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ORIGINAL ARTICLE

Walking duration and habitual exercise related to bone mineral density using computer-assisted X-ray densitometry in Japanese women

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Background: We conducted a survey to examine the difference in metacarpal bone mineral density (BMD) associated with the duration of walking and participation in habitual exercise in order to assess the benefits of walking for the prevention of bone loss in Japanese women.

Methods: The subjects were 1873 healthy women (premenopausal, $n = 1502$; postmenopausal, $n = 371$), aged 18–72 years, who were screened for osteoporosis at health-care centers. They were classified into pre- ($n = 1502$), early post- (0–5 years since menopause, $n = 195$) and late post-menopausal (6–20 years since menopause, $n = 176$) phases. The metacarpal BMD was measured by computer-assisted X-ray densitometry. Subjects completed a questionnaire on lifestyle factors that included habitual exercise and daily walking time. To consider the factors of aging and physical characteristics, the BMD of all subjects was adjusted for age and height using a multiple non-linear model based on the data for premenopausal women.

Results: ANOVA indicated significant differences in adjusted BMD (BMD_{adj}) in all menopausal phases according to walking duration and whether or not habitual exercise was engaged in. Premenopausal and early postmenopausal women who walked for over 30 min a day had a significantly greater BMD_{adj} than those walking for less than 30 min (2.743 vs 2.684 mm thickness of an aluminum equivalent [mm Al]; and 2.711 vs 2.597 mm Al, respectively). Late postmenopausal women who walked for over 120 min had a significantly greater BMD_{adj} than those walking under 30 min per day (2.746 vs 2.539 mm Al).

Conclusion: These findings suggest that daily walks of more than 30 min also affect the metacarpal BMD, which is a non-weight bearing site, although walking over 120 min seems required to benefit late postmenopausal women. We conclude that such daily walks appeared to be beneficial in maintaining BMD in Japanese women.

Keywords: bone mineral density, computer-assisted X-ray densitometry, Japanese women, menopause, walking duration.

Introduction

Osteoporosis, which is considered a major public health problem, is characterized by low bone mass and an increased risk of bone fractures. Moderate bone loss is

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accepted as a normal part of the aging process in women, and is especially inevitable after menopause with a rapid reduction in bone mass.[1–3] To prevent osteoporosis, various factors such as physical activity, adequate ingestion of calcium and vitamin D, and exposure to sunlight are acknowledged to be important.[4–6]

Numerous studies indicate that physical activity is positively related to bone mineral density (BMD). 'Weight-bearing' or 'muscle contraction' types of exercise are thought to be most effective in maintaining BMD in both younger and elderly women.[6,7] Other studies have reported that aerobic exercise combined with resistance training is effective in preventing bone loss.[8–12] Walking is a weight-bearing form of aerobic exercise and can be easily integrated into one's daily life. The types of exercise that induce the stress effective for bone mineralization include brisk walking and moderate walking or jogging.[13–16] However, other studies have shown that even brisk walking was insufficient for improving BMD.[17,18] There is no consensus on the relation between walking duration and BMD loss. Furthermore, it is necessary to distinguish the effect of walking on BMD from that of other habitual physical exercises.

Bone, a dynamic organ comprised of minerals, is associated with the two major functions, i.e. mechanical strain and systemic regulation by calcium and phosphate-regulating hormones.[19,20] Studies using dual-energy X-ray absorptiometry have generally demonstrated that the mechanical strain of walking affects the lumbar spine and femur, both of which are weight bearing sites.[13,14,16,21,22] To determine whether or not walking affects the systemic regulation of bone minerals, however, it is necessary to investigate the relation between BMD and non-weight bearing sites. Computer-assisted X-ray densitometry (CXD), a method for measuring metacarpal BMD, has the advantages of technical simplicity and feasibility at low cost.[23,24] This method has been used to screen for osteoporosis in many health-care centers in Japan. The metacarpal bone is a non-weight bearing site and, as such, provides a good index for evaluating the changes in cortical bone mass.[23,25]

The purpose of the present study was to investigate the discrepancies in metacarpal BMD (as measured by CXD) associated with the duration of walking time in healthy Japanese women who either did or did not engage in habitual physical exercise. We compared subjects from three periods: pre-, early post-, and late-postmenopausal phases. This study was designed to be cross-sectional.

Materials and methods

Subjects

A total of 3099 women were randomly selected from the general population in six areas of Japan. They underwent screening tests for osteoporosis at health-care centers. Four hundred and thirteen subjects were excluded because they had a disease or received treatment known to affect bone metabolism or because their menstruation status was interrupted by operations or medication. We ultimately enrolled 1873 women in the study who completed our investigation; 1502 were premenopausal (aged 18–66 years) and 371 were postmenopausal (aged 41–72 years). All subjects were in good health.

In the present study, the postmenopausal subjects were classified into early and late phases according to the number of years since menopause (YSM) because of their rapid rate of bone loss occurring 4–6 years after menopause and the considerably slower rate during their later years.[1,26] Therefore, we examined BMD differences in three classes of women: premenopausal (M), early post (MP_{early}; $n = 195$, 0–5 YSM) and late postmenopausal (MP_{late}; $n = 176$, 6–20 YSM).

This study was approved by the Ethics Committee of the National Institute of Health and Nutrition, Japan. Subjects gave written informed consent before they responded our questionnaire and permission for the use of their screening data for osteoporosis.

Methods

Bone mineral density of the second metacarpal was measured by CXD (BONALYZER, Teijin, Tokyo, Japan). This procedure provides an anterior–posterior radiographic view in comparison with the density of an aluminum step wedge (20 steps, 1 mm/step) as a standard.[23] The diagram of the quantity of absorbed light was converted into 256 grayscales of digital data. The computer automatically calculated the metacarpal BMD on the basis of the gradation patterns on the aluminum step wedge. BMD was expressed as the thickness of an aluminum equivalent (mm Al). The precision of this instrument was within 0.7% according to the manufacturer's standard.

Each subject completed a self-administered questionnaire designed to document anthropometric and lifestyle factors, including chronological age, menstruation status, age at menopause, height, weight and profiles of habitual physical exercise and daily walking time. Body mass index (BMI) was calculated as weight/height^2 in kg/m^2. A menstruation that paused more than half a year was decided as an age at menopause. The profile of habitual physical exercise included the kind, frequency per week, and length of time per day spent in sports or fitness activities exclusive of household chores. The questionnaire probed for the duration of daily walking time outside the home (average time per day), which included such activities as shopping, dining out, and walking around the neighborhood. The community nurse checked subject's responses to completed self-

Table 1 Physical characteristics, walking time, bone mineral density (BMD) and adjusted bone mineral density (BMD_{adj}) for each phase

	M ($n = 1502$)	MP_{early} ($n = 195$)	MP_{late} ($n = 176$)
Age (years)	37.0 ± 7.8	52.8 ± 3.3	59.3 ± 4.9
Height (cm)	156.6 ± 5.2	153.5 ± 4.7	152.8 ± 5.1
Weight (kg)	52.6 ± 7.1	53.7 ± 7.7	52.0 ± 7.1
BMI (kg/m^2)	21.48 ± 2.89	22.78 ± 3.02	22.26 ± 2.87
Walking time (min)	69 ± 89	66 ± 59	86 ± 115
BMD (mm Al)	2.724 ± 0.220	2.496 ± 0.258	2.295 ± 0.265
BMD_{adj} (mm Al)	2.724 ± 0.214	2.685 ± 0.244	2.645 ± 0.261

mm Al, thickness of an aluminum equivalent; BMD, bone mineral density; BMD_{adj}, bone mineral density adjusted for age and height; BMI, body mass index; M, premenopausal; MP_{early}, early postmenopausal; MP_{late}, late postmenopausal women; walking time, time spent walking each day.

administered questionnaires. Subjects were divided into two groups based on their participation in more than 60 min per week of total physical activities except walking either with or without exercise (exercise/nonexercise). Daily walking time was classified into three durations of over 120 min (long), from 30 to 120 min (medium), and less than 30 min (short).

Calculation of adjusted bone mineral density

To consider the relationship between BMD and the factors of aging and anthropometric characteristics (height, weight and BMI) excluding the menopausal factor, we made the calculation of the adjusted formula for BMD. Stepwise regression analysis was performed to extract fitted parameters on BMD using the data of premenopausal subjects, since the model for an adjusted formula that included the data of postmenopausal subjects was not able to estimate the BMD adjusted for aging and anthropometric characteristics without the menopausal factor. The following regression equation was obtained:

$$\begin{aligned} BMD = &-0.0005 \cdot age^2 + 0.0325 \cdot age \\ &+ 0.0053 \cdot height + 1.3377 \ (R = 0.258). \end{aligned}$$

The formula for the adjusted average BMD was calculated using the regression coefficients of the independent variables expressed as the result of stepwise regression analysis. This adjusted value was defined as the BMD_{adj}. The formula for BMD_{adj} was applied to all subjects in the following form:

$$\begin{aligned} BMD_{adj} = BMD_m &- 0.0005\ (\text{mean age}^2 - \text{age}^2) \\ &+ 0.0325\ (\text{mean age} - \text{age}) \\ &+ 0.0053\ (\text{mean height} - \text{height}), \end{aligned}$$

where BMD_m is the measured BMD in a particular subject. Using this adjustment formula, the means of age and height in premenopausal women were calculated.

Statistical analysis

Means and standard deviations were used as descriptive statistics. The BMD_{adj} values were submitted to two-way analysis of variance in which the factors were walking duration (long/medium/short) and the practice of habitual exercise (exercise/nonexercise). Differences in mean BMD_{adj} at each effect level were determined using Tukey's honestly significant differences. The significance level was set at 0.05.

Results

The anthropometric characteristics, walking time, BMD and BMD_{adj} of the three classes of subjects are detailed in Table 1. The BMD_{adj} of premenopausal women was significantly higher than that of early and late-postmenopausal women, $F(2, 1870) = 11.86$, $P < 0.001$. There was no significant difference in BMD_{adj} between the early and late-postmenopausal women.

Tables 2 and 3 show the BMD_{adj} as a function of walking duration and habitual exercise in each menopausal phase. In premenopausal women, we found a significant effect on BMD_{adj} due to walking duration, but not to habitual exercise. There was no interaction between walking duration and habitual exercise. The *post hoc* test indicated that BMD_{adj} in long- and medium-duration walking groups was significantly greater than that in the short-duration walking group (Fig. 1).

The results indicated that there were significant effects on BMD_{adj} due to walking duration in both early and late-postmenopausal women, but the effect of exercise and interaction between walking and exercise were not significant (Tables 2 and 3). In early postmenopausal women, the *post hoc* test indicated that BMD_{adj} in long- and medium-duration walking groups was significantly higher than that in the short-duration walking group, whereas in late postmenopausal women, BMD_{adj} in the long-duration walking group was significantly

Table 2 Adjusted bone mineral density (BMD_{adj}; in mm Al) for different walking durations and habitual exercise in each group

Walking duration	M		MP_{early}		MP_{late}	
	Exercise (*n*)	Non-exercise (*n*)	Exercise (*n*)	Non-exercise (*n*)	Exercise (*n*)	Non-exercise (*n*)
Long	2.795 ± 0.281 (43)	2.775 ± 0.205 (229)	2.766 ± 0.145 (7)	2.716 ± 0.261 (30)	2.882 ± 0.239 (7)	2.713 ± 0.251 (29)
Medium	2.722 ± 0.205 (97)	2.747 ± 0.215 (488)	2.721 ± 0.229 (25)	2.707 ± 0.240 (79)	2.614 ± 0.181 (22)	2.657 ± 0.280 (81)
Short	2.703 ± 0.213 (85)	2.681 ± 0.204 (560)	2.564 ± 0.194 (12)	2.607 ± 0.258 (42)	2.612 ± 0.249 (9)	2.516 ± 0.223 (28)

BMD_{adj}, adjusted bone mineral density with age and height; M, premenopausal; MP_{early}, early postmenopausal; MP_{late}, late postmenopausal women; Long, over 120 min; Medium, 30–120 min; Short, less than 30 min.

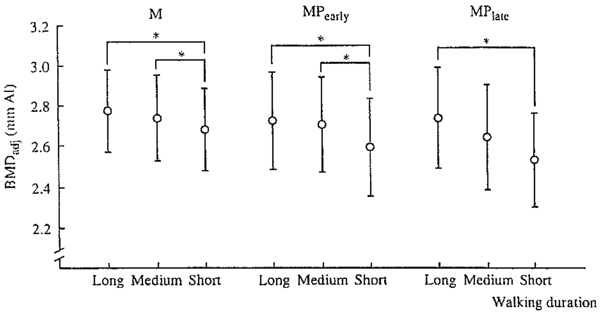

Figure 1 Adjusted bone mineral density (BMD_{adj}) at three walking durations in each menopausal phase. ($^{*}P < 0.05$. mm Al, thickness of an aluminum equivalent; BMD_{adj}, bone mineral density adjusted for age and height; M, premenopausal; MP_{early}, early postmenopausal; MP_{late}, late postmenopausal women; long, over 120 min; medium, 30–120 min; short, less than 30 min.)

higher than that in the short-duration walking group (Fig. 1).

Discussion

This cross-sectional study revealed that BMD of early and late-postmenopausal women showed respective declines of 8.4% and 15.7% compared with that of premenopausal women, while their adjusted BMD also showed correspondingly significant decreases of 1.4% and 3.5%. This suggests that the aging process and menopause following a reduction in estrogen secretion are major factors in BMD loss. These findings are consistent with those of previous studies.[3,27,28]

Our main finding was that significant differences in adjusted BMD in all menopausal phases were due to the duration of walking time irrespective of habitual exercise. This result suggests that long daily walks have the potential to minimize the amount of BMD loss in Japanese women. A widely accepted rationale for the positive effects of exercise on bone is that the attendant mechanical strain is a crucial signal for the maintenance of bone formation.[19,20] A number of studies which measured the lumbar spine and proximal femur have observed the effect of walking on BMD, and have demonstrated that the mechanical strain of physical exercise promotes the bone turnover of specific sites.[13,14,16,21,22] Since the current study has measured metacarpal BMD that does not directly sustain mechanical stress during walking, it is possible to assume that daily walking benefits the regulation of total bone-derived metabolism rather than that of localized weight-bearing sites. Thorsen *et al.* showed that brisk walking exerts a significant effect on the markers of bone collagen metabolism.[15] Other studies have shown that physical exercise positively affected the markers of bone turnover in both young and elderly women.[29,30] These findings suggest

Table 3 The results of ANOVAs for adjusted bone mineral density (BMD_{adj} in mm Al) for different walking durations and habitual exercise in each group

	M	*P*	MP_{early}	*P*	MP_{late}	*P*
Walk	$F(2, 1496) = 9.68$	< 0.01	$F(2,189) = 4.34$	< 0.05	$F(2, 170) = 5.51$	< 0.01
Ex	$F(1, 1496) = 0.13$	ns	$F(1,189) = 0.02$	ns	$F(1, 170) = 2.00$	ns
Walk and ex	$F(2, 1496) = 1.13$	ns	$F(2,189) = 0.29$	ns	$F(2, 170) = 1.79$	ns

BMD_{adj}, adjusted bone mineral density with age and height. M, premenopausal; MP_{early}, early postmenopausal; MP_{late}, late postmenopausal women. Walk, factor of walking time; Ex, factor of habitual exercise. ANOVA, analysis of variance; ns, not significance.

that long daily walks may induce a systemic retardation of bone resorption or a support of bone formation.

Conversely, the current result showed that adjusted BMD in a habitual exercise group tends to be higher than that in a nonexercise group, although there were no significant differences in each phase. The evidence that habitual exercise has any influence on metacarpal BMD remains unclear. It seems to assume that the habitual physical activities in our study may not have been of sufficient magnitude or frequency to affect metacarpal BMD, since almost all subjects who qualified for inclusion in an exercise group took part in 60 min of sport activities once or twice a week. Shimegi *et al.* have indicated that BMD at the distal radius (a non-weight bearing site) was not significantly different among volleyball players, joggers and controls.[30] This implies that different sports appear to have selective effects on specific skeletal sites. However, further investigation is needed into how exercise should be precisely defined to confirm our result.

The present results of premenopausal and early postmenopausal women indicated that those who walked 30 min or more daily had a significantly higher BMD than those who walked less than 30 min. In late postmenopausal women, we found that those who walked 120 min or more daily also showed a significantly higher BMD than those who walked less than 30 min. These findings suggest that late postmenopausal women require walks of longer duration to maintain BMD. Previous studies among premenopausal women have reported that high-impact exercise, sufficient walking or aerobic dance were able to prevent a decrease in BMD.[21,22,31] Among postmenopausal women, Nelson *et al.* showed the beneficial effects on BMD of walking for 50 min wearing a leaded belt.[14] Hatori *et al.* found that walking for 30 min at above the anaerobic threshold level was valuable to prevent bone loss.[13] These studies indicate that a program of high-intensity aerobic exercise 3–4 times per week is required to prevent BMD loss both in pre- and postmenopausal women. In the current investigation, medium-duration walkers in each menopausal phase walked 54, 59 and 57 min/day, respectively. Intensity of walking was thought to be moderate, though that was not examined. However, our findings are supported by other studies which indicate that, in postmenopausal women, moderate exercises both in leisure-time weight-bearing activities and in quantitative daily physical activities retard bone loss.[16,32] Thus, even if the intensity of exercise is at the level of moderate walking, it is assumed that a daily walk of at least 30 min may contribute to the regulation of bone minerals to maintain BMD regardless of a woman's menopausal phase. This issue, however, remains to be confirmed by further longitudinal studies.

In conclusion, our cross-sectional study showed that the duration of daily walking was effective in maintaining metacarpal BMD in Japanese women whether or not they also engaged in habitual exercise. The physical activities should include a daily walk of not less than 30 min to maintain bone mass in premenopausal and early postmenopausal women, and an ordinary walk for as long as is feasible in late postmenopausal women.

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The effects of Tai Chi Chuan on physiological function and fear of falling in the less robust elderly: An intervention study for preventing falls

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Abstract

The aim of this report is to investigate the effects of 8 weeks of intensive Tai Chi Chuan (TCC) training on physiological function and fear of falling (FOF) in the less-robust elderly. Forty-nine community-dwelling elderly, aged 60 or older, were classified randomly into a TCC training or control group. Physical performance measures (including one-leg stance, trunk flexion, and walking speed) and interviews were conducted before and after the intervention. The TCC group showed significant improvements in balance and flexibility, and a reduced FOF, when compared with the control group after the intervention. However, walking speed did not change significantly. The results suggest that a high-frequency, short-term TCC training program can improve balance, flexibility, and increase the confidence of less-robust elderly. These suggest the effectiveness of TCC for intervention as a means to prevent falling among high-risk elderly populations.

Keywords: Tai Chi exercise; Physiological function; Fear of falling; Prevention of falls; Elderly

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1. Introduction

Falls are the most common and serious problem facing elderly persons because of their frequency, morbidity, and cost (King and Tinetti, 1995; Lilley et al., 1995). Various programs have been developed to reduce major risk factors for falling caused by environmental hazards, risk-taking behaviors, or a decline in physical performance (McMurdo et al., 2000; American Geriatrics Society, British Geriatrics Society and American Academy of Orthopaedic Surgeons Panel on Falls Prevention, 2001; Moreland et al., 2003). Exercise is an intervention often proposed for preventing falls and fall-related injuries. Tai Chi Chuan (TCC) was originally developed as a martial arts form, but has been used for centuries in China as an exercise by the elderly. A variety of health-related benefits, including improved cardiorespiratory function and enhanced psychological well-being (Kutner et al., 1997; Hong et al., 2000; Li et al., 2001a), have been examined previously. In the Cochrane review, the study of TCC (Wolf et al., 1996) provides the only evidence suggesting the effectiveness of group exercise intervention for preventing falls among the elderly (Gillespie et al., 2004). TCC is a suitable exercise for older adults because of its low impact and low velocity. However, according to a recent review, the evidence for the effectiveness of TCC remains limited.

As Wu (2002) reported in a recent review, although TCC has been used as an exercise program to improve balance, results from these studies are scattered or inconsistent. This inconsistency is caused by differences in balance measurement, subject population, and the type and duration of TCC.

Results from previous studies have suggested that TCC training may improve flexibility and walking speed in older adults. Although these findings support the benefits of TCC as an exercise form, the participants in all these studies were robust elderly. Wolf et al. (1996) conducted a randomized, controlled clinical trial to investigate the effect of TCC training and balance training on the biomedical and psychosocial indices in healthy elderly. In this study, the level of fear of falling (FOF) was categorized into four levels, and the proportion of lower two levels decreased significantly by the 15-week of TCC training. Li et al. (2002a) reanalyzed their TCC intervention data set and found that TCC participants with lower levels of physical function at baseline benefited more from the TCC program than those with higher physical function scores. Because of its low impact and low velocity, TCC will be effective for the elderly with low physical performance or high risk for falling rather than only the healthy population. The unresolved question is therefore whether TCC benefits older individuals who are less robust.

The use of an optimal prescription for the TCC program is essential for the intervention. Because of the TCC characteristics, it is difficult to determine exactly the amount of TCC training needed. We selected the amount of exercise at 40 h, since Wu (2002) suggested it as a sufficient amount to improve balance measurement. In addition, to identify the amount of exercise involved, we asked the subjects to record the amount of their exercise in an exercise log.

In addition to the physical effects of TCC, we tried to examine the mental effects related to the prevention of falling. FOF occurs in 12–65% of older adults who live independently in the community and do not have a history of falling, and in 29–92% of those older adults who have experienced falling (Arfken et al., 1994; Legters, 2002). FOF is now recognized as a source of disability among older adults, because it independently contributes to fall risk (Howland et al., 1993; Franzoni et al., 1994; Tinetti et al., 1994). The Falls Efficacy Scale (FES), developed by Tinetti et al. (1990), extends the concept of FOF by assessing fall-related self-efficacy. Li et al. (2002b) pointed out that fall-related self-efficacy is a good mediator that explained the relation between FOF and functional ability in the elderly. In the prospective study of the impact of FOF on the health of older people, subjects with low FES scores related with future falls and a decline of ability of daily living (Cumming et al., 2000).

The aim of the present study was to determine the effect of 40 h of TCC training on static balance, flexibility and FOF on less-robust elderly subjects.

2. Methods

2.1. Study design

This study is a randomized, controlled trial designed to compare the effects of 8 weeks of TCC on physical performance and FOF in community-dwelling elderly with relatively-low balance performance. The present subjects were selected from our earlier study to investigate falls among community-dwelling elderly (Zhang et al., 2003; Study of Falling in the Elderly, SFE). Data were collected at baseline (August 2001) and at the end of the intervention (September 2001). The purpose and procedures of this study, and all of the measurements including were fully explained. The subjects were also told that they would be excluded from this study when their one-leg stance (OLS) time were over 20 s or less than 5 s. Then written informed consent was obtained from all subjects before the study.

2.2. Subjects

The present subjects were selected from the subjects in our previous study (Zhang et al., 2003; SFE). First, we selected 84 subjects whose OLS test time was less than 25 s based on their previous measurement. Then we conducted a baseline measurement for the present study, and selected the subjects according to the following criteria: (1) a lower ability for maintaining balance, (2) the ability to go out alone (self-reported in the interview), and (3) no prior experience of TCC (self-reported in the interview). In the present study, we defined "a lower ability for maintaining balance" as those subjects whose OLS time was between 20 and 5 s. This definition was made for the following reasons: subjects with OLS time less than 20 s had significantly higher risk for falling according to our previous study (Zhang et al., 2003). Twelve subjects whose OLS test time was less than 5 s were excluded because they were considered at risk to practice TCC. Then the qualified 49 subjects (25 men and 24 women) were selected for this study. Of the 49 subjects, 25 were assigned to the TCC training group, and 24 to the control group. In the process of the assignment, the 49 subjects were divided into 25 pairs (the 25th was only one subject) according to sex, experience of falling, and exercise habits. First, we made two pairs from three women and one man who had both exercise habit and experience of falling. Second, two women with exercise habit paired. Third, since there was only one man with exercise habit, he paired with a man without exercise habit. Forth, among five women and three men with experience of falling, we made four pairs. At last, remaining 14 women and 19 men without exercise habit and experience of falling were divided into 16 pairs according to their sex. Then we randomly assigned one of each pair to the TCC training group by tossing a coin.

2.3. *Intervention*

Subjects of the TCC training group attended a 1 h exercise session seven times per week for 8 weeks. TCC training was held in a park in Nanjing that was easily accessible by walking. Subjects participated in a simplified TCC with 24 forms (Zhou, 1984).

Each practice session included 10 min of warm-up exercise, 40 min of TCC practice, and 10 min of cool-down exercise. Each form of TCC emphasized multidirectional weight shifting, awareness of body alignment, and multisegmental movement coordination. In addition, regulated breathing was emphasized as part of the exercise. During the exercise, subjects were led by a TCC instructor and imitated his/her motions and postures at the same speed. The two instructors involved in the present study had taught TCC for at least 5 years. Since those practice sessions were held specifically for the present study, only subjects of the study participated in each session.

We also created a program for practicing TCC at home. This program consisted of 11 easy forms (the 1st to 11th forms of the 24 forms used in the practice session). This home program took about 30 min. In the first week of the intervention, subjects practiced this home program in the practice session. The subjects were asked to practice this home program when they could not participate in a practice session or whenever they wished, and were asked to record the time they practiced TCC at home in their exercise log.

Subjects in the control group were instructed to continue their current level of physical activity. There was no contact between the study staff and control subjects except during data collection.

2.4. *Measurements*

2.4.1. *Interview*

Face-to-face interviews by trained staff members were conducted for all subjects. Each interview took about 10 min. Subjects answered with respect to their age, sex, years of education, family members living with them, whether he/she could go out alone for daily shopping (yes or no), current health problems, experience of falling, and exercise habits. In the present study, a fall was defined as "falling all the way down to the floor or ground, or falling and hitting an object like a chair or stair" (Nevitt et al., 1991). After the interviewers explained the definition of falling, subjects were to answer if they had fallen at least once over the past year. The habit of exercise was defined as "doing continuous vigorous exercise for 30 or more minutes at least three times a week in the past year."

All subjects also completed the FES (Tinetti et al., 1990) which was used to assess fall-related self-efficacy. The FES is a 10-question scale that assesses the impact of FOF on a person's confidence to perform everyday tasks. Subjects were asked to rate each question on a scale of 0–10, and the scores were summed to give a total score between 0 (low fall-related self-efficacy) and 100 (high fall-related self-efficacy). This scale showed good test–retest reliability, and its validity has been established (Tinetti et al., 1990). We translated the scale into Chinese and used it as a part of the interview. In the translation process, first, two researchers translated the FES into Chinese from English, then revised the Chinese more naturally according to the initial translation. Second, two other researchers translated the Chinese version back into English to confirm that the FES had been accurately translated. The internal consistency reliability was estimated using the Cronbach alpha coefficient for the Chinese version of FES, and the alpha value was 0.85. We used FOF as a general term to describe low fall-related self-efficacy.

At the post-intervention interview, in addition to the questions asked in the baseline interview, we also asked all subjects if they had changed their lifestyle or participated in any events that might have affected the results of the measurement, such as hospital admission, participating in other exercise, or traveling.

2.4.2. *Measurement of physical performance*

The OLS test, trunk flexion test from a standing position, and 10 m walking were performed to examine physical performance. In the OLS test, subjects were asked to balance on one leg (with eyes open) for as long as possible, up to a maximum of 60 s (Shinkai et al., 2000). In the trunk flexion test from a standing position, subjects were asked to stand on a platform (height approximately 40 cm). Subjects were then asked to bend their upper body forward slowly while keeping their legs straight. The distance from the top of the platform to the tip of the middle finger was then measured. This distance was indicated in centimeters with positive value for a position reaching lower than the top of the platform (Tairyoku Hyoujunchi Kenkyukai of Tokyo Metropolitan University, 2000) (Fig. 1). Walking speed was determined by measuring the time required to walk 10 m. Subjects were instructed to walk from a standing still position as quickly as possible (Kim et al., 1997). Each test was repeated twice, and the highest score was recorded.

2.5. *Sample size and study power*

A previous study had reported a dropout rate of about 20% during the 4 months of TCC training (Wolf et al., 1996). We assumed the dropout rate in our 8-week intervention would be the same as the prior 4-month intervention. Schaller (1996) reported that the balance performance measure by the OLS increased by 50% from the baseline. We selected the larger effect size (0.5), and a power of 0.88 was expected to detect a 3.8 s difference between the intervention and control group with a 0.05 type I error rate, according to Cohen's power analysis for F-test (Cohen, 1988). Then we decided that we would need at least 25 subjects for each group at beginning of the study.

2.6. *Statistical analyses*

A bivariate analysis was conducted to compare demographic variables, history of falling, and exercise habits between the TCC training group and the control group. Baseline characteristics of the TCC training and control groups were compared by χ^2-test (proportional differences) or unpaired t-test (differences between means). Differences in the changes in time between TCC training and control groups were compared using two-

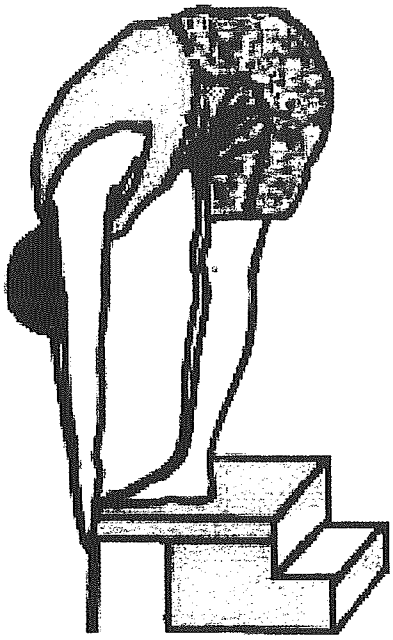

Fig. 1. Trunk flexion test from standing position as an index of flexibility.

way ANOVA (analysis of variance) with repeated measurements. All results were analyzed using the SPSS software package (version 10.0). The 0.05 alpha level was chosen to indicate statistical significance.

3. Results

During the intervention period, one subject in the TCC group and one subject in the control group dropped out when they moved away from the community under study. However, there was no significant difference between the dropouts and the remaining subjects when their measurements at baseline were compared. Finally, 24 subjects in the TCC training group and 23 subjects in the control group were included in the statistical analyses.

During the intervention period, 22 subjects (91.7%) practiced TCC 4 or more hours per week. On average, 32.1 h of TCC were conducted as a group intervention, and 3.5 h at home. No subjects in the control group changed their lifestyle during the intervention period.

There was no significant difference between the TCC and control groups in demographic variables, history of falling, exercise habits, physical performance, and FES scores at baseline (Table 1).

Table 2 demonstrates the changes in physical performance and FES scores of the TCC training and control groups, respectively. The TCC training group significantly improved

Table 1
Baseline characteristics of subjects

Variables	TCC training group (no. = 24)	Control group (no. = 23)	p
Age (year, mean ± S.D.)	70.2 ± 3.6	70.6 ± 4.9	0.754
Female (%)	50.0	43.5	0.772
Height (cm, mean ± S.D.)	163.2 ± 7.6	162.9 ± 7.4	0.917
Weight (kg, mean ± S.D.)	61.2 ± 9.3	62.0 ± 9.9	0.767
Years of education ≦ 6 (%)	45.8	43.5	1.000
Living alone (%)	4.2	0.0	1.000
Fell in past year (%)	25.0	26.1	1.000
Have exercise habit (%)	16.7	13.0	1.000
One-leg balance (s, mean ± S.D.)	13.0 ± 4.3	12.4 ± 3.2	0.587
Trunk flexion (cm, mean ± S.D.)	1.9 ± 7.0	3.5 ± 7.5	0.454
10 m walking (s, mean ± S.D.)	7.9 ± 1.0	7.9 ± 0.9	0.944
FES score (points, mean ± S.D.)	75.9 ± 5.1	75.6 ± 5.9	0.828

Table 2
Changes in physical performance and FES score

Variables	TCC training group (no. = 24)			Control group (no. = 23)			p^a
	Baseline	After 8 weeks	Change	Baseline	After 8 weeks	Change	
One-leg balance (s)	13.4 ± 4.4	25.7 ± 6.3	+12.3	12.4 ± 3.2	16.1 ± 3.8	+3.7	<0.001
Trunk flexion (cm)	1.7 ± 7.3	6.2 ± 6.3	+4.5	3.5 ± 7.5	3.0 ± 7.3	−0.5	<0.001
10 m walking (s)	8.0 ± 1.0	7.6 ± 0.9	−0.4	7.9 ± 0.9	7.7 ± 0.9	−0.2	0.404
FES score (points)	76.2 ± 5.2	78.3 ± 4.0	+2.1	75.6 ± 5.9	75.3 ± 5.9	−0.3	0.006

[a] Comparison of changes between TCC training group and control group.

OLS time, trunk flexion, and FES score, compared with the control group. Changes in 10 m walking were not significantly different between the TCC and control groups.

4. Discussion

In the present study, we found TCC improved balance function and flexibility, and reduced FOF in the community-dwelling elderly with a lower ability for maintaining balance. The results suggested that an 8-week intensive TCC training program for the elderly with a lower ability for maintaining balance had possibility to prevent falling by improving balance, flexibility, and reducing FOF. The use of an intensive TCC training program and the selection of subjects with lower balance ability made significant results even in this short-term study with a small sample size.

The present TCC training improved balance and flexibility but did not improve walking speed. In the physical training prescription, frequency, duration, and intensity of exercise are fundamental factors. Since the intensity of TCC did not exceed 55% of maximal oxygen uptake, it was classified as a moderate-intensity exercise (Li et al., 2001b). Wu (2002) indicated that 40 or more TCC practice sessions are required to show significant improvement in most of the balance measures among elderly populations. In the present study, most of the subjects practiced TCC four or more sessions per week over a period of 8 consecutive weeks, and the mean total TCC practice time was over 35 h per subject. The present amount of TCC training is thought to be enough to improve balance and flexibility among the elderly with a lower ability to maintain balance. However, the present training was not adequate to improve walking speed. The movement of TCC is mainly isometric exercises and several very slow isotonic exercises. Another type of training might be needed to improve walking speed.

FOF is a fundamental health problem in elderly people related to falling or maintaining physical independence. In the prospective study by Cumming et al. (2000), subjects with low fall-related self-efficacy experienced many falls and a decline in activities of daily living. Maki et al. (1991) noted that subjects who expressed FOF were found to exhibit significantly poorer performance in blindfolded spontaneous-sway tests and OLS tests with eyes-open. However, since FOF is known to be multifactorial with, at a minimum, physical, psychological, and functional influences (Legters, 2002), the mechanism for reducing FOF by TCC is unclear. In addition, Kutner et al. (1997) indicated that 12 weeks of TCC training improved confidence in balance. Thus the potential mechanism for reducing FOF is that the improvement in balance and flexibility in the present study increased confidence and thus reduced FOF. Another possible mechanism is the combination of deep diaphragmatic breathing and relaxation with slow gentle movements in the TCC program that confers a sense of mental control on the practitioner and reduces the FOF. Although FOF is a rational response to a very real threat, the present intervention is directed toward older adults whose FOF is blocking their engagement in activities necessary to remain physically functional, and to rebuild confidence in their physical capabilities.

Our study has several limitations. The first is our definition of subjects with low balance ability. We have already found that the elderly with an OLS time less than 20 s had a high risk of falling, and we therefore defined those subjects as having low balance ability (Zhang et al., 2003). To combine this measurement with other physical performance tests would be a more adequate procedure, however, we did not have sufficient data to add definitions from other physical performance tests. Second, the reliability and validity of the English version of FES were established, however, we could not estimate the content validity for Chinese version as Tinetti et al. (1990) did for English version, since few researchers or specialists addressed this issue in China. It might partly affect the results, regarding the subjects' responses to such instrument are dependent on underlying cultural trends. We calculated the alpha coefficient for estimating the internal consistency reliability of the Chinese version of FES, the result showed that there was a high internal consistency in the Chinese version of FES (alpha = 0.85). Third, the FES has a well-documented ceiling effect (McAuley et al., 1997; Myers et al., 1998). It is considered to be usable with older adults who are homebound and have low mobility. In the present study, although we used fall-related self-efficacy as FOF, the quality of assessment of FOF by FES among the present subjects is unclear. However, none of them showed a 0 or 100 score before and after the intervention. Fourth, social contact or support is thought to affect FOF since it depends on both physical ability and mental confidence. In the present study, the subjects in the training group were in contact with our staff more than the subjects in the control group. This difference might affect the changes of FOF. Fifth, blinding is difficult in a study using exercise intervention. Blinding the participants and the caregiver is impossible in this type of study, thus the "Hawthorne effect" could not be avoided. Further, we could not blind the outcome assessment because of the small number of our study staff.

5. Conclusion

The present study revealed that the intensive TCC training program improved balance and flexibility and reduced FOF in the elderly with low balance ability. The result shows the marked effectiveness of TCC on both physical performance and fall-related self-confidence among elderly persons with low balance ability. The present study thus supports the effectiveness of TCC as an intervention helpful to prevent falling, especially among high-risk populations.

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Changes in metacarpal bone mineral density with age and menopause using computed X-ray densitometry in Japanese women: Cross-sectional and longitudinal study

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Abstract

Background: Bone mineral density (BMD) loss with age and menopause is widely accepted in elderly women. However, only a few studies have utilized a multiple regression model that includes physical characteristics to assess comprehensive lifetime changes in BMD.
Objective: A prospective study was conducted to characterize the normal patterns in metacarpal BMD changes in Japanese women, and to assess the applicability of a fitting model using cross-sectional data compared with longitudinal variability.
Subjects and methods: The study consisted of 5422 healthy women in cross-sectional data and a 1-year follow-up of 359 women. The metacarpal BMD was measured by computed X-ray densitometry. Multiple linear and nonlinear regression analyses were performed in cross-sectional subjects. Nonparametric analysis was used to compare percentage rates of BMD changes between actual and estimated values.
Results: The cross-sectional data showed that the best-fit equation was a nonlinear change model using the variables of age and height in premenopausal women, and years since menopause (YSM), age and height in postmenopausal women. The results of longitudinal data indicated the following. In premenopausal women, the actual BMD changes were greater in the 30–39 age group than the 20–29 age group and were less in the 50–59 group than the 40–49 group. The rates of annual change in BMD between the actual value and estimated value by change model were very similar. In postmenopausal women, the actual changes in BMD indicated that the rapid rate of reduction observed was over 3% at 0–5 YSM and 1.5% at 6–10 YSM, and thereafter showed a slower rate of decline at 11 YSM. The change model represented the trend of actual change in BMD for postmenopausal women, whereas the rates of estimated BMD loss underestimated the actual changes at 1–10 YSM.
Conclusion: The change model for premenopausal women using cross-sectional data is beneficial in evaluating the actual metacarpal BMD variability, whereas that for postmenopausal women is insufficient in estimating the longitudinal BMD variability.

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Keywords: *Bone mineral density, change model, computed X-ray densitometry, Japanese women, years since menopause*

Introduction

Bone mineral density (BMD) is the most important measurable determinant of bone health status and osteoporotic fracture (Melton et al. 1988; Christiansen 1993). In healthy humans, the onset of age-related BMD loss occurs generally during the fourth decade of life and continues into extreme old age (Nuti and Martini 1993; Nakamura et al. 2000; Lu et al. 2001; Warming et al. 2002). The pattern of age-related change in BMD is a significant issue for quality of life in elderly populations, especially in women.

The decline in ovarian function that occurs with menopause is the most significant factor linked to BMD loss in women (Luisetto et al. 1993; Bjarnason et al. 1995; Warming et al. 2002). Therefore, numerous studies concerning the changes in BMD and menopause have classified women into pre- and postmenopausal groups. However, these studies used data from narrow intervals (Hansen 1994; Bjarnason et al. 1995; Goto et al. 1996), sometimes showing no continuity between the age groups (Matsumoto et al. 1994), and made a comparison of different skeletal sites (Gallagher et al. 1987; Heaney et al. 1997). In these cases, the general patterns of age-related BMD change are neither referenced nor delineated.

To estimate the BMD loss with age, previous studies have applied a simple linear model that failed to consider the menopausal factor (Seo et al. 1994; Löfman et al. 1997; Maggio et al. 1997; Nakamura et al. 2000). In addition, physical characteristics such as height and weight have been generally associated with BMD changes in many cross-sectional studies (Gallagher et al. 1987; Mazess et al. 1987; Nuti and Martini 1993; Seo et al. 1994; Heaney et al. 1997; Melton et al. 2000; Nakamura et al. 2000). However, there are only a few studies in the literature that utilize a multiple regression model that includes physical characteristics to assess comprehensive lifetime changes in BMD (Gallagher et al. 1987; Nuti and Martini 1993). Therefore, there is a need for more information about changes in BMD with age and menopause that includes physical characteristics.

Since there is a wide range of BMD measuring techniques and skeletal sites in current use, the pattern of change in BMD for each measuring technique and site is still under development (Lu et al. 2001). Computed X-ray densitometry (CXD) is a method for measuring metacarpal BMD, an index of cortical bone volume, and has the advantages of technical ease and feasibility at low cost (Derisquebourg et al. 1994; Matsumoto et al. 1994; Seo et al. 1994). The purpose of the present study was to characterize the best-fitting model of normal difference in metacarpal BMD for pre- and postmenopausal women. We measured metacarpal BMD using CXD in 5422 healthy Japanese women. Furthermore, we performed a 1-year follow-up study of 359 subjects to determine whether the prospective change model corresponded to the actual BMD changes.

Materials and Methods

Subjects

A total of 8807 women were recruited from the general population in eight communities of Japan. They were Japanese females aged 18–85 years and were invited by publicity in each community to a measurement of BMD and a health assessment at community health care centers in 1994–1996. Of these, 3365 subjects were excluded because they had a disease or received treatment known to affect bone metabolism or because their menstruation status was interrupted by operations or medications. The final study sample consisted of 5442 healthy women (aged 20–78 years); 3142 were premenopausal and 2280 were postmenopausal. Such a large sample enabled us to obtain normative data and to identify the patterns of differences in BMD with age and menopause. We also randomly selected samples for the longitudinal study and enrolled 359 women (aged 21–70 years) who agreed to participate in a 1-year follow-up survey; 185 were premenopausal, 14 were perimenopausal, and 160 were postmenopausal. In longitudinal data, premenopausal women were divided into decade-age groups, and postmenopausal women were classified into three groups: 1–5 years since menopause (YSM), 6–10 YSM, and 11–15 YSM.

This study was approved by the Ethics Committee of the National Institute of Health and Nutrition, Japan. Subjects gave written informed consent for joining the study and permission for our use of BMD data for evaluation.

The measurement variables included chronological age, menstruation status, age at menopause, height, and weight. Body mass index (BMI) was calculated as weight/height^2 (in kg m^{-2}). Absence of menstruation lasting more than half a year was taken as an age at menopause and was checked by community nurses. Perimenopausals were defined as those who had their menopause during the 1-year follow-up in longitudinal study.

BMD measurement

BMD of the second metacarpal was measured by CXD (Bonalyzer, Teijin, Tokyo, Japan). This procedure provides an anterior–posterior radiographic view in comparison with the density of an aluminum step wedge (20 steps, 1 mm step^{-1}) as a standard (Matsumoto et al. 1994). The diagram of the quantity of absorbed light was converted to 256-grayscale digital data. The computer automatically calculated the metacarpal BMD on the basis of the gradation patterns on the aluminum step wedge. BMD was expressed as the thickness of an aluminum equivalent (mm Al). The precision error of this instrument was within 0.7% according to the manufacturer's standard. The reproducibility of CXD *in vivo* were 0.3–1.2% coefficient of variation (CV) in short-term and 0.2–0.8% CV in midterm (Matsumoto et al. 1994).

Statistical analysis

The differences in BMD with age for premenopausals was analyzed by simple and polynomial regression in cross-sectional data. The differences in BMD with reference to both age and YSM for postmenopausals were analyzed by simple and polynomial regression in cross-sectional data separately. The difference in each correlation coefficient was determined by the following formula:

$$z = (Z_1 - Z_2)/\sqrt{[1/(n_1 - 3) + 1/(n_2 - 3)]} \tag{1}$$

$$Z_i = \ln[(1 + r_i)/(1 - r_i)]/2 \tag{2}$$

where z represents standardized distribution, r is the correlation coefficient, and n is the number of samples. The suitable model was chosen.

Table I. BMD and physical characteristics in cross-sectional population.

Groups	*n*	Age (years)	Height (cm)	Weight (kg)	BMI ($\mathrm{kg\,m^{-2}}$)	BMD (mm Al)
20–29*	365	26.5 ± 2.4	157.9 ± 5.1	50.9 ± 7.1	20.38 ± 2.52	2.710 ± 0.220
30–39*	1395	35.1 ± 2.9	157.3 ± 5.0	52.4 ± 7.1	21.18 ± 2.77	2.738 ± 0.216
40–49	1181	45.1 ± 3.0	156.2 ± 5.1	52.7 ± 7.0	21.63 ± 2.73	2.741 ± 0.253
Premenopause	1064	44.8 ± 2.9	156.3 ± 5.1	52.8 ± 7.0	21.64 ± 2.71	2.756 ± 0.249
Postmenopause	117	48.1 ± 1.7	155.5 ± 4.7	52.0 ± 7.4	21.51 ± 2.92	2.605 ± 0.248
50–59	1495	54.9 ± 3.1	153.8 ± 4.9	52.2 ± 7.0	22.06 ± 2.80	2.485 ± 0.300
Premenopause	291	52.0 ± 2.7	153.9 ± 4.8	52.8 ± 6.7	22.28 ± 2.78	2.668 ± 0.268
Postmenopause	1204	55.6 ± 2.7	153.7 ± 4.9	52.0 ± 7.0	22.00 ± 2.81	2.441 ± 0.290
60–69	969	63.0 ± 2.2	152.8 ± 5.0	52.1 ± 7.4	22.33 ± 3.01	2.254 ± 0.267
Premenopause	31	62.9 ± 2.2	151.6 ± 4.6	52.9 ± 8.1	23.04 ± 3.58	2.194 ± 0.285
Postmenopause	938	63.0 ± 2.2	152.8 ± 5.0	52.1 ± 7.3	22.31 ± 2.99	2.256 ± 0.266
70–78**	21	72.7 ± 2.2	149.1 ± 6.0	50.2 ± 8.0	22.52 ± 2.75	2.127 ± 0.220

Values are means ± SD; *premenopausal women; **postmenopausal women.

To estimate the prospective BMD change models in both pre- and postmenopausal women, stepwise regression techniques were used with age, YSM (when fitting for postmenopausals), height, weight and BMI as independent variables on the basis of the chosen model.

The annual percentage rates of BMD changes were calculated from longitudinal data. The predicted BMD in a particular individual was obtained using the change model at their baseline and 1 year after. The predicted annual rates of BMD changes were computed based on these values. To assess the validity of the change models calculated from stepwise regression in cross-sectional data, nonparametric analysis was used to compare actual percentage rates of BMD changes with predicted percentage rates of BMD changes within each group. The significance level was set at 0.05.

Results

Differences in BMD: Cross-sectional design

The BMD and physical characteristics of the cross-sectional population for each age group are shown in Table I. The recalled age at menopause was 50.4 ± 3.3 years. Height and BMI were correlated with age ($r = -0.353$, $p < 0.001$; and $r = 0.193$, $p < 0.001$), respectively. No correlation between weight and age was found. The BMD was significantly higher in the 40–49 age groups, and thereafter was significantly lower by 22.4% in the over 70 age group ($F(5,5416) = 574.9$, $p < 0.001$). Significant differences in BMD between pre- and postmenopausal women were observed both in the 40–49 and 50–59 age groups ($t(1117) = 6.26$, $p < 0.001$; and $t(1492) = 12.14$, $p < 0.001$), respectively. There was no significant difference that in the 60 year age group.

To analyze the pattern of age-related BMD differences for premenopausal women, we applied various regression analyses for the relationship between BMD and age. The simple and polynomial regression equations significantly fit the observed BMD differences (Figure 1). A significant difference was observed in the correlation coefficients between the two regression equations. Therefore, the suitable equation was a nonlinear-change model used to evaluate the age-related BMD differences for premenopausal women.