Shimane J. Med. Sci., Vol.26 pp.13-19, 2009

Comparison of the Effectiveness of Dual Energy X-Ray Absorptiometry, Ultrasound Bone Densitometry and Bioelectrical Impedance Analysis in Assessing of Bone Mass

Takahiko Nohara[1] and Masatoshi Asai[2]

[1] *Health Administration Center Izumo, Shimane University Faculty of Medicine, Izumo 693-8501, Japan*

[2] *Department of Biosignaling and Radioisotope Experiment Center for Integrated Research in Science, Shimane University Faculty of Medicine, Izumo 693-8501, Japan*

(Received September 7, 2009; Accepted October 21, 2009)

We investigated whether the assessment of bone density using the comparatively convenient and portable ultrasound bone densitometry and bioelectrical impedance analyzer, which do not involve radiation, could substitute for the dual energy X-ray absorptiometry (DXA). Bone mineral content (BMC) and bone mineral density (BMD) in the entire skeleton and BMD in the lumbar vertebrae were measured using DXA and trabecula bone area ratio in the calcaneus was measured using ultrasound bone densitometer with quantitative ultrasound method (QUS). Moreover, body height, weight, somatic fat volume and bone mass were measured using bioelectrical impedance analysis (BIA). DXA measurement of the lumbar vertebrae, calcaneal BAR using QUS and BMC using BIA were carried out in 1,073 adults, and DXA measurement of the lumbar vertebrae and that of the entire skeleton in 1,356 adults. So, we found statistically that there were well correlation between whole body BMC and BMD, lumbar BMD and whole body BMD and BMC, lumbar BMD and BMC using BIA, lumbar BMD and calcaneal BAR, respectively.

Key words: bone mineral density (BMD), bone mineral content (BMC), dual energy X-ray absorptiometry (DXA), quantitative ultrasound (QUS), bioelectrical impedance analysis (BIA)

INTRODUCTION

Today, with Japan's aging society, it has become increasingly important for seniors to maintain their health and quality of life (1). It is well known that, as people age, they are at risk of osteoporosis, a degenerative change of bone that easily leads to fractures at certain sites. If trabecular bone is affected most, compression fractures of the thoracic and lumbar vertebrae are common; should cortical bone be affected, fractures of the femoral neck become more likely in women after menopause (2,3,4,5). The former (i.e., thoracic/lumbar compression fractures) fractures usually give rise to acute lumbar or thoracic pain and the deformities subsequently developing after the fractures cause chronic pain at affected sites (6). Such conditions may restrict the daily activities of the aged to such an extent that their quality of life deteriorates until they finally become bedridden (7).

To prevent osteoporosis, early detection of a decrease in bone mineral content is important. In clinical settings, measurement of bone content or density frequently uses dual energy X-ray absorptiometry (DXA) chiefly of the entire skeleton or lumbar vertebra (8,9,10). As 80 % of the entire skeleton is composed of cortical bone (11), measurement of its bone mineral density accurately reflects the condition of cortical bone throughout the body. The measurement also yields good reproducibility of results with repetition, because the measured bone areas are large, and in addition, there is little interfering influence from deformities at nearby sites. As the lumbar vertebrae are known to most frequently succumb to compression fracture from osteoporosis, they are optimal choices for the measurement and detection of osteoporosis.

Bone mineral content and density of the entire skeleton are expressed as values of the actual measurement obtained, but those for the lumbar vertebrae are expressed as the average measurement of three lumbar vertebrae (the second to the fourth: L_2 -L_4). A decrease

Correspondence: Takahiko Nohara, M.D., Ph.D., Health Administration Center Izumo, Shimane University Faculty of Medicine, 89-1 Enya Cho, Izumo City, Shimane 693-8501, Japan
Tel: +81-853-20-2099
Fax: +81-853-20-2097
E-mail: nohara@med.shimane-u.ac.jp

in bone mineral content is defined as follows; less than peak bone mass of whole body or lumbar vertebra minus 2 standard deviation (SD) or minus 2.5 SD (12,13).

Lumbar BMD is performed more often than whole body bone mineral density (BMD) and bone mineral content (BMC), because it is quicker (about 5 minutes per person vs. 15 minutes per person). However, the BMC derived from measurement of lumbar vertebrae has not been proven. We therefore attempted to determine whether there was another way of easily measuring BMC other than DXA.

METHODS

Subjects

Our study protocol was approved by the institutional review board of Shimane Institute of Health Science. Following this approval, informed consent to participate in our study was obtained from patients visiting the Shimane Institute of Health Science for general medical examination. A total of 1,073 adults living in Izumo City (male, 429 and female, 644) aged from 33 to 88 years with an average age of 71 years consulted us for a medical examination for osteoporosis between 2003 and 2004 and were subjects in this study. In this study, measurement of lumbar vertebrae with DXA, BMD in the calcaneus with ultrasound bone densitometry and height, weight, fat volume and bone mineral contents with bioelectrical impedance analysis (BIA) were performed simultaneously. Further, a total of 1,356 adults living in the towns of Kisuki, Nita and Yokota, and students of Shimane Medical School (male, 241 and female, 1,115) aged from 18 to 83 years with an average age of 51 years consulted us for a check-up between 1994 and 1995 and were supplemented in this study. In the added study, measurement of the entire skeleton and lumbar vertebrae with DXA were performed simultaneously.

Measurement of bone mineral contents and density

DXA was performed using a QDR 2000 bone density measurement device (Hologic, Bedford, M.A. USA). If data were obtained twice at different times for the same person, the initial data were used for our analysis. When foreign substances such as metal were recorded, the relevant data were discarded.

For the entire skeleton

DXA was conducted for the skull, both clavicles, both scapulae, both arms, the ribs, spine, pelvis and both legs. The total area and total bone mineral content of the entire skeleton (whole body) were determined. The whole body bone mineral density was then calculated by dividing the bone mineral content by the total area of the entire skeleton.

For the lumbar vertebrae

DXA was conducted in the region from the first lumbar vertebra (L_1) to the fifth (L_5). Bone area and bone mineral content of each vertebra were obtained. Bone mineral density was calculated by dividing the bone mineral content by the bone area. The average bone area of three vertebrae (L_2-L_4) was calculated, as was the average bone mineral content of the same three vertebrae.

Measurement of bone mineral density in the calcaneus

Trabecular bone area (BAR) for the calcaneus was determined using the Benus 2 ultrasound bone densitometry device (Ishikawa Seisakusho Ltd., Ishikawa, Japan) by the quantitative ultrasound method (QUS).

Measurement of height, weight, fat volume and bone mineral contents

Height, weight, fat volume and bone mineral content were measured using an InBody bioelectrical impedance analysis (BIA) device (Biospace Co. Ltd., ROK) (14).

Statistical analysis

We investigated the relationship between: 1) whole body BMC and BMD with DXA, 2) whole body BMD and lumbar BMD with DXA, 3) whole body BMC and lumbar BMD with DXA, 4) lumbar BMD with DXA and calcaneal BAR with QUS, 5) lumbar BMD with DXA and BMC with BIA and 6) calcaneal BAR with QUS and BMC with BIA.

For the relationship between whole body BMC and BMD with DXA, a scatter diagram was constructed using Microsoft Excel, plotting subject whole body BMD with DXA along the x-axis and whole body BMC along the y-axis (Fig. 1). Similarly, for the other relationships we plotted lumbar BMD with DXA (x-axis) vs. whole body BMD (Fig. 2), whole body BMC (Fig. 3), calcaneal BAR on QUS (Fig. 4), or BMC with BIA (y-axis) (Fig. 5) and calcaneal BAR on QUS (x-axis) vs. BMC with BIA (y-axis) (Fig. 6). Pearson's

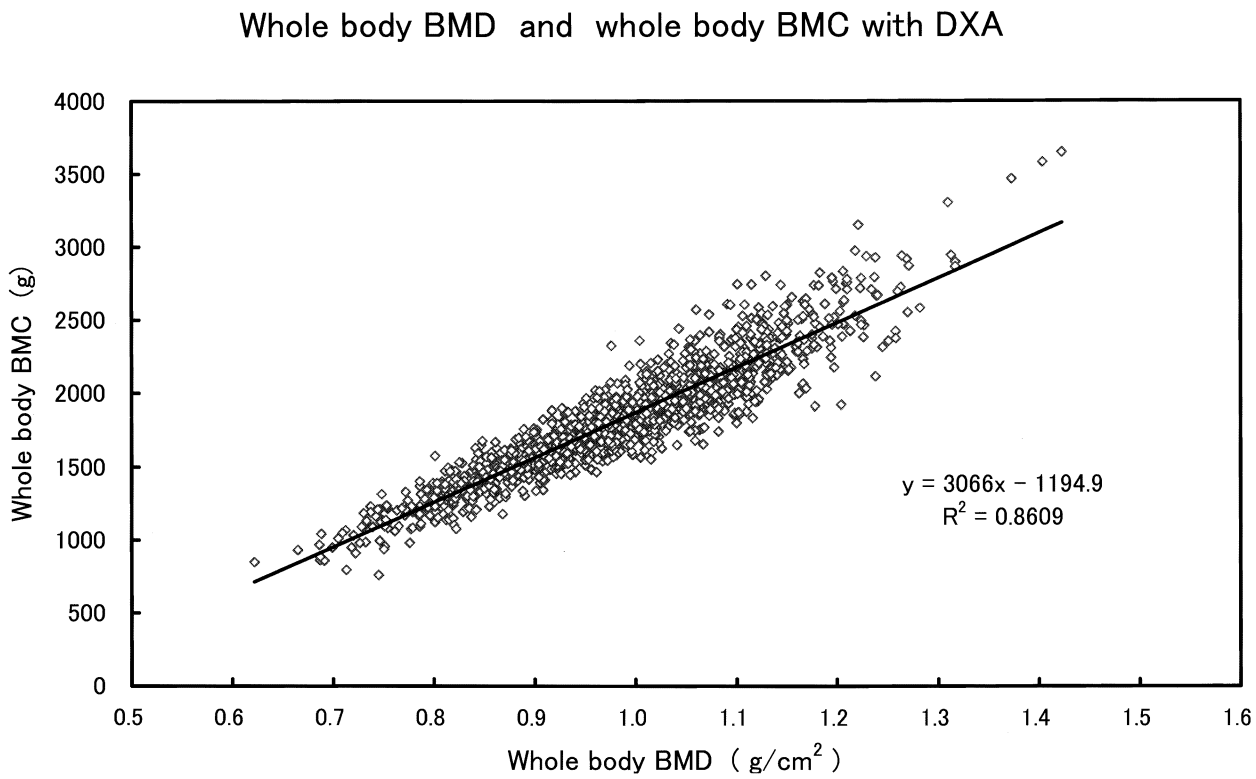

Fig. 1. Correlation between whole body BMD (g/cm^2) and whole body BMC (g) with DXA

The equation in the figure shows the approximate linear equation estimated by the least square method. "R" denotes the correlation coefficient between whole body BMD (g/cm^2) and whole body BMC (g) with DXA.

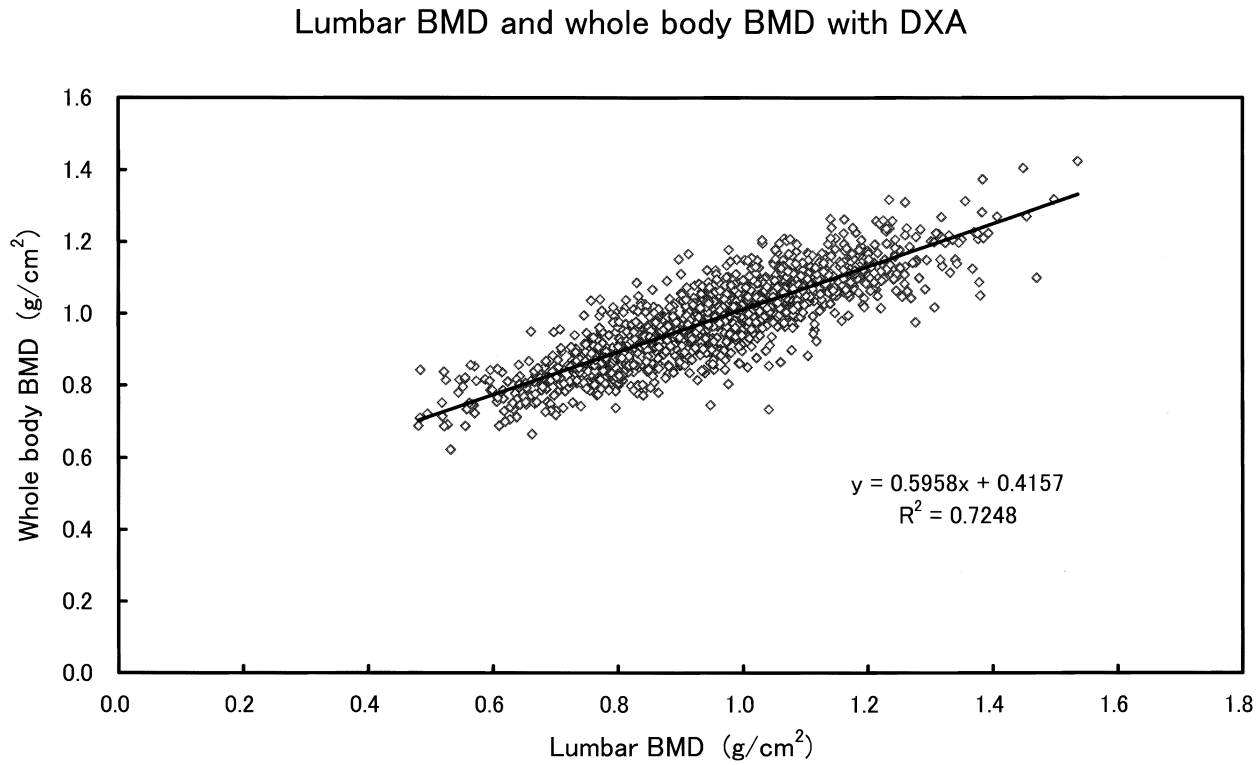

Fig. 2. Correlation between lumbar BMD (g/cm^2) and whole body BMD (g/cm^2) with DXA

The equation in the figure shows the approximate linear equation estimated by the least square method. "R" denotes the correlation coefficient between lumbar BMD (g/cm^2) and whole body BMD (g/cm^2) with DXA.

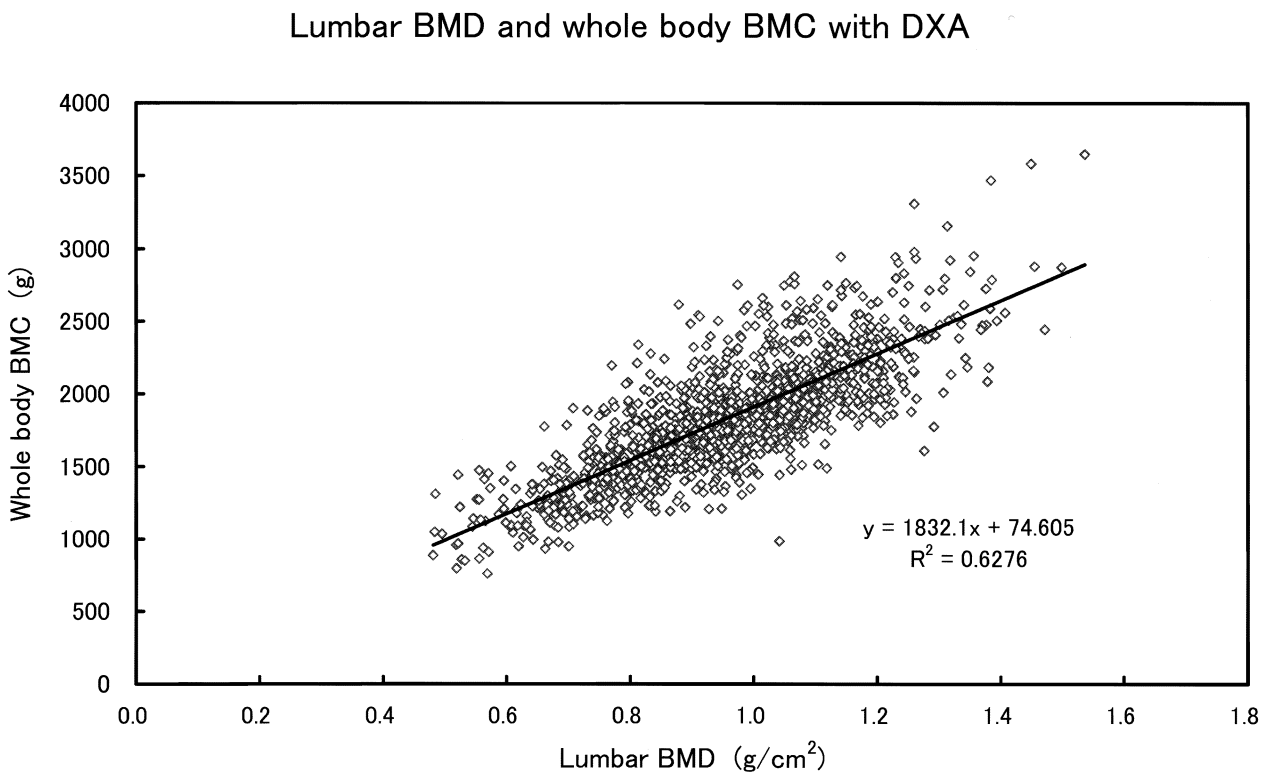

Fig. 3. Correlation between lumbar BMD (g/cm^2) and whole body BMC (g) with DXA

The equation in the figure shows the approximate linear equation estimated by the least square method. "R" denotes the correlation coefficient between lumbar BMD (g/cm^2) and whole body BMC (g) with DXA.

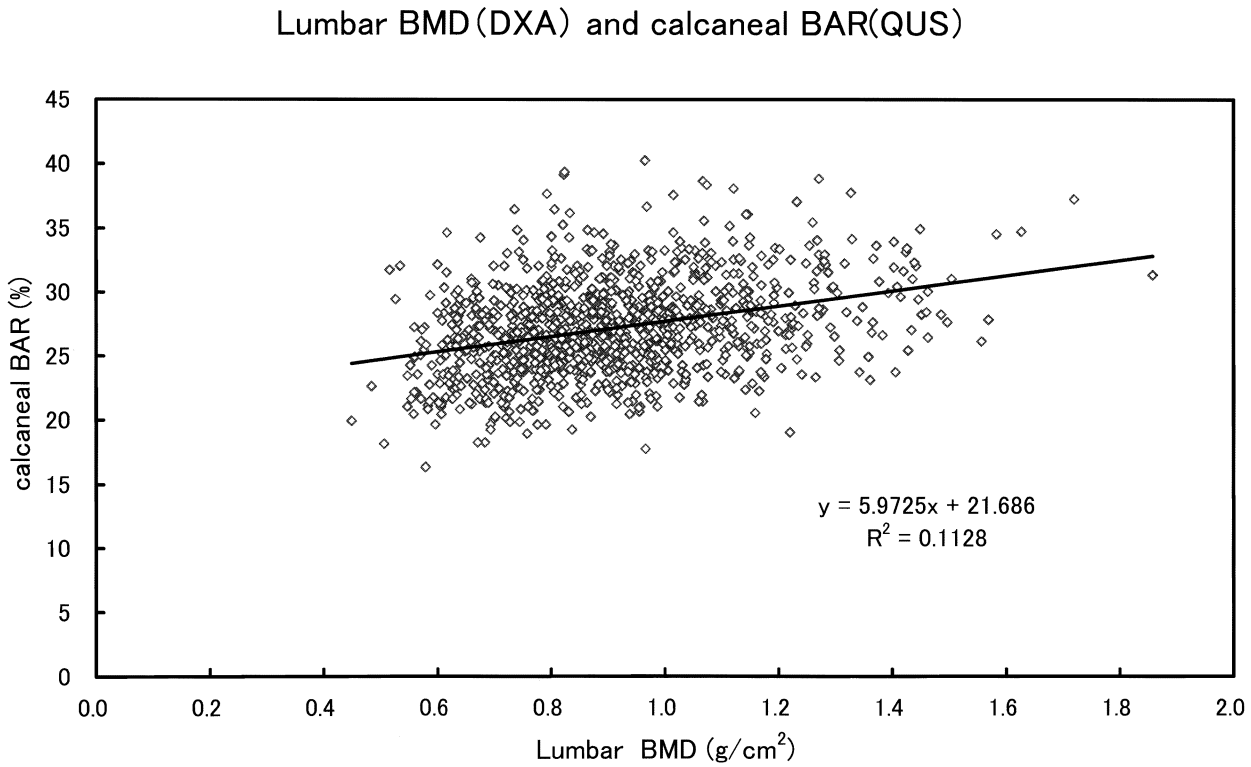

Fig. 4. Correlation between lumbar BMD (g/cm^2) with DXA and calcaneal BAR (%) with QUS

The equation in the figure shows the approximate linear equation estimated by the least square method. "R" denotes the correlation coefficient between lumbar BMD (g/cm^2) by DXA and calcaneal BAR (%) with QUS.

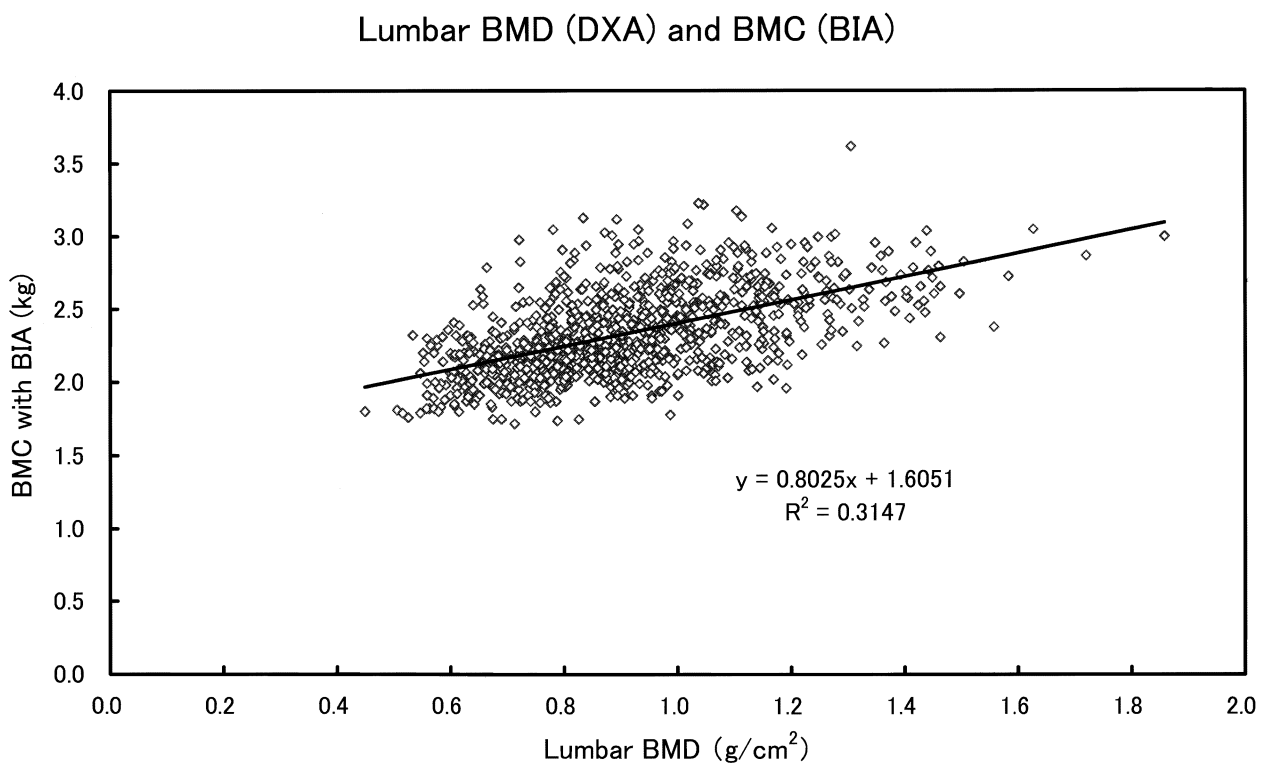

Fig. 5. Correlation between lumbar BMD (g/cm^2) with DXA and BMC (kg) with BIA

The equation in the figure shows the approximate linear equation estimated by the least square method. "R" denotes the correlation coefficient between lumbar BMD (g/cm^2) with DXA and BMC (kg) with BIA.

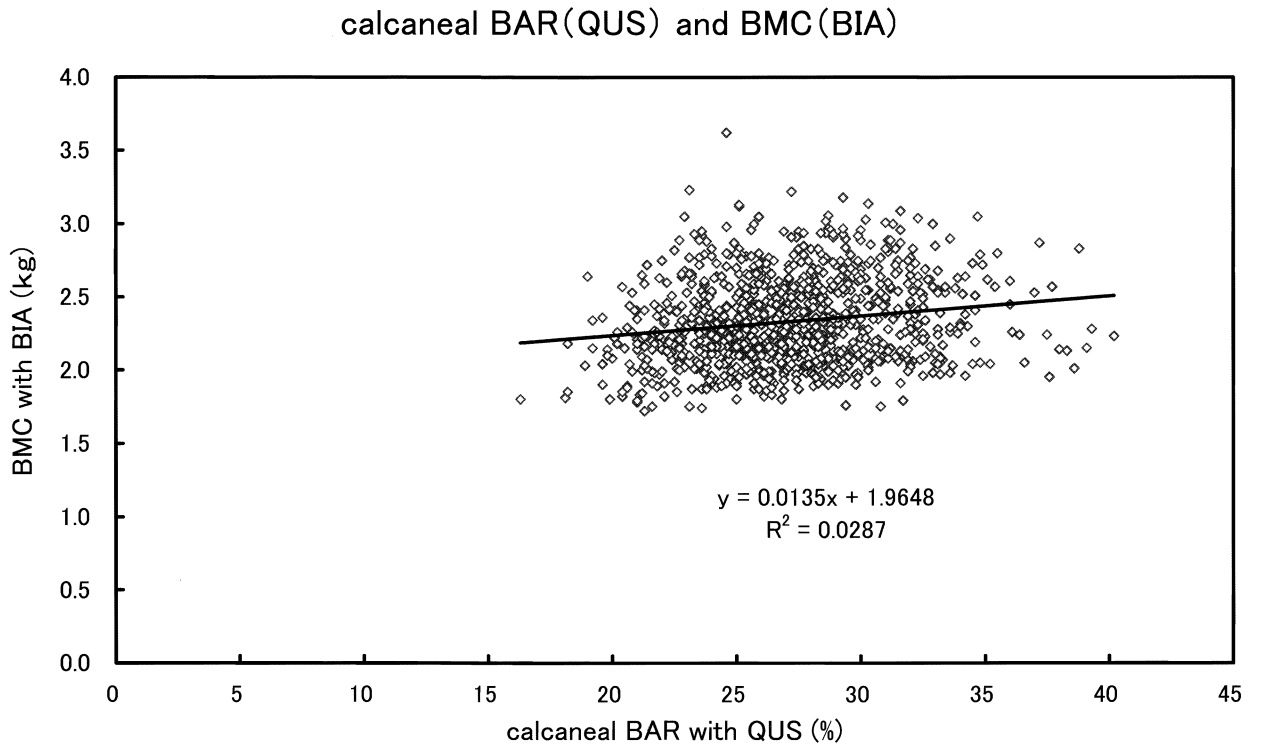

Fig. 6. Correlation between calcaneal BAR (%) with QUS and BMC (kg) with BIA

The equation in the figure shows the approximate linear equation estimated by the least square method. "R" denotes the correlation coefficient between calcaneal BAR (%) with QUS and BMC (kg) with BIA.

Table 1. Correlation coefficients between whole body BMD, lumbar BMD, and whole body BMC with DXA

	Whole body BMD	Lumbar BMD	Whole body BMC
Whole body BMD	1		
Lumbar BMD	0.8513	1	
Whole body BMC	0.9279	0.7922	1

Table 2. Correlation coefficients between lumbar BMD by DXA, BMC with BIA, and calcaneal BAR with QUS

	Lumbar BMD (DXA)	BMC (BIA)	BAR (QUS)
Lumbar BMD with DXA	1		
BMC with BIA	0.5610	1	
calcaneal BAR with QUS	0.3358	0.1694	1

product-moment correlation coefficient (r) was used to study the relationship between each the above-mentioned variables (Tables 1 and 2).

RESULTS

Strong statistical correlations were observed between: 1) whole body BMD and BMC with DXA: Pearson's correlation coefficient was (r=0.9279, p <0.001); 2) whole body BMD and lumbar BMD with DXA (r=0.8513, p<0.001); and 3) whole body BMC and lumbar BMD with DXA (r=0.7922, p<0.001) (Table 1).

Weaker but significant correlations were observed between: 1) lumbar BMD with DXA and BMC with BIA (r=0.5610, p<0.001); 2) lumbar BMD and calcaneal BAR with QUS (r=0.3358, p<0.001). However, there was no clear correlation between calcaneal BAR with QUS and BMC with BIA (Table 2).

DISCUSSION

Measurement of bone content or density is frequently uses DXA, chiefly of the entire skeleton or lumbar vertebrae. In the DXA method, the bone quantity is measured by the absorption characteristics of the bone, using alternate irradiation with two types of X-ray (140 kVp and 100 kVp). Bone density (g/cm^2) is then determined from the proportion of bone with an anteroposterior exposure area. In contrast, ultrasound densitometry is based on fractal dimension analysis of the trabecula bone area ratio (BAR) and is characterized by a coefficient of variation (CV) of 1.6% (15). The BAR refers to the proportion of bone tissue in a cross-section of the calcaneus, which is calculated from the ultrasound. Bioelectrical impedance analysis (BIA) applies 1mA of electric alternating current with a multifrequency band of 5, 50, 250 and 500 kHz to the body and determines the proportion of four components; water, protein, fat and bone mass. Although CV of the equipment for the bone mass is high (14.6%), measurements are easily reproducible (16).

Strong correlations were observed between whole body BMD and both whole body BMC and lumbar BMD with DXA. We suspect that these are accurate because identical equipment was used for measurements. The correlation between Lumbar BMD and whole body BMC was weaker than for the former two relationships. This may be because the exposure area decreases as a result of compressed fractures in the lumbar vertebrae, and the bone density per area therefore seems to enhance. Weaker but significant correlation was observed between lumbar BMD with DXA and BMC with BIA.

On the other hand, there was a relatively weak correlation between lumbar BMD with DXA and calcaneal BAR with QUS. This may be because the large difference in measurable region becomes apparent between the lumbar vertebrae and the calcaneum.

In contrast to the present findings, one study has found a strong correlation between the calcaneal BDM with DXA and the calcaneal BAR with QUS (correlation coefficient=0.83, n=40, $p<0.01$) (15). Although most published studies have reported BMD of the lumbar spine, our preliminary study (in press) has shown that calcaneal bone density is the optimum indicator for evaluation of effects of physical exercise on the body.

QUS is generally used in screening measurements of BMD instead of DXA, as an ultrasound bone densitometer is a portable and practical, similar to a stadiometer and involves no X-ray exposure (17). However, as there was no statistically significant difference between BMC with BIA and calcaneal BAR with QUS, it seems reasonable that calcaneal BAR with QUS could not be entirely substituted for whole body BMC. Therefore, it is likely that the combination of BMC with BIA and calcaneal BAR with QUS will yield a more accurate diagnosis of osteoporosis than either method alone.

REFERENCES

1) Ogawa T (2001) Social services for the elderly based on the new rurality; the Japanese experience. *J Rural Health* 17: 374-377.

2) Jones G, White C, Nguyen TV, Sambrook PN, Kelly PJ and Eisman JA (1996) Prevalent vertebral deformities. *Osteoporos Int* 233-239.

3) Nguyen TV, Eisman JA, Kelly PJ and Sambrook PN (1996) Risk factors for osteoporotic fractures in elderly men. *Am J Epidemiol* 144: 255-263.

4) Genant HK, Jergas M, Palermo L, Nevitt M, Valentin RS, Black D and Cummings SR (1996) Comparison of semiquantitative visual and quantitative morphometric assessment of prevalent and incident vertebral fractures in osteoporosis. *J Bone Miner Res* 11: 984-996.

5) Nohara T, Kamei T and Ohta A (2006) Accelerated decrease in bone mineral density in women aged 52-27 years. *Tohoku J Exp Med* 210: 341-347.

6) Mazanec DJ (1999) Evaluating back pain in older patients. *Cleve Clin J Med* 166: 89-91.

7) Ulrich CM, Georgiou CC, Gillis DE and Snow CM. (1999) Lifetime physical activity is associated with bone mineral density in premenopausal women. *J Women's Health* 8: 365-375.

8) Wahner H (1989) Technical aspects and clinical interpretation of bone mineral measurements. *Public Health Rep* 104: 27-30.

9) Wahner HW, Dunn WL, Brown ML, Morin RL and Riggs BL (1988) Comparison of dual-energy x-ray absorptiometry and dual photon absorptiometry for bone mineral measurements. *Mayo Clin Proc* 163: 1075-1084.

10) Carter DR, Bouxsein ML and Marcus R (1992) New approaches for interpreting projected bone densitometry data. *J Bone Miner Res* 7: 137-145.

11) Revilla M, Cardenas JL, Hernandez ER, Villa LF and Rico H (1995) Correlation of total-body bone mineral content determined by dual-energy x-ray absorptiometry with bone mineral density determined by peripheral quantitative computed tomography. *Acad Radiol* 2: 1062-1066.

12) Orimo H (2001) New diagnostic criteria of primary osteoporosis. *Clin Calcium* 11: 1133-1139.

13) Fukunaga M, Sone T and Tomomitsu T (2001) Diagnosis with bone mass. *Clin Calcium* 11: 1568-1571.

14) Lukaski HC (1999) Requirements for clinical use of bioelectrical impedance analysis (BIA). *Ann NY Acad Sci* 873: 72-76.

15) Kagechika K, Sueyoshi Y, Kitaoka K, Kawakita S and Tomita K (1996) Performance Evaluation of Ultrasound Bone Densitometry of the OS Calsis by Bone Area Ratio. *Research of New Medical Devices* 3: 9-18. (English Abstract)

16) Kichul Cha. (2000) A principle of bioelectrical impedance analysis. MP JAPAN Co. Ltd. (reference data)

17) Langton CM and Langton DK (1997) Male and female normative data for ultrasound measurement of the calcaneus within the UK adult population. *Br J Rdiol* 70: 580-585.