begun their physical exercises before or during the puberty. The controls, who had not performed any regular physical exercises training except in physical education, consisted of gender-, age-matched sedentary non-athletes. Training history, age at training onset, and condition of menorrhoea (only females) were investigated by direct

interview. The exercise, smoking and alcohol use habits, and medical history were obtained through questionnaires. The subjects were clinically healthy, and none had any disease, took medication affecting bone metabolism or had had tibial fractures except one jumper who had had a left tibial fracture. Group characteristics are given in Table 5. 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 mid-tibia of the non-dominant limb was measured using pQCT (Densiscan1000, Scanco Medical, Zurich, Switzerland) with an effective X-ray energy of 40 keV. The non-dominant leg defined as nonuse leg for jumping was positioned in a radiolucent cast anatomically suitable for the subject during CT scanning. After displaying an anterior-posterior projectional scout-view, a reference line was set at the right angle to the long axis of the leg and placed on the middle point of the endplate of the distal tibia. To limit X-ray radiation, a single slice 66 mm proximal from the reference line was analyzed as the site of the mid-tibia, which contains more than 90% of cortical bone. The thickness of one slice was 1.0 mm and a voxel size was 0.36 x 0.36 mm. A standard phantom measurement was performed daily, which resulted in a long-term reproducibility of 0.3%, as vBMD was measured in adults of various age

group of both sexes (78,79).

Data analysis

The pQCT bone image was transmitted to a Macintosh computer in Custom mode (resolution: 256 x 256 pixels), and imported into NIH Image (Version 1.61, Wayne Rasband, National Institute of Health) to analyze vBMD, BMC and geometric properties. The detail had been given before (CHAPTER IV. B). The PMI was calculated as a measure of the strength index of bone (81). Figure 5 shows an inverse image of the tibia on NIH image software.

Statistical analysis

Values were presented as means \pm SD. Group differences in descriptive data were evaluated using analysis of variance (ANOVA). Fisher's post hoc test analysis was performed for the significant values in ANOVA.

In addition to mechanical loading, measures of bone morphology and biomechanical indexes may also be influenced by interindividual variation in body size (both height and weight). To adjust potentially confounding differences related to height or weight, analysis of covariance (ANOCOVA) was performed, and the adjusted values were presented if necessary. Statistical significance was taken at the $p < 0.05$ level.

V. C. Results

Physical characteristics of the subjects

The physical characteristics of the groups are given in Table 5. The female athletes were significantly taller and heavier than the controls, although there were no significant differences between swimmers and jumpers. There was no significant difference in height among the male groups, while swimmers were significantly heavier than the other groups. The starting age of training was earlier and the training duration was longer for the swimmers than the jumpers in both males and females. The age of menarche and the number of menstrual cycles during the past 12 months were similar among the three female groups.

Bone measurement of BMD and BMC

There were no differences in vBMD of whole and cortical bone among the three male groups. In the females, the whole vBMD of the swimmers was lower than in the other groups, and the cortical vBMD of athletes was lower than that of the controls. The cortical BMCs of the male and female jumpers were greater than that of the controls and swimmers (Table 6).

Bone measurement of bone geometric properties

The periosteal areas of male jumpers and female athletes were larger than those of

controls, the endocortical area of female swimmers was larger than that of female controls, and the cortical area of jumpers was larger than the other groups in both males and females, the same significant result was also seen in the size-adjusted value of male's cortical area. Either the cortical thickness or the size-adjusted cortical thickness of jumpers was thicker than that of the swimmers, and the female jumpers' cortical thickness was also thicker than controls' (Table 6).

Bone measurement of bone strength

The PMI was greater in jumpers than in the other groups in both males and females, and the female swimmers' was greater than the controls' (Table 6).

Correlation

Periosteal and endocortical areas were negatively correlated with cortical vBMD in both sexes (Figure 8).

V. D. Discussion

Peripheral QCT allows estimation of true BMD, i.e., vBMD in grams per cubic centimeter, and the geometric properties of the bone (24,76,80). Studies concerning the effect of physical training on bone using pQCT are scarce, with a few studies analyzing the side-to-side difference in tennis players' arms (1,33,61), a limited number on

jumpers' legs (38), and a study on volleyball player's lower legs (75).

The present study evaluated vBMD, BMC, geometric properties and the strength index of the tibia of male and female jumpers as a typical example of bone exposed to an extremely high-impact mechanical load. The periosteal area, cortical area and PMI were greater in male and female jumpers than in controls. The results showed a significant periosteal drift (drift toward periosteal direction) and no increase in vBMD in jumpers' tibias, confirming the conclusions of previous studies of young subjects (1,33,38) that improvement of the mechanical properties of bone in response to long-term physical exercise was related to geometric adaptation and not to vBMD. The results suggested that there was no margin for physical exercise to increase bone mineral because the cortical bone of young sedentary subjects was already saturated with mineral, and, therefore, bone has expanded in a periosteal direction, resulting in periosteal drift. Contrary to the well accepted notion from studies using DXA that exercise increases aBMD, the cortical vBMD of jumpers in the present study was lower than that of controls, and the difference was statistically significant in female jumpers. The present results and previous observations in tennis players that the cortical vBMD of the dominant arm was lower than that of non-dominant arm (1,33) suggest that the cortical bone increased in size at the expense of bone density in young subjects.

Previous reports using DXA suggest that weight bearing activities (volleyball, basketball, handball, high jump and gymnastics etc.) increase aBMD (12,23,57,92). However, the BMD assessed by DXA represents areal density expressed as grams per square centimeter, and it reflects vBMD and bone geometry (8,24,28,52). On the other hand, in the first study of this thesis (61), we analyzed the side-to-side difference of the radius of middle-aged female tennis players, who initiated training after bone had matured. We found that compared with the non-dominant arm, the endocortical and periosteal areas of the dominant arm were smaller. The different result maybe explained by that the different intensity of exercise between young athletic and recreational players resulted in a different effect on bone geometry.

The present study also evaluated the tibia of male and female swimmers as a typical example of low impact and active load. In male subjects, there was no significant difference in any parameter between swimmers and controls, while female swimmers had significantly greater periosteal area, endocortical area and PMI and lower whole vBMD and cortical vBMD compared with controls. The enhanced PMI with cortical drift observed only in female swimmers was unexpected and worth discussing. First, Parfitt et al. divided the life span into five phases based on chronological changes of cortical bone geometry (67). The endocortical area expands during puberty, from age

6 to 12, and decreases from adolescence to middle age. Seeman suggested that delayed puberty resulted in larger periosteal and endocortical area in girls but not in boys (83). As an average in the present study, female swimmers began their training (7.6 ± 1.9 year) in the earlier part of puberty, but jumpers began training (12.7 ± 1.5 year) after puberty, and the athletes had slightly later menarche compared with the controls, although the difference was not statistically significant. Furthermore, a long-term unilateral use by tennis playing did not stimulate cortical drift toward the periosteal direction in another our recent study (61), because the middle-aged female subjects started their tennis training after bone had matured (35.7 ± 2.9 year). It suggested that mechanical loading stimulated cortical drift maybe only during puberty period, but not after the third decade of life. Consequently, the different starting age of training between swimmers and jumpers probably caused the cortical drift seen only in female swimmers. The question of whether physical exercise before puberty accelerates the expansion of the endocortical area remains to be settled. Second, the non-weight bearing sport such as swimming is associated with a larger endocortical area than the weight bearing jumping sport. Because swimming involve relatively less bone on bone axial compressive loading, and therefore, the nature and anatomical distribution of the strain patterns will vary considerably in this sport, compared with activity like jumping,

which impose both bending and higher axial compressive strain. The result was also derived from another study (17).

Interestingly, periosteal and endocortical areas were negatively correlated with cortical vBMD in both male and female subjects. Consistently, previous studies observed a negative correlation between relative side-to-side difference in periosteal area and cortical vBMD of mid radius in tennis player (1). Exercise seems to increase the cross-sectional area of bone at the expense of BMD. A preferential increase in cross-sectional area to cortical density has also been reported during the adolescent growth spurt (45). Thus, given a limited calcium intake (45), an increase in cortical drift due to exercise and growth is partly offset by an increase in cortical porosity. And it remains to be clarified how bone metabolism between the inner and outer edge of the cortical shell is integrated to effect the changes in cortical vBMD.

In conclusion, 1) an improvement of the mechanical properties of a young athlete's bone in response to long-term physical exercise is related to geometric adaptation and not to vBMD, 2) increases in periosteal and endocortical area are inversely related to reduced cortical vBMD in athletes, and 3) in female swimmers, physical training started in the earlier part of puberty may contribute to enlarged endocortical area. Thus, exercise affects bone geometry through loading mechanical

impact on the bone but may also affect the endocrine system by delaying puberty.