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Original Article

Bone Mass Measurement of Calcaneus by Quantitative Ultrasound Method (QUS)

Sanae Ko

Department of Human Nutrition, Faculty of Contemporary Life Science, Chugokugakuen University, Okayama 701-0197, Japan

The quantitative ultrasound method (QUS) for measuring bone mass at a calcaneus is a suitable method for screening osteoporosis with safety and simplicity. In the present paper the bone mass of 328 subjects, in association with their physical parameters, was measured by the QUS and the results were analyzed. The value measured by the QUS was expressed as osteosono-assessment indexes (OSIs).
1. The bone mass of the general adult population reached the maximum in their twenties and then decreased gradually. Annual reduction rates of bone mass during the gradual reduction period were 0.52% for women and 0.43% for men of the maximum value, respectively. Rapid reduction of bone mass occurred in women in their sixties and men in their seventies of men. Annual reduction rates of bone mass during the rapid reduction period were 15% for women and 13.5% for men.
2. The bone mass levels of female subjects were classified by the T score, which is the percentage of an average OSI (2.698×10^6) of female young adults. The low bone density level (T score less than 80) was 31.6% of the total female subjects, including 17.4% osteoporosis level (T score less than 70) subjects, indicating that they are afflicted by osteoporosis. The osteoporosis level subjects were mostly elderly women over the age of 69. There was no osteoporosis level subject at the age less than 50. The guidance-required level (T score is 80 and more than 80 and less than 90) subjects included 16% of the women in their twenties. They may have fallen even to osteoporosis level by their 50's. Therefore, it was thought to be important to find youths with low bone mass and to counsel them to improve their daily life to prevent osteoporosis.
3. In the female subjects aged 40 and older, positive correlations were observed in OSI, age, height, weight and BMI. Multiple regression analysis indicates that age was the most influential factor on OSI among these factors.

Key Words: Bone mass, Quantitative ultrasound method (QUS), Calcaneus, Physical constitution

Introduction

Low bone mineral density alone is the best predictor of fracture risk, even when the mineral density examination is conducted on peripheral bones such as calcaneus and phalanxes.

To detect fracture risk at an early stage, it is best to measure bone mineral density periodically. To do periodical examinations, it is desirable that the examination procedure is not a burden to the person receiving the examination. The quantitative ultrasound (QUS) method

Tel. & FAX; +81 86 293 0247

for measuring bone mass of calcaneus is an excellent method that can be used easily and safely at a low cost [1].

Thus far, the diagnostic standard for primary osteoporosis set by Japanese Bone Metabolism Society is based on data obtained not by the QUS method but by the X-ray method. However, the osteoporosis prevention manual provided by Health and Medical Service Law for the Aged adopted the QUS method as a standard method for screening for osteoporosis [2]. This procedure is expected to function effectively for early detection of fracture risk and for prevention of osteoporosis.

In the present paper, bone mass of 328 average persons measured by the QUS method, was analyzed by parameters of sex, age, physical constitution (height and weight) and BMI. The difference in bone mass according to sex and age and the rate of low bone mass is considered.

Subjects and Methods

1. Subjects

Subjects examined were 328 persons in total including 256 women and 72 men. Sex and age distribution of the subjects is shown in Table 1. The average age was 42.1 years, and 49% of the subjects were between 16-21 years of age. The youngest was a girl 16 years old and the oldest a woman 97 years old. The subjects aged 70-90 were mostly persons confined to institutions for the aged or outpatients who come to the institutions for day service. Subjects examined were mostly healthy persons, but some who needed assistance in movement and some restricted to wheel chairs were also included.

2. Bone mass analysis

Bone mass was measured at the right calcaneus with the quantitative ultrasound method (QUS) by using AOS-100 (Aloca Co. Ltd., Japan). The osteosono-assessment index (OSI) which was calculated from propagation speed of ultrasound (SOS) through the calcaneus and transmission index (TI) by the formula, [$SOS^2 \times TI$], was used as an index of bone mass.

In order to evaluate measured OSI, an average OSI (YAM, young adult mean) of male or female young adults (20-44 years old) was used as an average value 2.698 ($\times 10^6$) which Yamasaki and others calculated from the healthy 6,096 women's data [2]. Since suitable YAM was not obtained for males, this analysis was not performed on male subjects.

The percentage of measured OSI to the YAM is expressed as T score. In the present paper, OSIs are expressed in units of millions ($\times 10^6$).

3. Statistical analysis

Comparison of average values was done with a significance test of the Student's t-test. The relation of OSI to age and physical constitution was studied with Pearson correlation analysis, and further with stepwise multiple regression analysis, although the analyses were not performed for the male subjects due to the small subject number. These analyses were conducted with significance level of 5% or 1% by using Excel Statistics 2000.

Results and discussion

1. Distribution of osteo-sono assessment index (OSI) of the subjects

The OSI values of all female and male subjects were distributed normally as shown in Fig. 1. OSI values of female students were also distributed normally as I previously reported [3]. These results suggest that the bone strength of healthy adults generally shows normal distribution.

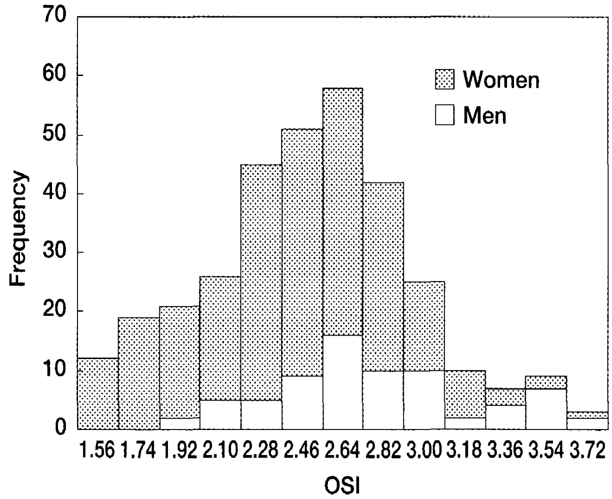

Fig. 1 Distribution of osteo-sono assessment index (OSI) of all the subjects examined in the present study.
Each value of the horizontal axis is a minimum mark of each class of OSI. The OSI values are expressed under the unit of million ($\times 10^6$). The subjects were 328 healthy persons in total including 256 women (■) and 72 men (□). The OSIs of them showed the normal distribution between 1.566 (the minimum value) and 3.898 (the maximum value). The average with standard deviation of OSI was 2.585 ± 0.464 and the median was 2.614.

The average of OSI values of all the subjects examined and the standard deviation were 2.585 ± 0.462, with the minimum OSI value of 1.566 in a 92 year-old female subject, and the maximum OSI value 3.898 in an 18 year-old male subject.

2. Age- and sex-dependent changes of bone mass and physical constitution

The OSI value and physical constitution of the subjects were analyzed according to age and sex (Table 1). The average OSIs of the female and male subjects were 2.507 and 2.866, respectively, indicating that the average bone mass of the female subjects was 87.5% of that of the male subjects. The highest bone mass was observed in both female and male subjects in their 20's, as previously reported [4]. Age-dependent decrease of bone mass after the 30's was observed. Age-dependent significant differences of bone mass were observed in female subjects between the ages of 20 and 40, and in male subjects between the ages of 20 and 50, indicating age-dependent, gradual decrease of bone mass. (The OSI values of male subjects in their 30's and 40's were not considered due to the limited number of subjects.)

Previous reports [4] suggested that women show a rapid decrease of bone mass in their 50's when menopause affects a majority of women, but in the present study the rapid decrease is observed in women in their 60's. The reason why bone mass of female subjects in their 50's showed a relatively high value in the present study may be

Table 1 The physical constitution and osteo-sono assessment index (OSI) according to sex and age

	Mean of age and (numbers)	Height (cm) Mean ± SD	Body weight (kg) Mean ± SD	BMI (kg/m^2) Mean ± SD	OSI (× 10^6) Mean ± SD
Late teens					
Women	18.0 (84)	156.9 ± 5.6	50.8 ± 6.8	20.6 ± 2.4	2.727 ± 0.324
Men	18.4 (21)	172.2 ± 3.9	60.7 ± 5.8	20.5 ± 1.8	3.020 ± 0.422
Twenties					
Women	22.4 (37)	155.9 ± 5.8	49.4 ± 5.2	20.3 ± 2.3	2.770 ± 0.342
Men	22.9 (21)	170.8 ± 4.3	60.9 ± 7.0	20.8 ± 2.0	3.094 ± 0.408
Therties					
Women	33.7 (11)	153.9 ± 3.1	51.7 ± 9.2	21.8 ± 3.3	2.739 ± 0.330
Men	37.0 (1)	-	-	-	3.092 [1)]
Forties					
Women	45.3 (25)	157.1 ± 4.3	54.5 ± 8.4	22.0 ± 3.0	2.600 ± 0.197 a [2)]
Men	47.0 (3)	172.0 ± 3.0	72.3 ± 2.1	24.4 ± 0.3	2.640 ± 0.187
Fifties					
Women	54.8 (29)	156.4 ± 5.4	56.7 ± 8.3	23.2 ± 3.1	2.629 ± 0.287
Men	53.6 (5)	171.6 ± 3.5	71.0 ± 8.7	24.1 ± 3.0	2.774 ± 0.104 b [3)]
Sixties					
Women	65.4 (12)	148.6 ± 5.4	52.7 ± 6.7	23.9 ± 3.3	2.234 ± 0.196 c [4)]
Men	63.7 (10)	165.3 ± 3.3	62.3 ± 5.5	22.8 ± 1.9	2.744 ± 0.355
Seventies					
Women	75.7 (21)	145.1 ± 6.4	48.7 ± 10.2	23.1 ± 4.3	1.996 ± 0.210
Men	75.4 (7)	162.3 ± 4.0	55.7 ± 10.6	21.0 ± 3.2	2.373 ± 0.274 d [5)]
Eighties					
Women	85.5 (24)	142.2 ± 9.3	44.2 ± 8.5	21.8 ± 3.8	1.903 ± 0.269
Men	83.0 (4)	158.7 ± 4.2	49.3 ± 6.1	19.6 ± 2.0	2.324 ± 0.251
Ninties					
Women	93.0 (13)	139.1 ± 4.4	39.4 ± 10.0	20.4 ± 5.2	1.875 ± 0.286

The subject examined were 328 persons (256 women and 72 men). The statistical analysis was conducted by a significance test of Student's t-test. The difference was considered to be significant when $p < 0.05$.

[1)] The values of the 30's of male subjects were obtained from only one person.

[2)] a: $p = 0.014$, compared between twenties and forties in the women.

[3)] b: $p = 0.002$, compaed between twenties and fifties in the men.

[4)] c: $p = 0.000$, compared between fifties and sixties in the women.

[5)] d: $p = 0.015$, compared between sixties and seventies in the men.

due to the fact that dietitians with good health care habits and women with good exercise habits were included as subjects. The present results may indicate that good dietary and exercise habits would contribute to significant maintenance of bone mass even if menopause occurs. This is an important implication, but detailed analysis was not conducted in the present study. Bone mass of the male subjects in their 70's decreased rapidly. Reduction rates of bone mass of female and male subjects in the rapid reduction terms (in the 60's and 70's) were 15.0% and 13.5% of the highest OSI value, respectively.

Lifetime reduction amounts, reduction rates and annual reduction rates of OSI were calculated comparing the OSI value of those in their 20's with those in their 80's. The results were 0.867, 31.3% and 0.52%, in the order, for female subjects, and 0.739, 23.9% and 0.43% for male subjects. The lifetime reduction amount and rate were both higher in female subjects than in male subjects. About 1/2 of the lifetime reduction was lost during the rapid reduction term in both female and male subjects.

Grampp *et al.* [5] reported that the change of bone mass can be evaluated by the annual reduction rate which is not so much influenced by a method and site of measurement. They obtained the mean female annual reduction rate of 0.57% by various methods and sites of measurement, and the rate of 0.52% by quantitative ultrasound method (QUS) at calcaneus. Mitsui *et al.* [6] and Yamasaki [7] reported the female annual reduction rates of 0.40% and 0.70%, respectively, measured by QUS at calcaneus. The present result (the female annual reduction rate: 0.52%) agrees roughly with these data. It may be generalized that the annual reduction rate of female bone mass is about 0.5%.

Concerning the annual reduction rate, measured by the calcaneus QUS, of bone mass of male subjects, the values of 0.64% [8] and 0.3% [9] were reported. The present result (0.43%) is at mid-range of these values thus suggesting that our result is appropriate.

3. Reverse correlation between T score and age of female subjects

Reverse correlation between T score and age of female subjects was observed as shown in Table 2. Assessing the result according to the osteoporosis judgment standard, 31.6% of them had a T score less than 80, low bone density level. NORA and The 3 rd United States Health and Nutrition Investigation (NHANES III) both reported that about 50% of healthy women 50 or more 50, showed low bone density [1, 10]. In the present study, 55% of the women 50 or more 50 reached this level. The result indicate that the ratio of the low bone mass in the present study is an average level. As for the breakdown, the subjects belonging to the low bone mass group were one person in her 50's and others aged 65 or older.

17.4% of the subjects hadan osteoporosis level with a T score less than 70. All the persons were women 70 and older. According to trial calculation by Fujiwara [4] and Yamasaki [7], the prevalence rate of osteoporosis measured by the calcaneus QUS method was 33% (70-89 years old persons) and 44% (60-89 years old persons). In the present study the prevalence rate of osteoporosis was 44% in 70 to 89 year olds and 35% in 60 to 89 year olds. These data suggest that the prevalence rate of osteoporosis is about 40% for women aged 60 or above. The guidance-required level for osteoporosis prevention in which T score is between 80 and 90 was 19.8% (34 women) of the subjects. At this level there were 6 persons (16%) in the 20's. As I reported previously, 13% of the female, 20 year old, junior college students were at the guidance-required level. These data

Table 2 The correlation between T score and age of female subjects older than twenty years old

	T score			
	Less than 70	70 and more than 70 and less than 80	80 and more than 80 and less than 90	90 and more than 90
Number (%)	30 (17.4)	24 (14.0)	34 (19.8)	84 (48.8)
Age Mean ± SD	85.9 ± 6.5	78.1 ± 9.3	51.2 ± 18.3	39.6 ± 16.7

Percentage to YAM (2.698×10^{6}) is expressed as T score. Here, YAM indicates the mean of female, young adult (20-44 years old) of OSI. 172 female subjects over 20 years of age were examind.

suggest that about 15% of women in their 20's are at the guidance-required level at present. The results indicate that bone mass of the guidance-required level youth tends to reach osteoporosis levels when they are in their 50's even if the average reduction in bone mass occurs. Instruction for preventing osteoporosis is very important for all guidance-required level people, especially those guidance-required level youths. It is necessary to take preventive measures from an early stage with such youths, considering their tendency for developing osteoporosis in the future.

4. Correlation of OSI to age and physical constitution of women

The OSI significantly correlated to age and physical constitution as shown in table 3. For the analysis, the subjects were divided into two groups, one group which consisted of subjects less than 40 years old and of which bone mass is increasing or maintaining constant levels, and another group which consisted of subjects 40 or older and of which bone mass is declining from the constant phase. Subjects over 90 years old were excluded from this analysis.

In the subjects 40 or older, the OSI had significant negative correlation to the age ($r = -0.78$, $p < 0.01$) and positive correlation to the height ($r = 0.68$, $p < 0.01$) and weight ($r = 0.61$, $p < 0.01$). Weak positive correlation was observed between the OSI and BMI ($r = 0.22$, $p < 0.05$). In subjects younger than 40, there was no correlation between the OSI and age ($r = -0.02$; ns, not significant) or height ($r = -0.03$, ns), and weak positive correlation between the OSI and weight ($r = 0.30$, $p < 0.01$) or between the OSI and BMI (0.35, $p < 0.01$).

Since the calcaneus is a load bone, the OSI is thought to be influenced by weight. There are some reports, which show the relation between bone mass and weight [11]. I reported previously on the correlation between the OSI and physical constitution of female junior college students [3]. The correlation coefficient was between the OSI and weight ($r = 0.30$, $p < 0.01$), and between the OSI and BMI ($r = 0.39$, $p < 0.01$). These coefficients practically coincided with the present result of subjects less than 40 years old. These results are thought to indicate that bone mass of the young women of the age whose bone mass of calcaneus is a plateau, there are weak, but positive correlations between the calcaneus bone mass and weight or bone mass and BMI.

On the other hand, in the subjects 40 or older, there was strong correlation between OSI and weight or OSI and age. Therefore, low weight and aging during the bone mass reduction period of life were thought to be risk factors for low bone mass.

In order to investigate factors affecting OSI, a multiple regression analysis was performed on the subjects 40 or older, by using OSI as a dependent variable and by using age, height, weight or BMI as an independent variable. As shown in Table 3, the correlation coefficient was high between BMI and weight ($r = 0.78$) or between height and age ($r = -0.68$). Since it was predicted from the result that multicollinearity arose in these combinations, BMI and height were excluded from the explanation variable. The variable selection of the stepwise method, shows that these variables (BMI and height) are not necessary in predicting occurrence of osteoporosis.

Multiple regression analysis using OSI as a dependent variable and by using age and weight as independent variables was conducted. The result is shown in Table 4. The standard regression coefficient is higher between OSI and age (-0.638) than between OSI and weight (0.329). The multiple correlation is high ($r = 0.837$) and the result of examination of a coefficient of determination is also significant (Table 5).

It is concluded from the above results that age is the most influencing factor on OSI. This result was in agreement with the report of NORA [1] that age was the most important risk factor for predicting low bone mass, even after adjusting for years passed from menopause and other covariates including BMI.

Table 3 Correlation coefficent due to simple regression analysis with osteosono-assessment index (OSI) and physical constitution

	OSI	Age	Height	Body weight
Age (years)	−0.783**			
	−0.0191			
Height (cm)	0.677**	−0.680**		
	−0.029	−0.140		
Body weight (kg)	0.612**	−0.444**	0.589**	
	0.301**	0.018	0.418**	
BMI (kg/m^2)	0.219*	−0.024	−0.041	0.776**
	0.350**	0.105	−0.124	0.848**

243 female subjects were examined. The numbers of top shelf of each item were the results of 111 elderly women (range of 40-89 years old) and of bottom shelf were 132 young women (range of 16-39 years old).
*: $p < 0.05$, **: $p < 0.01$

Table 4 The result of stepwise multiple regression analysis

	Partial regression coeffcient	Standerd partial Regression coefficient	F-value	P-Value	Precision	
Age	−0.01622	−0.6379	118.0486	0.000	R-Square	0.7013
Weight	0.01347	0.3287	31.3383	0.000	Multiple correlation	0.8374
Const	2.64666		197.4458	0.000		

The subjects were 111 women (range of 40-89 years old). The averages with standerd deviations of OSI, age and weight of them were 2.303 ± 0.400 (× 10^{6}), 64.0 ± 15.6 years old and 51.6 ± 9.7 kg, respecyively. The dependent variable is the OSI.
F-value is significant in $p < 0.05$.

Table 5 The Analysis of variance

Factor	DF	Sum of squares	Mean square	F-Value	P-Value
Regression	2	12.1678	6.0839	126.754	0.000
Residual	108	5.1837	0.0480		

F-value is significant in $p < 0.05$.

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