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RESEARCH ARTICLE

Influence of Aquatic and Weight-Bearing Exercises on Quantitative Ultrasound Variables in Postmenopausal Women

ABSTRACT

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Objective: In this prospective, controlled study, the effects of weight bearing and aquatic exercises on the calcaneal ultrasonic scores of postmenopausal sedentary women was investigated.

Design: A total of 62 postmenopausal sedentary women (mean age, 54.1 ± 7 yrs) with broadband ultrasound attenuation (BUA) T-score variables less than −1 were admitted to Atatürk Balneotherapy and Rehabilitation Center and randomized into aquatic exercise (n = 21), weight-bearing exercise (n = 21), and control (n = 20) groups. The subjects were told to perform the aerobic exercises according to the Borg scale. Quantitative ultrasound variables, BUA, and speed of ultrasound were evaluated after the 6-mo training study.

Results: Calcaneal BUA increased in aquatic exercise and weight-bearing exercise groups by 3.1% and 4.2% ($P < 0.05$, $P < 0.05$) respectively. There was a decrease in BUA by 1.3% in the control group ($P > 0.05$). Speed of ultrasound did not change in the aquatic exercise, weight-bearing exercise, or the control groups. There were no statistically significant differences between the exercise groups for BUA and speed of ultrasound. The percentage changes in the aquatic exercise and weight-bearing exercise groups were statistically significant when compared with the control group for BUA ($P < 0.01$, $P < 0.01$) and speed of ultrasound ($P < 0.05$, $P < 0.05$).

Conclusions: Although weight-bearing physical activity is known to be superior to non–weight-bearing activity to increase the bone mass, our present evidence shows that aquatic and weight-bearing exercises both can increase calcaneal BUA.

Key Words: Aquatic, Exercise, Osteoporosis, Quantitative Ultrasound, Weight Bearing

Osteoporosis due to estrogen deficiency in postmenopausal women is a significant health problem with a prevalence of 30–50%, and the prevalence of vertebral and hip fracture is rising as a consequence.[1] In 2010, it is estimated that there will be 32 million postmenopausal women in United States, and by the end of this decade some 5–10 million women will be diagnosed as having osteoporosis by clinical observations.[2] Fractures of the spine and hip are known to be the major determinants affecting quality of life in elderly people.[3] In addition, the annual expenditure of osteoporotic fractures is substantial and will increase with the age of the population.[1,3]

The role of regular exercise in the maintenance of good health is receiving more attention currently than in the past. Exercise may exert a very local effect on the highly stressed parts of the skeleton or make a systemic effect, mediated by increased growth hormone (GH) secretion, which in turn increases the production of insulin-like growth factor.[4,5] The mechanical strain theory predicts that a load-engendered strain will stimulate an osteogenic response until the bone becomes strong enough to bear that load with subthreshold strain. Exercise is considered to have a unique influence on bone, and the orientation of trabeculae is always reflective of the physical stresses and strains of bone. So, not only bone volume but also the distribution of the supporting bony struts within the bone volume are influenced by exercise.[5]

A recent meta-analysis revealed that the effects of exercise on bone mass does not support for increasing or maintaining lumbar spine or femoral neck bone mineral density (BMD) in premenopausal women who do resistance exercises.[6] However, some longitudinal, case-controlled studies support the notion that exercise increases the bone mass. In addition, weight-loaded exercises and regimens of vigorous aerobic and strength training have been correlated with bone density.[7–11] Smith et al.[8] investigated the efficacy of 4 yrs of weight-bearing exercise in deterring bone loss. A total of 80 exercise subjects exercised three times a week, 45 mins per session, and it was found that bone loss rates in the exercise subjects were lower than in the control subjects. Although regular physical activity has an influence on bone mass, the level of regular physical activity described in some of the studies is not applicable and standardized for everyone.[7,12,13] Chow et al.[7] offered aerobic and strengthening exercises three times a week with free weights, Kudlacek et al.[12] preferred a senior dancing program for 3.2 hrs/wk, and Tsukahara et al.[13] showed that a water exercise program more than once a week had anabolic effects on bone. However, in terms of identifying programs that offer public health benefits, it is important to determine whether adherence to such programs is adequate, in addition to assessing whether interventions are effective. Resistance programs that are feasible for elderly persons in research trials may not be practical in the long term because of the unknown cardiovascular compliance of the subjects.[14] The fact that subjects enjoy the group activities and aerobic compliance of the middle-aged or elderly people with unknown cardiovascular tolerance determine the adherence to the programs.

Research into the effects of exercise interventions on the trabecular thickness and orientation of the weight-bearing bones make quantitative ultrasound (QUS) a current issue. QUS measures the combination of elasticity, structure of trabeculae, and density, which will provide more sensitive information about fracture risk than techniques that reflect bone density alone.[15] QUS in vivo was first proposed in the evaluation of bone mass by Langton et al.[16] in 1984. It is an alternative method for noninvasive assessment of skeletal status. The technology is easy to perform, free of ionizing radiation, and portable, in contrast to dual-energy x-ray absorptiometry devices, which are relatively expensive, use ionizing radiation, and require patients to be referred to hospital-based activities.[17,18] The calcaneus has been most frequently used as a site for measurement, with promising clinical results. In two prospective studies, it was found that the risk of hip fracture was associated with low ultrasound values and that ultrasound variables predicted hip fracture in the elderly and BMD assessed by dual-energy x-ray absorptiometry.[19,20] In the study of Chappard et al.,[17] the correlation coefficients between calcaneal broadband ultrasound attenuation (BUA) and calcaneal BMD (range, 0.81–0.90) were higher than those found in previous in vivo studies. Initial clinical reports have suggested that calcaneal ultrasound does predict vertebral fracture.[21]

Because cancellous bone turns over much more rapidly than does cortical bone, functional adaptations are likely to occur first in this more metabolically active tissue.[22] Alternatively, the prediction of fracture risk is enhanced by measuring an additional trabecular-rich site (i.e., the calcaneus). As in our study, the os calcis is the most widely used bone for ultrasonic measurement for several reasons: (1) it has two nearly plane-parallel sides, (2) it is surrounded only by a thin layer of soft tissue, (3) it consists mainly of trabecular bone, and (4) it is also a weight-bearing bone.[23]

In the present study, we attempted to determine which of the moderately increased physical activities, aquatic or weight-bearing exercises, is more beneficial for bone in sedentary postmenopausal women.

MATERIALS AND METHODS

Subjects

A prospective, controlled, longitudinal study was carried out in which the therapeutic efficacy of aquatic and weight-bearing exercises was investigated in postmenopausal sedentary women. A total of 71 postmenopausal sedentary women from the outpatients of Atatürk Balneotherapy and Rehabilitation Center were elected according to their physical activity level and calcaneal BUA (QUS) T scores as inclusion criteria. All subjects who met the study criteria were informed of the nature of the study, and a written consent was obtained. The term sedentary was functionally defined as <1.5 km of walking or <4 hrs of standing a day, and activity questionnaires were used to confirm that all subjects were sedentary before enrollment in the protocol.[24] Seventy-one postmenopausal sedentary women with BUA T scores of −1 and less were randomized into three groups (aquatic exercise, weight-bearing exercise, and control groups) and enrolled in a 6-mo training study. The mean age of the subjects was 54.1 ± 7 yrs (range, 48–61 yrs). Physical examinations and routine laboratory analysis were performed to ensure that no preexisting condition would confound results. The subjects were free of preexisting cardiovascular, metabolic, and endocrine disorders. Thoracic and lumbar radiographs of the subjects were examined to define the previous compression fractures as an exclusion criteria, and it was found that none of the subjects had fractures. The groups were compared with mean age, years postmenopause, body mass index (BMI), cigarette smoking, urinary calcium, serum calcium, serum alkaline phosphatase, BUA, speed of ultrasound (SOS), and BUA T scores, and they were found to be homogeneous for all these variables at the beginning of the study (Table 1). The subjects were instructed not to take medications affecting calcium or bone homeostasis for 6 mos previous to or for the duration of the study. Average daily intake of calcium and relevant nutrients were standardized for every subject by the nutritionists. All the subjects took 1000 mg of elemental calcium a day.

The subjects were randomized into three groups called aquatic exercise ($n = 24$), the weight-bearing exercise ($n = 24$), and the control groups ($n = 23$). Exercisers were specifically instructed not to participate in any exercise class or organized activity outside of the study's exercise sessions. The 23 control subjects were instructed to maintain their sedentary lifestyle for the duration.

QUS

Measurements were performed with an osteometer DTU-one ultrasound instrument (osteometer medi Tech A/S, Denmark) on the nondominant heel (usually left) after replacing the heel in the container of demineralized water with the help of a transducer in lateral projection. All scans and analyses were performed by a single technician who was blinded to subjects' treatment. The water in the DTU-one instrument was warmed to 30°C before the measurement. A region of interest was determined with a half-automatic system (it can be directed manually by the user when necessity arises) to compare the results and to repeat the measurements at the same point. A region of interest is defined as the area in calcaneus where the attenuation is lowest and the amplitude is highest.[18] In the screening of the heel with the DTU-one, a computer image was obtained for each position. The manufacturer's phantom was checked regularly, and there were not any changes in the

TABLE 1 Clinical and ultrasonic characteristics of the groups

	G1 (MV ± SD)	G2 (MV ± SD)	G3 (MV ± SD)	Significance[a]
Age, yrs	54.28 ± 6.08	54.88 ± 3.85	55.11 ± 5.32	NS
PMP, yrs	7.77 ± 3.46	6.44 ± 3	6.83 ± 3.47	NS
BMI, kg/m^2	28.94 ± 3.42	30.98 ± 3.93	29.44 ± 4.63	NS
BUA T score	−2.68 ± 1.37	−2.06 ± 1.51	−2.10 ± 1.15	NS
BUA, db/MHz	34.5 ± 8.82	37.3 ± 12.45	38.4 ± 9.12	NS
SOS, m/sec	1549.5 ± 15.32	1548.4 ± 13.89	1549.7 ± 15.21	NS
Smoking Patients	4	7	5	NS
ALP, units/liter	71.82 ± 102.02	173.41 ± 75.65	155.00 ± 119.84	NS
Urinary calcium, mmol/liter	159.88 ± 102.02	173.41 ± 75.65	155.00 ± 119.84	NS
Serum calcium, mmol/liter	2.39 ± 0.10	2.37 ± 0.09	2.24 ± 0.51	NS

G1, aquatic exercise group ($n = 21$); G2, weight-bearing exercise group ($n = 21$); G3, control group ($n = 20$); MV, mean value; PMP, postmenopausal period; BMI, body mass index; BUA, broadband ultrasound attenuation; SOS, speed of ultrasound; ALP, serum total alkaline phosphatase.

[a]Significance was determined at $P < 0.05$; There were no statistically significant differences between the groups for the variables of age, PMP, BMI, BUA, BUA T scores, number of smoking patients, serum total ALP, serum and 24-hr urinary calcium.

phantom results. A phantom attempts to emulate the in vivo measurement as much as possible in terms of geometry and acoustic properties. Presently, there are no universally accepted QUS phantoms, only "manufacturer specific" phantoms that are not anthropomorphic. This procedure would guarantee that the device's results reflect the biological or therapeutic reality and not a device malfunction.[25] The results were expressed as the SOS (m/sec) and BUA (dB/MHz). BUA and SOS are considered to be the indicator of calcaneal structure (mineral content) and elasticity respectively.[18]

BUA T Score

To be clinically useful, BUA results for individual patients must be related to similar values obtained from a healthy reference population. In calculation of T scores, the mean and standard deviation of the young age group (20–35 yrs) are used as the reference range, regardless of the age of the patients whose BUA is being interpreted[26,27]: BUA T score = (measured BUA − young adult mean BUA)/young adult standard deviation.

Physical Activity Scale

The level of physical activity was determined by a graded questionnaire that varied from sedentary to heavy vocational and avocational activity levels.[24] Physical activity was categorized as related to housework, job, and sports. These categories were each rated on a scale ranging from 0 to 6, and the total score used in the analysis was defined as the sum of the three components. Walking <1.5 km/day or standing <4 hrs/day constitutes the term sedentary, and it is categorized as 0–1 according to the scale.[27] Aquatic exercise and walking three times a week for 40 mins/day represent moderate physical activity in daily life.[13,24]

Blood Chemistry

Liver and renal function tests (serum transaminases, gamma glutamyl transpeptidase, uric acid, urea, creatinine), thyroid function tests (thyroid stimulating hormone, free T3 and T4, total T3 and T4), serum calcium, phosphate, total alkaline phosphatase, glucose, and levels of urea, creatinine, calcium, and phosphate in 24-hr urine samples were measured for each subject. Routine laboratory analyzers (Abbott Alcyon 300i, Advia Centaur) were used to exclude the presence of underlying metabolic diseases. Blood and urine samples were collected between 8:00 and 10:00 a.m. after a 12-hr fast.

Exercise Program

Intensity of the exercises in both of the groups was adjusted to a submaximal level (intensity, 10–13) according to the Borg scale, and subjects were instructed to perform the exercises between these levels.[28] The exercises were performed in groups with the guidance of a physiotherapist as an exercise instructor.

According to the exercise regimen,[7,13] the first-week aquatic exercisers did 5 mins of warming up (walking slowly in the water and breathing), 10 mins of aerobic exercise (walking fast, jumping, and swaying in the water), 5 mins of cooling down (walking slowly in the water and breathing), and 5 mins of stretching to iliopsoas, hamstrings, quadriceps, gastrocnemius, pectoral muscles, and dorsal extensors (outside the pool). In the second week, aerobic exercise was prolonged to 15 mins. The duration of aerobic exercise was gradually prolonged to 25 mins until the fourth week. In the fourth and following weeks, the total duration of the exercise in one session was 40 mins. The submaximal aerobic exercises were done three times a week. The therapeutic pool in which the aquatic exercises were performed was 4.15 m in width, 8.20 m in length, and 1.25 m in depth. The water in the exercise pool was 1.20 m deep, and the water temperature was 29–30°C. The blood pressures of the subjects were checked before and after the exercises by a sphygmomanometer. The exercise was stopped two times in every session, and the radial pulses of the subjects were measured by the help of a chronometer. The exercise regimen was the same (warming up, walking, jumping, swaying, cooling down, and stretching) for the weight-bearing exercise group, and they performed the exercises on a flat platform in the rehabilitation department. The subjects of the control group were instructed to maintain their sedentary lifestyle for the duration.

Borg Scale

Ratings of perceived exertion, according to the 6–20 scale as proposed by Borg,[28] is an index of subjective exercise tolerability. According to the exercise intensity scale, 6–7 is very easy, 8–9 is easy, 10–11 is moderate, 12–13 is quite hard, 14–15 is hard, 16–17 is very hard, 18–19 is very very hard, and 19–20 is maximum.

Functional Capacity

Because the subjects were middle-aged women of unknown cardiovascular fitness, an evaluation of effort tolerance needed to precede the inception of the exercise program. The systolic pressure usually increases during the exercise. A moderate rise of the diastolic blood pressure is acceptable, but this increase should not exceed 20 mm Hg. A decrease in systolic pressure, chest pain, or dyspnea indicates that the heart is stressed beyond its capacity, and the physical activity needs to be stopped if the subject develops chest pain, dizziness, or dyspnea.[29,30] The blood pressures of the subjects were checked before, during, and after the exercises by a sphygmomanometer, and the exercise was stopped if there was an unexpected effect. The heart rates during the exercise should not increase to more than 60–80% of maximum for each subject. Maximum heart rate is roughly calculated at 220 minus age.[29–32] For example, if the mean age of the subjects is 54, maximum heart rate = 220 − 54 = 166; 60% of maximum heart rate = 166 × 0.60 = 99.6 beats/min; 80% of maximum heart rate = 166 × 0.80 = 132 beats/min. Therefore, heart rates must be in the range of 100 and 132 for a 54-yr-old participant.

The exercise was stopped two times in one session, and the radial pulses and blood pressures were measured during the exercises. The mean value of the radial pulses was determined to be 110 ± 10 beats/min. The subjects with the radial pulses or blood pressures beyond the appropriate target rate were asked to rest and then rejoin the group to continue.

Statistical Analysis

The groups were compared with Kruskal-Wallis test to determine whether any differences existed among the initial mean values of the groups for age, postmenopausal period, BMI (kg/m^2), BUA scores (dB/MHz), SOS scores (m/sec), serum calcium (mmol/liter), serum alkaline phosphatase (units/liter), and urinary calcium (mmol/liter). There were no statistically significant differences between the groups, and the groups were determined to be homogeneous for the clinical, laboratory, and ultrasonic characteristics (Table 1). Wilcoxon's rank-sum test was used to determine the changes between baseline and follow-up in each group (Table 2). Finally, Kruskal-Wallis and Mann-Whitney *U* tests were used to put forth the differences among the groups and to indicate their statistical significance, respectively (Table 3). Because of the nonnormal distribution of the raw scores and the small sample sizes, a nonparametric test (Mann-Whitney *U*) was selected. Pearson's correlation analysis was used for the assessment of the relation among BMIs and BUA scores at baseline for each group. The level of significance for all tests was $P < 0.05$.

RESULTS

During the study period of 6 mos, nine subjects were excluded who started to use medication affecting calcium and bone homeostasis (two of them started to use hormone replacement therapy and three of them started to use bisphosphates) and who failed to complete the study regardless of reason (five of them quit the exercise groups). Therefore, the aquatic exercise group, the weight-bearing exercise group, and the control group continued with 21, 21, and 20 subjects, respectively.

The percentage of changes in the BUA variable for the aquatic exercise group, weight-bearing exercise group, and control group were 3.1%, 4.2%, and −1.3%, respectively (Table 3). The changes were found to be statistically significant for both of the exercise groups ($P < 0.05$, $P < 0.05$) but not for the control group ($P > 0.05$) (Table 2). The changes in SOS scores ($P > 0.05$, $P > 0.05$, $P > 0.05$) and BMIs ($P > 0.05$, $P > 0.05$, $P > 0.05$) were not statistically significant for the aquatic exercise, weight-bearing exercise, and the control groups (Table 2).

There were no statistically significant differences in the comparison of the aquatic exercise and

TABLE 2 Statistical significance of the changes in aquatic exercise, weight-bearing exercise, and the control groups for ultrasonic parameters and body mass indexes (BMI)

	Groups	Initial Values (MV ± SD)	6-mo Values (MV ± SD)	Significance[a]
BUA, dB/MHz	G1	34.5 ± 8.82	35.6 ± 11.21	$P < 0.05$
	G2	37.3 ± 12.45	38.9 ± 9.09	$P < 0.05$
	G3	38.4 ± 9.12	37.9 ± 8.96	NS
SOS, m/sec	G1	1549.5 ± 15.32	1555.4 ± 13.01	NS
	G2	1548.4 ± 13.89	1554.8 ± 9.09	NS
	G3	1549.7 ± 10.54	1549.1 ± 15.21	NS
BMI, kg/m^2	G1	28.94 ± 3.42	28.07 ± 4.57	NS
	G2	30.98 ± 3.93	28.91 ± 5.93	NS
	G3	29.44 ± 4.63	29.51 ± 1.96	NS

MV, mean value; BUA, broadband ultrasound attenuation; G1, aquatic exercise group ($n = 21$), G2, weight-bearing exercise group ($n = 21$), G3, control group ($n = 20$); SOS, speed of ultrasound.

[a]Significance was determined at $P < 0.05$; the changes were found to be statistically significant for BUA ($P < 0.05$, $P < 0.05$) but not for SOS ($P > 0.05$, $P > 0.05$) in the exercise groups; in the control group, the changes in BUA and SOS were not significant ($P > 0.05$, $P > 0.05$); BMIs in G1, G2, and G3 did not change significantly ($P > 0.05$, $P > 0.05$, $P > 0.05$) in the 6-mo period.

TABLE 3 Comparison of the groups by percentage of changes in broadband ultrasound attenuation (BUA) and speed of ultrasound (SOS)

	G1 (MV ± SD)	G2 (MV ± SD)	G3 (MV ± SD)	G1–G2	G1–G3	G2–G3
BUA, %	3.1 ± 0.59	4.2 ± 0.25	−1.3 ± 0.49	NS	$P < 0.01$	$P < 0.01$
SOS, %	0.4 ± 0.8	0.4 ± 0.3	−0.2 ± 0.5	NS	$P < 0.05$	$P < 0.05$

G1, aquatic exercise group ($n = 21$), G2, weight-bearing exercise group ($n = 21$), G3, control group ($n = 20$); MV, mean value.

Significance was determined at $P < 0.05$; there was no statistical significance in the comparison of G1 and G2 for the percentage of changes in BUA and SOS; the comparison of G1 and G3 and G2 and G3 indicated statistical significance for BUA ($P < 0.01$, $P < 0.01$) and SOS ($P < 0.05$, $P < 0.05$).

weight-bearing exercise groups for the percentage of changes in BUA and SOS mean values ($P > 0.05$, $P > 0.05$). The comparison of the aquatic and weight-bearing exercise groups and weight-bearing exercise and control groups indicated statistical significance for BUA ($P < 0.01$, $P < 0.01$) and SOS variables ($P < 0.05$, $P < 0.05$), respectively (Table 3).

There were no significant correlations among BMIs and BUA scores for the aquatic exercise group ($P > 0.05$, $r = 0.13$) and the weight-bearing exercise group ($P > 0.05$, $r = 0.03$). In the control group, there was a weak positive correlation ($P < 0.05$, $r = 0.27$) among the same variables.

DISCUSSION

In this longitudinal study, it was determined that a moderate increase of the regular physical activity, either as aquatic or weight-bearing exercise, is effective to increase calcaneal BUA by 3.1% and 4.2%, respectively, in sedentary postmenopausal women.

The influence of several factors on the precision of calcaneal BUA was investigated. Cross-sectional studies on age-related changes of QUS variables demonstrated substantial decreases during the period immediately after menopause but also in very elderly subjects. The changes were comparable with those observed using conventional radiographic, based-bone densitometry.[33,34] Considering the relatively small age-related changes, immersion time, water depth, water temperature, rotation about the long axis of the foot and dorsal-plantar translation in QUS measurements, it is essential that everything is done to optimize precision. Roux et al.[35] found an average short-term coefficient of variation of 1–4% in a study of region of interests of different sizes. They also compared imaging QUS with BMD and found an r value of 0.88 for site-specific BUA and BMD measured at calcaneus in vivo. In the study of Chappard et al.,[17] the correlation coefficients between calcaneal BUA and calcaneal BMD (range, 0.81–0.90) were higher than those found in previous in vivo studies. The relationship between BUA and physical density has also been investigated in vitro. Bouxsein et al.[36] found that both calcaneal BMD and BUA were highly correlated with femoral failure load in vitro ($r = 0.63$ and $r = 0.51$, respectively).

Preliminary studies suggest that QUS might be appropriate as an assessment tool to measure response to antiresorptive therapies. QUS may be a perfect tool to screen very large numbers of people in the field for osteoporosis risk.[37] On the other hand, it is believed that peripheral measurements may not reflect changes in the axial skeleton, the places in which the fractures mostly exist. However, recent prospective fracture studies have demonstrated that BUA and SOS at the calcaneus can predict osteoporotic fracture, as can dual-energy x-ray absorptiometry at the spine and hip.[18] QUS is able to discriminate between normal subjects and subjects with low BMD or with osteoporotic fractures.[37] Moreover, QUS can measure the bone loss associated with aging,[33] estrogen defficiency,[38] and immobilization,[39] but the usefulness of QUS in monitoring the effects of specific treatment has yet to be defined by the follow-up studies.

Moreover, the response at a particular skeletal site may depend on the type of the treatment. In fact, exercise acts mainly on trabecular bone, which is characterized by a high turnover rate.[18,40] The calcaneus, which is composed almost entirely of trabecular bone, seems to be a good skeletal site to monitor the effects of aerobic exercises such as walking and jumping.

Alterations in the bone remodeling at the time of the menopause often cause rapid bone turnover and accelerated bone loss. A sedentary lifestyle is another risk factor for osteoporosis that augments the effects of postmenopausal bone loss.[12,41,42] Weight-bearing exercise is suggested to be a dynamic mechanical stress for the skeleton. It has generally been presumed that for exercise to be effective in preventing bone loss with aging, it must be weight bearing (i.e., walking, jogging, weightlifting, tennis playing, stair climbing) in nature to generate enough mechanical strain for ambulatory, healthy postmenopausal women.[42] In cross-sectional studies, regular physical activity and aerobic fitness have been correlated with bone density.[40,43] In general, this positive relationship has been supported by exercise intervention trials that have included weight-bearing exercises and regimens of vigorous aerobic and strength training but not by trials that have used low-intensity exercises such as walking.[40,41,43] However, Kudlacek et al.[12] reported that regular physical activity, such as senior dancing (waltz, folklore dancing) for 3.2 ± 0.8 hrs/wk for 12 mos, had a certain positive effect on spinal BMD in osteoporotic patients. Thus, it is suggested that dance movements have a weight-bearing effect on muscle strength at the back that is directly related to an increase of spinal BMD. Nevertheless, the type and optimal amount of the physical exercise needed to prevent bone loss still remain unclear.

There are various studies investigating the influences of exercise on bone. Lanyon[43] found that bone responds to the proportion and to the amount of stress placed on it. Abramson and Delagi[44] showed that weight-bearing forces and muscle contractions generate stress on bone necessary to prevent bone loss. Sinaki et al.[45] confirmed this finding and found a positive correlation between BMD of the lumbar vertebrae and back extensor strength with a strain-gauge dynamometer in postmenopausal women. In another study by Sinaki et al.,[42] it was demonstrated that non–weight-bearing exercise consisting of back-strengthening exercises with backpacks (containing weights equivalent to 30% of the maximum isometric back muscle strength) increased muscle strength, but it was not effective in decreasing vertebral bone loss in ambulatory, healthy, postmenopausal women. However, their exercise protocol, consisting of 10 back extensions per day, may not be enough to produce adaptive changes in the bone mass. Blanchet et al.[46] suggested that leisure physical activity could influence QUS variables independently of BMD and that quantitative ultrasound could be a suitable outcome measure in exercise studies in postmenopausal women. Brooke-Wavel et al.[41] demonstrated that in postmenopausal women, brisk walking three times a week for at least 20 mins was associated with an increase in calcaneal BUA, but unfortunately, no changes were seen in BMD of the calcaneus, hip, or spine, as measured with dual-energy x-ray absorptiometry. From this point of view, it cannot be taken for granted that there was any effect on the hip and spine. On the other hand, these findings suggest the possibility that loading through walking may produce structural reorganization of trabecular bone even in the absence of changes in BMD. In the study by Brooke-Wavel et al.[41] and in the present study, it was also determined that BUA scores improved but SOS did not, which may point that bone mineral content, reflected by BUA, may be more sensitive to short periods of exercise than the elasticity property reflected by SOS.

Krolner et al.[47] showed that 1 hr of walking twice a week for 8 mos increased bone mineral content of the lumbar vertebrae by 3–5%, whereas in the controls, it decreased by 2–7%. Therefore, the data suggest that physical exercise can inhibit or reverse involutional bone loss of the lumbar vertebrae in normal women and that physical exercise may prevent spinal osteoporosis.

On the other hand, there are only a few studies about the influences of non–weight-bearing exercise (i.e., swimming, aquatic, or water exercise and stationary cycling) on BMD.[13,31,48–50] Bloomfield et al.[31] showed that lumbar spinal densities of seven postmenopausal women exercising regularly at moderate intensities for 8 mos on bicycle ergometers revealed a significant increase. Tsukahara et al.[13] reported that the BMD of postmenopausal women increased slightly while participating in a water exercise program. The water exercise program included light calisthenics, swaying-jumping, and walking more than once a week for 35 mos. The level of physical activity had two maximum working heart rate peaks (approximately 120 beats/min) during the 45 mins. In the exercise group, it was found that the rate of change in the BMD showed a slight increase rather than a decrease, irrespective of the duration of menopause. Malliopoulos et al.[51] showed that aquatic exercise designed to improve flexibility, posture, and muscle strength increased vertebral bone mass and decreased the risk of new fractures. They explained this positive effect by the strains applied through the bones by muscle contractions. Orwoll et al.[48] documented a greater bone mass in the distal radius and in the lumbar spine of male masters swimmers who had been training for 13 ± 11 yrs, compared with sedentary controls. Interestingly this finding did not carry over to the female swimmers included in the study. In a preliminary study of Ay and Yurtkuran,[49] aquatic exercise was determined to make an anabolic effect (osteogenic response) on the bone of the women shown by the hormonal (insulin-like growth factor-1, growth hormone) and ultrasonic variables. Thus, it was put forth that aquatic exercise for postmenopausal sedentary subjects should be considered for inclusion in future exercise intervention protocols. In the study of Kelly et al.,[4] it was shown that the osteogenic response to exercise was followed by an increase in growth hormone and insulin-like growth factor-1, the potent cell mitogens. Also, in the study of Kudlacek et al.,[12] it was reported that the osteogenic response to exercise was followed by an increase in the bone-specific alkaline phosphatase, a marker for osteoblastic activity. In view of the gain in bone mass, this shows additional evidence of increased bone formation. Because calcaneus is a weight-bearing bone and the Achilles tendon is attached to it, both gravity and muscle contractions are thought to have an effect on it while walking and jumping. Owing to its high surface-to-volume ratio, trabecular bone in the calcaneus has presumed a turnover rate of about eight times that of a compact bone, and it is highly responsive to metabolic and mechanical stimuli for bone remodeling. On the other hand, experimental studies have demonstrated increases in bone density and histomorphometric measures of bone mass in female rats subjected to vigorous swimming training.[50] A total of 28 female Sabra rats (12 wks old) were randomly assigned to exercise and control groups. Exercised animals were trained to swim in a water bath of 35°C, loaded with lead weights (2% of body weight). It was reported that bone hydration properties, bone density, bone mineral content, and serum alkaline phosphatase were higher by 36%, 3%, 10%, and 67% in the exercise group, respectively.

There are data providing evidence of a prospective nature that aquatic exercise may be effective in reversing bone loss in healthy postmenopausal subjects.[13,48,51] It can be explained with hydrodynamic principles. Viscosity of water acts as friction or resistance when walking and jumping in the water. An isokinetic exercise model was created in which the load and the velocity was constant for the whole range of motion.[52] It allows the muscles and the skeleton to strengthen while encouraging greater physical activity and increasing self-confidence in this section of population.[13]

Cross-sectional evidence from other investigators remains inconclusive as to whether muscular contraction independent of weight-bearing impact forces is capable of producing an increase in bone mass.[42,48,53] Risser et al.[53] reported that BMD of eumenorrheic female athletes was evaluated, and it was found that mean calcaneal densities of the volleyball and basketball players were greater than those of the swimmers and nonathletes. It was concluded that the higher bone densities for athletes in vertical weight-bearing activities were consistent but the swimmers' low bone density in the lumbar spine; the less than published values for amenorrheic runners was unexpected. However, these results may be due to the difference in quantitative bone evaluation techniques used in different studies. Furthermore, recent studies also hypothesize that mechanical forces might influence trabecular microarchitecture and other BMD-independent factors such as muscular strength and coordination, which could reduce the risk of falling and fracture.[7,41,54] There are not any existing prospective studies in which the aquatic and the weight-bearing exercises are compared.

In this study, aquatic exercise was performed at the same magnitude of land-based aerobic activity for 40 mins/day and represents a moderate physical activity in daily life.[13,24] It has been reported that a moderate level of physical activity can be graded as follows: being on feet 50–70% of the time or performing a regular set of exercises, such as jogging, walking, biking, and aerobics for ≥30 mins/day and ≥2 times/wk.[13,24] Even though aquatic exercise can be considered a kind of nonloading exercise, it increased calcaneal BUA of the healthy postmenopausal subjects within this study. Our findings showed that exercise causing repeated mechanical loading in the long bones, outside of the normal physiologic range, produces significant increases in bone quality and quantity assessment variables.

There is a consistent positive correlation between BMI and BMD. The association between BMI and BMD remains strong even within normal ranges of body weight and is consistent across the different sites of BMD measured. The potential mechanisms to explain this are the increased mechanical loading of bone and the factors including the endocrine systems and growth factors such as insulin-like growth factor-1.[55] In the study of Tsukahara et al.,[13] BMIs of the groups were between 23 and 24, less than the study groups of the present study. It was found that the BMIs and BMDs of the lumbar spine were not closely related in the exercise group.[13] In our study groups, the BMIs were >29, and the subjects were considered as overweight. Because there was no statistically significant difference between the groups for BMIs at the beginning, it was not considered as a potential factor to change the results. Moreover, BMIs and BUA scores were not correlated in our exercise groups. In the control group, there was a weak correlation among the same variables ($P < 0.05$, $r = 0.27$) in accordance with the previous data.

The major finding of the present study is the significant ultrasonic increase of the calcaneal bone in response to the aquatic exercise regimen, which is traditionally considered nearly non–weight bearing in nature. Some postmenopausal women engage in fewer daily physical activities owing to their decreased physical capability and fitness or because of pain affecting the back and other joints. Thus, aquatic exercise such as walking, swaying, and jumping in the water provides a valuable alternative to weight-bearing activities, preparing an environment in which exercise can be done in a more pain-free and safe manner for people with established osteoporosis or balance and gait deficits. In addition, ultrasonic search results indicate that an aquatic exercise regimen is nearly as therapeutically effective as a weight-bearing exercise regimen on the control of calcaneal bone loss.

Several limitations to this study design should be noted. These include the small number of the subjects involved in the study and the short period of exercise. Because clinically relevant changes of bone density for prevention of osteoporosis in sedentary postmenopausal women may be achieved only after longer periods of time (e.g., 1–2 yrs), 6 mos is a relatively short study period to interpret the changes in ultrasound.[41]

It is concluded that aquatic and weight-bearing exercises are both determined to be effective in increasing the QUS scores of the calcaneal bone. In respect to the present study, the critical point is to increase the quantity of physical activity level to an unusual state for osteogenic stimulus, independent of the kind of exercise performed. Aquatic exercise is a suitable means by which the aged and nonswimmers can move their arms and legs easily and freely, without burdening the joints, while maintaining buoyancy with moderate physical exertion. It would therefore be sensible to offer to postmenopausal women to increase their physical activity systematically. Long-term effectiveness of aquatic and weight-bearing exercises on bone mass and fracture risk should be evaluated by means of follow-up studies, especially with synchronous measurements of calcaneal QUS and BMD of the hip and spine.

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