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Longitudinal Study on Physical Fitness Parameters Influencing Bone Mineral Density Reduction in Middle-aged and Elderly Women: Bone mineral density in the lumbar spine, femoral neck, and femur

Tadayuki IIDA[1,*], Hiromi IKEDA[2], Michihisa SHIOKAWA[2], Satomi AOI[2], Fumiko ISHIZAKI[2], Toshihide HARADA[2] and Yuichiro ONO[1]

1) Department of Public Health, Fujita Health University, Toyoake, Aichi 470-1192, Japan
2) Faculty of Health and Welfare, Prefectural University of Hiroshima, 1-1 Gakuen-cho, Mihara, Hiroshima 723-0053, Japan

ABSTRACT

The prolongation of the average life span of women has been associated with the rapidly aging society. However, serious problem have arisen as a result, such as an increase in the number of bed-ridden elderly patients with osteoporosis-associated femoral neck fracture. As preventive measures against osteoporosis for middle-aged to elderly women, 10,000 steps per day and intense exercise have been reported to inhibit bone mineral density (BMD) reduction. However, only a few studies have concretely reported on the type of physical fitness that is effective for BMD in particular parts of the body. In this study, a one-year longitudinal survey was performed involving generally healthy postmenopausal women to investigate physical fitness parameters influencing BMD in the lumbar spine, femoral neck, and femur.

The subjects were 38 female residents of M City, aged 49-73 years. As physical fitness parameters, sit-ups, anteflexion in a sitting position, grip strength, mean amount of exercise (kcal), and area of outer body sway on standing straight with the eyes closed (m^2) were measured. The BMD was measured in the lumbar spine (L2-L4), femoral neck, and femur. Logistic regression analysis was performed regarding the physical fitness parameters as explanatory variables and groups with and without BMD reduction over one year as those with and without risk as dependent variables.

The number of sit-ups (odds ratio: 0.76, 95% CI: 0.61-0.96, p=0.022) was a preventive factor against BMD reduction of the lumbar spine, and ante flexion in a sitting position was a preventive factor against BMD reduction of the femoral neck (odds ratio: 0.88, 95% CI: 0.78-0.99, p=0.029). Regarding BMD reduction of the femur, the area of outer body sway on standing straight with the eyes closed tended to be not significant to the risk. It is suggested that physical fitness and local muscle strength are associated with BMD reduction in the lumbar spine, femoral neck, and femur.

Key words: *Physical fitness parameters, Muscle strength, Bone mineral density, Lumbar spine, Femoral neck*

Aging has been progressing at an unprecedented speed in Japan. The ratio of the elderly, aged 65 years or older, currently accounts for 20.1% of the population and is predicted to reach 28.85% in 2020 (the Statistics Bureau and the Director-General for Policy Planning). Under these circumstances, various studies on the association between lifestyles and BMD have been reported because the number of elderly patients who are bed-ridden due to osteoporosis-associated fracture has rapidly increased[2,9,13,17,21].

Exercise is reportedly more important than nutrition in lifestyle management. Wolff et al[26] performed a meta-analysis, and concluded that

* Correspondence: Tadayuki Iida, R.T., Ph.D.
Department of Public Health, Fujita Health University School of Medicine, 1-98, Dengakugakubo, Kutsukakecho, Toyoake, Aichi 470-1192, Japan
Tel: +81-562-93-2453, Fax: +81-562-93-3079, E-mail: iida@fujita-hu.ac.jp (T. Iida)

exercise at least prevents BMD reduction of the vertebral body and femoral neck. Also, Wallace et al[23] reported that lumbar spine and femoral neck BMD were maintained or increased in an exercise group compared to those in a non-exercise group. In a recent report[25], bone resorption marker levels, such as blood NTX, decreased after 8 hr of resistance exercise at a moderate intensity. These findings are consistent with the viewpoint that exercise is directly involved in bone resorption and exhibits a preventive effect on BMD reduction[14,24]. However, there have been few studies on the relationship between the muscle strength directly supporting the body and limbs and BMD reduction. Shinaki et al[19] observed a positive correlation between dorsal muscle strength and lumbar spine BMD, and Sööt et al[20] suggested an association between lower limb muscle strength and BMD. Although cross-sectional studies have reported that the influence of stimulation by muscle contraction around bone and weight-bearing increased the BMD, no study has shown concretely which muscles are effective for the prevention of BMD reduction in which region, because a longitudinal field survey is essential to clarify the relationship between muscle strength and BMD reduction. To our knowledge, no muscle strength measurement or physical fitness survey has been performed in previous field surveys.

We performed a one-year longitudinal survey involving generally healthy postmenopausal women to investigate factors of physical fitness parameters influencing BMD reduction of the lumbar spine, femoral neck, and femur.

MATERIALS AND METHODS

Subjects

The BMD was measured in female subjects in their 40-70s living in M City, Hiroshima Prefecture, in December 2006 and December 2007. Persons who wanted to participate were recruited, the content and method of the study were fully explained before its initiation, and written consent was obtained. Fifty-eight subjects volunteered for the study in 2006. Subjects with artificial menopause due to hysterectomy or ovariectomy and diseases influencing bone metabolism were excluded at that time. The remaining thirty-eight subjects, whose physical characteristics, physical fitness parameters and BMD were measured, were the target subjects for analysis in both 2006 and 2007. A questionnaire about the use of therapeutic drugs (Bisphosphonate etc.) for the treatment of osteoporosis was completed. However, there was no user among the subjects of analysis. This study was performed in conformity with the Declaration of Helsinki after approval by the Ethics Committee of Prefectural University of Hiroshima (approval number: 10).

Measurement

We measured physical characteristics, physical fitness parameters, and the BMD. The body mass index (kg/m^2) (BMI) was calculated from the height and body weight measured as physical characteristics. As physical fitness parameters, sit-ups, anteflexion in a long sitting position, grip strength, mean amount of exercise, and body sway were utilized. In sit-ups, performance during a 30-sec period was counted calculated once. Anteflexion in a long sitting position was measured twice, and the longer distance was adopted. The grip strength of both hands was measured alternately twice each, using a hand dynamometer (ST100, TOEI LIGHT Co., Ltd.), and the higher values of the bilateral hands were averaged and regarded as the measured value. Regarding the mean amount of exercise, the subject had a life recorder (lifestyle recorder, Lifecorder EX, SUZUKEN) attached over the survey period (one year), and the mean daily amount (kcal) was calculated. In body sway measurement, the body sway path was recorded for 30 sec while standing with the eyes closed using a stabilometer (Gravicorder GS-7, ANIMA Corp.), and the area of outer body sway with the eyes closed was employed for the evaluation. The BMD (g/cm^2) was measured in the lumbar spine (L2-L4), left femoral neck, and left femur using an X-ray BMD measurement device (QDR-4500, Hologic Co., U.S.A.). This device was calibrated 99 times during the survey period: mean=1.038 g/cm^2, SD=0.003 g/cm^2, and cv=0.37%. These values were within the normal ranges specified by Hologic Co.

Outcome

BMD reduction was calculated by subtracting the value measured in 2007 from that in 2006 in the lumbar spine, femoral neck, and femur. BMD reductions were classified into a group with the BMD maintained for one year as within the normal range (lumbar spine: n=17, femoral neck: n=18. femur: n=16), and a group with reduction as an abnormal reduction (lumbar spine: n=21, femoral neck: n=20, femur: n=22)

Data analysis

The height, body weight, and BMI were compared between the subjects analyzed and those excluded, who were regarded as control subjects. The lumbar spine, femoral neck, and femoral BMD were compared between 2006 and 2007, employing the paired-t test.

Regarding variables of the outcome as dependent variables, influences of risk factors of BMD reduction were investigated employing a logistic regression model. Regarding sit-ups, anteflexion in a long sitting position, grip strength, mean amount of exercise, and area of outer body sway on straight standing with the eyes closed as

Table 1. Physical characteristics and results of physical fitness and muscle strength measurements in the subjects and those excluded from analysis

	Mean	(SD)	Min – Max	National Health and Nutrition Survey*1		Survey of physical strength and sporting ability*1		Subjects excluded from analysis (including those with missing data)		p-value*2
				50-59	60-69	55-59	60-64	Mean (SD)	Min – Max	
Age (years)	60.9	(7.0)	49 – 74					62.7 (8.1)	51.0 – 74.0	0.317
Height (cm)	153.7	(4.2)	145.1 – 162.2	154.5	151.4			153.4 (6.0)	141.5 – 163.6	0.873
Body weight (kg)	53.9	(9.2)	36.3 – 81.7	54.8	53.6			55.1 (7.8)	41.9 – 71.3	0.639
BMI	22.8	(3.9)	15.2 – 33.7	22.97	23.37			23.4 (3.1)	19.1 – 29.8	0.581
Sit-ups (number)	9.8	(5.9)	0 – 21			10.72	9.16			
Anteflexion in long sitting position (cm)	41.6	(8.7)	13 – 53			42.22	41.29			
Grip strength (kg)	24.1	(3.9)	15 – 32			26.87	25.64			
Mean amount of exercise (kcal)	223.5	(90.9)	74 – 464							
Area of outer body sway with eyes closed (g/cm^2)	2.1	(1.2)	0.6 – 5.12							

*1 Data from the 2004 National Health and Nutrition Survey and Survey of physical strength and sporting ability (Ministry of Education, Culture, Sports,Science and Technology).
*2 Subjects included in vs. subjects excluded from analysis

Table 2. Comparison of bone mineral density (lumbar spine, femoral neck, and femur) between 2006 and 2007

	2006		2007		Changes in BMD in 2007 from that in 2006		p-value
	Mean (SD)	Min – Max	Mean (SD)	Min – Max	Mean (SD)	Min – Max	
Lumbar spine BMD (g/cm^2)	0.879 (0.141)	0.620 – 1.358	0.872 (0.137)	0.636 – 1.322	-0.007 (0.023)	-0.061 – 0.037	0.0703
Femoral neck BMD (g/cm^2)	0.687 (0.116)	0.422 – 0.930	0.681 (0.114)	0.448 – 0.930	-0.006 (0.027)	-0.064 – 0.062	0.1824
Femoral BMD (g/cm^2)	0.827 (0.136)	0.605 – 1.142	0.815 (0.140)	0.581 – 1.108	-0.012 (0.040)	-0.097 – 0.081	0.0771

p-valueFpaired t-test of 2006 vs. 2007

explanatory variables, adjustment with the age and BMI influencing BMD was applied [10,16,22]. A p-value below 5% was regarded as significant. Statistical analysis was performed using SPSS 16.0J (SPSS Japan Inc., Tokyo).

RESULTS

Table 1 shows the physical characteristics and physical fitness parameters of the subjects included in and control subjects excluded from analysis in 2006. On comparison of the height (cm), body weight (kg), BMI, number of sit-ups, anteflexion in a long sitting position (cm), and grip strength (kg) with those in the National Health and Nutrition Survey and Survey of physical strength and sporting ability in 2004, all were slightly lower. On comparison of 38 subjects included in and 20 subjects excluded from analysis, there were no significant differences in the age (years), height (cm), body weight (kg), or BMI.

Table 2 shows the BMD in 2006 and 2007 in the subjects. The BMD values of the lumbar spine, femoral neck, and femur had decreased in 2007, but the changes were not significant.

In logistic regression analysis, when a low lumbar spine BMD was regarded as the outcome, a high number of sit-ups was associated as a preventive factor against a low lumbar spine BMD (OR: 0.763, 95% CI: 0.606-0.961, p=0.022) (Table 3). When a low femoral neck BMD was regarded as the outcome, the distance of anteflexion in a long sitting position was associated as a preventive factor against a low femoral neck BMD (OR: 0.876, 95% CI: 0.778-0.986, p=0.029) (Table 4). When a low femoral BMD was regarded as the outcome, the area of outer body sway on standing straight with the eyes closed tended to be associated with the risk factor of a low femoral BMD, although it was not significantly different (OR: 2.212, 95% CI: 0.935-5.231, p=0.071) (Table 5).

DISCUSSION

In this longitudinal study, physical fitness parameters were associated with BMD reduction after one year in postmenopausal women around 60 years of age. Muscle strength was particularly seen identified as a preventive factor against BMD reduction, which may be considered to be in accord with the mechanostat theory[5-7] proposed by Frost. The promotion of calcium deposition induced by

Table 3. Association of risk factors with bone mineral density reduction in the lumbar spine

	Odds ratio	95%CI	p-value
Sit-ups (number)	0.763	0.606 – 0.961	0.022
Anteflexion in long sitting position (cm)	1.026	0.913 – 1.153	0.665
Grip strength (kg)	0.906	0.710 – 1.156	0.427
Mean amount of exercise (kcal)	1.008	0.996 – 1.021	0.206
Area of outer body sway with eyes closed (g/cm^2)	0.650	0.304 – 1.390	0.266

*Logistic regression analysis after adjustment for age and BMI

Table 4. Association of risk factors with bone mineral density reduction in the femoral neck

	Odds ratio	95%CI	p-value
Sit-ups (number)	1.121	0.931 – 1.349	0.230
Anteflexion in long sitting position (cm)	0.876	0.778 – 0.986	0.029
Grip strength (kg)	1.064	0.866 – 1.308	0.554
Mean amount of exercise (kcal)	1.004	0.993 – 1.015	0.503
Area of outer body sway with eyes closed (gcm^2)	0.859	0.417 – 1.772	0.681

*Logistic regression analysis after adjustment for age and BMI

Table 5. Association of risk factors with bone mineral density reduction in the whole femur

	Odds ratio	95%CI	p-value
Sit-ups (number)	1.042	0.871 – 1.246	0.655
Anteflexion in long sitting position (cm)	1.001	0.896 – 1.118	0.985
Grip strength (kg)	0.903	0.728 – 1.120	0.354
Mean amount of exercise (kcal)	0.999	0.988 – 1.010	0.847
Area of outer body sway with eyes closed (g/cm^2)	2.212	0.935 – 5.231	0.071

*Logistic regression analysis after adjustment for age and BMI

microcrack is considered to be the mechanism of BMD increase. A mechanical load acting on bone distorts it (strain), and a strain greater than the threshold causes microfracture inside the bone. The transmission system (mechanostat) which repairs microfracture may promote calcium deposition through modeling and remodeling, increasing the BMD[8]. Blocks et al[3] reported that the continuation of aerobic exercise accompanied by weight-bearing increased the lumbar spine BMD even in middle-aged and elderly women, based on this theory. Rittweger et al[18] reported that the cross-sectional area of bone increased after that of muscle was widened by increasing the muscle strength. These reports suggest the following process: mechanical load → increase in muscle strength → maintenance of the BMD. The maintenance of the BMD in the middle-aged and elderly female subjects may have been due to a muscle strength increase brought about by mechanical stress in daily life, preventing BMD reduction.

The number of sit-ups was associated with lumbar spine BMD reduction as a preventive factor. A sit-up is a trunk-bending motion comprised of various factors. It includes exercise of the thoracic, intestinal, and low back regions, and involves the rectus abdominis, external and internal abdominal oblique, greater psoas, and psoas minor muscles[12]. Accordingly, the lower back region becomes more flexible as the strength in these muscles increases, which may result in the inhibition of lumbar spine BMD reduction. Regarding femoral neck BMD reduction, the distance of anteflexion in a long sitting position was associated as a preventive factor. Anteflexion in a long sitting position is a hip joint-bending exercise mainly involving the greater psoas and iliac muscles[12]. The greater psoas and iliac muscles mainly originate from the lumbar spine and iliac crest, respectively, and attach to the lesser trochanter of the femur. In anteflexion in a long sitting position, these muscles are extended to bend the joint. Thus, the hip joint can be moved as the muscles are readily extended and mobile, which may result in femoral neck BMD reduction. The area of outer body sway on standing straight with the eyes closed is a static body balance test, which may represent the balancing ability. Difficulty in walking due to reduced balance may lower the BMD[1]. The area of outer body sway with the eyes closed showed a tendency toward an association with femoral BMD reduction as a risk factor, but it was not significantly different. Since only 38 persons were the subjects of analysis, a significant relation was not shown ($p=0.071$). However, since the significant probability is less than 0.1, if the number of subjects increases, it will be thought that a significant relation may be shown. Wollacott et al[27] reported that activity of the quadriceps femoris muscle preceded that of the anterior tibial muscle in balance control in elderly subjects, showing a marked role of the quadriceps femoris muscle. However, balance ability involves other complex factors, such as the semicircular canal, in addition to the quadriceps femoris muscle. Although it was not significant, the area of outer body sway with the eyes closed tended to be associated with femoral BMD reduction as a risk factor, suggesting that quadriceps femoris muscle training improves balance ability and prevents femoral BMD reduction. Improvement of balance ability has also been shown to be effective for the prevention of falls and, consequently, of fracture[4].

The physical conditions of the subjects included in this analysis were close to the mean at the same age in other surveys in Japan[11] as were those of the excluded subjects. Therefore, at least, the external validity of the study results for young women in general was suggested based on the physical conditions of the subjects. However, the exertion of human muscle strength is influenced by various factors, including individual physical ability and condition, motivation, nutritional condition, and heredity[15]. It is difficult to measure muscle strength excluding these factors, which limits studies in humans. Since the subjects participated in the survey of their own free will, and they were not patients of medical institutions or residents in facilities, there may have been a bias toward subjects with a physically healthy condition and a deep concern for health. Although BMD changes were investigated over one year, about a 10% change may be observed even at a young age. BMD changes over the one-year period may have been sufficiently detected, because they could have included an error of cv=0.3% of the device. However, in order to clarify the result of this study further, it is necessary to perform a long-term follow-up. Further investigation involving a wider population is necessary in future.

CONCLUSION

A one-year longitudinal survey was performed involving 38 generally healthy postmenopausal women to elucidate the influence of physical fitness parameters on the BMD of the lumbar spine, femoral neck, and femur.

The number of sit-ups was extracted as a preventive factor against lumbar spine BMD reduction. The distance of anteflexion was extracted as a preventive factor against femoral neck BMD reduction. For femoral BMD reduction, the area of outer body sway with the eyes closed may have been a risk factor, although it was not statistically significant.

Therefore, we have suggested that physical fitness and local muscle strength influence BMD reductions of the lumbar spine and femoral neck.

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