Archives of Osteoporosis (2019) 14:103
https://doi.org/10.1007/s11657-019-0655-5

ORIGINAL ARTICLE

Effects of physical activity on bone mineral density in older adults: Korea National Health and Nutrition Examination Survey, 2008–2011

Ye An Kim[1] · Young Lee[2] · Ji Hyun Lee[1] · Je Hyun Seo[2]

Received: 15 July 2019 / Accepted: 9 September 2019

Abstract

Summary We compared the relationship between physical activity (PA) and bone mineral density (BMD) in men and women aged over 50 years. Only moderate-to-vigorous PA was positively associated with hip BMD in men. There was no association between PA and BMD at any site in women.

Introduction Physical activity (PA) is widely recommended for osteoporosis. However, epidemiological data regarding the intensity or volume of PA required for bone health are lacking. We aimed to investigate and compare the relationship between PA and bone mineral density (BMD) in men and women.

Methods This population-based cross-sectional study used data from the 4th and 5th Korea National Health and Nutrition Examination Surveys and included 2767 men and 2753 women aged > 50 years. The intensity, frequency, and duration of PA were assessed using a questionnaire, and the participants were divided into the no activity, walking-only, moderate PA, and vigorous PA groups. BMD was measured at the lumbar spine (LS), femur neck (FN), and total hip (TH) using dual-energy X-ray absorptiometry.

Results Adjusted-BMDs of the hip were higher in men and women in the moderate and vigorous PA groups than those in men and women in the walking-only and no activity groups, while frequency and duration of PA were not associated with BMD at any site. The odds ratios for osteoporosis were the lowest at the FN and TH in men in the vigorous PA group (0.354, 95% confidence interval (CI) 0.139–0.901, $P < 0.002$, and 0.072, 95% CI 0.007–0.766, $P < 0.003$, respectively), while it was not significant in women.

Conclusion Only moderate-to-vigorous PA was positively associated with the hip BMD in men. There was no association between PA and BMD at any site in women. It is necessary to assess the PA intensity for bone health based on the site and sex.

Keywords Aging · Bone mineral density · Osteoporosis · Exercise · Gender · Physical activity

Introduction

Osteoporosis is a metabolic bone disease that is characterized by reduced bone strength with an increased risk of fragility fractures [1]. With increasing life expectancy, the prevalence of osteoporosis has increased, with an estimated global prevalence of 200 million [2]. In South Korea, the reported prevalence of osteoporosis is 7.3% for men and 38.0% women aged over 50 years [3]. The mechanisms through which bone mineral density (BMD) reduces following peak bone mass are multifaceted and complex—changes in sex hormones, nutrition, and bone-loading, which contribute to bone loss across the lifespan of men and women—but there is an essential difference between the sexes [4]. Previous studies have demonstrated that the effects of exercise and sedentary behaviors on bones were different in women and men [5–7].

Regular physical activity (PA) is recommended as a safe strategy to counter the loss of bone mass that accompanies aging. It has been long established that to improve bone density, bone tissue must be subjected to more mechanical loading than that experienced during daily activities [8]. The effects of exercise on osteoporosis in women are controversial [9–12]. The results of exercise on the skeleton have been examined predominantly in pre- and post-menopausal women

Ye An Kim and Young Lee contributed equally to this work.

✉ Je Hyun Seo
jazmin2@naver.com

[1] Division of Endocrinology, Department of Internal Medicine, Veterans Health Service Medical Center, Seoul, South Korea

[2] Veterans Medical Research Institute, Veterans Health Service Medical Center, Jinhwangdo-ro 61-gil 53, Gangdong-gu, Seoul 05368, South Korea

Published online: 26 October 2019

due to the high rate of osteoporosis in women [13, 14]. Furthermore, few epidemiological studies have reported a conflicting relationship between PA and BMD in the elderly population over the age of 50 years. Consequently, it is noteworthy to evaluate the relationship between PA and BMD in elderly men and women using a nationally representative cohort. Therefore, the purpose of this study was to investigate the association between PA and BMD using the data from the Korea National Health and Nutrition Examination Survey (KNHANES 2008–2011).

Methods

The study was a cross-sectional investigation that was performed using the data from KNHANES IV–V performed in 2008–2011 by the Korea Centers for Disease Control and Prevention. KNHANES is an annual nationwide survey that evaluates the health and nutritional status of the Korean population and is a nationally representative cross-sectional survey that consists of medical history, physical examination, health behavior survey, and anthropometric and biochemical measurements.

We analyzed data of 4010 men and 5377 women over 50 years of age who underwent BMD evaluations during the survey period. The exclusion criteria were as follows: missing exercise data ($n = 107$), diseases that affect osteoporosis [rheumatoid arthritis ($n = 412$), malignancy ($n = 374$), chronic liver diseases ($n = 25$), chronic kidney disease ($n = 96$), and thyroid disease ($n = 109$)], medications affecting BMD [estrogen ($n = 664$), vitamin D and/or calcium ($n = 673$), and osteoporosis medications ($n = 317$)]. Overall, 6610 subjects (3357 men, 3253 women) were included in our analysis. If there was a missing PA-related variable or unknown weighted value calculated in the composite sample design ($n = 1090$), it was excluded from this study. Finally, 2767 men and 2753 women were included in the analyses.

Assessments of bone mineral density and biochemical parameters

BMD was measured in the lumbar spine (LS), femur neck (FN), and total hip (TH) using dual-energy X-ray absorptiometry (DXA; QDR4500A; Hologic Inc., Bedford, MA). The left hip was scanned routinely; however, in cases of left hip fractures, the right hip was scanned. Osteoporosis was defined as T-score < -2.5 at each skeletal site. The participants fasted for 8 h, and blood samples were collected and directly transported to the Central Testing Institute in Seoul, Korea (NeoDin Medical Institute, Seoul, Korea). Serum 25-hydroxyvitamin D [25(OH)D] levels were measured using a radioimmunoassay kit (DiaSorin Inc., Stillwater, MN, USA). Serum parathyroid (PTH) level was analyzed using a chemiluminescence assay (DiaSorin Inc.).

Assessment of physical activity: intensity, frequency, and duration

PA was evaluated using the International Physical Activity Questionnaire. The questionnaires were classified according to the intensity as we reported previously [15]. In brief, subjects were asked if they had exercised for at least 10 min during the last week in the form of different types of PA, such as walking only, moderate PA (slow swimming, playing tennis doubles/volleyball/badminton, and transporting light objects), and vigorous PA (running, mountain climbing, soccer/basketball/squash/tennis singles, fast cycling, fast swimming, skipping rope, and transporting heavy objects). A majority of questions were related to the intensity of PA, followed by questions related to the frequency and duration.

Since it was a questionnaire-based analysis, it was necessary to properly define a group to reflect, both, the structure of the questionnaire and the actual characteristics of the population. The frequency and duration for each PA intensity overlapped in those who indulged in walking, moderate PA, and vigorous PA, while they were limited in those who never performed PA. There was a group with no PA, including walking. Overall, the subjects were divided into four groups: "no activity," "walking-only," moderate PA, and vigorous PA groups. The "walking-only" group was defined separately because the "walking-only" group demonstrated a different pattern from those of the moderate PA and vigorous PA groups, which demonstrated similar volumes of walking, in addition to moderate-to-vigorous intensity.

Data analyses

To analyze the baseline characteristics of the participants according to the exercise activity, data were expressed as means and standard deviations for continuous variables after one-way analysis of variance and after a Rao–Scott chi-square test for categorical variables. Subgroup comparisons were performed using Bonferroni's correction after t test as the post hoc test since KNHANES dataset included a complex sampling design. Regression models were sequentially adjusted for the following variables: unadjusted, adjusted by body mass index (BMI) and age (model 1), and adjusted by age, BMI, smoking, alcohol intake, household income, total energy intake, and serum 25(OH)D (model 2). To further analyze BMD according to the physical activity groups, trend analysis and linear trend analysis were used. Statistical analyses were performed using R software version 3.5.1 (R Foundation, Vienna, Austria). Statistical significance was set at $P < 0.05$.

Table 1 Baseline characteristics of study subjects

	Men					Women				
	No activity ($n = 264$)	Walking-only ($n = 1090$)	Moderate ($n = 574$)	Vigorous ($n = 839$)	*P*	No activity ($n = 445$)	Walking-only ($n = 1106$)	Moderate ($n = 669$)	Vigorous ($n = 533$)	*P*
Age (years)	63.43 ± 0.74 a	62.51 ± 0.348 a	60.84 ± 0.456 b	57.93 ± 0.266 c	< 0.001*	66.55 ± 0.704 a	64.03 ± 0.345 b	62.28 ± 0.418 c	58.81 ± 0.448 d	< 0.001*
BMI (kg/m^2)	23.27 ± 0.189 a	23.7 ± 0.109 a	23.73 ± 0.157 ab	24.27 ± 0.121 b	< 0.001*	24.5 ± 0.201	24.31 ± 0.124	24.27 ± 0.127	24.32 ± 0.17	0.795*
Monthly household income (%)					< 0.001†					< 0.001†
Lowest	30.4 (3.21)	28.6 (1.7)	24.3 (2.01)	14.7 (1.34)		41.5 (2.83)	34.4 (1.91)	33.2 (2.23)	19.9 (1.89)	
Medium-lowest	23.8 (3)	27.9 (1.9)	27.3 (2.33)	25.7 (1.79)		23 (2.6)	27.3 (1.69)	28.1 (2.14)	29.5 (2.52)	
Medium-highest	28.2 (3.49)	21.4 (1.66)	23.8 (2.23)	26.3 (1.77)		19.8 (2.33)	20.2 (1.49)	20.5 (1.8)	25.5 (2.55)	
Highest	17.6 (3.11)	22.2 (1.58)	24.5 (2.22)	33.2 (2.18)		15.7 (2.02)	18.2 (1.64)	18.2 (1.94)	25.1 (2.54)	
Smoking status (%)					0.6411†					0.4001†
Never	12.5 (2.4)	16.4 (1.45)	16.2 (1.72)	16.7 (1.54)		88.7 (1.82)	90 (1.19)	92.8 (1.38)	92.9 (1.39)	
Ex-	50.8 (3.79)	49 (1.83)	44.7 (2.62)	47.7 (2.16)		4.4 (1.15)	4.3 (0.74)	3 (0.85)	2.8 (0.87)	
Current	36.7 (3.77)	34.6 (1.69)	39.1 (2.44)	35.6 (2.08)		7 (1.58)	5.7 (0.99)	4.2 (0.93)	4.3 (1.13)	
Alcohol consumption (%)					0.0051†					< 0.001†
None	25.1 (3.11)	23.9 (1.52)	22.1 (2.09)	15.9 (1.46)		57.5 (3.23)	54.3 (2.03)	56.6 (2.43)	42.1 (2.77)	
Moderate	37.8 (4.07)	33.7 (1.76)	33.7 (2.45)	39.2 (2.09)		37 (3.06)	39.7 (2.03)	38.5 (2.33)	48.6 (2.73)	
Heavy	37.1 (3.5)	42.4 (1.97)	44.2 (2.56)	44.9 (2.02)		5.5 (1.24)	5.9 (0.89)	5 (1.01)	9.4 (1.51)	
Total energy intake (kcal/day)	2080.44 ± 62.689 b	2051.59 ± 28.342 b	2272.15 ± 51.908 ab	2303.26 ± 34.347 a	< 0.001*	1415.95 ± 31.71 c	1499.52 ± 24.201 bc	1577.22 ± 34.417 ab	1603.85 ± 34.236 a	< 0.001*
Age adjusted	2075.88 ± 59.007	2025.61 ± 26.797	2208.26 ± 49.723	2173.34 ± 32.622	< 0.001*	1447.38 ± 31.628	1501.08 ± 23.84	1558.11 ± 34.112	1543.52 ± 33.92	0.069*
Dietary calcium intake (kcal/day)	488.67 ± 23.545 c	530.66 ± 12.075 bc	587.37 ± 24.455 ab	599.77 ± 15.516 a	< 0.001*	353.69 ± 17.116 b	390.78 ± 11.628 b	405.14 ± 13.375 ab	451.41 ± 16.125 a	0.001*
Age adjusted	487.33 ± 22.645	523.05 ± 11.617	568.65 ± 23.828	561.71 ± 15.062	0.017*	366.38 ± 17.198	391.41 ± 11.611	397.42 ± 12.934	427.05 ± 16.886	0.095*
Serum 25(OH)D	20.32 ± 0.569 b	20.69 ± 0.345 b	21.86 ± 0.508 a	21.4 ± 0.376 a	0.031*	16.84 ± 0.394 b	17.64 ± 0.355 ab	18.26 ± 0.351 a	18.13 ± 0.371 ab	0.033*
Age adjusted	20.34 ± 0.568	20.72 ± 0.345	21.93 ± 0.511	21.54 ± 0.381	0.023*	16.75 ± 0.394	17.64 ± 0.354	18.33 ± 0.354	18.35 ± 0.383	0.009*
Serum PTH	65.94 ± 1.996	63.49 ± 0.849	64.51 ± 1.478	64.86 ± 1.103	0.563*	74.26 ± 1.943 a	69.26 ± 1.141 ab	65.73 ± 1.673 bc	62.4 ± 1.304 c	< 0.001*
Age adjusted	66.03 ± 1.973	63.67 ± 0.836	64.88 ± 1.479	65.62 ± 1.1	0.410*	73.42 ± 1.977	69.24 ± 1.111	66.35 ± 1.686	64.33 ± 1.32	< 0.001*
Exercise frequency (times/week)										
Walking activity	0	5.03 ± 0.088 a	4.55 ± 0.148 b	4.4 ± 0.099 b	< 0.001*	0	4.9 ± 0.089	4.87 ± 0.109	4.56 ± 0.146	0.101*
Moderate activity	0	0	3.76 ± 0.109	2.17 ± 0.097	< 0.001‡	0	0	4.27 ± 0.101	2.68 ± 0.132	< 0.001‡
Vigorous activity	0	0	0	3.18 ± 0.091		0	0	0	3.35 ± 0.117	
Exercise duration (min/week)										
Walking activity	0	88.86 ± 3.507 ab	79.17 ± 5.654 b	97.5 ± 3.932 a	0.018*	0	69.38 ± 2.68	65.3 ± 3.842	71.07 ± 3.544	0.528*
Moderate activity	0	0	139.12 ± 6.262	77.03 ± 4.736	< 0.001‡	0	0	138.17 ± 9.154	78.94 ± 5.98	< 0.001‡
Vigorous activity	0	0	0	133.01 ± 5.054		0	0	0	131.48 ± 5.844	

Data with the same lowercase letters indicate non-specific differences between groups, while those with different letters are statistically different, based on post hoc test

Data are expressed as the mean ± SE or the percentage (SE)

**P* from ANOVA post hoc test was Bonferroni's correction after *t* test

†*P* from Rao-Scott chi square

‡*P* from independent *t* test

Table 2 Bone mineral density of study subjects according to physical activity

	Men					Women				
	No activity ($n = 264$)	Walking-only ($n = 1090$)	Moderate ($n = 574$)	Vigorous ($n = 839$)	*P*	No activity ($n = 445$)	Walking-only ($n = 1106$)	Moderate ($n = 669$)	Vigorous ($n = 533$)	*P*
Lumbar spine BMD (g/m^2)	0.93 ± 0.012	0.94 ± 0.006	0.94 ± 0.008	0.96 ± 0.006	0.047*	0.78 ± 0.009	0.8 ± 0.005	0.8 ± 0.007	0.85 ± 0.008	< 0.001*
	a	a	a	a		b	b	b	a	
Age and BMI adjusted	0.93 ± 0.011	0.94 ± 0.006	0.93 ± 0.007	0.94 ± 0.006	0.578*	0.8 ± 0.007	0.8 ± 0.004	0.79 ± 0.006	0.82 ± 0.007	0.101*
Femur neck BMD (g/m^2)	0.72 ± 0.009	0.74 ± 0.004	0.75 ± 0.006	0.79 ± 0.004	< 0.001*	0.59 ± 0.007	0.62 ± 0.004	0.63 ± 0.005	0.67 ± 0.006	< 0.001*
	c	bc	b	a		c	bc	b	a	
Age and BMI adjusted	0.72 ± 0.007	0.74 ± 0.004	0.74 ± 0.005	0.76 ± 0.004	< 0.001*	0.61 ± 0.005	0.62 ± 0.003	0.62 ± 0.004	0.63 ± 0.005	0.021*
Total hip BMD (g/m^2)	0.89 ± 0.01	0.92 ± 0.005	0.93 ± 0.006	0.96 ± 0.005	< 0.001*	0.74 ± 0.007	0.76 ± 0.004	0.78 ± 0.005	0.82 ± 0.007	< 0.001*
	c	bc	b	a		d	c	b	a	
Age and BMI adjusted	0.9 ± 0.008	0.91 ± 0.004	0.92 ± 0.005	0.94 ± 0.004	< 0.001*	0.76 ± 0.005	0.77 ± 0.003	0.77 ± 0.004	0.78 ± 0.006	0.004*

Data with the same lowercase letters indicate non-specific differences between groups, while those with different letters are statistically different, based on post hoc test

Data are expressed as the mean ± SE or the percentage (SE)

*P from ANOVA post hoc test was Bonferroni's correction after t test

Results

Characteristics of the study participants

The clinical characteristics of the study participants according to PA are summarized in Table 1. In both men and women, the mean age was lower in the vigorous PA group than that in the "no activity" group (all $P < 0.001$). Furthermore, the monthly household income was different according to PA in both men and women (all $P < 0.001$). Smoking status was not different but alcohol consumption was different in men and women ($P = 0.0051$ and $P < 0.001$, respectively). The total energy intake in the vigorous PA group was higher than that in the no activity group following adjustments for age in men ($P < 0.001$), while it was marginally different in women ($P = 0.069$). Similarly, the dietary calcium intake in the vigorous exercise group was higher than that in "no activity" group following adjustments for age in men ($P = 0.017$), while it was marginally different in women ($P = 0.095$). Serum 25(OH)D level was significantly higher in both men and women of the vigorous PA group ($P = 0.023$ and $P = 0.009$, respectively). Serum PTH levels were lower in only women with vigorous PA ($P < 0.001$), while there was no difference in men ($P = 0.410$). Differences in the frequency and duration of exercising were observed between groups according to PA in both men and women, except for walking in women. The frequency of PA tended to be proportional to PA intensity. Moderate PA and vigorous PA had comparable walking parameters when compared with those in the "walking-only" group. The vigorous PA group had the most abundant PA time, when compared with PA time in groups of walking-only and moderate PA.

Bone mineral density according to physical activity

In both men and women, BMD at LS varied according to the physical activity, but there were no statistical differences after adjusting for age and BMI ($P = 0.578$ and $P = 0.101$, respectively, Table 2). However, BMD at both FN and TH demonstrated differences in PA even after adjusting for age and BMI in men ($P < 0.001$ and $P < 0.001$, respectively). Similarly, in women, BMD at FN and TH demonstrated significant differences ($P = 0.021$ and $P = 0.004$, respectively). Linear trend analysis in both men and women revealed that PA intensity was related to BMD at FN ($P < 0.001$ and $P = 0.019$, respectively; Fig. 1) and TH ($P = 0.001$ and $P = 0.004$, respectively) but not to BMD at LS ($P = 0.964$ and $P = 0.224$, respectively).

The BMD data according to the frequency or duration of PA in both men and women following adjustments are summarized in Table 3. Although statistically significant findings were not observed, the frequency of walking activity was related with BMD at LS in men ($P = 0.007$), the

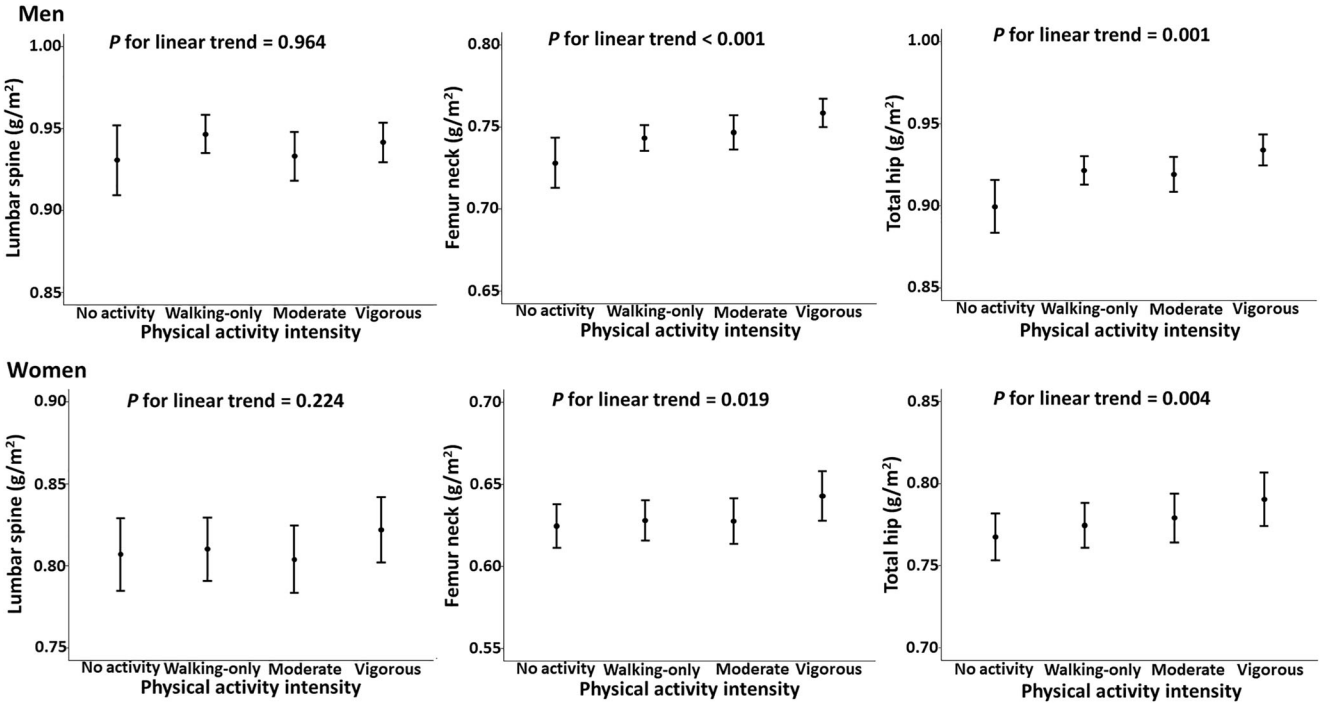

Fig. 1 Mean bone mineral density at the lumbar spine, femur neck, and total hip according to the intensity of physical activities in men and women aged over 50 years using linear trend analysis. *P* for linear trend by linear regression model after adjusting for age, body mass index, serum 25-hydroxyvitamin D concentration, smoking, monthly income, and total energy intake

duration of walking was related with BMD at TH in men ($P = 0.034$), and the duration of vigorous PA was related with BMD at FN in women ($P = 0.039$). In men, trend analysis demonstrated that exercise frequency was significantly correlated with BMD at LS (*P* for trend = 0.012; Fig. 2), and exercise duration was marginally related to BMD at FN and TH (*P* for trend = 0.072 and 0.071, respectively). In women, trend analysis revealed that the exercise duration was related to BMD at FN and TH (*P* for trend = 0.032 and 0.037, respectively; Fig. 2).

In the vigorous PA group in men, the odds ratio (OR) of osteoporosis defined by T-score < − 2.5 at FN and TH were 0.345 (95% confidence interval (CI) 0.145–0.817) and 0.078 (95% CI 0.009–0.662) in model 1 and 0.354 (95% CI 0.139–0.901) and 0.072 (95% CI 0.007–0.766) in model 2, respectively (Table 4). Men with moderate PA also demonstrated a lower risk of osteoporosis at FN (0.450, 95% CI 0.206–0.984 and 0.397, 95% CI 0.158–0.994, respectively) in models 1 and 2, at TH (0.146, 95% CI 0.028–0.745 and 0.127, 95% CI 0.018–0.876, respectively) in models 1 and 2, while there was no risk reduction in the "walking-only" group. In women, the ORs of osteoporosis were low in LS, FN, and TH with vigorous PA and in FN and TH with moderate physical activity; however, the significance disappeared in adjusted models 1 and 2.

Discussion

This cross-sectional study demonstrated that PA intensity was positively correlated with BMD at FN and TH in men and women aged > 50 years, whereas it was not associated with BMD at LS. The frequency and duration of physical activity, however, did not demonstrate a consistent association with BMD at any site in, both, men and women. The risk of osteoporosis was lower in men with moderate-to-vigorous PA when compared with those who only walked or had no activity, although there was no similar risk reduction with PA in women.

Our findings are consistent with those of a systematic review that suggested regular resistance training and impact-loading activities other than walking as a strategy to prevent osteoporosis among middle-aged and older men [16]. The meta-analyses showed that walking was less effective in increasing BMD in older adults [17, 18]. A randomized controlled trial that investigated the effects of a multi-component exercise program and vitamin D3-milk demonstrated that exercise was effective on BMD at FN in older men; however, additional vitamin D3 did not enhance the osteogenic response [19]. In a subsequent study, they demonstrated that high-impact loading exercise resulted in a net gain of 2.1% and 2.2% in BMD of FN and LS, respectively [20], which is different from the negligible association with LS BMD in our

Table 3 Adjusted mean values of bone mineral density according to the frequency or duration of physical activities in men and women

	Men			Women		
	Lumbar spine	Femur neck	Total hip	Lumbar spine	Femur neck	Total hip
Walking group	*n* = 1090			*n* = 1106		
Frequency						
1–3	0.92 ± 0.01	0.73 ± 0.007	0.9 ± 0.008	0.8 ± 0.014	0.61 ± 0.009	0.76 ± 0.01
4–6	0.96 ± 0.014	0.74 ± 0.01	0.92 ± 0.01	0.82 ± 0.015	0.62 ± 0.009	0.77 ± 0.011
Everyday	0.95 ± 0.009	0.74 ± 0.006	0.92 ± 0.006	0.79 ± 0.013	0.62 ± 0.009	0.76 ± 0.009
P	0.007	0.248	0.214	0.089	0.322	0.731
Duration						
< 3	0.94 ± 0.007	0.73 ± 0.005	0.91 ± 0.005	0.8 ± 0.012	0.62 ± 0.008	0.77 ± 0.009
3–7	0.95 ± 0.017	0.74 ± 0.01	0.91 ± 0.012	0.8 ± 0.018	0.61 ± 0.012	0.76 ± 0.013
≥ 7	0.99 ± 0.029	0.78 ± 0.022	0.96 ± 0.019	0.8 ± 0.042	0.61 ± 0.02	0.74 ± 0.019
P	0.237	0.070	0.034	0.951	0.511	0.358
Moderate PA group	*n* = 574			*n* = 669		
Frequency						
1–3	0.93 ± 0.011	0.74 ± 0.007	0.91 ± 0.007	0.81 ± 0.025	0.63 ± 0.016	0.78 ± 0.018
4–6	0.91 ± 0.015	0.75 ± 0.011	0.92 ± 0.012	0.82 ± 0.025	0.64 ± 0.017	0.79 ± 0.02
Everyday	0.94 ± 0.014	0.73 ± 0.01	0.91 ± 0.01	0.8 ± 0.026	0.63 ± 0.015	0.79 ± 0.017
P	0.392	0.404	0.791	0.680	0.674	0.885
Duration						
< 3	0.93 ± 0.009	0.74 ± 0.006	0.91 ± 0.007	0.8 ± 0.024	0.63 ± 0.015	0.78 ± 0.017
3–7	0.93 ± 0.014	0.75 ± 0.01	0.92 ± 0.01	0.81 ± 0.029	0.65 ± 0.019	0.8 ± 0.02
≥ 7	0.95 ± 0.023	0.77 ± 0.019	0.94 ± 0.016	0.82 ± 0.035	0.65 ± 0.02	0.79 ± 0.022
P	0.738	0.151	0.156	0.780	0.091	0.290
Vigorous PA group	*n* = 839			*n* = 533		
Frequency						
1–3	0.96 ± 0.007	0.78 ± 0.006	0.95 ± 0.006	0.86 ± 0.021	0.68 ± 0.015	0.83 ± 0.014
4–6	0.95 ± 0.013	0.77 ± 0.009	0.94 ± 0.01	0.83 ± 0.024	0.66 ± 0.02	0.81 ± 0.019
Everyday	0.95 ± 0.016	0.77 ± 0.011	0.95 ± 0.01	0.85 ± 0.027	0.66 ± 0.017	0.82 ± 0.015
P	0.807	0.373	0.542	0.231	0.105	0.375
Duration						
< 3	0.95 ± 0.007	0.77 ± 0.006	0.95 ± 0.006	0.86 ± 0.02	0.67 ± 0.014	0.82 ± 0.014
3–7	0.95 ± 0.011	0.79 ± 0.009	0.96 ± 0.009	0.83 ± 0.023	0.66 ± 0.016	0.82 ± 0.015
≥ 7	1 ± 0.031	0.79 ± 0.027	0.95 ± 0.025	0.86 ± 0.032	0.72 ± 0.025	0.86 ± 0.025
P	0.345	0.230	0.383	0.147	0.039	0.189

Regression analysis adjusted with age, BMI, smoking, drinking, total energy intake, monthly income, serum 25-hydroxylvitamin D concentration

study. The effect of PA is not consistent in population studies due to the heterogeneity of the type of exercises and the composition of the study population. Recent studies have emphasized the effects of sedentary behavior on bone health and compositional analyses of habitual PA with sex specificity have been undertaken [5, 7, 21]. Interestingly, these studies consistently demonstrated a positive correlation between moderate-to-vigorous PA and hip bone in men, while the results were inconsistent in women.

Osteoporosis in men is increasingly recognized as a heterogeneous condition with diverse etiologies [22, 23]. Three predominant factors contribute to bone fragility in men: alterations in sex hormone levels, genetic factors, and secondary modifiable factors such as alcohol abuse and glucocorticoid use [23, 24]. In men of 50–70 years of age, born turnover and microarchitectural parameters were more stable than those in men aged < 50 or > 70 years [25]. PA is considered an essential stimulus for bone osteogenesis and its protective action might reduce the effects of bone resorption owing to other factors [26]. According to the Wolff's law of describing bone formation on mechanical loading, which emphasized the concept of coupled association of muscles on bone remodeling [26], there may be differences between the sexes due to the higher muscle mass in men.

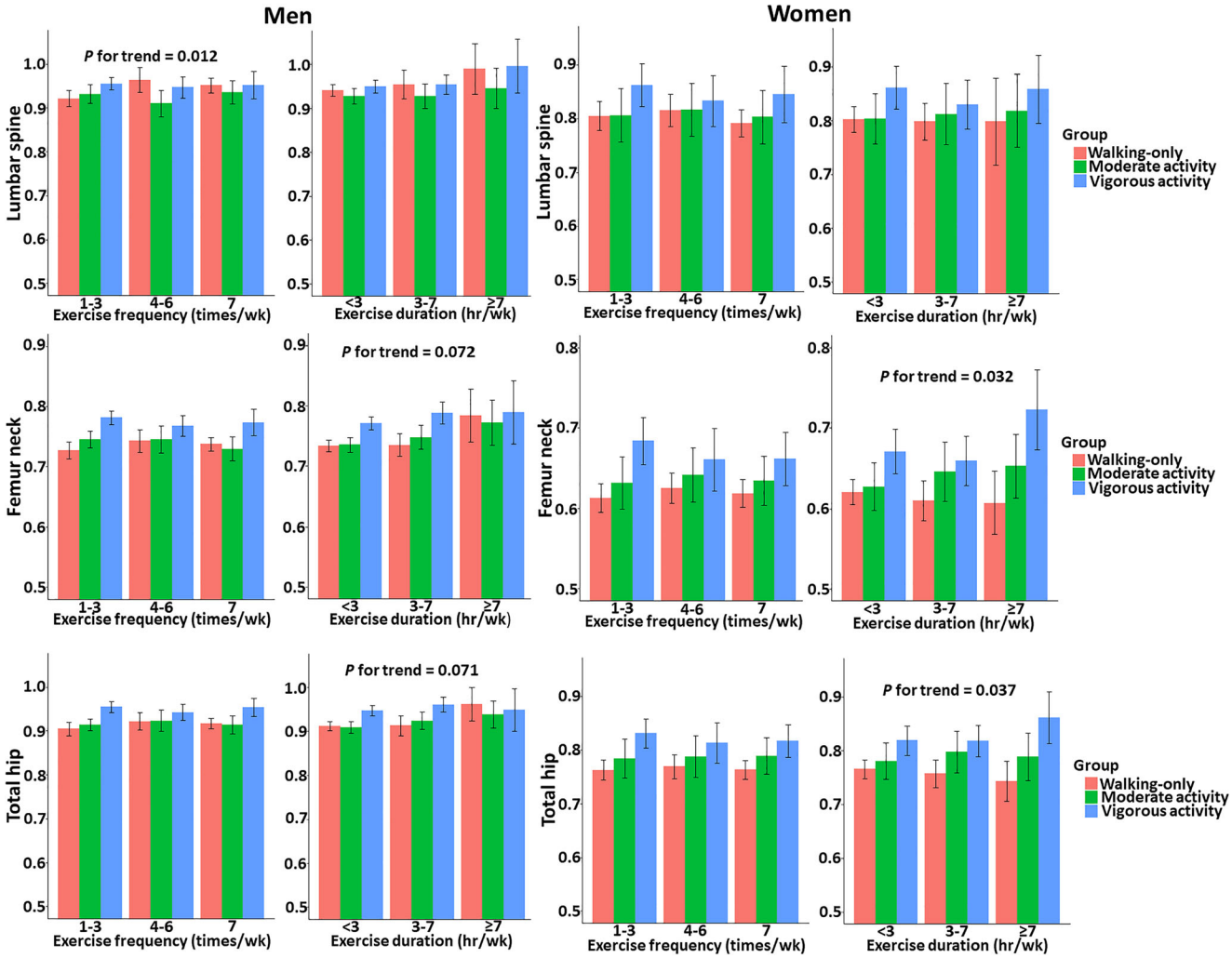

Fig. 2 Mean bone mineral density at lumbar spine, femur neck, and total hip according to the frequency and duration by physical activities in men and women aged over 50 years using trend analysis. *P* for trend by linear regression model after adjusting for age, body mass index, serum 25-hydroxyvitamin D concentration, smoking, monthly income, and total energy intake. In case of P for trend is less than 0.1 is indicated on the graph

On the other hand, age-related reduction in BMD is generally accelerated in women after menopause [27]. However, the type of PA that would be better in stimulating bone metabolism and enhancing the physical function in postmenopausal women is unclear. Only a few studies have reported on the effects of exercise on BMD in postmenopausal women with exercise periods of 5 years or more [28–30]. Although the findings of these studies were not consistent, there is increasing evidence that physical exercise can prevent BMD changes in postmenopausal women [31]. Kemmler et al. demonstrated that BMD reduction in LS was significantly lower in the exercise group, while the same in TH was not significant [11]. This is a significant study with a long observation period; however, the small number of subjects was one of its limitations. According to another study [12], exercise did not affect bone loss at any site in postmenopausal women; however, the study suggested interaction effects of calcium supplements and exercise at the femoral site. Rapid bone loss owing to menopause makes it more difficult for women to respond to increases in BMD, and older women may need osteoporosis medications in addition to PA to increase BMD. In this study, we excluded people who took medications affecting BMD ($n = 664$ for estrogen, $n = 673$ for vitamin and/or calcium, $n = 317$ for osteoporosis medications), while other studies showed that combining structured PA and osteoporosis medications is important to increase bone density among older women [32–34]. Thus, it may be one of the reasons that women in our study did not show significant increase in BMD as those who were on medications for osteoporosis were excluded. Future research should investigate if patients on medications for osteoporosis showed increase in BMD.

Table 4 Odds ratio for osteoporosis according to exercise intensity

	No activity	Walking-only	Moderate	Vigorous	*P*
Men ($n = 2767$)	$n = 264$	$n = 1090$	$n = 574$	$n = 839$	
T score < −2.5 at lumbar spine					
Unadjusted	1	0.791 (0.443–1.412)	0.541 (0.285–1.029)	0.462 (0.255–0.836)	0.003
Model 1	1	0.902 (0.502–1.622)	0.661 (0.346–1.264)	0.773 (0.407–1.466)	0.330
Model 2	1	0.742 (0.396–1.390)	0.534 (0.274–1.042)	0.653 (0.335–1.275)	0.248
T score < − 2.5 at femur neck					
Unadjusted	1	0.764 (0.407–1.431)	0.314 (0.144–0.685)	0.123 (0.055–0.275)	0.000
Model 1	1	0.990 (0.517–1.896)	0.450 (0.206–0.984)	0.345 (0.145–0.817)	0.001
Model 2	1	0.985 (0.457–2.125)	0.397 (0.158–0.994)	0.354 (0.139–0.901)	0.002
T score < − 2.5 at total hip					
Unadjusted	1	0.439 (0.177–1.090)	0.095 (0.021–0.426)	0.021 (0.003–0.170)	0.000
Model 1	1	0.581 (0.231–1.460)	0.146 (0.028–0.745)	0.078 (0.009–0.662)	0.001
Model 2	1	0.487 (0.181–1.310)	0.127 (0.018–0.876)	0.072 (0.007–0.766)	0.003
Women ($n = 2753$)	$n = 445$	$n = 1106$	$n = 669$	$n = 533$	
T score < − 2.5 at lumbar spine					
Unadjusted	1	0.824 (0.624–1.087)	0.895 (0.671–1.195)	0.485 (0.345–0.682)	0.000
Model 1	1	1.056 (0.754–1.478)	1.382 (0.974–1.962)	0.965 (0.655–1.420)	0.625
Model 2	1	0.960 (0.675–1.365)	1.174 (0.818–1.684)	0.910 (0.608–1.364)	0.947
T score < − 2.5 at femur neck					
Unadjusted	1	0.640 (0.479–0.855)	0.498 (0.357–0.695)	0.330 (0.228–0.477)	0.000
Model 1	1	0.872 (0.616–1.234)	0.806 (0.513–1.266)	0.919 (0.590–1.431)	0.619
Model 2	1	0.842 (0.587–1.209)	0.849 (0.542–1.330)	0.975 (0.608–1.563)	0.991
T score < − 2.5 at total hip					
Unadjusted	1	0.514 (0.323–0.816)	0.390 (0.242–0.630)	0.147 (0.066–0.326)	0.000
Model 1	1	0.801 (0.468–1.369)	0.760 (0.425–1.356)	0.453 (0.175–1.172)	0.097
Model 2	1	0.631 (0.339–1.175)	0.742 (0.381–1.446)	0.515 (0.203–1.309)	0.219

Unadjusted: no adjustment; model 1: adjusted by age; BMI, model 2: adjusted by age, BMI, smoking, alcohol intake, household income, total energy intake, and serum 25(OH)D

It is necessary to analyze whether intensive PA was associated with increase in BMD at the FN and TH, and not at the LS for men. Recent systematic review reported significant effects of exercise on BMD of the femur, but not for LS among older men [9]. The reason for the effect of the site-specific exercise might be related to trabecular bone loss in femur and hip bone, which is more susceptible to mechanical unloading and might be resistant to age-related changes [32, 33]. According to a study of long-duration spaceflight, trabecular bone loss was greater in the hip compared with that in the spine (2.2–2.7% per month vs. 0.7% per month) [35]. Another spaceflight study reported that exercise interventions attenuated bone loss at the hip and the integrated muscle loss [36]. Although the effect of PA on LS BMD has not been identified in our study, other studies that showed increased LS BMD through PA among older men incorporated a structured weightlifting program with specific resistance training exercises that load the LS [18, 20]. Many studies showed that structured exercise programs with weight-bearing activity among older women were also effective in increasing the BMD [11, 12, 31]. In our study, PA was measured using the International Physical Activity Questionnaire short form (IPAQ-SF), which reflects "recreational and daily PA" and not structured exercise. These findings may suggest that recreational and daily PA can be beneficial in improving BMD at the FN and TH among older men, but older adults, including postmenopausal women should be recommended to undergo a structured exercise program to increase BMD with exercise designed to produce site-specific effects [37].

The effect of exercise on BMD was more prominent among men than among women. Unlike a gradual decrease among men, BMD changes after menopause among women were abrupt, suggesting the limited effects of exercise without the support of osteoporosis medications. In addition, our study showed that intensive PA was associated with BMD at FN and TH among older men, but not with BMD at LS, which suggested that a more structured PA might be required to increase BMD at LS or among postmenopausal women. A

major strength of our study is the inclusion of a large representative population with weighted data to reflect nationwide prevalence estimates. Additionally, we did not systematically organize the exercise programs and analyze the effects; instead, we divided the exercise patterns according to the IPAQ-SF and its validity in Koreans [38]. However, there are a few limitations to this study. First, it was a cross-sectional design and, therefore, our results could not identify a causal relationship. Second, since all of the information was based on self-reported health surveys, there may be acquiescence bias or recall bias, which may have resulted in misclassification. Third, the relationship between exercise volume and osteoporosis may be underestimated or overestimated in our analyses, which were mainly based on the exercise intensity.

Conclusion

In both men and women, there was no statistically significant difference in BMD at LS according to the intensity of PA after adjusting for age and BMI. However, BMD at both FN and TH demonstrated differences based on the exercise intensity even after adjusting for age and BMI. Logistic regression analysis of the intensity of PA and BMD at FN and TH revealed a strong relationship between them in men, which may suggest the protectives effect of intense exercise, whereas, in women, similar findings were not observed.

Compliance with ethical standards

Ethical approval Korea National Health and Nutrition Examination Survey (KNHANES) adheres to the principles outlined in the Declaration of Helsinki for research involving humans; all participants provided written informed consents and the protocol for KNHANES was approved by the Institutional Review Board of Korea Center for Disease Control and Prevention (No. 2008-04EXP-01-C, 2009-01CON-03-2C, 2010-02CON-21-C, and 2011-02CON-06-C). The current study did not require additional approval because the KNHANES dataset is publicly available (http://knahnes.cdc.go.kr).

Informed consent Informed consent was not required for this study because anonymized and de-identified data was used for the analyses.

Conflict of interest None.

References

1. Raisz LG (2005) Pathogenesis of osteoporosis: concepts, conflicts, and prospects. J Clin Invest 115:3318–3325
2. Reginster JY, Burlet N (2006) Osteoporosis: a still increasing prevalence. Bone 38:S4–S9
3. Park EJ, Joo IW, Jang MJ, Kim YT, Oh K, Oh HJ (2014) Prevalence of osteoporosis in the Korean population based on Korea National Health and Nutrition Examination Survey (KNHANES), 2008-2011. Yonsei Med J 55:1049–1057
4. Amin S, Khosla S (2012) Sex- and age-related differences in bone microarchitecture in men relative to women assessed by high-resolution peripheral quantitative computed tomography. J Osteoporos 2012:129760
5. Chastin SF, Mandrichenko O, Helbostadt JL, Skelton DA (2014) Associations between objectively-measured sedentary behaviour and physical activity with bone mineral density in adults and older adults, the NHANES study. Bone 64:254–262
6. Rodriguez-Gomez I, Manas A, Losa-Reyna J, Rodriguez-Manas L, Chastin SFM, Alegre LM, Garcia-Garcia FJ, Ara I (2019) The impact of movement behaviors on bone health in elderly with adequate nutritional status: compositional data analysis depending on the frailty status. Nutrients 11:
7. Onambele-Pearson G, Wullems J, Doody C, Ryan D, Morse C, Degens H (2019) Influence of habitual physical behavior - sleeping, sedentarism, physical activity - on bone health in community-dwelling older people. Front Physiol 10:408
8. Frost HM (1987) Bone "mass" and the "mechanostat": a proposal. Anat Rec 219:1–9
9. Kemmler W, Shojaa M, Kohl M, von Stengel S (2018) Exercise effects on bone mineral density in older men: a systematic review with special emphasis on study interventions. Osteoporos Int 29: 1493–1504
10. Kemmler W, von Stengel S, Kohl M (2016) Exercise frequency and bone mineral density development in exercising postmenopausal osteopenic women. Is there a critical dose of exercise for affecting bone? Results of the Erlangen Fitness and Osteoporosis Prevention Study. Bone 89:1–6
11. Kemmler W, Engelke K, von Stengel S (2016) Long-term exercise and bone mineral density changes in postmenopausal women–are there periods of reduced effectiveness? J Bone Miner Res 31:215–222
12. Lau EM, Woo J, Leung PC, Swaminathan R, Leung D (1992) The effects of calcium supplementation and exercise on bone density in elderly Chinese women. Osteoporos Int 2:168–173
13. Kelley GA, Kelley KS (2006) Exercise and bone mineral density at the femoral neck in postmenopausal women: a meta-analysis of controlled clinical trials with individual patient data. Am J Obstet Gynecol 194:760–767
14. Kelley GA, Kelley KS, Tran ZV (2002) Exercise and lumbar spine bone mineral density in postmenopausal women: a meta-analysis of individual patient data. J Gerontol A Biol Sci Med Sci 57:M599–M604
15. Lee SH, Lee Y, Seo JH, Kim YA (2018) Association between exercise and metabolic syndrome in Koreans. J Obes Metab Syndr 27: 117–124
16. Bolam KA, van Uffelen JG, Taaffe DR (2013) The effect of physical exercise on bone density in middle-aged and older men: a systematic review. Osteoporos Int 24:2749–2762
17. Nikander R, Sievanen H, Heinonen A, Daly RM, Uusi-Rasi K, Kannus P (2010) Targeted exercise against osteoporosis: a systematic review and meta-analysis for optimising bone strength throughout life. BMC Med 8:47
18. Benedetti MG, Furlini G, Zati A, Letizia Mauro G (2018) The effectiveness of physical exercise on bone density in osteoporotic patients. Biomed Res Int 2018:4840531
19. Kukuljan S, Nowson CA, Bass SL, Sanders K, Nicholson GC, Seibel MJ, Salmon J, Daly RM (2009) Effects of a multi-component exercise program and calcium-vitamin-D3-fortified milk on bone mineral density in older men: a randomised controlled trial. Osteoporos Int 20:1241–1251
20. Kukuljan S, Nowson CA, Sanders KM, Nicholson GC, Seibel MJ, Salmon J, Daly RM (2011) Independent and combined effects of calcium-vitamin D3 and exercise on bone structure and strength in older men: an 18-month factorial design randomized controlled trial. J Clin Endocrinol Metab 96:955–963

21. Rodriguez-Gomez I, Manas A, Losa-Reyna J, Rodriguez-Manas L, Chastin SFM, Alegre LM, Garcia-Garcia FJ, Ara I (2018) Associations between sedentary time, physical activity and bone health among older people using compositional data analysis. PLoS One 13:e0206013
22. Mohamad NV, Soelaiman IN, Chin KY (2016) A concise review of testosterone and bone health. Clin Interv Aging 11:1317–1324
23. Kanis JA, Bianchi G, Bilezikian JP, Kaufman JM, Khosla S, Orwoll E, Seeman E (2011) Towards a diagnostic and therapeutic consensus in male osteoporosis. Osteoporos Int 22:2789–2798
24. Khosla S (2010) Update in male osteoporosis. J Clin Endocrinol Metab 95:3–10
25. Chaitou A, Boutroy S, Vilayphiou N, Munoz F, Delmas PD, Chapurlat R, Szulc P (2010) Association between bone turnover rate and bone microarchitecture in men: the STRAMBO study. J Bone Miner Res 25:2313–2323
26. Frost HM (1994) Wolff's law and bone's structural adaptations to mechanical usage: an overview for clinicians. Angle Orthod 64: 175–188
27. Manolagas SC, Kousteni S, Jilka RL (2002) Sex steroids and bone. Recent Prog Horm Res 57:385–409
28. Korpelainen R, Keinanen-Kiukaanniemi S, Nieminen P, Heikkinen J, Vaananen K, Korpelainen J (2010) Long-term outcomes of exercise: follow-up of a randomized trial in older women with osteopenia. Arch Intern Med 170:1548–1556
29. Sinaki M, Itoi E, Wahner HW, Wollan P, Gelzcer R, Mullan BP, Collins DA, Hodgson SF (2002) Stronger back muscles reduce the incidence of vertebral fractures: a prospective 10 year follow-up of postmenopausal women. Bone 30:836–841
30. Uusi-Rasi K, Sievanen H, Heinonen A, Vuori I, Beck TJ, Kannus P (2006) Long-term recreational gymnastics provides a clear benefit in age-related functional decline and bone loss. A prospective 6-year study. Osteoporos Int 17:1154–1164
31. Kelley GA, Kelley KS, Kohrt WM (2012) Effects of ground and joint reaction force exercise on lumbar spine and femoral neck bone mineral density in postmenopausal women: a meta-analysis of randomized controlled trials. BMC Musculoskelet Disord 13:177
32. Zhao R, Xu Z, Zhao M (2015) Effects of oestrogen treatment on skeletal response to exercise in the hips and spine in postmenopausal women: a meta-analysis. Sports Med 45:1163–1173
33. Zhao R, Xu Z, Zhao M (2015) Antiresorptive agents increase the effects of exercise on preventing postmenopausal bone loss in women: a meta-analysis. PLoS One 10:e0116729
34. Zhang J, Gao R, Cao P, Yuan W (2014) Additive effects of antiresorptive agents and exercise on lumbar spine bone mineral density in adults with low bone mass: a meta-analysis. Osteoporos Int 25:1585–1594
35. Lang T, LeBlanc A, Evans H, Lu Y, Genant H, Yu A (2004) Cortical and trabecular bone mineral loss from the spine and hip in long-duration spaceflight. J Bone Miner Res 19:1006–1012
36. Konda NN, Karri RS, Winnard A, Nasser M, Evetts S, Boudreau E, Caplan N, Gradwell D, Velho RM (2019) A comparison of exercise interventions from bed rest studies for the prevention of musculoskeletal loss. NPJ Microgravity 5:12
37. Giangregorio LM, Papaioannou A, Macintyre NJ et al (2014) Too fit to fracture: exercise recommendations for individuals with osteoporosis or osteoporotic vertebral fracture. Osteoporos Int 25:821–835
38. Kim YA (2018) Association between exercise and metabolic syndrome in Koreans (J Obes Metab Syndr 2018;27:117-24). J Obes Metab Syndr 27:264–266