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Vertebral Bone Mineral Density Measured with Dual Photon Absorptiometry Using a Gamma Camera: Clinical Application to Metabolic Bone Diseases

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ABSTRACT. Dual photon absorptiometry (DPA) with a gamma camera, instead of a rectilinear scanner, has been developed for vertebral bone mineral density (BMD) measurement. The system consists of 50 mCi (1,850 MBq) 153-Gd as the emitting source, and an Anger-type gamma camera with a rectangular NaI (T1) crystal and 22 photomultiplier tubes. The effective field of a view was enough to cover more than 3 vertebrae. With the patient sitting, data acquisition was performed. The spatial resolution and uniformity of the gamma camera were good. With the introduction of a correction equation, the error in calculated BMD due to body thickness was reduced. A data acquisition of 7.5 to 15 min led to a satisfactory C.V. value (less than 2.0%). The precision (1.63% of C.V. in vitro and 3.53% in vivo) and accuracy (r=0.999) of the BMD measurements were also good. Vertebral BMD values in 300 normal Japanese females decreased with aging. Although in involutional osteoporosis and secondary hyperparathyroidism both vertebral and radial % BMDs decreased, in steroid-induced osteoporosis and primary hyperparathyroidism, disproportionate bone loss (relatively lower in vertebral bone) was demonstrated.

Thus, it was shown that a newly developed DPA system using a gamma camera provided sufficient precision and accuracy to quantificatcn of vertebral BMD, and its application should provide reliable information for clarification of the pathophysiology of metabolic bone diseases.

Key words : bone mineral density — dual photon absorptiometry — gamma camera — vertebra — metabolic bone disease

Among the several non-invasive methods for assessing bone minerals,[1-7] increasing attention has been focused on photon absorptiometry in recent years. Single photon absorptiometry (SPA) is applied to measurement in the appendicular skeleton, predominantly consisting of cortical bone, while dual photon absorptiometry (DPA), used with either 153-Gd or dual energy X-ray as a source, is mainly applied to measurement in the axial skeleton, predominantly consisting of trabecular bone. As the metabolic activity of trabecular bone

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and cortical bone is different, the measurement of not only cortical but also trabecular bone mass is important to the study and diagnosis of metabolic bone diseases.

In a conventional DPA system using 153-Gd, a rectilinear scanner is used as the detector.[8,9] We have developed a new DPA system using a gamma camera in which the intensity of 153-Gd is reduced.[10] In this paper, an outline and the fundamental performance of the gamma camera type DPA system which was recently improved are described and evaluated. In addition, the vertebral bone mineral density (BMD) in metabolic bone diseases was measured and compared with the distal radial BMD.

OUTLINE OF DPA SYSTEM USING A GAMMA CAMERA

The system consists of a radiation source of 50 mCi (1,850 MBq) of 153-Gd, a gamma camera equipped with a focusing collimator with a focus distance of 100 cm, and a computer system. The Anger-type gamma camera consists of a rectangular NaI (Tl) crystal of $21.0 \times 19.0 \times 0.51$ cm and 22 photomultiplier tubes of 5.08 cm in diameter. The effective field of a view was 12.5×15.6 cm, which covered more than 3 vertebrae. The distance between the source and the detector was 100 cm.

With the patient sitting, data acquisition was performed. The procedure for bone mineral analysis of vertebral bones is as follows; after the termination of data acquisition, an image of the lumbar vertebrae from the antero-posterior view is displayed. The upper end of the 2nd lumbar vertebra (L_2) and the lower end of the 4th lumbar vertebra (L_4) are then identified by moving image cursors. The mean area (cm^2) is determined along with other parameters such as the mean bone mineral content (BMC, g/cm), the mean bone width (BW, cm), and the mean bone mineral density (BMD, g/cm^2), which is achieved by dividing the mean BMC by the mean BW. The mean BMC profiles of L_2-L_4, sliced at intervals of 1 mm from the upper end of L_2 to the lower end of L_4, are also displayed. Based on the profiles, such parameters as area, BMC, and BMD over the range of BW are calculated. BW is defined as the region which is demarcated by the adjacent soft tissue and is less than 80% of the total counts of 153-Gd at the baseline.

The basic performance of the gamma camera was evaluated in accordance with the NEMA standard.[11] The spatial resolution, assessed by FWHM, was 6.9 mm and 4.2 mm at 44 keV and 100 keV, respectively. The uniformity, assessed from the maximum deviation in 80% of the area of the effective field of a view, was less than 5% and 3% at 44 keV and 100 keV, respectively. The resolution time of the count rate was 1.39 μsec. As for count rate performance, the linearity between count rates and radiation intensity was observed within a range of less than 35 kcps.

Since two energies were simultaneously used in our DPA system with 153-Gd for the radiation source, a spill-over effect over the 44 keV energy window, which is due to the scattering of 100 keV photon, was seen. After the spill-over effect was corrected in this DPA system, the effect on the whole detector was calculated as 1.5% of error.

The BMD values obtained with this DPA system were adjusted with a vertebral phantom consisting of hydroxyapatite as a bone mineral equivalent

material (Hologic, Mass.).

MATERIALS AND METHODS

1. Fundamental study

As the amount of scattering of radiation depends on the thickness of the object, the measured BMD values are changeable depending on the body thickness of the examinees. Therefore, it is essential to adjust the individual body thickness to the standard body size. The BMD values were initially determined for a 10 min-data acquisition time on a DPA phantom with a standard of mixture of $CaCO_3$ and urethane placed in various thickness of 15, 20 and 25 cm of water, and then the correction equation (y: correction coefficient, x: body thickness of 20 cm) was calculated.

The data acquisition time is influenced by both the body thickness of the examinees and the intensity of the radiation source. Therefore, the relations of these three factors were studied under the following conditions: data acquisition times of 2.5, 5, 7.5, 10 and 15 min, total thicknesses of 20, 25 and 30 cm of water and a DPA phantom, and the intensity of the radiation source of 50 mCi (1,850 MBq).

The accuracy of the DPA system was evaluated from the correlation between the concentration of bone mineral equivalent material of K_2HPO_4 solution of 62.5, 125, 250 and 500 mg/cm^3 and the measured BMD values.

The precision of the DPA system was evaluated from the daily variation in the measured BMD values in both in vitro and in vivo studies. For the in vitro study, a DPA phantom was measured 10 times repeatedly during a 2-week period. For the in vivo study, 7 normal subjects (6 males and 1 female, aged from 22 to 54 yrs.) were measured weekly 5 times during 4 weeks.

2. Clinical study

Vertebral BMDs were determined by a gamma camera type DPA (DUALOMEX HC-1, Chugai, Tokyo) and 1/3 distal radial BMDs by SPA (Bone Densitometer, Norland) in 300 normal Japanese females, aged 30 to 79 yrs., 30 senile osteoporotic females, 23 steroid-induced osteoporotic females, 7 primary hyperparathyroidism (PHP) patients with renal or ureteral stones and 8 secondary hyperparathyroidism (SHP) patients on hemodialysis. Involutional osteoporosis was diagnosed by the presence of a spontaneous vertebral fracture or deformity indicating a low Nordin score (less than 0.8). SHP was defined as the existence of subcortical resorption and a high parathyroid hormone level (more than 10 ng/ml of C-terminal PTH). The BMD values in metabolic bone diseases were assessed as % BMD, which was corrected from individual BMDs to a mean BMD for the vertebrae and radius of age- and sex-matched controls.

RESULTS

1. Fundamental study

With increases in the body thickness, the calculated BMD values increased linearly (Fig. 1), and a correction equation of $y=0.084x+0.832$ (y: correction coefficient, x: body thickness of 20 cm) was obtained. With this correction

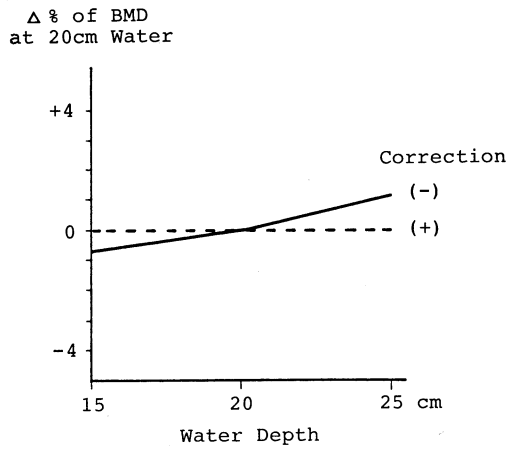

Fig. 1. Effect of body thickness on calculated BMD values

TABLE 1. Relation between C.V. values and phantom thickness or data aquisition time with a radiation source of 50 mCi (1,850 MBq)

Phantom Thickness	Count Rate	Data Acquisition Time	C.V. of Measured BMD
20 cm	26 kcps	2.5 min	1.8%
		5	0.8
		7.5	0.7
		10	0.4
		15	0.4
25 cm	11 kcps	2.5 min	2.0%
		5	1.7
		7.5	1.6
		10	1.4
		15	0.7
30 cm	4.6 kcps	2.5 min	4.2%
		5	3.1
		7.5	2.0
		10	1.9
		15	1.3

equation, the error due to body thickness was reduced within a range of body thickness of 15 to 25 cm. Table 1 shows the relation between the C.V. values and the phantom thickness or the data acquisition time with a radiation source of 50 mCi (1,850 MBq). The C.V. values increased as the phantom thickness increased and the acquisition time decreased. The C.V. of the BMD measurements at 7.5 min-data acquisition was less than 2.0% within a range of body thickness of less than 30 cm. This means that 15 min is necessary to maintain similar levels of C.V. at one half life decay of 153-Gd. The accuracy of the BMD measurements was satisfactory ($r=0.999$, $N=4$). Their precision was 1.63% ($N=10$) and 3.53% ($N=7$) of C.V. for in vitro and in vivo, respectively.

2. Clinical study

Figure 2 shows the age distribution of vertebral BMD in 300 normal Japanese female subjects. The BMD values decreased linearly after about 40 years old, and the BMD at an age of 75–79 years reached about 67% of that at 35–39 years old.

Table 2 shows the % BMDs in vertebral and radial bone in metabolic bone diseases. In involutional osteoporosis and SHP, both vertebral and radial % BMDs decreased, in steroid-induced osteoporosis and PHP a greater decrease in BMD was observed in vertebral bone than in radial bone.

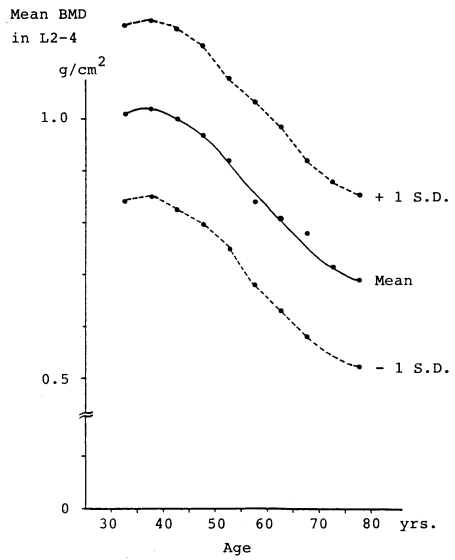

Fig. 2. Age distribution of vertebral BMDs in normal Japanese females

TABLE 2. % BMDs in vertebral and radial bone in metabolic bone diseases

	N	% BMD	
		L_{2-4}	Radius
Involutional Osteoporosis	30	86.6±14.9	93.8±17.3
Steroid-induced Osteoporosis	23	90.0±15.2	99.5± 9.8
Primary Hyperparathyroidism	7	79.3±15.0	94.3±16.9
Secondary Hyperparathyroidism	8	82.8±38.4	69.5±16.1

DISCUSSION

With a growing interest about osteoporosis, intensive efforts have been directed toward the early detection of bone loss and prevention of the disease. Bone mineral analysis of the vertebrae, which consist predominantly of cancellous bone and which show faster bone loss relative to the peripheral bone, is of great aid in elucidation of the underlying pathological process of the disease.

Among various noninvasive bone mineral determinations for axial bone, QCT and DPA have been widely used. QCT, however, involves relatively high radiation exposure. On the other hand, as the radiation exposure in DPA is relatively low, repeated measurements of BMD are feasible. Several DPA instruments are now available, with the scintillation scanner being adopted exclusively for the detector system.[8,9] To obtain good accuracy and high precision in those scintillation scanner types, a relatively large radiation dose is inevitable. For our new DPA instrument using a gamma camera, however, a relatively small amount of 153-Gd (50 mCi) is sufficient to obtain the same levels of precision achieved by other conventional instruments. With corrections, the error in BMD measurements due to the instrument itself was less than 2.0%, which was a satisfactory performance for hardware. The accuracy and precision both in vitro and in vivo were equal or superior to those obtained by other gamma scanners.[12] The duration of data acquisition is also important for the clinical use of BMD determinations. With this instrument, 7.5 to 15 min-data acquisition should be expected to yield good reproducibility of less than 3% of C.V., when the body thickness is less than 30 cm and the radiation source is more than 25 mCi (925 MBq).

Bone loss with aging is well-known fact, especially in females. The present results in Japanese females coincided with previously reported data.[13] As bone fractures are linearly related to BMD, the measurement of BMD at the actual sites of fracture is preferable. Therefore, the sensitive and reliable detection of bone loss with our DPA system will contribute to the anticipation of spinal fracture risk. When BMDs in both the vertebral and radial skeletons were evaluated in the same patients with involutional osteoporosis, bone loss occurred in both sites, although bone loss in the former was more accelerated. These results also indicate that direct vertebral determination using DPA will provide accurate information of vertebral bone loss.

It is well-known that a variety of skeletal lesions such as osteitis fibrosa, osteomalacia, osteosclerosis or osteoporosis occur because of multi-factorial causes in bone lesions on hemodialysis.[14] Among these, osteitis fibrosa due to SHP is curable by surgical treatment, and is subjective to bone deformity and fracture. It has been reported that PTH not only has a catabolic effect (bone resorption) but also an anabolic effect (bone formation). In severe SHP, as shown in the present study, BMDs were low in both the axial and appendicular skeletons, but especially in appendicular bone. This finding of lower BMD values in cortical bone, compared with BMDs in trabecular bone, was interesting with regard to evaluation of the biological effect of PTH on bone.

Differential effects on the axial and appendicular skeletons were observed in steroid-induced osteoporosis and PHP. A significant and disproportionate loss of trabecular bone was demonstrated in steroid-induced osteoporosis. The early detection of vertebral bone loss is important in the clinical management of patients treated with long-term steroid administration.

PHP has been classified clinically into an early stage (chemical type), an intermediate stage (stone type) and an advanced stage (bone type). In the present cases, which were of the stone type, we found that BMD had substantially decreased in the lumbar spine, but was within normal range in the radius. Thus, the moderate PTH excess in PHP had more effect on predominantly trabecular bone, similar to remarkably high PTH secretion in SHP.

In addition, the different effect of PTH on bone loss in PHP and SHP suggests the presence of different factors in chronic renal failure.

CONCLUSION

It was shown that our newly developed DPA system with a gamma camera provided sufficient precision and accuracy for the determination of vertebral BMD and it should provide reliable information for clarification of the pathophysiology of metabolic bone diseases.

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