

## Effects of Physical Training on Bone Mineral Density and Bone Metabolism

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**Abstract** The purpose of this study was to examine the influences of long-term walking training and walking and jumping training on bone mineral density (BMD) and bone metabolism. Data from 28 healthy premenopausal women was assessed. The subjects were divided into the walking group (WG; 17 women mean $\pm$ SE age 35 $\pm$ 2 years), and the walking and jumping group (WJG; 11 women mean $\pm$ SE age 39 $\pm$ 1 years). BMD was measured in the lumbar spine and proximal femur using dual energy X-ray absorptiometry (DXA). As markers of bone metabolism, this study was to measure bone formation markers, bone-alkaline phosphatase (B-ALP: measured by enzyme immunoassay/EIA) and osteocalcin (BGP: by radioimmunoassay/RI) as well as bone resorption markers, parathyroid hormone (PTH: measured by/RI) and type I collagen cross-linked N-telopeptides (NTx: by EIA). Despite the significant decrease in body weight ( $p<0.05$ ), no corresponding decrease in BMD was observed. Moreover, no significant difference in bone markers BGP, PTH, and NTx was observed. B-ALP was significantly increased ( $p<0.05$ ) after one year, and the rate of this increase was greater in the WJG than in the WG. It is thus concluded that walking training for one year is beneficial for the promotion of bone formation, and that jumping stimulus maintain BMD effectively. *J Physiol Anthropol Appl Human Sci* 22 (4): 203–208, 2003 <http://www.jstage.jst.go.jp/en/>

**Keywords:** Bone Mineral Density, Bone Formation Marker, Jumping and Walking

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### Introduction

Japan is known for the longevity of its people, and in aging societies primary osteoporosis, which is closely related to both past and present living habits, is now regarded as one of the leading lifestyle diseases in Japan (Sato, 2000; Department of

Health and Human Services, 1996). Since the decrease in bone mineral density (BMD) accompanied by age cannot be avoided, it is desirable to acquire the highest possible bone density during younger ages. Therefore the development of specific exercise programs and other measures are urgently needed to prevent osteoporosis.

BMD decreases with aging, and there is a particular decline in women approaching the menopausal period due to the sudden deficiency of estrogen, which plays an important role in bone formation (Jilka et al., 1992). A positive correlation between BMD and body weight has also been reported (Kin et al., 1991; Treharne, 1981).

Numerous studies have reported that the mechanical load from exercise acts to increase BMD (Chilibeck et al., 1995; Grisso et al., 1990; Macdougall et al., 1992). But, differences in BMD are observed according to the type of exercise. Previous studies have shown that volleyball and handball, include jumping movements that place great mechanical stress such as impact or compressive force on bone in a single stimulus and are thought to be more effective (Fehling et al., 1995). In our previous study, we measured BMD in members of volleyball teams on the 9-player system, and found that BMD was significantly higher in the attacker group, whose movements consisted mostly of jumps, than in the receiver group and the control group (Shibata et al., 1999).

In recent years, specific bone metabolism markers have been developed, and indicators of bone formation and resorption as a reflection of general metabolism dynamics have been noticed. These markers are used especially in understanding the pathologic state and in assessing the effect of treatment for osteoporosis and related diseases (Garnero et al., 1994; Szulc et al., 1993; Garnero et al., 1994). However, there have been few reports concerning the effects of exercise on healthy people on metabolic markers. The aims of the present study, therefore, were to assess the effects of continued exercise consisting mainly of walking on BMD and the fluctuations in

metabolic markers. And further, based on the results of our previous study, combined effects of walking and jumping exercise on BMD and bone metabolism were also investigated.

## Methods

### Subjects

The subjects were 43 women (mean age  $37 \pm 7$  years) who attended the class on the prevention of lifestyle-related diseases. Of these 43 women, 41 premenopausal subjects (mean age  $36 \pm 7$  years) having had no disease that would affect BMD, and having bone metabolism markers within the normal range, were selected for the study. All subjects volunteered to the study and gave written informed consents.

### Interventions

The study protocol was approved by the Ethics Committee of the Research Center of Health, Physical Fitness and Sports, Nagoya University and the study was carried out in accordance with Helsinki Declaration. Subjects were given instruction with a final goal of walking 10,000 steps. The subjects were randomly divided into two groups: a walking group (WG; 26 women), and a walking and jumping group (WJG; 15 women). Members of the WJG were instructed to jump straight up as high as they could, and were asked to jump and land with both legs. Subjects were instructed to make a single, properly executed jump 10 times totally each day. Excluding those subjects who withdrew during this year, a comparison before and after the exercise training was made for 17 WG women (mean  $\pm$  SE age  $35 \pm 2$  years) and 11 WJG women (mean  $\pm$  SE age  $39 \pm 1$  years).

### Procedure and instrumentation

#### (1) Background questionnaire

The questionnaire was given to ascertain whether there were any abnormalities in menstruation, histories of diseases that would affect BMD, and present and past daily living circumstances.

#### (2) Percent body fat

Percent body fat (%fat) was measured using a Tanita TBF-210 body fat meter.

#### (3) Blood chemical data

Plasma total cholesterol (TC), triglycerides (TG), high-density lipoprotein-cholesterol (HDL-C), low-density lipoprotein-cholesterol (LDL-C), fasting plasma glucose (FBS), and HbA<sub>1c</sub> were determined before and after the training.

#### (4) Walking

The numbers of steps walked in daily life were recorded with Life Coders® (Suzuken. Co, Nagoya, Japan).

#### (5) Bone mineral density

Using dual energy X-ray absorptiometry (DXA; QDR2000, Horologic), BMD was measured on the front of the 2–4 lumbar spine and the femurs of both legs (femoral neck, trochanter, intertrochanter, and Ward's triangle).

#### (6) Bone metabolism

Bone metabolism markers were determined as follows: plasma bone-specific alkaline phosphatase (B-ALP) by enzyme immunoassay (EIA), osteocalcin (BGP) by radioimmunoassay (RI) as markers of bone formation and parathyroid hormone (PTH; RI) and type I collagen cross-linked N-telopeptides (NTx; EIA) as markers of bone resorption.

### Statistical analysis

Data is presented as means  $\pm$  SEM. The subjects were divided into WG and WJG, and the mean values were compared by un-paired *t*-test (SPSS) for age, height, and weight. Blood biochemical data, body weight, %fat, BMD, and bone metabolism were compared before and after exercise with paired *t*-test (SPSS). The level for statistical significance was set at  $p < 0.05$ .

## Results

### Walking

Before training, the mean total numbers of steps per day were  $6422 \pm 1911$ , and significantly increased to  $7723 \pm 2248$  per day ( $p < 0.05$ ) after 6 months.

### BMI (Body mass index), %fat, blood pressure, blood biochemical data

#### (1) Changes before and after training

Table 1 shows a comparison of BMI, %fat, blood pressure, and blood biochemical data values in the beginning of the study and one year later. The mean body weight at the end of the study ( $63.3 \pm 10.5$  kg) was significantly lower than that in the beginning ( $66.3 \pm 8.8$  kg) ( $p < 0.05$ ). The value of BMI after one year was significantly lower ( $p < 0.05$ ) than the initial value. The level of HDL-C after one year was significantly higher ( $p < 0.05$ ) than that at the start of the program.

#### (2) Percent changes before and after training

Figure 1 shows the percent changes in BMI, %fat, blood pressure, and blood biochemical data for both the WG and WJG. In both groups significant decreases in body weight were accompanied by decreases in BMI and %fat. Both WG and WJG groups showed high rates of increase in HDL-C after one year.

### Bone mineral density

#### (1) Changes in BMD values before and after training

The BMD values in the lumbar spine and bilateral femoral neck, trochanter, intertrochanter, and Ward's triangle of the subjects at the start of the study and one year later are shown in Table 2. No significant difference in BMD was observed in any of these 5 locations between the initial and post-training values.

#### (2) Percent change in BMD before and after training

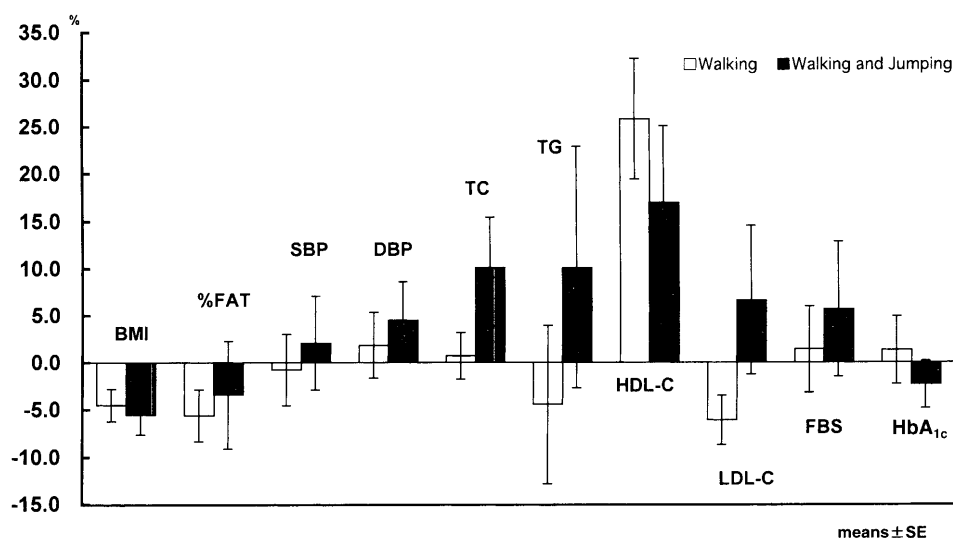
Figure 2 shows comparisons of the percent change in BMD before and after one year for both the WG and WJG. No

**Table 1** BMI, %Fat, Blood chemical data

Measurement	before	after
Body mass index (kg/m <sup>2</sup> )	27.3±0.6	26.6±0.7*
Fat (%)	35.9±0.9	34.3±1.1
Systolic blood pressure (mmHg)	121±3	121±3
Diastolic blood pressure (mmHg)	78±2	79±2
Total cholesterol (mg/dl)	194±6	204±5
Triglyceride (mg/dl)	84±8	85±8
High density lipoprotein cholesterol (mg/dl)	59±2	72±3*
Low density lipoprotein cholesterol (mg/dl)	126±6	123±4
Fasting blood sugar (mg/dl)	91±4	96±3
Hemoglobin A <sub>1c</sub> (%)	5.0±0.1	4.9±0.1

Data values at the start of the study (before) and one year later (after).

\* $p < 0.05$ ; Significantly different from pre-levels. (n=28) means±SE



**Fig. 1** Percent changes in BMI, %fat, blood pressure and blood chemical data before and after training in walking group (□) and walking and jumping group (■). Values are means±SE.

**Table 2** Bone mineral density (g/cm<sup>2</sup>)

Skeletal site		before	after
Lumbar spine	(L2–L4)	1.066±0.023	1.070±0.022
Femoral neck	(Rt)	0.806±0.020	0.710±0.021
	(Lt)	0.803±0.022	0.795±0.022
Trochanter	(Rt)	0.645±0.019	0.644±0.020
	(Lt)	0.636±0.020	0.636±0.020
Intertrochanter	(Rt)	0.997±0.028	0.998±0.029
	(Lt)	1.005±0.026	0.997±0.028
Ward's triangle	(Rt)	0.736±0.030	0.719±0.031
	(Lt)	0.731±0.030	0.718±0.029

Data values at the start of the study (before) and one year later (after). (n=28) means±SE

significant changes were found in either group after one year. In the areas of lumbar spine, trochanter, and intertrochanter where increases were found the percent increase was greater in the WJG than in the WG. However in the areas of femoral neck and Ward's triangle where decreases were observed, the

percent decrease was smaller in the WJG than in the WG.

#### Bone metabolism

(1) Changes in bone metabolism marker before and after training

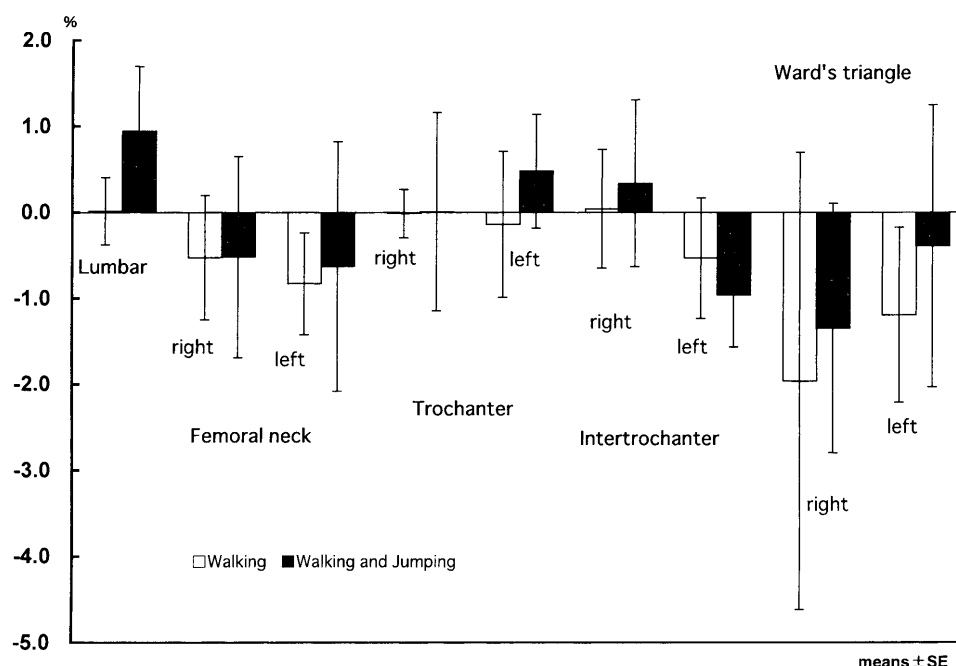


Fig. 2 Percent changes of bone mineral density before and after training in walking group (□) and walking and jumping group (■). Values are means  $\pm$  SE.

Table 3 Markers of bone metabolism

Measurement	before	after
B-ALP (U/l)	17.3 $\pm$ 1.1	20.6 $\pm$ 1.0*
BGP (ng/ml)	2.9 $\pm$ 0.3	3.3 $\pm$ 0.3
PTH (pg/ml)	45.5 $\pm$ 4.9	40.4 $\pm$ 3.8
NTx (nmol BCE/mmol Cr)	39.0 $\pm$ 3.0	37.1 $\pm$ 2.6

Data values at the start of the study (before) and one year later (after).

\* $p < 0.05$ ; Significantly different from pre-levels. ( $n = 28$ ) means  $\pm$  SE

B-ALP: bone-specific alkaline phosphatase

BGP (bone Gla-containing protein): osteocalcin

PTH: parathyroid hormone

NTx: type I collagen cross-linked N-telopeptides

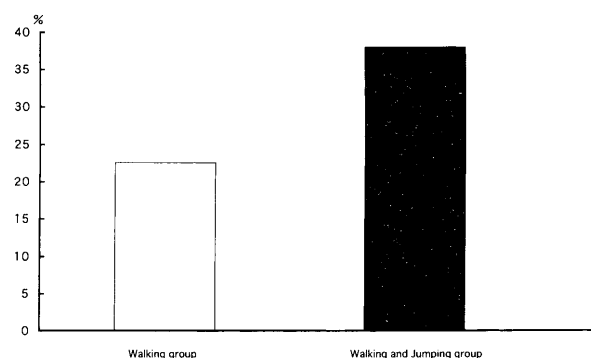


Fig. 3. Difference of percent increase for B-ALP showing significant difference in walking group (□) and walking and jumping group (■).

Table 3 shows the results for markers of bone metabolism in the beginning of the study and one year later.

Bone formation markers: B-ALP at the start of the program  $17.3 \pm 1.1$  U/l was significantly increased to  $20.6 \pm 1.0$  U/l ( $p < 0.05$ ) after one year. The difference in BGP, from an initial value of  $2.9 \pm 0.3$  ng/mg to  $3.3 \pm 0.3$  ng/mg one year later, was not significant.

Bone resorption markers: No significant difference was seen in either PTH (initial value  $45.5 \pm 4.9$  pg/ml, final value  $40.4 \pm 3.8$  pg/ml), or Ntx (initial value  $39.0 \pm 3.0$  nmol BCE/mmol Cr, final value  $37.1 \pm 2.6$  nmol BCE/mmol Cr).

(2) Percent change in bone metabolism markers before and after training

Of the bone metabolism markers, the percent changes in the WG and WJG for B-ALP showed significant increases after the training program (Figure 3). The percent increase was 12.3% higher in the WJG than in the WG.

## Discussion

The present study demonstrates that walking at least 10,000 steps per day has beneficial effects on BMD and moreover that this is a level that can be maintained. In addition, a significant increase was seen in the present study in B-ALP, which affects bone formation, and thus walking serves to effectively maintain BMD in bone metabolism also. Together with these changes, an improved health state, significant decreases in body weight and BMI ( $p < 0.05$ ) and a significant elevation in HDL-C ( $p < 0.05$ ) were observed.

Previous studies showed that maintenance or increase of BMD was not seen with walking or other low-impact exercise (Cavanaugh & Cann, 1998; Dalen & Olsson 1974; Martin & Notelovitz, 1993). Therefore these findings are new and interesting.

It has also been reported from numerous studies that a decrease in body weight leads to decreased BMD (Ribot et al., 1987; Dawson-Hughes et al., 1987; Carter, 1984). However, it is noteworthy that no significant decrease was seen in BMD in the present study, despite the significant decrease in body weight.

Furthermore, a phased walking program was developed for each individual with a long-term view so as to avoid rapid reductions in body weight, physical damages or injuries, and poor physical condition. During the year-long exercise program, each subject was interviewed once a month. A mental support was also provided, and guidance was given to maintain nutritionally-balanced meals so that subjects would not be placed under undue physical or mental stress. This made it possible for subjects to significantly increase the number of steps walked per day, from an overall number of  $6422 \pm 1911$  at the start of the program to  $7723 \pm 2248$  six months later ( $p < 0.05$ ). A high percentage of the initial participants continued until the end of the study period, with 65.4% in the WG completing the program, and rather higher 73.3% in the WJG, even though jumping exercise had been added. Thus it implied that the importance of understanding the physical strength of each person, and setting graded walking targets suited to each person's strength so that they continue walking, and approach the goal of 10,000 steps.

A difference was found between the WG and WJG in the percent change in BMD after the one-year exercise program. A very interesting result was that in Ward's triangle, the area with the largest contribution to femur fractures, the percent decrease was smaller in the WJG than in the WG. From examinations of ground reaction forces, Marino, Leavitt (1987) and Shorten et al. (1988) reported that walking produced a ground reaction force 1.1 times body weight. Whereas, Kohrt, Ehsani, and Birge (1997) reported that exercise with a large ground reaction force led to a greater increase in BMD than that with a small ground reaction force. From these results we speculated that the stimulus from jumping in addition to walking in the WJG served to more effectively maintain or increase BMD in the present study.

In bone metabolism as well, overall increases were seen in both the bone formation markers B-ALP and BGP, with the increase in B-ALP being significant ( $p < 0.05$ ). In this study, BAP in the serum was measured with enzyme immunoassay (EIA) using a Osteolinks 'BAP' (Sumitomo Pharmaceuticals Biomedical, Osaka, Japan; detection limit 2U/mL). The kit used can detect bone-specific ALP, and was authorized as a diagnostic reagent (Gomez B et al., 2001). Comparing the two groups, the increase in B-ALP was 12.3% higher than that in the WJG. From these findings it appears that walking with the addition of jumping has a more positive influence on bone metabolism than walking alone.

And it might be essential to measure bone metabolism together with BMD.

However, in measuring markers of bone metabolism, the elimination of various change factors is a problem. One

includes uncontrollable factors such as age, sex, menopausal state, diseases, and fractures, and the other controllable factors such as 24-h cycle, menses, and exercise. In the latter, influences can be minimized by means such as the timing of test sample collection and standardization of conditions.

In the present study, we paid careful attention to minimize the effects of controllable change factors in the measurement of bone metabolism markers, including the validity of the date and time.

Recently Wolff et al. (1999) reported that the over all treatment effects for the nonrandomized controlled trial were almost twice as high as those for the randomized controlled trials. This study is nonrandomized. Therefore a further study should be performed to examine the randomized controlled trials concerning physical exercise and bone mass.

In conclusion, the present study suggests that walking about 10,000 steps per day, if done continuously, could maintain BMD. It might be also suggested a strong possibility that the jumping exercise and walking would serve to promote bone formation further.

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