Comparison of bone mineral densities between postmenopausal women who swam regularly and those who took art classes

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(abstract)

The effects of swimming exercise on the bone mineral density (BMD) and bone metabolism of postmenopausal women were ascertained by comparing the data of 10 women who belonged to a swimming club (swimming group) with an average age of 63.2±5.9 years and those of 10 women who belonged to an art (handicrafts) club (art group) with an average age of 64.3±5.3 years. Dual energy X-ray absorptiometry was performed to measure the BMD of the whole body and the proximal femur, and a biochemical test (bone metabolism markers) was conducted to measure the levels of serum calcium, urinary creatinine, urinary calcium, and urinary deoxypyridinoline. The results were as follows:

1) While the whole body BMD for the swimming group was higher than that for the art group, there was no significant intergroup difference.

2) The leg muscle endurance for the swimming group was significantly higher than that for the art group.

3) The BMD of the proximal femur Ward’s triangle tended to be maintained for the swimming group when compared to the art group, regardless of body weight.

These findings suggest that swimming exercise maintains leg muscle endurance and affects the proximal femur region in postmenopausal women. It is extremely important to consider how the elderly might incorporate swimming exercise into their daily life and maintain their physical fitness and walking ability.

Key words: postmenopausal women, swimming exercise, bone mineral density

I. Objectives

In Japan, the growth of the elderly population has raised important social issues regarding remaining healthy without developing lifestyle-related and chronic diseases while preventing age-induced osteoporosis.

By utilizing the physical properties of water, it is possible to swim for a long period of time to improve muscle strength safely without excessively stressing joints, muscles, or ligaments. The main objective of swimming is not only to perform exercises in water that can otherwise be done on land, but also to gain effects that can only be achieved in the water. Water exercises such as aqua aerobics, aqua exercises, and underwater walking have been viewed as exercise techniques that can promote health for people in all age groups. Furthermore, water exercises are used to not only promote health, but also administer aqua
therapy and water exercise therapy. While many studies are being performed on exercise equipment to maintain health and BMD in the elderly \(^{12-13,25}\), few studies have focused on BMD and bone metabolism of the proximal femur, the site where a fracture is most likely to occur in the elderly \(^{14}\).

Greater numbers of older people are taking classes such as swimming and art because they want to engage in an activity at their own pace without worrying about time, get together with friends with similar interests, and enrich their minds. Participating in these classes is important because it gives them something to look forward to in their daily lives. Hence, in the present study, we investigated the influence of exercise in preventing osteoporosis (as measured by BMD and bone metabolism markers) between postmenopausal women who swam regularly and those who took art classes.

II. Subjects and Methods

The study objectives and contents, BMD measurement, and biochemical analysis were explained to the subjects and their written informed consent was obtained. The study was approved by the Ethical Committee of the Osaka University of Health and Sport Sciences.

1. Subjects

The subjects were divided into two groups, a swimming group and an art group, and the results were compared between the two groups. The swimming group comprised 10 women who took a class at a sports club (1.3±0.3 hours/session, 3.7±1.5 sessions/week; age, 64.3±5.3 years; height, 150.9±3.7 cm; body weight, 52.6±5.4 kg; BMI, 23.1±2.1 kg/m\(^2\); percent body fat, 28.6±6.4%; swimming history, 4.2±1.0 years). The art group comprised 10 women who did not exercise and took an art class (age, 63.2±5.9 years; height, 150.7±5.5 cm; body weight, 56.0±7.4 kg; BMI, 24.7±3.1 kg/m\(^2\); percent body fat, 31.3±5.5%) (Table 1).

<table>
<thead>
<tr>
<th>Table 1 Physical characteristics of subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Swimming group</td>
</tr>
<tr>
<td>n=10</td>
</tr>
<tr>
<td>Age (years)</td>
</tr>
<tr>
<td>Height (cm)</td>
</tr>
<tr>
<td>Body weight (kg)</td>
</tr>
<tr>
<td>Body Mass Index (kg/m(^2))</td>
</tr>
<tr>
<td>Body fat (%)</td>
</tr>
<tr>
<td>Average age of menopause (years)</td>
</tr>
<tr>
<td>Duration of amenorrhea after menopause (years)</td>
</tr>
<tr>
<td>Calcium intake volume (mg/day)</td>
</tr>
<tr>
<td>History of regular swimming (years)</td>
</tr>
<tr>
<td>Duration of swimming (hours/time)</td>
</tr>
<tr>
<td>Distance of swimming (m/time)</td>
</tr>
<tr>
<td>Frequency of swimming (times/week)</td>
</tr>
<tr>
<td>Daily activity level (duration of walking/day)</td>
</tr>
<tr>
<td>Grip strength (kg)</td>
</tr>
<tr>
<td>Flexibility (anterior flexion with legs extended) (cm)</td>
</tr>
<tr>
<td>Knee extension force (kg)</td>
</tr>
<tr>
<td>Leg muscle endurance (squatting) (times)</td>
</tr>
<tr>
<td>Abdominal muscle endurance (times)</td>
</tr>
<tr>
<td>Balance (one-leg balancing with open eyes) (seconds)</td>
</tr>
</tbody>
</table>

Mean±S.D., * : p<0.05

Twenty females, consisting of 10 who were taking a swimming course in a sports club (64.3±5.3 years) as the swimming group and 10 who were taking an art course (63.2±5.9 years) as the art group, were examined. The muscular endurance in the legs was significantly higher in the swimming group than the art group (p<0.05).
2. Swimming exercise program

The basic exercise program consisted of 4 weekly sessions with professional guidance. Session 1 was designed to build basic strength by swimming the freestyle and breaststroke laps. Session 2 was designed to practice starting and turning in the water and swimming the freestyle and backstroke laps. Session 3 was designed to concentrate on arm movements and swimming the freestyle and backstroke laps. Session 4 was designed to build overall physical strength around the individual medley (Table 2). The average duration of exercise per session was 1.3±0.3 hours, the average distance swum per session was 737.5±199.6 m, and the average number of sessions per week was 3.6±1.5 sessions.

3. Physical fitness measurement

According to the New Physical Fitness Test as established by the Ministry of Education\(^{15}\), the following 6 test were measured: grip strength (muscle strength), forward bending while sitting (flexibility), knee extension (knee joint extension), standing on one leg with the eyes open (balance), sit-ups (abdominal muscle endurance), and squats (leg muscle endurance).

1) Grip strength: Grip strength was measured using the DN-100 hand dynamometer (Yagami, Inc.). With legs comfortably apart and arms positioned along the trunk in a standing position, subjects were instructed to hold the hand dynamometer laterally so as to prevent its pointer from touching the body, and grip strength was alternately measured twice each for the left and right hands. The mean of the maximum values was recorded as grip strength (kg).

2) Flexibility (anterior flexion with legs extended): Flexibility was measured using the WLT-90 measurement device for long sitting anterior flexion (Yagami, Inc.). Subjects assumed a long sitting position with the palms of both hands placed on a table shoulder width apart and slowly performed anterior

<table>
<thead>
<tr>
<th>Practice</th>
<th>Training category</th>
<th>Form of training</th>
<th>Distance (m)</th>
<th>Stroke rates (sec)</th>
<th>Number of times</th>
<th>Number of sets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practice1</td>
<td>Warm-up</td>
<td>12.5m swim + 12.5m walk</td>
<td>25</td>
<td>90</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Kick</td>
<td>Back crawl stroke, Breaststroke, Free style; Glide kick</td>
<td>25</td>
<td>80 (rest 60)</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Swim</td>
<td>Free style One hand</td>
<td>25</td>
<td>80</td>
<td>4</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Swim</td>
<td>Free style Catch up</td>
<td>25</td>
<td>70</td>
<td>4</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Swim</td>
<td>Back crawl One hand</td>
<td>25</td>
<td>90</td>
<td>4</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Swim</td>
<td>Back crawl stroke</td>
<td>25</td>
<td>80</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Kick</td>
<td>Breaststroke</td>
<td>25</td>
<td>90</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Kick</td>
<td>Breaststroke Straight Kick</td>
<td>25</td>
<td>90</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Swim</td>
<td>Breaststroke</td>
<td>25</td>
<td>80</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Practice2</td>
<td>Warm-up</td>
<td>12.5m swim + 12.5m walk</td>
<td>25</td>
<td>90</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Kick Swim</td>
<td>Back crawl stroke, Breaststroke, Free style</td>
<td>25</td>
<td>90 (rest 60)</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Swim</td>
<td>Free style (Start at the center, practice of the turn)</td>
<td>25</td>
<td>75</td>
<td>6</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Swim</td>
<td>Back crawl stroke, Breaststroke (Start at the center, practice of the turn)</td>
<td>25</td>
<td>80</td>
<td>6</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Swim</td>
<td>Free style Other than Free style at 3imes</td>
<td>50</td>
<td>120</td>
<td>4</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Swim</td>
<td>Back crawl stroke, Breaststroke, Free style</td>
<td>25</td>
<td>90</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Practice3</td>
<td>Warm-up</td>
<td>12.5m swim + 12.5m walk</td>
<td>25</td>
<td>90</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Kick Swim</td>
<td>Back crawl stroke, Breaststroke, Free style</td>
<td>25</td>
<td>100</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Swim</td>
<td>Free style Catch up</td>
<td>25</td>
<td>70</td>
<td>4</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Swim</td>
<td>Free style One hand (Right 2times, Left 2times)</td>
<td>25</td>
<td>90</td>
<td>4</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Swim</td>
<td>Free style Scooter (Right 2times, Left 2times)</td>
<td>25</td>
<td>90</td>
<td>4</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Swim</td>
<td>Back crawl stroke (2times), Breaststroke (2times)</td>
<td>25</td>
<td>Bas, Br, 100</td>
<td>4</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Swim</td>
<td>Free style Finger tip</td>
<td>25</td>
<td>60</td>
<td>4</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Swim</td>
<td>Free long stroke (2times), Free short stroke (2times)</td>
<td>25</td>
<td>long 80, short 100</td>
<td>4</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Practice4</td>
<td>Warm-up</td>
<td>on 50°</td>
<td>25</td>
<td>50</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Choice</td>
<td>on 1.30°</td>
<td>50</td>
<td>90</td>
<td>4</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Swim</td>
<td>Individual medley</td>
<td>25</td>
<td>100</td>
<td>4</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Swim</td>
<td>Dolphin breaststroke</td>
<td>25</td>
<td>90</td>
<td>4</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Swim</td>
<td>Free style catch up</td>
<td>25</td>
<td>70</td>
<td>4</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Swim</td>
<td>Individual medley (One hand by one hand)</td>
<td>25</td>
<td>100</td>
<td>8</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Swim</td>
<td>Individual medley</td>
<td>25</td>
<td>90</td>
<td>4</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

The major programs consisted of 4 swimming styles to improve basic physical strength.
flexion. The maximum value of anterior flexion was recorded as the indicator of flexibility.

3) Knee extension force: Knee extension force was measured using the GT-160 hydromusculator (OG Giken Co., Ltd.). Subjects were positioned in a seated posture with the upper body fixed with a seat belt in a reclining position, and measurements were conducted with the legs fixed at a knee flexion of 70°. For measurement results, the maximum isometric muscular strength for a 10-s knee extension was measured and converted into the maximum muscular strength for the quadriceps femoris to obtain the knee extension force (kg).

4) Balance (one-leg balancing with open eyes): Balance was measured with the subjects assuming a standing posture barefoot with both hands on their hips. With the non-dominant leg lifted vertically from the floor, the length of time (maximum, 120 s) the subjects were able to stand on one leg was recorded as the indicator of balance.

5) Abdominal muscle endurance: Abdominal muscle endurance was measured using sit-ups. However, due to consideration of lower back pain, neck pain, and other disorders, subjects were positioned on a table (height, 45 cm; length, 55 cm; slope, 30°) with their backs fixed on the table and asked to assume a supine position with a knee flexion of 90°; measurements were conducted with the arms extended forward. The number of repetitions of a repetitive motion of raising the upper body 90° from the supine position in 60 s was recorded as the abdominal muscle endurance.

6) Leg muscle endurance (squats): Leg muscle endurance was measured using squat exercises. Subjects placed their legs shoulder-width apart after having assumed a standing position with the arms extended forward. A bending exercise involving the bending of the legs until the femur becomes parallel to the floor was performed in accordance with a metronome rhythm of once per second. The number of repetitions completed at the point at which the exercise could no longer be performed in accordance with the rhythm was recorded.

4. Calcium intake survey and daily living activities survey
Calcium intake was ascertained through a questionnaire survey consisting of 35 questions: 5 related to milk and milk products, 5 to soybeans and soybean products, 10 to fish, 11 to vegetables, and 4 to seaweeds. Mean daily calcium intake was calculated based on the diet during a 3-day period from 3 days prior to measurement to the day before measurement.

In addition, a questionnaire survey was conducted regarding the following test: age at onset of menopause, duration of amenorrhea after menopause, and daily activity level (duration of walking/day).

5. Bone mineral density
The BMD of the proximal femur and the whole body was measured by dual energy X-ray absorptiometry (DXA: QDR-2000, Hologic, USA) with each subject in the recumbent position. To measure the BMD of the proximal femur, X-rays were taken with the femur in an internally rotated position and perpendicular to the direction of irradiation. Because an X-ray of the whole body was taken from the front surface, the BMD of the whole body as well as the proximal femur was measured. Bone mineral content (BMC, g) was divided by area (cm²) to calculate bone mineral density (BMD, g/cm²).

In the proximal femur, BMD was measured at the total proximal femur, neck, greater trochanter, and Ward’s triangle (Fig. 1).

6. Biochemical test (measurement of bone metabolism markers)
Of the subjects in whom BMD was measured, blood and urine samples were collected from 9 consenting subjects: 4 women in the swimming group and 5 in the art group. These samples were collected on the final day of the fourth week of training sessions, which consisted
of practice sessions 1 through 4 of the swimming program each week. For both swimming and art groups, blood and urine samples were collected at 9 a.m. while the subjects were at rest. In addition, for the swimming group, blood and urine samples were collected 90 minutes after the end of swimming exercise (850 m of swimming in 90 minutes).

With regards to blood collection, 2.5 cc of blood was collected from the intermediate cubital vein. After separating the serum, serum calcium level (sCa) was measured by the OCPC method\(^6\).

Concerning urine collection, first urine in the morning was sampled. Urinary creatinine level (uCr) was measured by the POD method\(^27\), and urinary calcium level (uCa) was measured by the OCPC method\(^6\). In addition, urinary calcium level (uCa) was corrected by uCr to standardize the effects of individual differences in muscle mass due to body shape (uCa/uCr). Urinary deoxypyridinoline level (Dpyr) was measured by the EIA method\(^24\).

7. Statistical analysis

The means and standard deviations were calculated for BMD, biochemical tests (bone metabolism markers), physical characteristics, physical fitness measurement, and calcium intake. The obtained data were statistically analyzed using Macintosh Statview software, version 5.0, and significance tests were performed. For statistical analysis, a significance level of \(_{\leq} 5\%\) was considered statistically significant.

For comparisons of BMD, physical characteristics, physical fitness measurement, and calcium intake between the swimming and art groups, significance tests were performed using an unpaired two-group t-test. In addition, Pearson correlation coefficients were calculated between BMD, physical characteristics, and physical fitness measurement for both the swimming and art groups.

For the results of bone metabolism marker measurements, no statistical analysis was performed in consideration of the fact that the number of subjects in the swimming group was rather small. Instead, due to the importance of changes among individuals, changes in Dpyr at rest and after exercise were determined for each individual in the swimming group.
III. Results

1. Physical fitness, body weight, and calcium intake (Table 1)

Regarding physical fitness, leg muscle endurance was significantly lower in the art group than in the swimming group (28.6±7.9 times/min vs. 44.1±8.5 times/min, p<0.05). No significant intergroup difference was observed for balance, grip strength, flexibility, knee extension, or abdominal muscle endurance.

Leg muscle endurance measurement was discontinued in two swimming group subjects and one art group subject due to pain in the knee, hamstrings, or hip.

Calcium intake was higher in the art group than in the swimming group (553.3±301.0 mg/day vs. 476.4±189.7 mg/day, not significant).

2. Bone mineral density measurement

Table 3 shows the BMD measurements for the swimming and art groups. The whole body BMD was greater for the swimming group than for the art group (0.960±0.075 g/cm² vs. 0.929±0.079 g/cm²); there was no significant intergroup difference (not significant). This tendency was also evident for the proximal femur (swimming group, 0.745±0.104 g/cm²; art group, 0.718±0.122 g/cm²) and Ward’s triangle (swimming group, 0.447±0.088 g/cm²; art group, 0.441±0.138 g/cm²).

One art group member reported pain in the hip joint during BMD measurement of the proximal femur, so this subject was instructed to turn inward so that the femur was positioned vertical to the direction of X-ray irradiation. Therefore, because measurement reproducibility was slightly lower for this region, the BMD of the proximal femur for this patient was excluded and data from the other 9 art group subjects were used for analysis.

Figures 2 and 3 show the relationship between body weight and BMD at Ward’s triangle in terms of scatter diagrams for the swimming and art groups. For the swimming group, the tendency was that the heavier the body weight, the higher BMD, but no significant positive correlation was confirmed. In the same manner, for the art group, Figure 3 appears to show a slightly negative correlation between body weight and BMD at Ward’s triangle, but standard deviation was larger.

3. Results of biochemical testing (bone metabolism markers)

Table 4 shows the results of biochemical testing for the swimming and art groups. The serum calcium level (sCa) at rest for the swimming and art groups was

<table>
<thead>
<tr>
<th>Skeletal site</th>
<th>Swimming group n=10</th>
<th>Art group n=10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neck</td>
<td>0.665±0.088</td>
<td>0.636±0.090</td>
</tr>
<tr>
<td>Trochanters</td>
<td>0.545±0.078</td>
<td>0.543±0.098</td>
</tr>
<tr>
<td>Ward’s</td>
<td>0.447±0.088</td>
<td>0.441±0.138</td>
</tr>
<tr>
<td>(n=9)</td>
<td></td>
<td>(n=9)</td>
</tr>
<tr>
<td>Proximal region</td>
<td>0.745±0.104</td>
<td>0.718±0.122</td>
</tr>
<tr>
<td>Whole body</td>
<td>0.960±0.075</td>
<td>0.929±0.079</td>
</tr>
</tbody>
</table>

Mean ± S.D., No significant difference between two groups.

The bone mineral density in the whole body was slightly higher in the swimming group than the art group. The bone mineral density in Ward’s region of the proximal femur and the proximal femur region was slightly higher in the swimming group than the art group.
There was no correlation between the bone mineral density in Ward’s region of the proximal femur and body weight in the swimming group. In the swimming group, the bone mineral density in Ward’s region of the proximal femur, the tendency for bone mineral density to be maintained for the swimming group have no relation of body weight.

Standard deviation was large although it seemed to the bone mineral density in the Ward’s of the proximal femur on the art group that there was a little negative correlation.

10.0±0.4 and 9.9±0.2 mg/dl, respectively. For the swimming group, sCa did not change significantly after exercise (10.0±0.3 mg/dl). The uCa/uCr ratio at rest for the art group was 0.3±0.1 mg/mg, while those at rest and after exercise for the swimming group were 0.2±0.1 mg/mg and 0.2±0.1 mg/mg, respectively.

Urinary deoxypyridinoline (Dpyr) at rest was 10.5±3.0 nmol/mmol uCr for the swimming group and 8.9±
The swimming group had a slightly higher mean level than the art group, and all subjects in the swimming group tended to have a reduced Dpyr level after exercise. The magnitude of decreases in Dpyr after swimming exercise was greater for subjects with high levels at rest (Fig. 4).

### IV. Discussion

In water, the body is subjected to the mechanical properties of water, such as water temperature, water pressure, buoyancy, and viscosity. The body thus reacts differently in water than on land. Buoyancy lowers stress on the knee and hip due to landing associated with walking and is effective in supporting and assisting movements of damaged knees and ankles. Moreover, movement in the water is subjected to pressure resistance, wave resistance, and friction resistance. Fins and gloves can be used to increase pressure resistance to movement; increasing not only energy consumption, but also muscle and bone stimulation.

Studies have previously been conducted to ascertain the effects of swimming exercise on bone in postmenopausal women. In these studies, women who were at least 3 years postmenopausal served as subjects. The degree of decrease in BMD was relatively gradual in these subjects and changes in BMD due to exercise...
were likely to be revealed. At 7-9 years after meno-
pause, the degree of decrease in BMD remains gradu-
al \cite{21}, and when compared to immediately after meno-
pause or in old age, the effects of exercise are more
likely to appear. This age group is not faced with rapid
BMD decreases or greater risk of fracture. The present
subjects were postmenopausal women over 63 years
old. At 13 years after menopause, BMD again markedly
decreases and prevention of BMD loss at the proximal
femur is important during this period. The reason
for this acceleration in BMD is that age-related bone
atrophy is marked in cancellous bone and therefore
particularly affects Ward's triangle, an area of the
proximal femur predominantly comprising cancellous
bone. While aging is an important factor in bone weak-
ening, other factors such as decreased calcium absorp-
tion by the upper small intestinal mucosa, decreased
vitamin D activity in the liver and kidney, and de-
creased gastric acid secretion are also involved. Al-
though no significant intergroup differences were ob-
served, calcium intake was greater in the art group
than the swimming group, who displayed an intake of
250 mg/day less than the recommended daily calcium
requirement for elderly Japanese (850 mg/day) \cite{22}.
While diurnal variations in calcium intake exist, mean
monthly intake is 7500 mg/month. Although increased
calcium intake is essential for preventing osteoporosis,
whether increased calcium intake offers an effective
measure for increasing BMD remains uncertain.

The target of osteoporosis therapy has changed from
pharmacotherapy to pain alleviation, BMD elevation,
and most recently to fracture prevention. Regarding
the effects of exercise on bone, a previous cross-section-
al study of BMD among young sports players revealed
that BMD was higher among basketball and volleyball
players \cite{8}. Since lumbar and femoral neck BMDs re-
portedly increase more among middle-aged individuals
who regularly engage in resistance exercises twice
weekly than among those who regularly engage in
walking \cite{19}, types of exercise that exert greater effects
on muscle and bone are thought to be more effective
with regard to BMD.

In a study on BMD in middle-aged women who en-
gaged in swimming exercise comprising swimming
freestyle for 1000 m and breaststroke, backstroke, and
butterfly for 150 m each, 1.5 times a week for 2 years \cite{11},
the exercise did not inhibit age-related reductions in
lumbar BMD, but was thought to have either main-
tained or increased BMD of the proximal femur. The
effects of exercise on BMD may thus be localized. The
absence of significant differences in BMD between
swimming and art groups may have been due to issues
such as the fact that subjects in the present study
were relatively old and marked reductions in BMD oc-
cur $\geq$13 years after menopause, in addition to vari-
ations in stress exerted on bone due to differences in ex-
ercise intensity and training contents. However,
consideration of the age and fitness of subjects and
bone weakening is necessary in the implementation of
postmenopausal exercise.

Basically, the objective of osteoporosis therapy is to
maintain BMD rather than to achieve increases. More-
over, because BMD decreases 2-3% within the first 3
years of menopause \cite{22}, resistance exercise with impact
force \cite{16} is being recommended as an exercise modality
for when decrease in BMD is gradual. However, such
activity can also put considerable stress on muscles
and tendons and can potentially lead to arthritis. Vari-
ous attempts have been made to maintain and improve
physical fitness in the elderly. While the necessity for
developing exercise programs that take into account
physical fitness levels and individual differences has
been recognized, from the perspective of maintaining
quality of life or preventing low BMD, exercise pro-
grams involving impact force risk inducing marked
physical damage, such as knee osteoarthritis or femo-
ral neck fracture. Such conditions can seriously impair
activities of daily living. The risk of fracture is high
due to bone weakening caused by falling or aging, de-
creased muscle strength of the gluteus maximus, thin-
ning of the subcutaneous tissue in the gluteal region,
decreased ratio of cancellous bone, femoral cross-sec-
tional shape and decreased BMD of the neck, trochanter and Ward’s triangle in the proximal femur.

Leg muscle endurance was significantly lower for the art group than for the swimming group, and the average percent body fat of 31% and BMI of 24 kg/m² in the art group suggest the importance of strengthening the trunk, including the antigravity muscles, in individuals with low-intensity activity in daily life. Moreover, the BMD of Ward’s triangle for the swimming group was 0.447±0.088 g/cm² and the range of BMD was 0.335-0.598 g/cm². In that group, while differences in body weight were large, standard deviation for BMD was smaller than in the art group, and BMD was maintained irrespective of body weight. In addition, although a correlation between body weight and entire body BMD was observed in the art group (r=0.76, p<0.05), no relationship was observed in the swimming group (n.s.). Moreover, no strong correlations were observed between the BMD of Ward’s triangle and body weight in either group. Mechanical stress is thus thought to play an important role in maintaining BMD of the proximal femur.

For the art group, BMD of Ward’s triangle was 0.441±0.138 g/cm² and these subjects tended to be slightly heavier than those in the swimming group. Average BMD of Ward’s triangle was broadly comparable to the swimming group, although the standard deviation was slightly larger. The reason for this large standard deviation was that BMD of the proximal femur was measured at the neck, Ward’s triangle and trochanter, and since Ward’s triangle consists predominantly of cancellous bone and has the lowest BMD, slight differences in this area exert a profound effect on BMD.

Compared to cortical bone, cancellous bone has a larger bone surface area, faster bone turnover, and earlier and more marked reductions in BMD due to aging and menopause. In the proximal region of the femur, cancellous bone is abundant and a close correlation exists between BMD and fracture. As BMD decreases, fracture rate decreases. The present results suggest that swimming exercise suppresses bone resorption at the trabecular surface of the cancellous bone-rich proximal femur. In other words, kicking the legs up and down to propel the body forward works muscles in the quadriceps femoris and posterior aspect of the femur, and the resulting stress due to water resistance appears to suppress bone resorption in cancellous bone-rich areas of the proximal femur. Leg muscle strength and endurance due to repeated kicking movements generates mechanical stress and affects BMD in the femur.

In addition, the femoral neck region is an area of the proximal femur comprising predominantly cortical bone, and the rate of menopause-related decreases in BMD is thought to differ from that of Ward’s triangle, which consists predominantly of cancellous bone. Implementation of measures to prevent BMD reduction that consider differences in bone composition between Ward’s triangle and the femoral neck of the proximal femur is thus necessary. This need is supported by the fact that femoral neck BMD did not differ significantly between swimming and art groups, but tended to be higher in the swimming group and the difference in femoral neck BMD was greater than that in the BMD of Ward’s triangle. These results suggest that kicking movements in swimming exercise may be effective for the femoral neck region. In addition, leg muscle endurance itself was greater in the swimming group than in the art group, while subjects in the art group with a greater body weight displayed a lower BMD at Ward’s triangle and a higher body fat percentage compared to those with a lower body weight. Although these results may have been influenced by the lack of regular daily exercise, the repetition of kicking movements in swimming exercise is considered likely to have affected leg muscle strength and muscle endurance in the swimming group. Furthermore, although subjects in the art group had no history of exercise habits in the past, some subjects had a relatively high BMD. Considering these individual differences in BMD, physiological fac-
tors such as BMD were thought to be strongly influenced by environmental factors such as lifestyle habits, in addition to age-related changes in muscle strength. Notably, individuals with no exercise habits after menopause are not necessarily at a high risk for osteoporosis. Although continuous swimming exercise was considered effective for maintaining leg muscle endurance and preventing BMD loss in Ward's triangle, an area of the proximal femur that predominantly consists of cancellous bone, no clear findings could be obtained based on the present study alone.

However, according to the Japanese Society for Bone and Mineral Research, the femoral neck region is a common site for fractures caused by age-related reductions in BMD and falls that result in bedridden status. According to the diagnostic criteria for osteoporosis established by the Japanese Society for Bone and Mineral Research, BMD of the femoral neck decreases by about 1% each year after menopause. Hence, for subjects in the present study, BMD of the femoral neck for the art and swimming groups in 10 years should be around 0.576 and 0.601 g/cm², respectively. For the art group, BMD of the femoral neck would fall within grade I bone atrophy and these women will thus be at greater risk of osteoporosis. However, the present study was unable to sufficiently verify that swimming exercises that use water resistance or buoyancy are effective for maintaining BMD in the proximal femur. We were thus unable to obtain sufficient data for reinvestigating calcium absorption, lifestyle habits, and swimming programs or for investigating whether factors influencing the maintenance of BMD are internal or external factors. However, future studies must closely investigate these factors in addition to the effects of exercise.

BMD and bone metabolism markers are useful parameters in the assessment of exercise and activity. Bone resorption markers reflect the systemic homeostasis of blood calcium concentration and the metabolic state of bone matrix degradation products. In addition, values for bone metabolism markers are affected by biological variation, specifically diurnal variation. Bone turnover generally reflects diurnal variations in bone metabolism, increasing at night and peaking from late at night to early morning, and decreasing during the daytime. Although the degree of this variation differs depending on marker type, differences of 50% have been reported for urinary NTx, a bone resorption marker. These diurnal variations in bone resorption markers also occur for urinary Dpyr. Due to these diurnal variations, the recommendation has been made that bone metabolism markers be measured at a fixed time period of the day, particularly using the second morning urine. Bone metabolism markers at rest and after exercise were thus investigated for the swimming group. The present study on water exercise showed that swimming did not markedly affect levels of serum calcium after menopause, but did increase urinary calcium after exercise. With regard to transient changes in bone metabolism caused by exercise, aerobic whole body exercises such as walking, jogging, and swimming can be expected to result in systemic effects due to changes in the circulatory system, such as increased oxygen uptake and improved blood flow. The early effects of whole body exercise on bone may thus include promotion of bone resorption, subsequent facilitation of bone formation, and activation of bone metabolism. This suggests that swimming activates cytokine and hormone functions in bone, but whether water exercise tips systemic bone metabolism toward bone formation remains inconclusive. This results from differences in sex and age and the fact that, during exercise, stimulation is applied to areas at which force was applied. In terms of endocrinological reactions, parathyroid hormone (PTH) secretion was induced. In bone, PTH facilitates osteoclast actions and increases levels of deoxypyridinoline, a bone resorption marker. In areas with bone resorption, osteoblasts secrete stromal substances. Hence, after exercise, bone resorption occurs prior to bone formation, causing many decomposition products of collagen links to be excreted in urine.

In the present study, statistical analysis was not
performed for biochemical tests due to the small number of subjects. As a result, changes in Dpyr could not be confirmed. However, measurement results for subjects in both swimming and art groups were relatively high compared to the mean Dpyr level observed among Japanese women according to the guidelines for the use of biochemical markers of bone turnover in osteoporosis of 2.8-7.6 nmol/mmol Cr. In addition, the swimming group showed a slightly higher mean level of Dpyr than the art group, and all subjects in the swimming group tended to have reduced levels after exercise. The magnitude of decreases in Dpyr after swimming exercise was greater for subjects with high levels at rest. Although changes in Dpyr in the swimming group do not directly imply that swimming exercise acts to suppress bone resorption, investigation of whether the effects on urinary calcium excretion lead to increased differences in BMD between swimming and art groups with advancing age may be necessary. Such an investigation may be of great interest, considering the fact that while some subjects in each group had uCa/uCr ratios at rest that were higher than the upper limit of the reference interval (0.2 mg/mg), the mean for the swimming group was similar to the reference interval both at rest and after exercise, whereas that for the art group at rest exceeded the upper limit by +0.1 mg/mg, indicating increased urinary calcium excretion.

Furthermore, the present study used early morning spot urine sampling (single voided) in consideration of clinical convenience and the characteristics of circadian variations in Dpyr. For more detailed elucidation of the effects of swimming exercise, longitudinal studies involving measurements from each subject at the same time period in the morning on different sampling days are necessary. Future issues regarding detailed investigation of the effects of swimming exercise on bone metabolism include consideration of long-term longitudinal studies that consider circadian variations in a greater number of subjects, in addition to biochemical analysis of relationships to body fat and the decomposition products of the components of cancellous and cortical bone. Moreover, when conducting longitudinal studies on changes in Dpyr with respect to the effects of swimming exercise, analysis of whether long-term increases in BMD can be most accurately predicted by age at menopause or changes in Dpyr from baseline values at the start of exercise is expected to broaden the application of swimming exercise as an exercise method for preventing osteoporosis.

We hope that the findings of the present cross-sectional study will contribute to field research aimed at maintaining BMD in postmenopausal women, as well as the establishment of exercise therapy for preventing osteoporosis.

As the present study was cross-sectional, regular swimming exercise following menopause cannot be concluded to directly suppress bone resorption. However, these findings indicate that swimming exercise affects the BMD of the proximal femur and levels of urinary Dpyr, a bone resorption marker. In the future, for the elderly to live healthfully with vigor and without requiring nursing care, swimming exercise may aid in the maintenance and improvement of motor functions. However, ascertaining how swimming exercise can be incorporated into activities of daily living will be important.

References


