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Factors influencing lumbar spine bone mineral density assessment by dual-energy X-ray absorptiometry: Comparison with lumbar spinal radiogram

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Abstract: A study was conducted to determine the effect of radiographic findings of lumbar spinal changes upon bone mineral density measurements obtained by dual energy X-ray absorptiometry (DXA). Four hundred subjects were chosen from among 1543 community residents, aged 40–79 years. Study groups of 50 subjects each were selected by sex and 10-year age groups. This study investigated 390 of the 400 subjects who agreed to the conduct of spine bone mineral density measurement and spinal radiography. Lumbar spine radiograms were examined for findings of osteophyte formation, facet joint osteoarthritis, vertebral fracture, and aortic calcification. The prevalence of osteophyte formation, facet joint osteoarthritis, vertebral fracture, and aortic calcification increased with age in both men and women. On multiple regression analysis, bone mineral density was significantly higher ($P < 0.001$) in subjects with osteophyte formation or facet joint osteoarthritis than in those without these conditions, while bone mineral density was significantly lower in subjects with vertebral fracture. This study demonstrated that osteophyte formation, facet joint osteoarthritis, and vertebral fracture should be taken into account in the evaluation of bone mineral density by DXA in people in older age groups, since these conditions occur at a considerable rate in such subjects.

Key words: DXA, bone mineral density, lumbar spine, epidemiological study

Introduction

In examinations of the lumbar spine by dual-energy X-ray absorptiometry (DXA), the mean values from antero-posterior projections of the second to fourth lumbar vertebrae are most frequently used because of the greater ease of reproducibility of the body position in comparison with lateral projections. With antero-posterior projections in the lumbar spine, pathophysiological changes in the lumbar vertebrae have been reported as important confounding factors, i.e. (1) the size and shape of the bones; (2) bone marrow fat; (3) calcification of soft tissue, such as aortic calcification; (4) changes associated with aging of the lumbar spine, such as osteophyte formation and facet joint changes; and (5) the effect of body position.[7,11,16] The effects of such confounding factors upon lumbar spine bone mineral density, however, have not, to our knowledge, been quantitatively examined.

In the present study, a general resident population in the community was examined to determine the prevalence by age of lumbar vertebral osteophyte formation, facet joint osteoarthritis, vertebral fracture, and aortic calcification, as well as to determine the effects of such factors upon bone mineral density measurements of the lumbar spine (L2–L4). In addition, changes in lumbar spine bone mineral density by age were examined after exclusion of such confounding factors.

Study participants and methods

Four hundred subjects were chosen from among 1543 inhabitants (726 men and 837 women, aged 40–79 years) based on the resident registration of Miyama Village, Wakayama Prefecture. Study groups of 50 members each were selected by sex and 10-year age groups, and participants consisted of 390 of the 400 subjects who consented to the conduct of lumbar spine bone mineral density measurement and spinal radiography (Table 1).

Lumbar spine bone mineral density measurements were conducted by dual-energy X-ray absorptiometry (Lunar DPX, Lunar Radiation, Madison, WI, USA).

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Table 1. Number of participants by sex and age

	Age (years)				
	40–49	50–59	60–69	70–79	Total
Men	47	48	50	49	194
Women	48	49	50	49	196
Total	95	97	100	98	390

Measurements were obtained from antero-posterior projections of the second to fourth lumbar vertebrae and analysis was based upon the mean value of these measurements. Reproducibility of the measurements of bone mineral density by DXA was evaluated by spine phantom.

Lumbar spine radiography was conducted with the patient in the supine position for the anterior view, and in the lateral position for the lateral view, using a film-tube distance of 1 m, and with the third lumbar vertebra in the center of the field. Four findings: lumbar vertebral osteophyte formation; facet joint osteoarthritis; vertebral fracture of the second, third, and fourth vertebrae; and aortic calcification in the region of the second, third, and fourth vertebrae, were reviewed and graded. Facet joint osteoarthritis and aortic calcification were classified as present or absent.

Vertebral fracture was assessed in terms of three findings: wedge, biconcave, and compound appearance. As shown by the diagnostic criteria presented in Fig. 1, wedge appearance is where the anterior height of the vertebra is 75% or less than its posterior height, biconcave appearance is where the height of the center part of a vertebra is 80% or less than that of the anterior and posterior parts of the vertebra, and compound appearance is where the height of the anterior, center, and posterior parts of an axial vertebra are all reduced to 80% or less of the normal value.[3]

Osteophyte formation was assessed as absent (0 degrees) or present, with presence classified as of first to fourth degrees, according to Nathan's classification.[12]

The effects of age upon lumbar spine bone mineral density were examined by multiple regression analysis, with adjustment for sex, body weight, osteophyte formation, facet joint osteoarthritis, vertebral fracture, and aortic calcification. In this regression model, the presence of facet joint osteoarthritis, vertebral fracture, and aortic calcification, respectively, was given a value of 1, and their absence was given a value of 0. Based on the results of a preliminary examination of the association between osteophyte formation and lumbar spine bone mineral density, the degree of osteophyte formation was grouped into three categories, i.e., 0-first degree osteophyte formation, second degree osteophyte formation, and third-fourth degree osteophyte formation, graded according to Nathan's classification.[12] Thus, the degree of osteophyte formation was defined as a two-dimensional dummy variable (X_1,X_2), where (0,0) was for osteophyte formation 0-first degree, (1,0) for second degree, and (0,1) for third-fourth degree. Sex was given a value of 0 for men, and 1 for women.

Student's *t*-test was used to compare mean values for bone mineral density differences between two groups.

Results

As shown in Table 2, the height, body weight, and body mass index (BMI) of participants decreased with age for both sexes. The prevalence by age of osteophyte formation, facet joint osteoarthritis, vertebral fracture, and aortic calcification in the region of the second, third, and

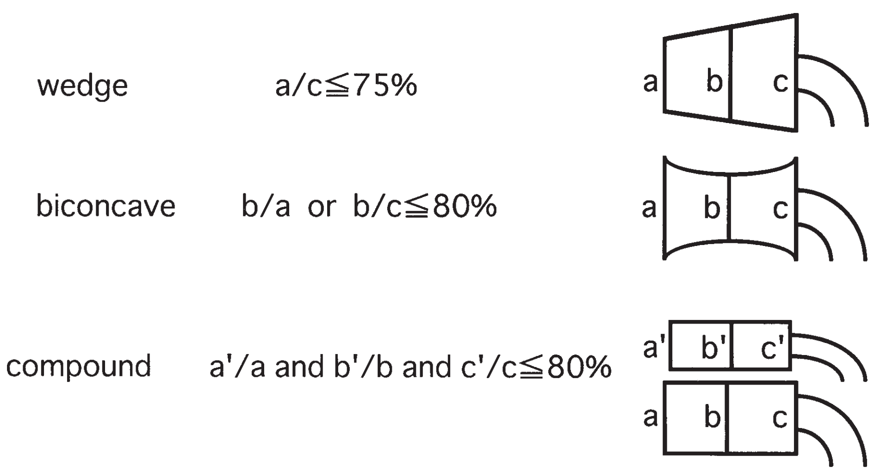

Fig. 1. Diagnostic criteria for vertebral fracture. *a*, Anterior; *b*, center; *c*, posterior; a′, anterior; b′, center; c′, posterior

Table 2. Background of participants

	Age (years)			
	40–49	50–59	60–69	70–79
Men				
Height (cm)	165 ± 6.3	162 ± 6.1	159 ± 5.6	154 ± 4.6
Weight (kg)	63.2 ± 8.0	60.3 ± 8.6	55.7 ± 7.9	46.3 ± 7.0
BMI (kg/m^2)	23.0 ± 2.6	22.7 ± 2.4	21.9 ± 2.2	19.3 ± 2.4
Women				
Height (cm)	152 ± 4.7	150 ± 4.9	147 ± 5.1	146 ± 2.8
Weight (kg)	53.7 ± 8.5	51.0 ± 6.9	46.9 ± 7.6	43.9 ± 6.0
BMI (kg/m^2)	23.1 ± 2.7	22.6 ± 2.7	21.8 ± 3.3	20.7 ± 2.5

Values are means ± SD
BMI, body mass index

Table 3. Prevalence of osteophyte formation, vertebral fracture, osteoarthritis of facet joint, and calcification of aorta

	Degree of osteophyte formation					
Age (years)	0–1st	2nd	3rd–4th	Osteoarthritis of facet joint	Vertebral fracture	Calcification of aorta
Men						
40–49	19 (40.4)	25 (53.2)	3 (6.4)	4 (8.5)	0 (0.0)	1 (2.1)
50–59	9 (18.6)	30 (62.5)	9 (18.8)	9 (18.8)	3 (6.3)	4 (8.3)
60–69	5 (10.0)	24 (48.0)	21 (42.0)	12 (24.0)	4 (8.0)	5 (10.0)
70–79	4 (8.2)	19 (38.8)	26 (53.1)	16 (32.7)	6 (12.2)	11 (22.4)
Women						
40–49	35 (72.9)	13 (27.1)	0 (0.0)	3 (6.3)	0 (0.0)	0 (0.0)
50–59	25 (51.0)	20 (40.8)	4 (8.2)	7 (14.3)	1 (2.0)	2 (4.1)
60–69	18 (36.0)	25 (50.0)	7 (14.0)	11 (22.0)	3 (6.0)	2 (4.0)
70–79	15 (30.6)	26 (53.1)	8 (16.3)	15 (30.6)	6 (12.2)	17 (34.7)

Figures in parentheses are percentages

fourth lumbar vertebrae is shown in Table 3. Osteophyte formation was most prevalent in men with second degree or greater osteophyte formation found in 157 of 194 men (80.9%). The rate increased with age, and second degree or greater osteophyte formation was noted in more than 90% of men in the 60- to 69- and 70- to 79-year age groups. Second degree or greater osteophyte formation was found in 103 of 196 women (53.6%). The prevalence of second degree or greater osteophyte formation increased with age in women, being 64% in the 60- to 69-year age group, and 69.4% in the 70- to 79-year age group.

Facet joint osteoarthritis was noted in 41 of 194 men (21.1%), and its prevalence increased with age, from 8.5% in the 40- to 49-year age group to 32.7% in the 70- to 79-year age group. It was found in 36 of 196 women (18.4%), and the prevalence was almost the same as in men, with an increase with age from 6.3% in the 40- to 49-year age group to 30.6% in the 70- to 79-year age group.

Vertebral fracture was found in 13 of 194 men (6.7%), and in 10 of 196 women (5.1%). The prevalence increased with age from 0% in the 40- to 49-year age group to 12.2% in the 70- to 79-year age group in both men and women.

Aortic calcification in the region of the second to fourth lumbar vertebrae was found in 21 of 194 men (10.8%), and in 21 of 196 women (10.7%). In men, its prevalence by age was 10.0% in the 60- to 69-year age group and 22.4% in the 70- to 79-year age group. In women, the rate was 4% in the 60- to 69-year age group and 34.7% in the 70- to 79-year age group. A sharp increase in prevalence was noted in the 70- to 79-year age groups in both men and women, but the increase was more marked in women.

Table 4 shows factors found to be significantly associated with lumbar spine bone mineral density on multiple regression analysis.

Aortic calcification did not show any significant contribution to lumbar spine bone mineral density ($P >$

Table 4. Multiple regression analysis of the effects of age, sex, weight, vertebral fracture, osteoarthritis of facet joint, and osteophyte formation on lumbar spine bone mineral density

Independent variable	Coefficient of variation	SE	*P*
Constant	0.6528	0.1049	
Sex (male = 0, female = 1)	0.5018	0.0881	<0.001
Vertebral fracture (none = 0, present = 1)	−0.0762	0.0345	<0.05
Osteoarthritis of facet joint (none = 0, present = 1)	0.1045	0.0208	<0.001
Osteophyte (2nd degree)	0.0613	0.0196	<0.001
Osteophyte (3rd–4th degree)	0.1319	0.0270	<0.001
Age (years)	−0.0035	0.0012	<0.001
Weight (kg)	0.0100	0.0010	<0.001
Sex X age (interaction between sex and age)	−0.0092	0.0015	<0.001

$R^2 = 0.56$

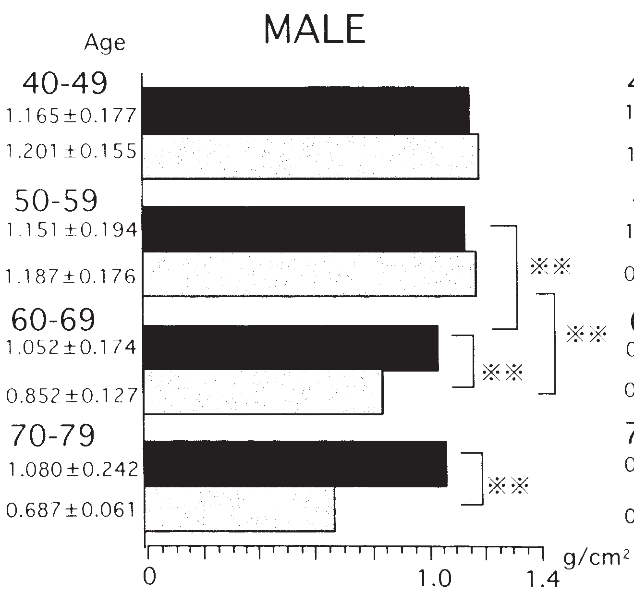

Fig. 2. Bone mineral density of the lumbar spine (L2–L4). Comparisons by 10-year age groups. *Black bars*, Subjects with osteophytes, vertebral fracture, or osteoarthritis of facet joint; *gray bars*, subjects without osteophytes, vertebral fracture, and osteoarthritis of facet joint. $*P < 0.05$; $**P < 0.01$

0.10). Second-degree and third-fourth degree osteophyte formation showed significantly higher regression coefficients, of 0.061 and 0.132, respectively, than 0-first degree osteophyte formation.

Lumbar spine bone mineral density was significantly lower in the presence of vertebral fracture than in the absence of fracture ($P < 0.05$).

Individuals with facet joint osteoarthritis had significantly higher lumbar spine bone mineral density values ($P < 0.001$).

There was a significant sex difference in lumbar spine bone mineral density ($P < 0.001$); that is bone mineral density in women was 0.502 higher than in men. The interactions between sex and osteophyte formation, facet joint osteoarthritis, and vertebral fracture were all insignificant. This indicates that the effect of osteophyte formation, vertebral fracture, and facet joint osteoarthritis upon lumbar spine bone mineral density is the same in men and women.

The multiple correlation coefficient between the observed and the expected lumbar spine bone mineral density was 0.749, and thus the proportion of variance explained was 0.56.

The value for lumbar spine bone mineral density after adjustment for osteophyte formation, facet joint osteoarthritis, and vertebral fracture can be predicted as follows:

$$\text{Observed bone mineral density} - 0.061X_1 - 0.132X_2 - 0.105X_3 + 0.076X_4$$

where $X_1 = 1$ if osteophyte formation is second degree, $X_1 = 0$ if not; $X_2 = 1$ if osteophyte formation is third or fourth degree, $X_2 = 0$ if not; $X_3 = 1$ if facet joint osteoarthritis is present, $X_3 = 0$ if absent; and $X_4 = 1$ if vertebral fracture is present, $X_4 = 0$ if absent. The value adjusted in this fashion indicates the lumbar spine bone mineral density that can be expected when osteophyte formation is 0 or first degree, and facet joint osteoarthritis and vertebral fracture are absent. When adjusted for osteophyte formation, facet joint osteoarthritis, and vertebral fracture, the correlation coefficient between bone mineral density and age was −0.563, higher than the observed correlation coefficient of −0.449. This suggests that the association between observed lumbar spine bone mineral density and age is obscured by the presence of osteophyte formation, facet joint osteoarthritis, and vertebral fracture.

Figure 2 shows the distribution of bone mineral density by age in subjects with and without osteophyte formation, facet joint osteoarthritis, or vertebral fracture. In men, bone mineral density was significantly higher ($P < 0.01$) in the groups with these factors in the 60- to 69-year and 70- to 79-year age groups. In women, bone mineral density was higher ($P < 0.05$) in the groups with these factors in the 50- to 59-year, 60- to 69-year, and 70- to 79-year age groups. When the confounding factors were excluded, bone mineral density by age in men showed a significant difference between the 50- to 59-year and 60- to 69-year age groups. In women, there was a significant difference between the 40- to 49-year and 50- to 59-year age groups, and between the 50- to 59-year and 60- to 69-year age groups.

Discussion

A study cohort was developed in 1988 in Miyama Village, Wakayama Prefecture, to determine the pathogenic factors in cancer, and a questionnaire survey of daily habits was conducted among all residents aged 40–79 years. Information from the questionnaire survey is thus also available for residents other than those who participated in the bone mineral density assessment. The present study group was not a randomly selected population, as most of the members were chosen from among residents in the vicinity of the examination clinic to enable easier transportation of participants. However, their daily habits, including the number of hours of sleep and walking, and their smoking and drinking habits, are in good agreement with those in the total resident population.[5] The participants selected according to the respective age groups can be regarded as of average Japanese physical constitution, since their physical characteristics, such as height, weight, and BMI, were generally the same as those of the average Japanese, in comparison with results of the 1988 National Nutrition Survey.[10]

We reviewed the literature in regard to the prevalence of osteophyte formation, facet joint osteoarthritis, vertebral fracture, and aortic calcification. Orwoll et al.[13] reported osteophyte formation of the second, third, and fourth vertebrae in 55 of 129 white men. Although the participants in our investigation were younger than the subjects examined by Orwoll et al.,[13] the frequency of osteophyte formation was higher in our study. The age factor does not seem to be responsible for this finding, and although possibile differences in the methods of evaluation of osteophyte formation may explain the different results, differences in the study populations or racial differences may have been involved. Even though their method for the grading of osteophyte formation was different, Ito et al.[4] reported that, in their study of 203 volunteer Japanese men, large osteophyte formation was found in 17 of 42 participants in the 50- to 59-year age group, and in 20 of 34 subjects in the 60- to 69-year age group.[4]

Concerning the prevalence of osteophyte formation in women, Reid et al.[14] examined 130 postmenopausal women, and noted osteophyte formation in 63%, while Masud et al.[9] similarly reported osteophyte formation in 63% of postmenopausal women with vertebral fractures. Our study included 41 premenopausal women among 48 members of the 40- to 49-year age group (85.4%), and 11 among the 49 women in the 50- to 59-year age group (22.4%), but the prevalence of osteophyte formation in postmenopausal was 53%, similar to that reported by Reid.[14]

The prevalence of aortic calcification in a study of men by Orwoll et al.[13] was 66.7%, and it was 25.4% in a study of women by Reid et al.[14] In our study, we found a low prevalence, of 11%, in both men and women. The differences in prevalence may reflect differences in races and populations, but all the reports cited have bias in the study populations. The study group in our investigation was confirmed to be representative of the local resident population, and the prevalence of osteophyte formation, facet joint osteoarthritis, vertebral fracture, and aortic calcification was determined to a higher degree of accuracy.

Changes in the spine, such as osteophyte formation, facet joint osteoarthritis, and vertebral fracture, as well as ossification and calcification of the soft tissue, such as aortic calcification, and ligament ossification or calcification, have been reported to be confounding factors in the assessment of lumbar spine bone mineral density by DXA with antero-posterior projections. There are few reports in the literature, however, that have quantitatively determined the extent of effects produced by such confounding factors upon bone mineral density. Results of our multiple regression analysis showed the effect not only of sex upon bone mineral density, but also the effect of body weight, facet joint osteoarthritis, osteophyte formation, and vertebral fracture. In particular, the effects of facet joint osteoarthritis and third to fourth degree osteophyte formation were marked as confounding fractors. It is anticipated that the DXA technique will continue to be used for lumbar spine bone mineral density measurement with antero-posterior projections in population surveys because of the low radiation exposure dose that is received and the high reproducibility of results. Therefore, it is imperative to carry out comparative studies with lumbar spine radiography in subjects aged 60 years and more. Since the frequency of facet joint osteoarthritis, osteophyte formation, and vertebral fracture is low in the 40- to 49-year age and younger age groups, only a few of them will show effects upon lumbar spine bone mineral density measurements.

Osteophyte formation was reported by Orwoll et al.[13] and Ito et al.[4] to affect lumbar spine bone mineral density in men similarly to the results of our present study.

In women, osteophyte formation was reported to have little effect by Reid et al.,[14] but our study showed effects on lumbar spine bone mineral density measurements similar to those reported by Masud et al.[9] and Dawson-Hughes and Dallal.[1]

Few reports are available concerning the effect of facet joint osteoarthritis upon bone mineral density. Laitinen et al.[8] described the effects of osteophyte formation and osteoarthritis, and their results indicated that osteoarthritis and osteophyte formation affected bone mineral density either independently or in combination. However, they did not evaluate the independent effect of facet joint changes. Our study demonstrated that lumbar spine bone mineral density measurements are affected by osteophyte formation, whether facet joint osteoarthritis is present or not.

Aortic calcification is thought to have effects upon lumbar spine bone mineral density measurements, but our study, similarly to the reports of Orwoll et al.[13] and Reid et al.[14] showed a negligible effect upon lumbar spine bone mineral density measurements in both men and women. Accordingly, aortic calcification probably has little effect on measurements of bone mineral density by DXA with antero-posterior projections.

Bone mineral density in women was higher than in men. Caution, however, is needed in the interpretation of this finding, because differences in body weight between men and women must be taken into account when differences in lumbar spine bone mineral density are examined. The significant interaction we found between sex and age suggests a significant sex difference in the age dependency of lumbar spine bone mineral density.

Bone mineral density by age groups was affected by osteophyte formation, facet joint osteoarthritis, and vertebral fracture. Such changes of the vertebra increased with age in our study participants. In particular, more men than women were likely to be affected by osteophyte formation, so that the difference in distribution by age of bone mineral density we noted between men and women in the 60- to 69-year and 70- to 79-year age groups after exclusion of osteophyte formation, facet joint osteoarthritis, and vertebral fracture probably is not as great as previously reported.[2,6,15] As described in the results of our multiple regression analysis, osteophyte formation, facet joint osteoarthritis, and vertebral fracture, respectively, independently affect lumbar spine bone mineral density. In an examination of bone mineral density of the lumbar spine by age, caution is needed in the evaluation of the results, because older subjects usually have osteophyte formation, facet joint osteoarthritis, or vertebral fracture, and it has been demonstrated that the absence of such abnormalities in older subjects is exceptional.

Conclusions

1. The prevalence of osteophyte formation, facet joint osteoarthritis, vertebral fracture, and aortic calcification increased with age in both men and women in a general resident population. In particular, the prevalence of osteophyte formation was high, and this condition was noted in almost all men aged 60 years and more.
2. Osteophyte formation, facet joint osteoarthritis, and vertebral fracture affected lumbar spine bone mineral density, regardless of sex or age.
3. The presence of osteophyte formation and facet joint osteoarthritis caused lumbar spine bone mineral density to appear high in older subjects.
4. Aortic calcification did not affect lumbar spine bone mineral density measurements.
5. The rates of osteophyte formation, facet joint osteoarthritis, and vertebral fracture are consider-

able in older subjects, and it was verified clinico-epidemiologically that this point should be taken into account in making a diagnosis of osteoporosis.

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