

Unipedal standing exercise and hip bone mineral density in postmenopausal women: a randomized controlled trial

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Abstract The aim of this study was to test the effect of unipedal standing exercise on bone mineral density (BMD) of the hip in postmenopausal women. Japanese postmenopausal women ($n = 94$) were assigned at random to an exercise or control group (no exercise). The 6-month exercise program consisted of standing on a single foot for 1 min per leg 3 times per day. BMD of the hip was measured by dual-energy X-ray absorptiometry. There was no significant difference in age and baseline hip BMD between the exercise group ($n = 49$) and control group ($n = 45$). Exercise did not improve hip BMD compared with the control group. Stepwise regression analysis identified old age as a significant determinant ($p = 0.034$) of increased hip total BMD at 6 months after exercise. In 31 participants aged ≥ 70 years, the exercise group ($n = 20$) showed significant increase in the values of hip BMD at the areas of total ($p = 0.008$), intertrochanteric ($p = 0.023$), and Ward's triangle ($p = 0.032$). The same parameters were decreased in the control group ($n = 11$). The percent changes in hip BMD of the exercise group were not significantly different from those of the control group either in the participants with low baseline hip total BMD ($<80\%$ of the young adult mean) or high baseline hip total BMD ($\geq 80\%$ of the young adult mean). In conclusion, unipedal

standing exercise for 6 months did not improve hip BMD in Japanese postmenopausal women. Effect of exercise on hip total BMD was age dependent. In participants aged ≥ 70 years, the exercise significantly increased hip total BMD.

Keywords Exercise · Unipedal standing · Bone mineral density · Hip · Postmenopausal women

Introduction

Osteoporosis is a common condition in postmenopausal women and is associated with increased risk of fragile fractures, notably at the hip, spine, wrist, and proximal humerus. Recent data from North America and Finland indicate that the incidence of hip fractures is on the decline [1–3], whereas most reports from Asia indicate that the incidence is increasing [4–6]. A survey conducted in the Tottori prefecture of Japan identified 851, 906, and 1059 patients with hip fractures in 2004, 2005, and 2006, respectively [4]. Furthermore, the estimated number of patients with hip fractures increased significantly from 1986 to 2006 for both genders in Japan.

Physical exercise prevents bone loss in postmenopausal women. Meta-analysis of 24 randomized controlled trials (RCT) of postmenopausal women reported that hip bone mineral density (BMD) in the exercise group was maintained or increased compared to that in the non-exercise group [7]. On the other hand, the lack of skeletal loading on bone induces disuse osteoporosis, which is characterized by bone fragility resulting from decreased bone mass and disruption of normal bone architecture [8–11]. We postulated that skeletal loading of the lower extremities in postmenopausal women is an important factor that is

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associated with hip BMD, in a manner either dependent or independent of age.

Unipedal standing exercise is convenient and cost free for the elderly to perform. Unipedal standing for 1 min is equivalent to the amount of integral load gained through walking for approximately 53 min [12]. RCT in the elderly showed that the cumulative number of falls was significantly less in the unipedal standing exercise group than that in the non-exercise control group [13]. Furthermore, a case–control retrospective study showed that unipedal standing exercise could improve hip BMD [14]. To our knowledge, there is little or no information on the association between unipedal standing exercise and hip BMD. In the present study, we tested the hypothesis that unipedal standing exercise for 6 months improves hip BMD in postmenopausal women.

Materials and methods

Subjects

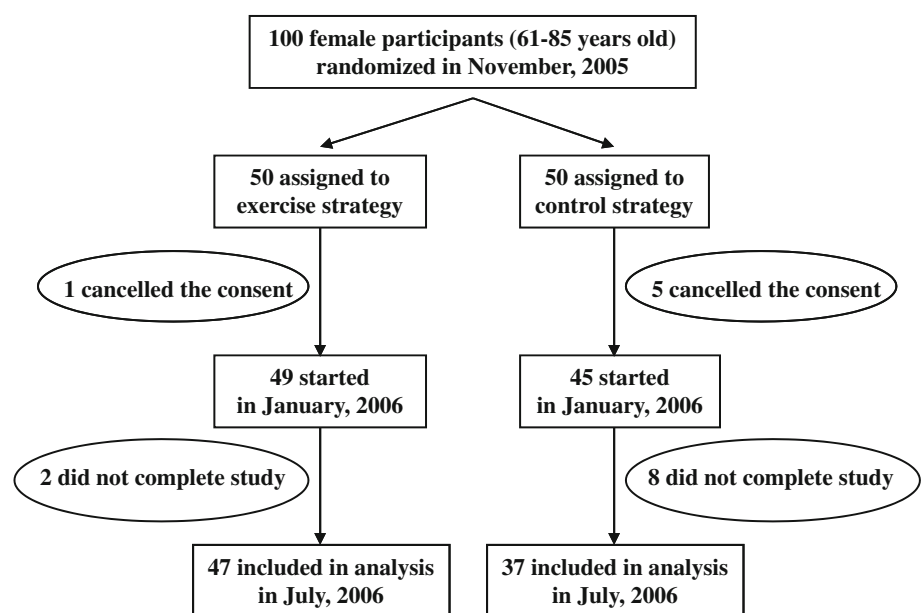
We recruited Japanese postmenopausal women who weekly participated in the regional exercise club. We also explained the study protocol at the same time to more than 100 women who were assembled in the same hall in November 2005 (Fig. 1). At study entry, none of the participants was institutionalized and all lived independently. After obtaining informed consent that involved agreeing to be randomized to the exercise or control group, a total of 100 respondents were assigned at random by envelopes to the 2 groups: unipedal standing exercise (exercise group,

$n = 50$) or no unipedal standing exercise (control group, $n = 50$). Among the 100 women, 94 (49 in the exercise group and 45 in the control group) participated in the baseline examination in January 2006. The mean age of 94 women was 68.3 years (range 61–85 years). All aspects of the study were approved by the institutional review board.

Unipedal standing exercise

This exercise program consisted of 3 sets per day for 6 months from January 2006 to July 2006. With their eyes open, subjects were instructed to stand on one leg for 1 min and then on the other leg for another 1 min. If the subject was unable to stand on one leg continuously for 1 min and required several breaks, she was instructed to stand on either leg until the total duration of one-leg standing reached 1 min. A single set of this one-leg standing exercise consisted of standing on the right leg for 1 min and the left leg for 1 min. Each day, subjects performed 3 sets, 1 in the morning, 1 at noon, and 1 in the afternoon. The control group was observed without this unipedal standing exercise in the follow-up period. The individuals who were assigned to the unipedal standing exercise were asked to complete a survey sheet once every month. They were monitored to accomplish the exercise at frequencies of more than 70%; 70% means accomplishment of the stated exercise frequency, which is exercise days/exercise days + non-exercise days. Before starting this study, we were afraid that the participants would not perform the exercise for reasons of poor physical condition or long-term vacations on approximately 30% of the total days. If the participants performed the exercise only on weekdays, the accomplishment rate is 71.4%

Fig. 1 Trial profile and subject recruitment



(5 days/7 days \times 100). Thus, we determined the permissible lowest accomplishment rate as 70%.

Physical measurements

We measured body height and weight in light clothing and without shoes.

Assessment by dual-energy X-ray absorptiometry

Bone mineral density of the hip was measured by dual-energy X-ray absorptiometry (QDR4000; Hologic, Waltham, MA, USA) just before and 6 months after the start of the study. The participants were examined in a fixed position of leg internal rotation by the same radiology technologist, who had long experience with hip BMD measurements, at the Department of Radiology, Arita-Kyouritsu Hospital.

We were afraid that the subjects would like to gain the BMD by excessive exercise in addition to unipedal exercise if we informed to them of their lower BMD at the starting point. We informed the subjects of their BMD data after they had finished this study, 6 months after the start of the study.

Changes in hip BMD

We calculated the percent change in hip BMD from baseline to 6 months after the study using the following formula: $(\text{BMD at 6 months after study} - \text{BMD at baseline}) / (\text{BMD at baseline}) \times 100$. Hip BMD was measured at areas of total, neck, trochanter, intertrochanter, and Ward's triangle. We compared the percent change in hip BMD between the exercise and control groups using the data of all participants.

We divided the subjects of the exercise group into those who showed increase or decrease in total hip BMD after 6-month exercise. We compared age, body height, body weight, body mass index, and baseline BMD between

participants with increased total hip BMD and those with decreased total hip BMD after 6-month exercise. Then, we determined the significant factors associated with increased hip total BMD after 6-month exercise by stepwise regression analysis.

We compared the percent change in hip BMD between the exercise and control groups separately in the participants aged <70 and ≥ 70 years, or in the participants with low and high BMD at the baseline. The participants were divided into 2 groups of low and high BMD on the basis of the baseline hip total BMD <0.692 or ≥ 0.692 g/cm^2 (80% of the young adult mean).

Statistical analysis

Results were expressed as mean \pm standard error of the mean (SEM). Differences between the 2 groups were evaluated using the Mann–Whitney *U* test. The significant factors associated with increased hip total BMD were determined by stepwise regression analysis. A *p* value <0.05 was considered significant. Statistical analysis was performed using StatView 5.0 software (SAS Institute, Cary, NC, USA).

Results

Subjects

Among the 100 women, 94 (49 of the exercise group and 45 of the control group) participated in baseline examination (Fig. 1). As shown in Table 1, there were no significant differences in age, body height, body weight, body mass index, and hip BMD between the 2 groups at baseline. Data of 10 (2 of the exercise group and 8 of the control group) of the 94 participants were not included in the analysis because these individuals did not adhere to the study protocol within the 6-month period.

Table 1 Baseline characteristics of the participants

	Control group	Exercise group	<i>p</i> value
<i>n</i>	45	49	
Age (years)	68.2 \pm 0.5	68.3 \pm 0.8	0.973
Body height (kg)	151.4 \pm 0.9	151.4 \pm 0.7	0.928
Body weight (cm)	51.7 \pm 0.9	51.4 \pm 1.1	0.449
Body mass index (kg/m^2)	22.6 \pm 0.4	22.4 \pm 0.4	0.425
Bone mineral density (g/cm^2)			
Total	0.733 \pm 0.015	0.710 \pm 0.017	0.253
Neck	0.612 \pm 0.013	0.594 \pm 0.013	0.189
Trochanter	0.536 \pm 0.013	0.529 \pm 0.015	0.527
Intertrochanter	0.874 \pm 0.019	0.840 \pm 0.020	0.233
Ward's triangle	0.417 \pm 0.016	0.396 \pm 0.016	0.405

Data are mean \pm SEM
There were no significant differences in the above parameters between the control and exercise groups by Mann–Whitney *U* test

Changes in hip BMD in all participants

In all participants, the percent change in BMD was not significantly different in any part of the hip between the control and exercise groups (Fig. 2).

Differences in characteristics between the subjects with increased and decreased hip total BMD after 6-month exercise

We divided the subjects of the exercise group into those who showed increase ($n = 21$) or decrease ($n = 26$) in total hip BMD after 6-month exercise (Table 2). Subjects who showed an increase in postexercise total hip BMD were significantly older and had lower intertrochanteric BMD at baseline than those of the other group. The total hip BMD ($p = 0.052$) and BMD of the trochanter ($p = 0.053$) of the former group tended to be lower than those of the latter group, but the difference was not statistically significant.

A significant factor associated with increased hip total BMD after 6-month exercise

We analyzed the factors associated with increased hip total BMD after 6-month exercise by stepwise regression analysis (Table 3). In this analysis, we used age, body height, body weight, body mass index, and baseline BMD values

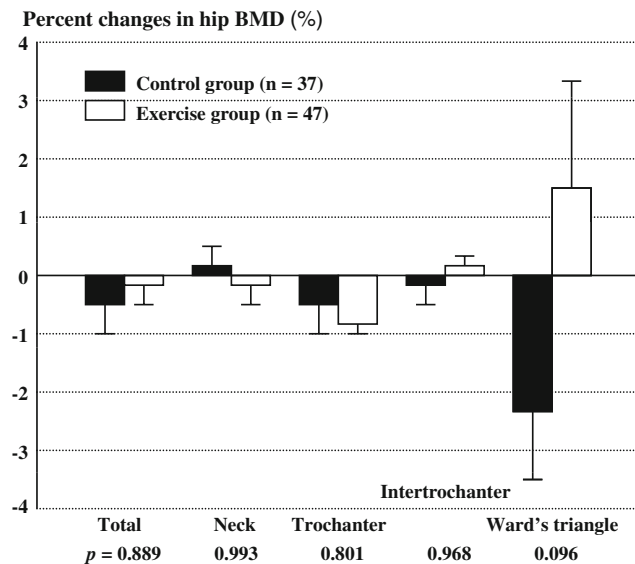


Fig. 2 Percent changes in hip bone mineral density (BMD) for all participants. The percent change in BMD was calculated by $(\text{BMD at 6 months after study} - \text{BMD at baseline}) / (\text{BMD at baseline}) \times 100$. Data are mean \pm SEM. There were no significant differences in all BMD values between the control and exercise groups by Mann–Whitney U test

(total hip, neck, trochanter, intertrochanter, and Ward’s triangle) as the independent parameters. Such analysis identified old age as the only significant and independent determinant of increased hip total BMD after 6-month exercise (standard $r = 0.31$, $p = 0.03$), whereas the baseline hip BMD in any of the hip/femur areas was not significant.

Changes in hip BMD in the participants aged <70 and ≥ 70 years

We analyzed the data of participants who were <70 and ≥ 70 years of age separately. In the participants aged <70 years, the percent changes in hip BMD of the exercise group were not significantly different from those of the control group (Fig. 3a). On the other hand, in the participants aged ≥ 70 years, the percent changes in total BMD, BMD of intertrochanter, and BMD at Ward’s triangle of the hip of the exercise group were significantly different

Table 2 Characteristics of participants of the exercise group with decreased and increased hip total bone mineral density (BMD)

	Decreased group	Increased group	p value
n	26	21	
Age (years)	67.0 \pm 0.9	70.3 \pm 1.2*	0.032
Body height (kg)	151.0 \pm 1.0	151.3 \pm 1.2	0.708
Body weight (cm)	52.1 \pm 1.5	50.7 \pm 1.7	0.578
Body mass index (kg/m ²)	22.8 \pm 0.6	22.1 \pm 0.6	0.514
Bone mineral density (g/cm ²)			
Total	0.734 \pm 0.022	0.682 \pm 0.024	0.052
Neck	0.609 \pm 0.020	0.577 \pm 0.017	0.309
Trochanter	0.552 \pm 0.020	0.503 \pm 0.021	0.053
Intertrochanter	0.870 \pm 0.027	0.807 \pm 0.030*	0.044
Ward’s triangle	0.411 \pm 0.023	0.381 \pm 0.021	0.280

Data are mean \pm SEM

* $p < 0.05$ vs. decreased group by Mann–Whitney U test

Table 3 Significant explanatory factor associated with increased hip total BMD in the exercise group

	Standard regression coefficient	p value
$n = 47$		
Age	0.309	0.034

Association with increased hip total BMD was identified by stepwise regression analysis and included age, body height, body weight, body mass index, and BMD at the baseline

A significant factor associated with increased hip total BMD after 6-month exercise is old age, not low BMD

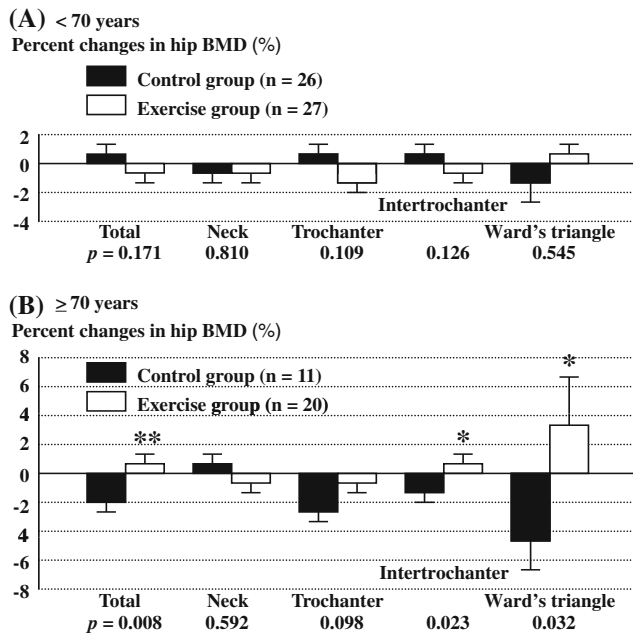


Fig. 3 Percent changes in hip BMD in participants aged <70 and ≥70 years. **a** Participants aged <70 years. **b** Participants aged ≥70 years. The percent change in BMD was calculated by $(\text{BMD at 6 months after study} - \text{BMD at baseline}) / (\text{BMD at baseline}) \times 100$. Data are mean \pm SEM. * $p < 0.05$, ** $p < 0.01$ vs. control group (Mann–Whitney U test)

from those of the control group (Fig. 3b). The percent change in hip total BMD after 6-month exercise was 0.238 ± 0.393 in the elderly exercise group, which was significantly higher than the value of the control group (-2.177 ± 0.766 , $p = 0.008$). There were no significant differences in age, body height, body weight, body mass index, and hip BMD between the control and exercise groups at baseline in the participants aged ≥70 years (Table 4).

Changes in hip BMD in the participants with low and high BMD at the baseline

We analyzed the data of the participants who had low and high BMD separately. The percent changes in hip BMD of the exercise group were not significantly different from those of the control group either in the participants with low BMD (Fig. 4a) or in those with high BMD (Fig. 4b).

Discussion

The present study demonstrated that unipedal standing exercise did not increase hip BMD in all participating postmenopausal women but did significantly increase hip total BMD in participants aged ≥70 years. Participants who showed increased postexercise hip total BMD were

Table 4 Baseline characteristics of 31 participants aged ≥70 years

	Control group	Exercise group	p value
n	11	20	
Age (years)	72.2 ± 0.6	73.4 ± 0.8	0.591
Body height (kg)	147.4 ± 1.9	150.4 ± 1.3	0.375
Body weight (cm)	49.8 ± 1.9	51.5 ± 2.1	0.984
Body mass index (kg/m^2)	22.9 ± 0.8	22.7 ± 0.8	0.967
Bone mineral density (g/cm^2)			
Total	0.727 ± 0.040	0.709 ± 0.030	0.918
Neck	0.605 ± 0.034	0.603 ± 0.023	0.869
Trochanter	0.524 ± 0.029	0.534 ± 0.027	0.999
Intertrochanter	0.872 ± 0.051	0.832 ± 0.036	0.710
Ward's triangle	0.401 ± 0.039	0.405 ± 0.025	0.433

Data are mean \pm SEM

There were no significant differences in the above parameters between the control and exercise groups by Mann–Whitney U test

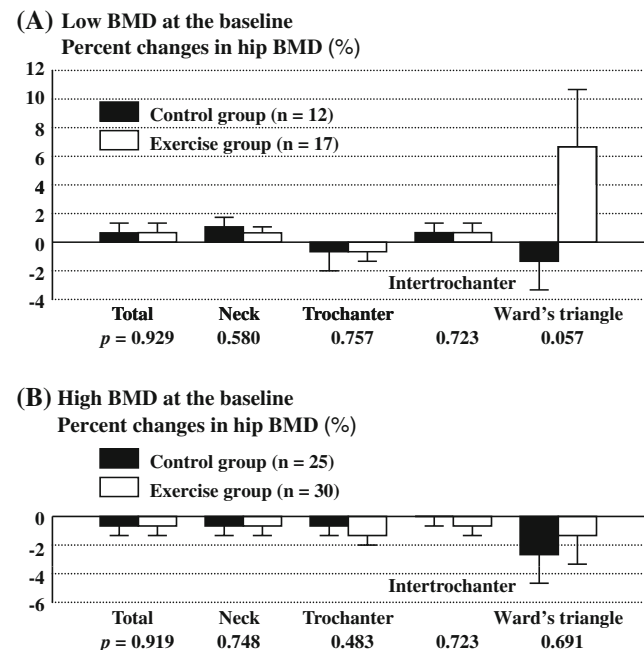


Fig. 4 Percent changes in hip BMD in participants with low and high BMD at the baseline. **a** Participants with hip total BMD at the baseline $< 0.692 \text{ g}/\text{cm}^2$ (80% of the young adult mean). **b** Participants with hip total BMD at the baseline $\geq 0.692 \text{ g}/\text{cm}^2$. The percent change in BMD was calculated by $(\text{BMD at 6 months after study} - \text{BMD at baseline}) / (\text{BMD at baseline}) \times 100$. Data are mean \pm SEM. There were no significant differences in all BMD values between the control and exercise groups by Mann–Whitney U test

older and had lower baseline BMD compared to those who showed decreased postexercise hip total BMD. Furthermore, stepwise regression analysis of the exercise group identified old age as the only significant factor associated with increased hip total BMD after 6-month exercise, but not low baseline BMD. Thus, unipedal standing exercise is

useful to increase hip BMD in postmenopausal women aged ≥ 70 years.

Previous studies on the effects of physical exercise on age-related bone loss showed controversial results [15–18]. The inconsistencies in the reported results might be caused by the use of different exercise protocols and the characteristics of the subjects. The present study showed that unipedal standing exercise is efficacious in increasing hip BMD in women aged 70 years and over. Stepwise regression analysis identified old age as a significant factor associated with increased hip total BMD after 6-month exercise. Recently, we reported that short unipedal standing time in women aged ≥ 70 years was closely associated with lower BMD [19]. Thus, the relationship between physical activity and BMD seems to be closer in women aged ≥ 70 years compared with younger women. We consider that the degree of physical activity in daily life activities is sufficient for younger women to maintain mechanical loading on the skeleton. On the other hand, in elderly women, the degree of physical activity differs widely among individuals, and is very likely low in the majority, and these differences in physical activity seem to exert robust influence on BMD. Thus, the elderly could have better responsiveness to exercise (mechanical stress).

Taaffe et al. [20] reported that the association between physical capacity and hip BMD was most significant in women who exhibited the poorest functional capacity, although that was only modest in well-functioning young-old seniors. This result is comparable with our recent report that the physical ability of the lower extremity closely relates to BMD in elderly women [19]. The participants of this study routinely took part in the regional exercise club and exercised for 1 h per week. It seems that such individuals have a substantial habit of physical exercise and better physical ability compared to community-dwelling women of similar age. Thus, it might be difficult to detect additional increase in hip BMD after daily unipedal standing exercise in women who regularly perform exercise for 1 h per week. Different results might be obtained in sedentary subjects who are not engaged in regular physical activity. This study has the limitation that we could not clarify whether the BMD in the increased group gained in an exercise accomplishment rate-dependent manner.

The combination of osteoporosis and falls underlies most fragile fractures, such as hip fractures. A previous study reported that unipedal standing exercise resulted in reduced number of falls among clinically defined high-risk elderly persons [13]. In this study, we showed that unipedal standing exercise significantly increased hip total BMD in participants aged ≥ 70 years. Taken together, it is conceivable that unipedal standing exercise could reduce the incidence of osteoporotic hip fractures by preventing bone

loss and decreasing the chance of falls, especially in fragile postmenopausal women aged 70 years or more.

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References

- Newman ED, Ayoub WT, Starkey RH, Diehl JM, Wood GC (2003) Osteoporosis disease management in a rural health care population: hip fracture reduction and reduced costs in postmenopausal women after 5 years. *Osteoporos Int* 14:146–151
- Jaglal SB, Weller I, Mamdani M, Hawker G, Kreder H, Jaakkimainen L, Adachi JD (2005) Population trends in BMD testing, treatment, and hip and wrist fracture rates: are the hip fracture projections wrong? *J Bone Miner Res* 20:898–905
- Kannus P, Niemi S, Parkkari J, Palvanen M, Vuori I, Järvinen M (2006) Nationwide decline in incidence of hip fracture. *J Bone Miner Res* 21:1836–1838
- Hagino H, Furukawa K, Fujiwara S, Okano T, Katagiri H, Yamamoto K, Teshima R (2009) Recent trends in the incidence and lifetime risk of hip fracture in Tottori, Japan. *Osteoporos Int* 20:543–548
- Chie WC, Yang RS, Liu JP, Tsai KS (2004) High incidence rate of hip fracture in Taiwan: estimated from a nationwide health insurance database. *Osteoporos Int* 15:998–1002
- Lim S, Koo BK, Lee EJ, Park JH, Kim MH, Shin KH, Ha YC, Cho NH, Shin CS (2008) Incidence of hip fractures in Korea. *J Bone Miner Metab* 26:400–405
- Wallace BA, Cumming RG (2000) Systematic review of randomized trials of the effect of exercise on bone mass in pre- and postmenopausal women. *Calcif Tissue Int* 67:10–18
- Sakata T, Sakai A, Tsurukami H, Okimoto N, Okazaki Y, Ikeda S, Norimura T, Nakamura T (1999) Trabecular bone turnover and bone marrow cell development in tail-suspended mice. *J Bone Miner Res* 14:1596–1604
- Sakai A, Sakata T, Tanaka S, Okazaki R, Kunugita N, Norimura T, Nakamura T (2002) Disruption of the p53 gene results in preserved trabecular bone mass and bone formation after mechanical unloading. *J Bone Miner Res* 17:119–127
- Sakai A, Nakamura T, Tsurukami H, Okazaki R, Nishida S, Tanaka Y, Norimura T, Suzuki K (1996) Bone marrow capacity for bone cells and trabecular bone turnover in immobilized tibia after sciatic neurectomy in mice. *Bone* 18:479–486
- Sakai A, Sakata T, Ikeda S, Uchida S, Okazaki R, Norimura T, Hori M, Nakamura T (1999) Intermittent administration of human parathyroid hormone(1–34) prevents immobilization-related bone loss by regulating bone marrow capacity for bone cells in ddY mice. *J Bone Miner Res* 14:1691–1699
- Sakamoto K (2006) Effects of unipedal standing balance exercise on the prevention of falls and hip fracture. *Clin Calcium* 16:2027–2032
- Sakamoto K, Nakamura T, Hagino H, Endo N, Mori S, Muto Y, Harada A, Nakano T, Itoi E, Yoshimura M, Norimatsu H, Yamamoto H, Ochi T, Committee on osteoporosis of the Japanese Orthopaedic Association (2006) Effects of unipedal standing

- balance exercise on the prevention of falls and hip fracture among clinically defined high-risk elderly individuals: a randomized controlled trial. *J Orthop Sci* 11:467–472
14. Sakamoto K, Sugimoto F, Sato Y, Fujimaki E, Tashiro Y (1999) Dynamic flamingo therapy for prevention of femoral neck osteoporosis and fractures. Part 1: theoretical background. *Showa Univ J Med Sci* 11:247–254
 15. Chow R, Harrison JE, Notarius C (1987) Effect of two randomised exercise programmes on bone mass of healthy postmenopausal women. *Br Med J* 295:1441–1444
 16. Gerber NJ, Rey B (1991) Can exercise prevent osteoporosis? *Br J Rheumatol* 30:2–4
 17. Asikainen TM, Kukkonen-Harjula K, Miilunpalo S (2004) Exercise for health for early postmenopausal women: a systematic review of randomised controlled trials. *Sports Med* 34:753–778
 18. Kemmler W, Lauber D, Weineck J, Hensen J, Kalender W, Engelke K (2004) Benefits of 2 years of intense exercise on bone density, physical fitness, and blood lipids in early postmenopausal osteopenic women: results of the Erlangen Fitness Osteoporosis Prevention Study (EFOPS). *Arch Intern Med* 164:1084–1091
 19. Sakai A, Toba N, Takeda M, Suzuki M, Abe Y, Aoyagi K, Nakamura T (2009) Association of unipedal standing time and bone mineral density in community-dwelling Japanese women. *Osteoporos Int* 20:731–736
 20. Taaffe DR, Simonsick EM, Visser M, Volpato S, Nevitt MC, Cauley JA, Tylavsky FA, Harris TB, Health ABC Study (2003) Lower extremity physical performance and hip bone mineral density in elderly black and white men and women: cross-sectional associations in the Health ABC Study. *J Gerontol A Biol Sci Med Sci* 58:M934–M942