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Bone Mineral Density of Opposing Hips Using Dual Energy X-Ray Absorptiometry in Single-Beam and Fan-Beam Design

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Abstract. Bone densitometry focuses on bone mineral area density (BMD in g/cm^2) of the proximal femur and spine in anterior-posterior (AP) projections. Artifacts, such as osteoarthritis and osteophytic calcifications (OC) influence spine BMD, especially in AP scans. If only two sites are measured, as is usual in clinical practice, there may be advantages to measuring both femora rather than one femur and the spine. This would not be useful, however, if there was strong symmetry between the two sides. Furthermore, fan beam (FB) techniques have become available for measuring BMD with less data acquisition time. We compared densitometry of opposing femora in 421 patients (369 women, mean age 59.0 ± 4.8; 52 men, mean age 56.9 ± 7.4) using dual-energy X-ray absorptiometry (DXA): both single-beam (SB) and FB modes were evaluated. The precision errors *in vivo* (short- and midterm) of total BMD were 0.7% for both SB and FB. The total BMD and BMC of the left hip (0.817 ± 0.124 g/cm^2, 31.3 ± 6.4 g) were significantly ($P <$ 0.001) higher (2–3%) than the corresponding values of the right hip (0.801 ± 0.125 g/cm^2, 30.3 ± 6.3 g) in both SB and FB (left BMD 0.802 ± 0.117 g/cm^2, BMC 30.0 ± 6.2 g versus right BMD 0.795 ± 0.117 g/cm^2, BMC 29.3 ± 6.3 g) modes. However, BMD of the femoral neck and Ward's triangle were not significantly ($P > 0.05$) different between the two sides. The FB results were generally 2% lower than SB results. There were highly significant ($P < 0.001$) correlations ($r > 0.9$) between both hips using both SB and FB. For diagnostic procedures and longitudinal studies, one should consider that there are bilateral differences of femur BMD, as well as differences between FB and SB scan modes.

Key words: Bone densitometry — Bilateral hip — Femur — DXA — Single beam — Fan beam.

Hip fractures have substantially greater morbidity, mortality, and economic cost than fractures of the spine and wrist. Bone experts emphasize bone mineral area density (BMD in g/cm^2) measurements of the proximal femur and spine, where trabecular bone loss is accelerated and where fractures occur [1]. However, artifacts such as osteoarthritis and osteophytic calcifications (OC) of the lumbar spine influence spine BMD measurements [2–7]. BMD of the femoral neck is a stronger predictor of hip fractures than measurement of the spine or radius [8].

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Conventionally, densitometry is done on only one femur. Several studies have previously shown a high correlation between the two sides ($r > 0.9$) and a modest standard error of estimate (SEE 0.05 g/cm^2) [9–13]. Despite this, some of these reports recommend measuring both femora. Recently, fan beam (FB) densitometers have been developed by several manufacturers (Aloka, Hologic, Lunar and Sopha) to reduce acquisition time. This makes measurement of both femora practical.

Consequently, we reevaluated femoral symmetry using dual X-ray energy absorptiometry (DXA) in a large series of patients using both single beam (SB) and FB of DXA.

Materials and Methods

Characteristic Features of the Fan Beam DXA System

The FB design of QDR 2000 (Hologic, Inc., Waltham, MA, USA) includes an X-ray-generator, providing continuous X-ray output at two different levels of energy (70 and 140 KVp). The FB width is 11–15 cm depending on the area measured.

The QDR 2000 has the ability to measure rapidly using FB and also to facilitate lumbar spine and hip scans in SB design. The detector uses a line of 31 cadmium tungstate detectors (2 cm × 1 cm). The source slit width and length are 0.5 × 65 mm for FB compared with 2.2 mm circular hole for SB. The corresponding width and length of the detectors are 2.0 × 43.7 cm and 2.25 × 4.2 cm, respectively.

To ensure reproducibility, the foot was strapped into a foot brace, the leg being rotated inwards and abducted from the midline. This provided an adequate separation between the ischium and the femoral neck for the analysis of the scan. The right and left leg were scanned in SB (5 minutes) and FB (2 minutes) mode using the same procedure. Hip and spine scans were analyzed by the same operator using the manufacturer's recommended software (version 7.20A).

Precision

Bone mineral content (BMC in g) and BMD were determined *in vitro* over 1 and 6 months on an anthropomorphic spine phantom [7].

Short-term precision errors of BMD measurements of the hip were assessed in 25 normal individuals (ages 39–63, mean age 54.8 ± 5.2 years) on the QDR 2000 using both SB and FB modes.

Each individual was scanned twice on the same day with repositioning between the scans. Midterm precision was assessed in 11 healthy volunteers (ages 38–59, mean age 52.6 ± 6.7 years) using one assessment at baseline and another at 4 weeks.

The coefficient of variation (CV) was determined according to Slosman et al. [14]. We used multiple regression analysis, Pearson's correlation coefficient to assess relationships and the ordinary *t*-test, and Wilcoxon test to assess differences.

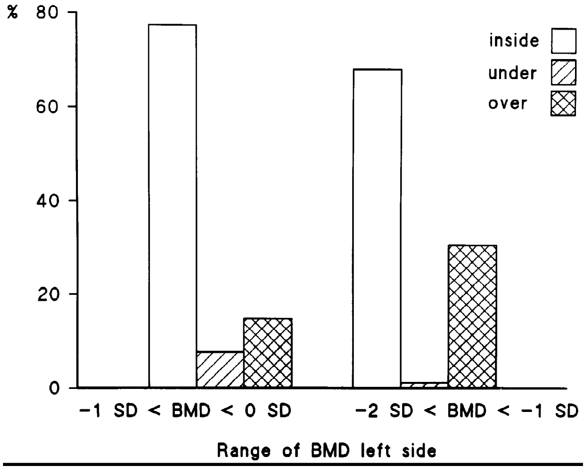

Fig. 1. Range of BMD in the left femur.

BMD and BMC Measurements of the Right and Left Hip

BMDs of the opposing hips were measured in 421 patients (369 women, mean age 59.0 ± 4.8, range 26–84 years; 52 men, mean age 56.9 ± 7.4, range 39–82 years) of our clinic using SB and FB (medium and fast array). The subjects had AP and lateral lumbar spine radiographs performed within several days of BMD measurement. In each subject, all vertebrae for L4–T6 were identifiable. This patient group had no evidence of clinical, laboratory, or radiological bone-related disease except for osteopenia. They had no fractures of the spine, hip, or wrist.

We examined the (1) systematic differences between the two sides, (2) regression relationship between the two sides, and (3) effect of SB and FB mode on symmetry.

Results

The precision errors *in vitro* were all below 0.7%, as reported earlier [7]. The precision errors *in vivo* (short- and midterm) were about 0.67–1.1% for neck and BMD total, and 1–3.5% for the other regions (Table 1).

In SB mode, total BMD and BMC (0.817 ± 0.124 g/cm^2, 31.3 ± 6.4 g) of the left hip were significantly ($P < 0.001$) higher than corresponding values of the right hip (0.801 ± 0.125 g/cm^2, 30.3 ± 6.3 g). In FB mode, the total BMD and BMC of the left hip were also significantly ($P < 0.001$) higher (0.802 ± 0.117 g/cm^2, 30.0 ± 6.2 g) than those of the right hip (0.795 ± 0.117 g/cm^2, 29.3 ± 6.3 g). All BMD and BMC values using FB mode were significantly ($P < 0.008$) lower than those using SB mode in each case.

BMD of the femoral neck and Ward's triangle in SB mode were not significantly ($P > 0.05$) different between the right side (0.693 ± 0.115 g/cm^2; 0.501 ± 0.134 g/cm^2) and left (0.693 ± 0.110 g/cm^2; 0.508 ± 0.130 g/cm^2) side. The average BMD difference was close to zero for femoral neck and Ward's triangle, but above 1% for total and trochanter (Table 2). In FB mode, there was also close symmetry for the femoral neck and Ward's Triangle region, and the lower total BMD on the right side was not as great. There were highly significant ($r > 0.9$) ($P < 0.001$) correlations between both hips in both SB and FB modes with a standard errors of estimate (SEE) of 0.06 g/cm^2 (Table 3). The correlation coefficients were in the same range, if compared for regions within one femur (BMD total and neck $r = 0.85$, BMD total and Ward's triangle $r = 0.783$, BMD total and trochanter $r = 0.90$). In addition, there were highly significant correlations between FB and SB mode of BMD values on the same hip ($r = 0.99$, $P < 0.001$). However, the FB values averaged 2% lower than SB values.

Table 1. Precision errors (%) *in vivo* of (short- and midterm) BMD total, femoral neck, Ward's triangle, and trochanter in single beam (SB) and fan beam (FB) mode

Region	SB	FB
Short-term		
BMD total	0.68	0.64
Neck	0.67	1.1
Ward's triangle	1.91	3.5
Trochanter	1.21	1.3
Midterm		
BMD total	0.81	0.86
Neck	0.92	0.94
Ward's triangle	3.6	3.7
Trochanter	1.3	1.4

Table 2. Systematic BMD differences (%) between opposing hips in single beam (SB) and fan beam (FB) mode

Region	Average BMD% difference ± SD (FB)	Average BMD% difference ± SD (SB)
BMD total	0.65 ± 4.22	1.49 ± 5.02
Neck	0.13 ± 5.38	0.08 ± 6.78
Ward's triangle	0.07 ± 6.58	0.69 ± 7.67
Trochanter	0.25 ± 3.94	1.15 ± 4.84

Discussion

We and others have reported good precision (1%) for femoral neck and BMD total *in vivo* [7, 9–13]. In comparison, precision errors of Ward's triangle and trochanter were greater, as also reported [10, 15, 16]. Precision in FB mode is slightly poorer than in SB mode, however, this is probably not important clinically. The faster scanning mode possible with FB allows measurement of both femora. This should be advantageous, and would more than offset the slightly poorer precision.

The studies that have looked at femoral symmetry have found (1) high correlations ($r > 0.9$) between the two sides, (2) little systematic difference between the sides, and (3) a SEE of about 5–10% [9–13, 17]. Our study, which is several times larger than most reported series, confirms those findings. Mean differences between opposing hips were only significant for total BMD, but not for femoral neck of Ward's Triangle. Similar data for the femoral neck were reported by Faulkner et al. [13] with mean BMD differences of 1.5% ± 4.7% (SB) and −0.6% ± 6.3% (FB).

Some of the researchers who have examined the problem of femoral symmetry believed that the high correlation between sides meant that only one femur needs to be measured. Others have pointed out that a SEE of 0.05–0.07 g/cm^2 can equate to differences of 5–20% between sides in the individual patients.

Consequently, Lilley et al. [9] reported large differences between the femora in individual volunteers, but also found

Table 3. Linear regression predicting right from left hip with correlation coefficients (r) and standard errors of estimate (SEE) for 421 subjects in single beam (SB) and fan beam (FB) mode

Scan mode	Site	r	SEE	Intercept	Slope
SB	BMD total	0.904	0.048	0.089	0.907
	Proximal femur	0.821	0.063	0.150	0.784
	Trochanter	0.895	0.042	0.126	0.882
	Ward's triangle	0.833	0.072	0.105	0.803
FB	BMD total	0.935	0.042	0.055	0.939
	Proximal femur	0.869	0.053	0.121	0.823
	Trochanter	0.918	0.039	0.055	0.914
	Ward's triangle	0.857	0.064	0.086	0.832

an average BMD percentage difference over their population to be close to zero. In our population the standard deviation (SD) for BMD averaged about 0.12 g/cm^2, so the SEE amounts to about 0.5 SD. Since risk of hip fracture increases almost threefold for a 1 SD decline of femoral BMD, it does appear that a 0.5 SD uncertainty would be important, at least in terms of risk of hip fracture.

In accordance with others [18, 19], we demonstrated highly significant correlation coefficients between SB and FB on the QDR 2000. These same studies have shown that FB results on the femur are lower than the corresponding SB values. This may help explain recent observations of relatively high proportion of low femur BMD cases with the QDR 2000 when using the manufacturer's reference data based on the QDR 1000 [20].

For both diagnostic and monitoring applications, one should consider that there are possible differences between BMD of opposing hips. Moreover, there is a 2% difference due to scan mode. This should be considered especially in those patients where therapeutic decisions depend on femur BMD.

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