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Comparative Studies of Values of Bone Mineral Density Measured with Different Photon Absorptiometries : A Preliminary Report

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ABSTRACT In order to compare values of bone mineral density measured with various photon absorptiometries, fundamental studies, using four different types of phantoms were performed in four instruments. The QDR-1000 (dual energy X-ray absorptiometry, DEXA) and Dualomex HC-1 (dual photon absorptiometry) were employed for the determination of bone mineral of a lumbar phantom and a cylindrical phantom, and the DCS-600 (DEXA) and Bone Densitometer (single photon absorptiometry) were used for the determination of bone mineral of a rectangular phantom and a ring phantom.

The results indicate that the methodology for identification of the bone edge, which is necessary to calculate bone area or bone width, and the bone mineral per unit volume, which is defined as the line bone mineral content per cross-sectional area, differ with the instruments used. Furthermore, the bone mineral per unit volume depends on the bone shape of the measured objects. Therefore, it seems that the cross calibration of bone mineral density between instruments using phantoms is limited and in vivo investigation will be required in the future.

Key words : bone mineral density — comparative study photon absorptiometry — phantom

In recent years, single photon absorptiometry (SPA), dual photon absorptiometry (DPA) and dual energy X-ray absorptiometry (DEXA) have been widely applied to determination of the bone mineral density (BMD) of appendicular and axial bone.[1-4] However, differences of BMD exist between instruments produced by different manufacturers and limit the direct comparison of BMD for clinical use. Different methodologies of detection of the bone edge are employed in software and different kinds of bone mineral equivalent materials are used as a standard. Therefore, in order to compare such BMD values, cross calibration of BMD between these different systems is necessary.

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In the present paper, fundamental and comparative studies of the BMD values obtained from various photon absorptiometries are described.

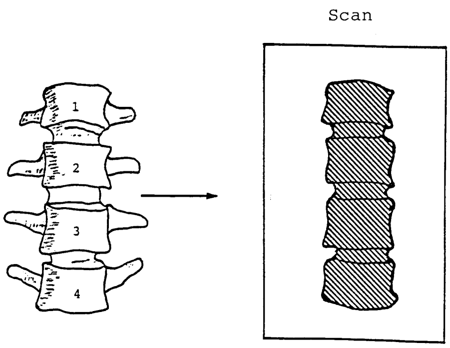


Fig. 1a Lumbar phantom
Area(cm^2)
Area BMC(g)
BMD(g/cm^2)
=Area BMC(g)/Area(cm^2)

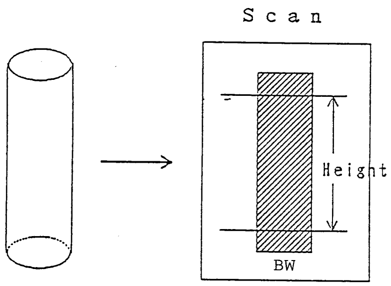


Fig. 1b Cylindrical phantom
Area(cm^2)
Area BMC(g)
Height(cm)=10 cm
BW(cm)=Area(cm^2)/Height(cm)
Line BMC(g/cm)
=Area BMC(g)/Height(cm)
BMD(g/cm^2)
=Line BMC(g/cm)/BW(cm)

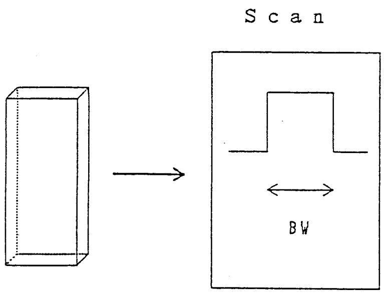


Fig. 1c Rectangular phantom
BW(cm)
Line BMC(g/cm)
BMD(g/cm^2)
=Line BMC(g/cm)/BW(cm)

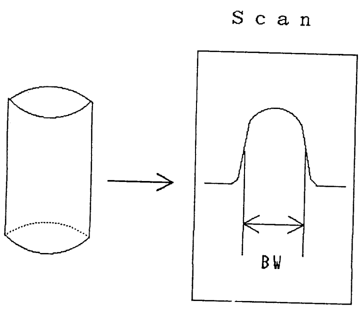


Fig. 1d Ring phantom
BW(cm)
Line BMC(g/cm)
BMD(g/cm^2)
=Line BMC(g/cm)/BW(cm)

Fig. 1. Schematic diagrams of bone mineral indices in four phantoms.

MATERIALS AND METHODS

(1) Instruments

In the present study, to compare the actual values of BMD, four bone mass quantifying instruments, i.e., the QDR-1000 (DEXA, Hologic), Dualomex HC-1 (DPA, Chugai), DCS-600 (DEXA, Aloka) and Bone Densitometer (SPA, Norland) were used.[1–4)] Routinely, the QDR-1000 and Dualomex HC-1 were applied to the determination of axial bone mineral, and the DCS-600 and Bone Densitometer were used for the determination of appendicular bone mineral.

(2) Phantoms

As cross calibration phantoms, cylindrical, lumbar, rectangular and ring phantoms were used. A cylindrical phantom and lumbar phantom were used in the study of BMD determination employing the QDR-1000 or Dualomex HC-1. On the other hand, a rectangular phantom and a ring phantom were used in the study of BMD determination using the DCS-600 or Bone Densitometer.

The lumbar phantom consisted of hydroxyapatite immersed in $15.3\times17.7\times17.9$ cm of epoxy resin. The cylindrical phantom, 4 cm in diameter and 20 cm in height, was composed of calcium carbonate immersed in $15\times20\times20$ cm of urethane. The rectangular phantom was composed of polyvinyl chloride of $2.1\times5.0\times0.5$ cm. The ring phantom consisted of aluminum immersed in $12.2\times2.8\times4.8$ cm of acryl.

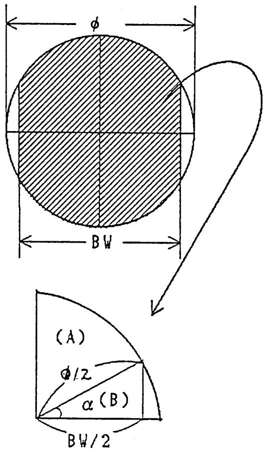
(3) Indices of Bone Mineral

For the lumbar phantom, area (cm^2), area bone mineral content (area BMC, g), and BMD (area BMC/area, g/cm^2) were measured (Fig. 1a). For the cylindrical phantom, bone width (BW, area/height, cm), line BMC (area BMC/height, g/cm) and BMD (line BMC/BW, g/cm^2) were measured within a range of 10 cm height of the cylinder (Fig. 1b). For both the rectangular phantom and the ring phantom, however, BW (cm), line BMC (g/cm) and BMD (area BMC/BW, g/cm^2) were measured, as in the SPA system, and line BMC, not area BMC, was obtained (Fig. 1c,d).

These bone mineral indices were compared between two pairs of instruments (the QDR-1000 vs. Dualomex HC-1, and the DCS-600 vs. Bone Densitometer). In addition, to compare the actual values of BMD, the bone mineral per unit volume was defined as the line BMC per cross sectional area (CSA), and was calculated as follows; first, the CSA used in the determination of the line BMC was calculated, and then the bone mineral per unit volume was determined (Fig. 2).

RESULTS

Table 1 shows the results of the measured bone mineral indices. The BWs between the QDR-1000 and Dualomex HC-1 obtained by the cylindrical phantom, and BWs between the DCS-600 and Bone Densitometer obtained by the rectangular phantom or ring phantom were not identical; 3.85 cm (100%) vs. 4.00 cm (104%) for the cylindrical phantom, 1.980 cm (100%) vs. 2.023 cm (102%) for the rectangular phantom, and 1.843 cm (100%) vs. 1.917 cm (104%)



1. Cylindrical phantom
   $\alpha = \cos^{-1}((BW/2)/\phi/2)$
   $A = \frac{(90° - \alpha)}{360_0} \times (\phi/2)^2 \pi$
   $B = \frac{BW/2 \times BW/2 \cdot \tan(\alpha)}{2}$
   Cross sectional area (CSA, cm^2)
   $= A + B$
   Bone mineral per unit volume(g/cm^3)
   $=$ Line BMC(g/cm)/CSA(cm^2)
2. Rectangular phantom
   CSA(cm^2)
   $=$ BW(cm) $\times$ Phantom thickness(cm)
   Bone mineral per unit volume(g/cm^3)
   $=$ Line BMC(g/cm)/CSA(cm^2)

Fig. 2. The calculation for determination of a cross sectional area.

TABLE 1. Bone mineral indices obtained in four phantoms, and BMD ratios between two instruments.

(I) Cylindrical or Lumbar Phantom

Instrument	Cylindrical Phantom			Lumbar Phantom	A/B
	BW (cm)	Line BMC (g/cm)	BMD(A) (g/cm^2)	BMD(B) (g/cm^2)	
QDR-1000	3.85 (100%)	4.462 (100%)	1.159 (100%)	1.026 (100%)	1.130 (100%)
Dualomex HC-1	4.00 (104)	3.972 (89)	0.993 (86)	0.796 (78)	1.247 (110)

(II) Rectangular or Ring Phantom

Instrument	Rectangular Phantom			Ring Phantom			A/B
	BW (cm)	Line BMC (g/cm)	BMD(A) (g/cm^2)	BW (cm)	Line BMC (g/cm)	BMD(B) (g/cm^2)	
DCS-600	1.980 (100%)	1.448 (100%)	0.752 (100%)	1.843 (100%)	1.308 (100%)	0.710 (100%)	1.059 (100%)
Bone Densitometer	2.023 (102)	1.587 (107)	0.784 (104)	1.917 (104)	1.522 (116)	0.794 (112)	0.987 (93)

for the ring phantom. The line BMC also differed; 4.462 g/cm (100%) vs. 3.972 g/cm (89%) for the cylindrical phantom, 1.448 g/cm (100%) vs. 1.587 g/cm (107%) for the rectangular phantom, and 1.308 g/cm (100%) vs. 1.522 g/cm (116%) for the ring phantom. The BMDs were as follows; 1.159 g/cm^2 (100%) vs. 0.993 g/cm^2 (86%) for the cylindrical phantom, 1.026 g/cm^2 (100%) vs. 0.796 g/cm^2 (78%) for the lumbar phantom, 0.752 g/cm^2 (100%) vs. 0.784 g/cm^2 (104%) for the rectangular phantom, and 0.710 g/cm^2 (100%) vs. 0.794 g/cm^2 (112%) for the ring phantom. To evaluate the dependency of the measured BMD values on the phantom shape, the ratios of two phantoms, e.g., the cylindrical phantom vs. the lumbar phantom, and the rectangular phantom vs. ring phantom, were calculated. The ratios of the former were

1.130 (100%) and 1.247 (110%), and those of the latter were 1.059 (100%) and 0.987 (93%), respectively.

Table 2 shows the data of the line BMC, CSA and bone mineral per unit volume obtained by using the cylindrical phantom in the QDR-1000 and Dualomex HC-1, and by using the rectangular phantom in the DCS-600 and Bone Densitometer. The values of the line BMC and the CSA were different; when the cylindrical phantom was used, a line BMC of 4.462 g/cm and a CSA of 14.458 cm^2 were obtained for the QDR-1000, and a line BMC of 3.972g/cm and a CSA of 12.566 cm^2 for the Dualomex HC-1. When the rectangular phantom was employed, a line BMC of 1.488 g/cm and a CSA of 0.990 cm^2 were obtained for the DCS-600, and a line BMC of 1.587 g/cm and a CSA of 1.012 cm^2 for the Bone Densitometer. The bone mineral per unit volume from the calculation formula (Fig. 2) was higher in the QDR-1000 (0.358 g/cm^3, 100%) than in the Dualomex HC-1 (0.225 g/cm^3, 71%) in a study using the cylindrical phantom, and was higher in the Bone Densitometer (1.569 g/cm^3, 104%) than in the DCS-600 (1.503 g/cm^3 100%). Thus, the bone mineral per unit volume was not identical.

TABLE 2. Bone mineral per unit volume, i.e. the line BMC per cross sectional area, in QDR-1000 and Dualomex HC-1 when a cylindrical phantom was used, and in DCS-600 and Bone Densitometer when a rectangular phantom was employed.

(I) Cylindrical Phantom

Instrument	Line BMC (g/cm)	Cross Sectional Area (cm^2)	Bone Mineral per Unit Volume (g/cm^3)
QDR-1000	4.462	14.458	0.358 (100%)
Dualomex HC-1	3.972	12.566	0.225 (71)

(II) Rectangular Phantom

Instrument	Line BMC (g/cm)	Cross Sectional Area (cm^2)	Bone Mineral per Unit Volume (g/cm^3)
DCS-600	1.488	0.990	1.503 (100%)
Bone Densitometer	1.587	1.012	1.569 (104)

DISCUSSION

Recently SPA, DPA and DEXA have been introduced in the clinical field to assess the appendicular or axial bone mass in osteoporotic patients. However, the BMD values of different systems are not identical due to the different methodologies used for the detection of the bone edge and different bone mineral equivalent material used as a standard. Therefore, it is difficult to compare BMD values directly. In this study, the possibility of cross calibration of BMD values between different instruments was investigated.

In the present study, individual instruments exhibited not only different BW and line BMC values but also different BMD values. The BMD values in SPA, DPA and DEXA were determined by the methods used for detection of bone edge, i.e. BW or area, and by the bone mineral per unit volume. Different BW values reflect different performances of the software employed in detection of the bone edge. This leads to different line BMC and BMD. The bone mineral per unit volume which was calculated with a cylindrical or rectangular phantom differed with the instrument used. If the methods of detection of the bone edge were identical in all systems, cross calibration of BMD could be accomplished by employing a correction factor alone, which could be calculated between different systems. However, detection of the bone edge which was evaluated from BW with a cylindrical or rectangular phantom was different. Furthermore, the present study, in which the BMD ratio between two different shapes of phantoms differed, indicated that detection of the bone edge depended on the shape of the measured objects.

As the phantoms used in this study were made of homogeneous materials, and were of cylindrical or rectangular shape, the distribution of bone mineral, e.g. no discrimination between trabecular and cortical bone, and the shape of the phantom itself were not identical to real human vertebrae or the human radius. These findings suggest that it is impossible to apply the regression formula or the correction factor, which are calculated from phatom study, to cross calibration between different instruments. Therefore, it seems that cross calibration using phantoms is of limited and further in vivo investigation will be required.

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