

## **CHAPTER IV EFFECTS OF TENNIS PLAYING ON MATURE RADIUS ASSESSED BY PQCT**

### **IV. A. Purpose**

The positive effects of physical exercise on human bone mass have been well documented in many cross-sectional studies comparing athletes with sedentary controls (35,42,64) as well as in longitudinal follow-up studies (15,36,54). In DXA study of tennis players in which the playing arm was compared with the non-dominant arm, the side-to-side differences showed a positive effect of physical loading on bone (32). On the other hand, applying pQCT, which has the advantage of measuring vBMD and distinguishing between trabecular and cortical components, it was demonstrated in young athletes that cortical vBMD of the dominant arm was not greater than that of the non-dominant arm. Cortical drift toward the periosteal direction and an increase in cortical thickness resulted in an improvement of mechanical characteristics of the mid-radius on playing arm (1,33). An improvement of mechanical properties of young adult bone in response to long-term exercise was therefore related to geometric adaptation, but not to an increase in vBMD.

The ability of bone to adapt to mechanical loading is much greater in the growing

than in the matured bone and exercise after maturity has a much smaller effect (67). Furthermore, the manner in which the recruitment and function of bone cells are coordinated differs between the growing and the matured bone. In the former, modeling is the dominant mode, and in the latter it is remodeling. In the present study, the side-to-side difference in tennis players who initiated training after bone had matured is analyzed by pQCT and tries to investigate the adaptation of mature radius to unilateral use in tennis playing.

#### **IV. B. Materials and methods**

##### **Subjects**

Recreational female tennis players more than 35 years old (n= 134) from local tennis clubs in an urban area were invited to participate in the present study. By direct interview, recreational tennis players, who initiated their playing activity at more than 30 years old, had a history of playing over a 3-year-period, and did not participate in other unilateral sports, were selected (n = 102). Players with an incidence of upper extremity fractures (n = 2), ovariectomy (n = 3), or medication for affecting bone (n = 5) were excluded from the study. The remaining 92 players, including 5 left-handed players, used only a dominant hand for the forehand stroke, but 66 players used both

hands for the backhand stroke. The majority of the players (n = 89) initiated their playing while in their thirties. They were playing tennis an average of 3.8 times per week, and the duration of each session was 180 min., ranging from 90 to 360 min. Since this is a side-to-side different study, the results could exclude the effects of several confounding factors, such as genetic, nutritional and hormonal factors, therefore the subjects include both premenopausal and postmenopausal women. The group characteristics are given in Table 2. Written informed consents were obtained before the study.

### **Bone measurement**

Two sites of radius of both arms were scanned by a pQCT (Densiscan 1000, Scanco Medical, Zurich, Switzerland) with a single-energy X-ray source, according to a method previously described (1,33,77). To limit X-ray radiation, pQCT scan was applied on only two slices. The measurement sites of the radius included a proximal site (at midradius, 52 mm from the distal end) and a distal site (at distal radius, 6 mm from the distal end) (Figure 4). The distal measuring site, which typically contains 70% trabecular bone, was used specifically for examination of trabecular bone, and a proximal site, which contains more than 90% cortical bone, was used for cortical bone. All computed tomography scans had a slice thickness of 1.0 mm and a pixel size of 0.36

mm.

The high-resolution images were transferred to a Macintosh computer as TIFF (Tagged Image File Format) images, with fixed scale, density and resolution (256 x 256 pixels). Periosteal area and endocortical area were measured by the threshold method using NIH IMAGE software (version 1.61, Wayne Rasband, National Institute of Health). The cortical bone was defined as that with a volumetric density of more than 0.7 g/cm<sup>3</sup> (93). Endocortical and periosteal areas were defined as cross-sectional areas surrounded by the inner and outer surface of the cortical bone, respectively. Cortical area was defined by the difference between periosteal and endocortical areas. Cortical thickness was defined as the mean distance between the inner and outer edge of the cortical shell (Figure 5). BMC was defined as the mineral content of the bone within a 1-mm slice (g/mm). Coefficients of variation for triplicate measurements of three human subjects after repositioning were 0.10% - 0.72% for vBMD, 0.44% - 0.74% for bone area and 0.79% for cortical thickness. PMI, SM, and SSI were calculated as measures of bone strength indexes (81, Figure 5).

### **Statistical analysis**

Statistical analysis was performed using the STATVIEW program and data are expressed as means  $\pm$  standard deviation (SD). The side-to-side difference in parameters

was analyzed by paired *t*-test. Statistical significance was taken at the  $p < 0.05$  level.

#### IV. C. Results

Side-to-side differences in geometric parameters, vBMD, BMC and indexes of bone strength of radius were analyzed with a paired *t*-test as shown in Table 3. Endocortical area, periosteal area, BMC and indexes of mechanical strength of dominant midradius were significantly smaller compared with those of the non-dominant radius. There was no significant side-to-side difference in cortical thickness, cortical vBMD, and vBMD of whole bone at the midradius. At the distal portion of the radius, the periosteal area of the dominant radius was significantly smaller and vBMD of the trabecular and whole bone were significantly greater in comparison to those of the non-dominant radius. BMC of dominant distal radius was greater than that of non-dominant radius, but the difference was not statistically significant ( $p = 0.052$ ).

Because the present study recruited subjects in the age range of 35-55 years, dependency of the geometric parameter, vBMD, and indexes of mechanical strength on age were assessed, as shown in Figure 6 and Table 4. Volumetric BMDs of cortical bone and whole bone at the midradius were lower in older subjects, and age-related

differences were significant when statistical analyses were applied on the dominant, non-dominant, and mean of both radii ( $p < 0.01$ ). The age-related differences in endocortical area and cortical thickness of the midradius were statistically significant in the non-dominant radius, but the relation was not statistically significant in the dominant radius and the mean of both radii. The periosteal area of the midradius of the non-dominant radius showed a tendency to increase with age, but the difference was not statistically significant (non-dominant radius,  $p = 0.089$ ; dominant radius,  $p = 0.140$ ).

Dependency of side-to-side differences in bone parameters on age and training duration were also assessed (Table 4). The side-to-side difference in endocortical area was negatively correlated with age and that in cortical thickness was positively correlated with training period (Figure 7). Side-to-side differences in other parameters were not correlated with age or training period.

#### **IV. D. Discussion**

In addition to age-related changes, there was large individual variability in geometric parameters, vBMD, BMC, and mechanical strength, as shown in Figure 6. Recent studies have suggested a strong genetic influence on BMD (10,20,21,59,65,66, 68), and it is reasonable to assume that geometric parameters such as endocortical area

and periosteal are also influenced by genetic factors. In addition, the nutritional and hormonal influence on bone metabolism and exercise habit other than tennis must also be considered as sources of individual variability in bone geometry and BMD. To eliminate the influence of these genetic and environmental influences, we analyzed the side-to-side difference of the radius of tennis players.

Compared with the non-dominant arm, the endocortical and periosteal areas of the dominant arm were smaller and long-term unilateral use by tennis playing did not stimulate cortical drift toward the periosteal direction in our subjects. Side-to-side differences in geometric parameters, index of mechanical strength, vBMD, and BMC of the tennis players remained statistically significant when 20 menopausal players were excluded from the statistical analysis. These findings were unexpected and quite in contrast to previous observations on young tennis players (1,33), in which cortical drift toward the periosteal direction was observed in the dominant arm. A comparison between the present observations on middle-aged recreational tennis players and our previous one on young athletic players (the average ages are  $20.1 \pm 0.6$  for female and  $20.2 \pm 0.7$  for male subjects) (1), suggests several possibilities. The first possible explanation is that unilateral mechanical loading stimulated cortical drift only during the adolescent period, but not after the third decade of life. Bone loss from the endocortical

surface is enhanced and it outpaces bone formation in the periosteal area and thus cortical thickness tends to decrease throughout most of life except for a relatively short period during adolescence (72). It is therefore conceivable that habitual exercise, after peak bone mass has been attained, suppresses acceleration of bone loss from the endocortical area in cortices, resulting in suppression of compensatory bone formation at the periosteal surface. Interestingly, we showed that age-related expansion of the endocortical area was statistically significant in the non-dominant radius, but not in the dominant. And the side-to-side difference in cortical thickness was positively correlated with the training period. Second, differences in intensity of exercise between athletic and recreational players resulted in a different effect on bone geometry. Third, subject gender may have interacted with the effect of exercise on bone metabolism. Previous reports on radial BMC of male life-time tennis players ( $73 \pm 12$  years) are noteworthy (40). BMC measured by transmission scanning with a low-energy X-ray beam at the midradius of the dominant arm was greater than that of the non-dominant arm. Although a residual effect of training history during the adolescent period cannot be excluded in the study of life-time tennis players, it is possible that hard training done by male tennis players enhanced the BMC of cortical bone, whereas the female recreational players investigated in the present study did not.



After the third decade of life, the endocortical area begins to increase and expansion of the periosteal area slows, resulting in decreased cortical thickness (67). Consistent with previous observations in femoral radiographs, direct measurement of specimens, and mathematical model-based bone modeling theory (9,55,67,88,96), progressive increases in endocortical and periosteal areas and decreases in cortical thickness were observed in the midradius of the non-dominant arm, although dependency of periosteal area on age was not statistically significant ( $p = 0.089$ ) due to large individual variability. It is noteworthy that age-related differences in these parameters were not observed at least in the dominant radius, suggesting that unilateral use of the arm after the third decade of life suppressed age-related changes in bone geometry.

Similar to midradius, periosteal area increased and vBMD decreased with age in the distal radius, but the age-related changes were not statistically significant in both arms. At the distal radius, which typically contains 70% trabecular bone, the vBMD of the dominant arm was greater than that of non-dominant arm, consistent with a previous report showing that BMD of trabecular bone was more sensitive to the effects of exercise than cortical bone (91). Periosteal area at the distal site of the dominant arm was smaller than that of the non-dominant arm and this observation in middle-aged

tennis players is quite in contrast to that in young tennis players (1). As noted earlier, the differences in the findings between young athletic tennis players and middle-aged recreational tennis players remain to be clarified.

To evaluate the physiological significance of suppressed cortical drift, indexes of mechanical strength were calculated. SSI, which is function of geometry and vBMD, slightly and significantly decreased in the dominant radius in comparison to the non-dominant radius. Thus, BMC and bone strength decreased at the mid-portion of the dominant radius. On the other hand, BMC increased at the distal portion of the dominant radius, although the difference did not reach statistical significance. One possible explanation for these observations is that tennis playing triggered a bone mass shift from the middle to the distal portion within the radius. The possibility of bone mass shift within a body by physical exercise has already been indicated in studies wherein the non-dominant arm of the tennis players was "the weakest of all" among dominant and non-dominant arms of players and sedentary controls (33), and BMD of the skull decreased in athletes whose femoral BMD had increased (11,44). In an experiment on rats, controlled dynamic loading produced a change in shape, which stimulated periosteal expansion in some areas and decreased it in others (60). The study emphasized assessment of whole bone architecture instead of measurement at select

bony sites, an approach that remains to be done in a human study.

The side-to-side differences in geometric parameters, vBMD, BMC, and indexes of mechanical strength were relatively small although they were statistically significant. These results clearly suggest that the most of the individual variability in parameters of the radius derived from factors other than age and unilateral use of the arm. The present study therefore focused on side-to-side differences in players' radius, and "control" subjects were not recruited. Furthermore, in the previous study on young control subjects (1), the significant side-to-side differences were not found in periosteal area, endocortical area as well as cortical thickness of radius. Although the side-to-side difference in radius was not detected in the control group, it remains possible that the side-to-side difference in middle-aged subjects in the present study reflects not only tennis playing but lifelong daily unilateral use. This possibility remains to be clarified.

Unexpectedly in the present study, the periosteal and endocortical areas as well as the bone strength indexes at the midradius were smaller in the dominant arm than in the non-dominant arm, and the cortical drift toward the periosteal direction was not found in middle-aged tennis players. Although the present study did not recruit control subjects, Kontulainen et al (46) assessed the side-to-side differences of adult control women at the humeral shaft. They found that cortical and endocortical areas as well as

bone strength indexes were greater in the dominant arm than non-dominant. These results were in contrast to the present study on middle-aged tennis players, and several reasons were considered. Firstly, the subjects of the present study had the habit of exercise, but those of the previous study did not. Secondly, the average age of subjects is different. The age of middle-aged tennis players in the present study was 46.4 years old, while that of controls in the previous study was 33.6 years old. Thirdly, the measurement site of radial shaft in the present study was taken at the 52mm from the distal end of radius, but that of humeral shaft in the previous study was taken at 50% of the estimated humeral length. Due to the limited number of literature concerning geometric measurement of trained bone assessed by pQCT, the reasons for the discrepancy between the present and previous results were not identified.

Unlike what was seen in young subjects, tennis playing after bone had matured did not stimulate cortical drift toward the periosteal direction in middle-aged female subjects. Unexpectedly, the periosteal area at the middle and distal radius and endocortical area at the midradius were smaller in the dominant arm than in the non-dominant arm of the middle-aged players. These findings suggest that unilateral use of the arm after the third decade of life suppresses age-related changes in bone geometry, although the mechanism behind this phenomenon remains to be clarified.