Original article

Association between bone mass as assessed by quantitative ultrasound and physical function in elderly women: The Fujiwara-kyo study

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ABSTRACT

Objectives: This study aimed to investigate differences in physical function by bone mass category as assessed by speed of sound, and the association between bone mass and physical function in Japanese elderly women.
Methods: Participants ($\geq$65 years, n = 954) were divided into the osteoporosis, osteopenia, and normal groups based on speed of sound values, and physical function parameters were compared among groups. In addition, the predictive ability of physical function for low bone mass was determined by area under the curve analysis. Data were collected in 4 cities in Nara, Japan, in 2007 or 2008.
Results: All physical functions were significantly lower in the osteoporotic group than in the normal group. Lower bone mass was associated with poor muscle strength and physical function after adjusting for age, height and weight. In addition, one-leg standing time and 10-m gait time were predictive of low bone mass (osteopenia and osteoporosis levels, respectively). Elderly women with low physical function, especially those with a short one-leg standing time, should be suspected of having decreased bone mass.
Conclusions: Measurements of physical function can effectively identify elderly women with low bone mass at an early stage without the need for bone mass measurements. In particular, one-leg standing time and 10-m gait time were good predictors of low bone mass, and is easy to measure, low-cost, and can be self-measured. These findings will be helpful in the prevention and treatment of osteoporosis.

1. Introduction

Physical function becomes impaired and bone mass decreases with aging. Sex difference in gait speed and one-leg standing time increase after 64 years of age [1], and the rates of reduction in skeletal muscle mass, hand grip strength (HGS), and gait speed are higher in elderly women than in elderly men [2], although the rates of reduction in muscle mass and quality are greater in elderly men than in elderly women [3,4]. Onder et al. [5] reported a 16%–27% decrease in lower-extremity function over the course of 3 years in elderly women. It is also well-known that bone loss occurs rapidly in postmenopausal women. A decline in physical function can lead to physical inactivity in the elderly, and this in turn can reduce total

loading on bones. That is, a decrease of total loading on bones due to a decline in physical function can increase the risk of fracture. In fact, low physical activity has been reported as a factor that contributes to the risk of falls and fractures [6,7], with falls and fractures ranking fourth with respect to care need and support in the elderly [8]. Moreover, the risk of requiring care services in elderly women with the lowest tertile of speed of sound (SOS) at cancellous bone was 2.55 fold higher, compared to elderly women with the highest tertile of SOS [9]. Therefore, it is essential to prevent fractures as early as possible. Despite the above, Japan has a low rate of osteoporosis screening, due to reasons such as financial burden and insufficient human resources [10]. In contrast, care prevention services are widespread, and physical function in the elderly is measured as part of these services, such as during classes for fall prevention, inactivity prevention, and/or improvement of physical function [11]. The Japan Osteoporosis Society introduced an Osteoporosis Liaison Service and an authorized Osteoporosis Manager System in order to make the service more widely available [12]. Identification of elderly women who are likely to have osteopenia or osteoporosis can

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contribute to fracture prevention. Consistent with this it has been reported that heel SOS is associated with hip bone mineral density (BMD) [13], and that heel quantitative ultrasound (QUS) parameters can predict fracture risk [14,15]. For example, elderly women at risk of osteopenia or osteoporosis can be identified promptly if the osteoporosis manager conducts physical function measurements and care prevention services. Since physical function measurements are considered a screening tool for low bone mass, investigating the association between bone mass and physical function can not only help prevent falls and fractures, but may also promote screening among elderly individuals with low bone mass.

The present study aimed to investigate differences in physical function by bone mass category, and between osteoporosis, osteopenia, and normal groups by SOS [16], and examine the association between SOS and physical function in elderly women.

2. Methods

2.1. Participants

Participants were elderly women aged ≥65 years (range, 65—96 years) who participated in a cohort study (the Fujiwara-kyo study) [17]. The Administrative Center of the Fujiwara-kyo study recruited participants with the cooperation of local residents' associations and elderly people's clubs in four cities in Nara, Japan. Participants were able to walk either with or without walking sticks, and able to communicate. Applicants came to the place for a cohort study. A total of 2253 elderly women provided written informed consent and underwent a baseline examination in 2007 or 2008. The numbers of women examined for anthropometric data, physical function data, and SOS measurements were 2239 (99.4%), 2081 (3 sites of muscle strength, 92.4%), 1291 (3 kinds of physical performance, 57.3%), and 1906 (85.1%), respectively. We enrolled 954 women for whom all data were available from the baseline examination.

This study was approved by the Ethics Committee for Human Subjects, Nara Medical University (No. 111).

2.2. Anthropometric data collection

Height (cm) and weight (kg) were measured with an automatic scale. Participants stood upright for height measurements.

2.3. Physical function data collection

HGS, knee extension and flexion strength (knee extension strength [KES] and knee flexion strength [KFS]), 10-m gait time (10MGT), one-leg standing time with opened eyes (OLST), and chair rise time (CRT) were measured. All physical function parameters were measured twice and mean values were used for analysis.

HGS of the dominant hand was measured in the sitting position and with an extended elbow joint using a digital hand grip dynamometer (TKK5401, Takei Scientific Instruments Co., Ltd., Niigata, Japan). Isometric muscle strength of knee extension and flexion were measured in the sitting position on a chair with the knees flexed at 90° using an isometric muscle strength dynamometer (μTasMF-01, ANIMA Corp., Japan). Arm length was determined as the distance from the cleft between articulations at the knee to the center of the measuring dynamometer. KES and KFS were calculated as the isometric muscle strength of knee extension and flexion multiplied by arm length, respectively. 10MGT was measured using a 2-channel display timer (Takei Scientific Instruments Co., Ltd.), which records the time when participants pass the sensor system. Participants walked straight for 14 m at maximum effort, and 10MGT was measured at the middle of 10 m to reduce the effects of acceleration and deceleration. OLST was measured as the time participants stood on one leg with both hands on the waist, and with one leg raised forward using a stopwatch (SEIKO Watch Corp., Tokyo, Japan). CRT was measured as the time it took to stand up and sit on the chair five times using a multi timer (TKK5801, Takei Scientific Instruments Co., Ltd.).

2.4. SOS measurements for bone mass

Calcaneal SOS was measured as an index for bone mass using an ultrasound bone densitometer (CM-100, Fruno Electric Co., Ltd., Hyogo, Japan). Measurements were generally made on the right foot, but the left heel was evaluated when the participant had a history of fractures or bone disease in the right foot. The precision of QUS measurements *in vivo*, expressed as a coefficient of variation, was 0.51% based on five daily measurements in five different individuals. Participants were divided into osteoporosis (1479 m/s ≥ SOS), osteopenia (1501 m/s ≥ SOS ≥ 1478 m/s), and normal (SOS ≥ 1502 m/s) groups [16] to compare physical function by bone mass category. This grouping was based on SOS values rather than the diagnostic category of osteoporosis.

2.5. Statistical analysis

Measured values are expressed as mean and standard deviation. Differences among the 3 groups were examined by one-way analysis of variance, and followed by pairwise comparisons using the Games-Howell test. Multilinear regression analyses were conducted to identify associations between SOS (dependent variable) and each physical function parameter (independent variable), adjusting for age in model 1, and for height and weight, in addition to age, in model 2. Receiver operating characteristic curves were used to compare physical functions by SOS for osteopenia and osteoporosis groups, and areas under the curve (AUCs) were calculated for physical function parameters that were significant in model 2. The point of the nearest coordinate (0, 1), the upper left corner, was used to select cutoff values for the parameters. AUC values were also compared between each physical function parameter. P < 0.05 was considered statistically significant. All statistical analyses were performed using SPSS ver. 17.0 (SPSS Japan Inc., Tokyo, Japan) and the Excel Statistics software (BellCurve for Excel version 2.11 for Windows; Social Survey Research Information Co., Ltd., Tokyo, Japan).

3. Results

The prevalence of osteopenia and osteoporosis based on SOS were 38.4% (n = 366) and 37.0% (n = 353), respectively. Compared with normal women, osteoporotic women had a significantly higher mean age, and significantly lower height and weight (Table 1). In addition, all measured physical function parameters in osteoporotic women were significantly lower than those of normal women (Table 1). In addition, relative to normal women, osteopenic women were significantly older, and had significantly lower KES, KFS, and OLST values (Table 1). Relative to osteopenic women, osteoporotic women were significantly older, and showed significantly lower values for all measured physical function parameters, with the exception of KES and KFS. The effect (standardized partial regression coefficient, β) of physical function on SOS was greater after adjusting for age, height, and weight, than when adjusting for age only (Table 2).

The AUC value of 10MGT was significantly higher than those of HGS and KES for osteoporosis (Table 3). OLST was a good predictor of osteopenia and osteoporosis, and 10MGT was a good predictor of osteoporosis, by SOS (Table 3). Moreover, the difference between cutoff values for osteopenia and osteoporosis in OLST was larger than those for other physical function parameters (Table 3).

Table 1
Anthropometric characteristics and physical function parameters.

Characteristic	Normal (n = 235)	Osteopenia (n = 366)	Osteoporosis (n = 353)
Age, yr	70.3 ± 4.2	72.3 ± 5.0[*]	74.4 ± 5.4[*,†]
Height, cm	150.3 ± 5.3	150.1 ± 5.3	149.1 ± 5.3[*]
Weight, kg	52.1 ± 7.3	51.3 ± 7.6	50.4 ± 8.0[*]
Hand grip strength, kg	22.6 ± 4.0	21.9 ± 3.9	21.1 ± 3.9[*,†]
Knee extension strength, kg	5.25 ± 1.71	4.81 ± 1.49[*]	4.59 ± 1.49[*]
Knee flexion strength, kg	2.96 ± 0.88	2.76 ± 0.78[*]	2.62 ± 0.77[*]
10-m gait time, s	5.85 ± 1.02	6.04 ± 1.19	6.48 ± 1.47[*,†]
One-leg standing time with opened eyes, s	35.6 ± 21.1	30.0 ± 20.6[*]	24.5 ± 19.8[*,†]
Chair rise time, s	8.91 ± 3.41	9.25 ± 2.87	9.87 ± 3.04[*,†]
Speed of sound, m/s	1516.9 ± 14.2	1490.6 ± 6.2[*]	1467.3 ± 9.6[*,†]

Values are presented as mean ± standard deviation.
[*]Significant difference vs. normal (P < 0.05). [†]Significant difference vs. osteopenia (P < 0.05).

4. Discussion

Muscle mass and strength and bone mass decrease with aging. Thus, physical abilities such as sitting up, gait speed, balance, and other parameters should correspondingly decrease. The present study investigated the association between bone mass and physical function (muscle strength and physical performance). Our results indicate that SOS and physical function decreased with age, and that a lower SOS was associated with poor physical function.

Muscle strength and physical performance are reportedly associated with BMD. In particular, lower HGS was associated with lower BMD [18–22] and was a predictor of incident vertebral fracture [18] and previous fragility fracture [19]. HGS and leg extension strength of osteoporotic women classified by femoral neck and spine BMD were significantly lower than those of osteopenic and normal women [20], and knee muscle strength in osteoporotic women was also significantly lower than that in normal women [22,23]. Calcaneal bone quality and femoral neck BMD were associated with quadriceps strength in women with rheumatoid arthritis [24]. Moreover, sarcopenic women had a 12.9 fold higher likelihood of having osteoporosis compared with nonsarcopenic women [25]. These studies suggest that muscle mass and strength affect BMD. In the present study, HGS, KES, and KFS as assessed by SOS were significantly lower in osteoporotic women than in normal women, and lower muscle strength was associated with lower SOS.

Similarly, 10MGT, OLST and CRT in osteoporotic women were inferior to those in normal women, and lower 10MGT and OLST were associated with lower SOS. According to a previous study, BMD is a good predictor of physical performance, and the relationship is stronger in women than in men [26]. Lindsey et al. reported that normal and brisk step length, normal and brisk gait speed, OLST and HGS were significantly associated with BMD at various skeletal sites [27]. In addition, OLST was significantly shorter in osteoporotic women classified by femoral neck BMD than in osteopenic and normal women, although 10-m regular walk time did not significantly differ between them [20]. OLST has also been reported to be associated with BMD in community-dwelling Japanese women [28]. In a previous study that investigated the association between SOS and physical function [29,30], SOS was associated with maximum or usual gait speed and step length with maximum gait speed, but not with HGS, OLST or step length with usual gait speed [29]. Another study reported that OLST less than 60 s was independently associated with reduced SOS [30]. In contrast, early postmenopausal women with low BMD did not exhibit differences in balance, strength or gait speed, but had increased step time and stance time during gait compared to those with normal BMD [31]. Physical performance tests also were not associated with SOS in women [6]. These results may reflect differences in participants (e.g., age, age range, and race) and performance measurement conditions (e.g., speed and distance of gait, upper limit of OLST, and the type of measurement method). However, maximum gait speed is likely associated with BMD and SOS. In addition, the AUCs of gait speed and OLST for predicting women with femoral neck osteoporosis were 0.76 and 0.65, respectively [20]. Our results are consistent with previous studies regarding the relationship between bone mass and physical function.

This study has some limitations. First, participants were all recruited from a certain area in Japan. However, mean SOS values in the present study were similar to those reported using the same QUS device in a previous study [29,30], and physical performance levels were similar to those reported in a previous study of Japanese women [1]. Second, we measured SOS as bone mass, rather than using BMD measured with dual-energy x-ray absorptiometry. However, this study aimed to investigate the association between SOS and physical function and identify women with suspected osteopenia or osteoporosis. Moreover, SOS is related with BMD [13]. Finally, assessment of the temporal relationship of independent and dependent variables could not be performed given the cross-sectional design of the study.

We found that low SOS was associated with low physical function. Thus, elderly women with low physical function are very likely to have low bone mass. In particular, OLST can be a predictor of osteopenia and osteoporosis based on SOS because it is considered to reflect daily physical activity levels through its association with muscle strength and physical activity [32]. In addition, 10MGT can predict osteoporosis based on SOS. Moreover, OLST and walking

Table 2
Association between speed of sound and each physical function parameter, with adjustments for age, height, and weight.

Variable	Model 1		Model 2	
	B	P-value	β	P-value
Hand grip strength, kg	0.066	0.04	0.077	0.03
Knee extension strength, kg	0.090	<0.01	0.089	<0.01
Knee flexion strength, kg	0.088	<0.01	0.100	<0.01
10-m gait time, s	−0.092	<0.01	−0.101	<0.01
One-leg standing time with opened eyes, s	0.113	<0.01	0.126	<0.01
Chair rise time, s	−0.040	0.21	−0.044	0.18

Model 1, adjusted for age; model 2, adjusted for age, height and weight; β, standardized partial regression coefficient.

Table 3
Area under the curve (AUC) and cutoff value of physical function for osteopenia and osteoporosis by speed of sound.

Variable	Osteopenia (n = 366)			Osteoporosis (n = 353)		
	AUC	Cutoff value	Odds ratio	AUC	Cutoff value	Odds ratio
Hand grip strength, kg	0.576	21.8	1.64	0.574[*]	21.5	1.54
Knee extension strength, kg	0.593	5.05	1.97	0.571[*]	4.48	1.66
Knee flexion strength, kg	0.592	2.68	1.90	0.581	2.65	1.71
10-m gait time, s	0.588	5.9	1.68	0.620	6.1	2.17
One-leg standing time with opened eyes, s	0.610	29.6	2.15	0.605	21.1	2.19

[*]Significant difference vs. 10-m gait time (P < 0.05).

speed reportedly predict the onset of functional dependence in the elderly living at home [33]. Physical function measurements can be easily performed at a low cost and do not require specialized equipment. Thus, they can be used to effectively identify elderly individuals with low bone mass at an early stage, without the need for bone mass measurements. We anticipate that our findings will contribute to the early detection of low bone mass in elderly women. Further studies that investigate associations between physical function and SOS and BMD are warranted, as are those for determining cutoff levels for recommending osteopenic and osteoporotic examinations.

Conflicts of interest

No potential conflict of interest relevant to this article was reported.

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