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Total Body and Regional Bone Mineral Densitometry (BMD) and Soft Tissue Measurements: Correlations of BMD Parameter to Lumbar Spine and Hip

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Abstract. Bone loss in men and women seems to differ according to the skeletal regions or particular areas being evaluated. Dual energy X-ray absorptiometry (DXA) is the method of choice for measuring total body and regional bone mineral area density (BMD). The aim of the study was to evaluate the importance of DXA measurements of total body in relation to lumbar spine and hip in different scan beam designs. In 300 patients, ages 43–80 years, lumbar spine, hip, total body and regional bone mineral area density, and soft tissue measurements were performed on all subjects in the supine position on a QDR 2000 using single beam (SB) and fan beam (FB). Short-term precision errors were 0.7% (SB) and 1.2% (FB) for BMD total of the total body and between 1.2% and 8.0% for soft tissue measurements. All mid-term precision errors of BMD total, right and left leg, and pelvis were below 2.0% with SB and FB, whereas precision errors of thoracic and lumbar spine varied depending on the scan mode being applied. In contrast, all mid-term precision errors of soft tissue measurements were greater (2.6–11.0%). All SB values of BMD and soft tissue measurement were significantly higher than FB values, except for BMD values of the head, thoracic spine, and pelvis. Furthermore, BMD total of the total body scan correlated significantly ($P < 0.001$) with all subregional parameters with best "r"-values (0.86–0.92) for the right and left leg in SB and FB design. In addition, there were excellent correlations ($r > 0.94$, $P < 0.001$) between the right and left legs (SB and FB) or arms (SB). There were also highly significant correlations between the lumbar spine (or hip) and total body, being best for the subregional thorax. Our data demonstrate short-and mid-term precision errors of BMD with reproducible results for most areas in SB and FB design, whereas soft tissue measurements vary depending on the area being measured. Furthermore, there is a close relationship between BMD values of total body total and subregional parameters and lumbar spine and hip scans, respectively.

Key words: Bone densitometry — Total body — Subregional BMD.

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Age-related bone loss in men and women seems to differ according to the skeletal regions or particular areas being evaluated. Dual energy X-ray absorptiometry (DXA) is the method of choice for measuring total body and regional bone mineral content (BMC) and bone mineral area density (BMD). DXA instruments provide various X-ray beam and detector configurations. As reported, [1–3] single beam (SB) and fan beam (FB) design can present with different precision errors. Short-term precision errors *in vivo* of total body and regional scans using Lunar DPX or Hologic QDR can vary between 0.6% and 5.0% depending on the area and technique or software used [4–8]. In addition, body composition estimates from DXA seem to be accurate compared with those from a four-component model in young adults [9]. Few data are available on the relationship of total body BMD and hip or spine BMD, consequently, we evaluated the importance of DXA measurements of total body in relation to lumbar spine and hip in a large series of patients by using SB and FB of DXA.

Materials and Methods

FB and SB design of QDR 2000 (Hologic, Inc., Waltham, MA, USA) includes an X-ray generator providing X-ray output at two different levels of energy (70 KVP and 140 KVP). The QDR 2000 has the ability to rapidly measure FB and also to facilitate total body, 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 2.3 × 4.2 cm, respectively.

Total body and regional BMC and BMD and soft tissue measurements (head, trunk, pelvis, arms, and legs) were performed on all subjects in the supine position. Scans were analyzed by the same operator using the manufacturers' recommended software. In addition, in all patient groups, lumbar spine and hip measurements were done as reported [2, 3].

Precision

The reproducibility of BMC and BMD determinations *in vitro* over 1 and 6 months were determinated with an anthropomorphic spine phantom (Hologic QDR 2000) [2]. Short-term precision errors of BMD and soft tissue measurements of the total body were assessed in 12 normal volunteers (mean age 54.8 ± 5.2 years, range 39–63 years) on the QDR 2000 using both SB and FB. Each subject was tested at approximately the same time each day. Each individual was scanned twice on the same day with repositioning between the scans. Each was positioned according to the manufacturers suggestions. The forearms and hands of larger subjects were placed in the semiprone position, not touching the legs.

A standard Hologic tissue bar was scanned simultaneously with each patient. The total radiation dose (effective dose aquivalent) for the two total body scans was approximately 0.0013 mSv [4]. All scan analyses were performed by the same technician. The regions of interest (ROI) were placed according to the manufacturer's recommendations for placement: head, left and right arm, left and right hips, thoracic spine, lumbar spine, pelvis, and left and right legs. The same criteria were used for the analyses of the FB and SB scan. These measurements were also performed to assess mid-term precision errors in 113 healthy volunteers (mean age 51.3 ± 8 years, range 30–70 years) once at baseline and after 4 weeks. Subjects were instructed to maintain consistant habits in diet, sleep, and exercise throughout their participation in the study. The coefficient of variation (CV) was determined according to Slosman et al. [10].

BMD Measurements of Total Body and Subregional Parameters

In addition to total body BMD and total body soft tissue measurements, lumbar spine and hip BMD were measured as reported by Franck et al. [2, 3] in 755 patients (607 women: mean age 54.2 ± 7.8 years, range 26–84 years; 148 men: mean age 53.0 ± 8.6 years, range 32–83 years). The subjects had anterior-posterior and lateral lumbar spine radiographs performed within several days of BMD measurement. In each subject, all vertebrae for L 4–T 6 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) mean values of BMD, both total and subregional areas and soft tissue parameters; (2) relationship of BMD total of the total body scan and its subregional parameters; (3) correlations of BMD values of the total body scan and lumbar spine or hip; and (4) relationship of subregional values of the lean and fat tissue parameters.

Results

Mid-term precision errors of total body and regional bone and soft tissue measurements are listed in Table 1. Short-term precision errors were 0.7% (SB) and 1.2% (FB) for BMD total of total body and between 1.2% and 8.0% for soft tissue measurements.

Mid-term precision errors of BMD total, right and left leg, and pelvis were well below 2.0% with SB and FB, whereas precision errors of the thoracic and lumbar spine varied depending on the scan mode being applied (Table 1). In contrast, most mid-term precision errors of soft tissue measurements were of a different magnitude (1.2–11.0%).

The precision errors *in vitro* were all below 0.7%, as reported earlier [2]. The precision errors *in vivo* (short-and mid-term) were 0.65–1.0% for neck and hip total and <1.1% for lumbar spine [2, 3].

All SB values of BMD and soft tissue measurements were significantly ($P < 0.001$) higher than FB values, except for BMD values of the head, thoracic spine, and pelvis (Table 2).

BMD total of the total body scan correlated significantly ($P < 0.001$) with all subregional bone parameters with best r-values for the right and left leg in SB (Table 3) and FB (Table 4) design. Furthermore, there were excellent correlations (r > 0.93, $P < 0.001$) between the right and left leg (SB or FB) and arms (SB).

Table 1. Precision errors of total body and regional BMD and soft tissue measurements (mid-term)

	SB (%)	FB (%)
BMD total of whole body	0.8	1.4
Right arm	1.8	1.7
Left arm	0.8	1.9
Right leg	1.7	1.2
Left leg	1.2	1.5
Thoracic spine	2.0	3.0
Lumbar spine	3.1	1.6
Pelvis	1.9	1.3
Head	1.4	2.7
Fat right arm	6.7	10.9
Fat left arm	9.3	8.6
Fat right leg	6.5	6.2
Fat left leg	7.2	8.1
Fat trunk	10.8	9.3
Fat head	4.7	3.4
Lean right arm	6.7	10.9
Lean left arm	9.3	8.6
Lean trunk	3.7	1.2
Lean head	5.8	3.9
Lean right leg	3.7	2.4
Lean left leg	3.1	2.7

Table 2. SB and FB values of BMD (g/cm^2) and soft tissue measurement

	SB (mean ± SD)	FB (mean ± SD)
BMD total of total body	1.069 ± 0.11[c]	1.026 ± 0.09
Right arm	0.846 ± 0.16[c]	0.744 ± 0.09
Left arm	0.827 ± 0.14[c]	0.684 ± 0.08
Right leg	1.170 ± 0.17[c]	1.118 ± 0.12
Left leg	1.165 ± 0.17[c]	1.114 ± 0.12
Right rib	0.628 ± 0.05[c]	0.607 ± 0.07
Left rib	0.628 ± 0.05[c]	0.587 ± 0.07
Thoracic spine	0.836 ± 0.12[c]	0.877 ± 0.11
Lumbar spine	0.822 ± 0.14[b]	0.854 ± 0.15
Pelvis	0.934 ± 0.11[c]	1.042 ± 0.14
Head	1.829 ± 0.29[a]	1.891 ± 0.31
Fat head	679.30 ± 433[c]	354.47 ± 470.1
Fat right arm	1232.47 ± 968.2[c]	720.28 ± 1090.8
Fat left arm	1169.43 ± 917.4[c]	685.37 ± 1004.8
Fat right leg	2894.27 ± 1999.5[c]	1679.82 ± 2336.9
Fat left leg	2841.59 ± 1968.4[c]	1646.24 ± 2285.9
Fat trunk	6815.81 ± 5076.4[c]	4259.86 ± 6048.6
Lean head	2988.99 ± 1888.0[c]	1477.19 ± 1948.9
Lean trunk	17097.67 ± 10845.3[c]	7966.42 ± 10616.8
Lean right arm	1634.94 ± 1109.5[c]	782.41 ± 1111.6
Lean left arm	1534.82 ± 1035.7[c]	675.95 ± 959.5
Lean right leg	5065.17 ± 3267.6[c]	2485.76 ± 3367.2
Lean left leg	5028.93 ± 3242.9[b]	2448.61 ± 3304.9

[a] $P < 0.05$; [b] $P < 0.01$; [c] $P < 0.001$

As for the relationship of BMD total of the lumbar spine and the total body scan, best correlations ($P < 0.001$) were found between the lumbar spine and the total body for the subregional lumbar and thoracic spine area in SB and FB design (Table 5). In addition, we found highly significant ($P < 0.001$) correlations between BMD total values of the hip

Table 3. Correlations[a] of BMD total and subregional parameters of the total body scan (SB)

BDM	Total	Head	Left arm	Right arm	Left rib	Right rib	Thoracic spine	Lumbar spine	Pelvis	Left leg	Right leg
Total	1.000	0.6030	0.7673	0.7500	0.6128	0.6067	0.4348	0.5303	0.5691	0.9211	0.9267
Head	0.6030	1.000	0.1929	0.1497	0.4888	0.4297	0.5267	0.5329	0.4147	0.3638	0.3695
Left arm	0.7673	0.1929	1.000	0.9257	0.4737	0.4872	0.2278	0.3224	0.3930	0.7104	0.7336
Right arm	0.7500	0.1497	0.9257	1.000	0.4085	0.4297	−0.0081	0.1556	0.1303	0.7070	0.7225
Left rib	0.6128	0.4888	0.4737	0.4058	1.000	0.8486	0.3298	0.5439	0.3805	0.4647	0.4596
Right rib	0.6067	0.4297	0.4872	0.4297	0.8486	1.000	0.3142	0.5149	0.3889	0.4776	0.4832
Thoracic spine	0.4348	0.5267	0.0485	−0.0081	0.3298	0.3142	1.000	0.7049	0.7967	0.3589	0.3609
Lumbar spine	0.5303	0.5329	0.2220	0.1556	0.5439	0.5149	0.7049	1.000	0.6980	0.4115	0.3954
Pelvis	0.5691	0.4147	0.1798	0.1303	0.3805	0.3889	0.7067	0.6980	1.000	0.5457	0.5378
Left leg	0.9211	0.3638	0.7104	0.7070	0.4647	0.4776	0.3589	0.4115	0.5457	1.000	0.9669
Right leg	0.9267	0.3695	0.7336	0.7225	0.4596	0.4832	0.3609	0.3954	0.5378	0.9669	1.000

[a] All correlations were significant ($P < 0.001$)

Table 4. Correlations[a] of BMD total and subregional parameters of the total body scan (FB)

BDM	Total	Head	Left arm	Right arm	Left rib	Right rib	Thoracic spine	Lumbar spine	Pelvis	Left leg	Right leg
Total	1.000	0.6722	0.7452	0.6169	0.6825	0.6328	0.7278	0.7088	0.6900	0.8628	0.8559
Head	0.6722	1.000	0.1976	0.2538	0.3017	0.2965	0.4403	0.5425	0.4224	0.3203	0.3261
Left arm	0.7452	0.1976	1.000	0.6797	0.7368	0.6546	0.5048	0.3761	0.3767	0.7861	0.7806
Right arm	0.6169	0.2538	0.6797	1.000	0.5790	0.5363	0.3651	0.2921	0.2469	0.5598	0.5540
Left rib	0.6825	0.3017	0.7368	0.5790	1.000	0.8536	0.5740	0.4350	0.3542	0.5943	0.5769
Right rib	0.6328	0.2965	0.6546	0.5363	0.8536	1.000	0.5386	0.4034	0.3616	0.5529	0.5527
Thoracic spine	0.7278	0.4403	0.5084	0.3651	0.5740	0.5386	1.000	0.6229	0.7029	0.5818	0.5674
Lumbar spine	0.7088	0.5425	0.3761	0.2921	0.4350	0.4034	0.7473	1.000	0.6641	0.5311	0.5354
Pelvis	0.6900	0.4224	0.3767	0.2469	0.3542	0.3616	0.5853	0.6641	1.000	0.6468	0.6151
Left leg	0.8628	0.3203	0.7861	0.5598	0.5943	0.5529	0.5818	0.5311	0.6468	1.000	0.9479
Right leg	0.8559	0.3261	0.7806	0.5540	0.5769	0.5527	0.5674	0.5354	0.6151	0.9479	1.000

[a] All correlations were significant ($P < 0.001$)

Table 5. Correlations[a] of BMD values of the total body scan and of the lumbar spine

	BMD total of the lumbar spine	
	Single beam	Fan beam
BMD total	0.671	0.712
Left arm	0.216	0.362
Right arm	0.195	0.322
Left ribs	0.493	0.373
Right ribs	0.428	0.325
Thoracic spine	0.713	0.614
Lumbar spine	0.912	0.864
Pelvis	0.724	0.588
Left leg	0.526	0.458
Right leg	0.508	0.440
Head	0.388	0.487

[a] All correlations were significant ($p < 0.001$)

and the total body parameters in the SB and FB modes. Most r-values of these correlations were slightly greater for the right (Table 6) than for the left hip in SB. This difference was less pronounced for FB. Corresponding significant correlations were also obtained for the trochanteric regions (Table 6).

There were significant correlations ($P < 0.001$) between all subregional values of the lean or fat tissue parameter in SB (Table 7) and FB modes; fat tissues with best r-values ($r > 0.95$) were found for bilateral parameters (arms or legs).

Discussion

Precision errors of the total body and subregional BMD measurements were in the same range as reported by Mazess et al. [5], Pritchard et al. [6], Fuller et al. [7], and Johnson and Dawson-Hughs [11]. Recently, comparison between SB and FB and analysis software of total body scan resulted in different precision errors [4]. In all large series, we can confirm that these differences between SB and FB are greater for total body and regional scans, especially in soft tissue measurements, than reported earlier for lumbar spine and hip scans [1, 2]. However, all mid-term precision errors for total body and regional bone measurements were below 3.1% and except for spine and head, below 2.0%. The variations of soft tissue precision mid-term errors were greater or in the same range as reported by Spector et al. [4] and Economos et al. [12]. However, we found separate precision errors for right and left leg and arms. In addition, correlations among total body, subregions, and lumbar spine and hip scans using different techniques (SB and FB) were not presented up to now. BMD total of the total body cor-

Table 6. Correlations[a] of BMD values of the total body scan and the right hip (single beam)

BMD	Total right hip	Right proximal neck	Right trochanter	Right intertrochanter	Right Ward's triangle
Total	0.7223	0.6762	0.7224	0.6832	0.6248
Head	0.2543	0.2650	0.2451	0.2369	0.3335
Left arm	0.3707	0.2957	0.3406	0.3438	0.2129
Right arm	0.3364	0.2729	0.3079	0.3088	0.1987
Left ribs	0.5768	0.5347	0.5594	0.5337	0.4554
Right ribs	0.5431	0.4872	0.5215	0.5042	0.4080
Thoracic spine	0.5495	0.5784	0.6057	0.5218	0.5653
Left spine	0.6537	0.6576	0.6830	0.6162	0.6616
Pelvis	0.7028	0.6746	0.7282	0.6829	0.6640
Left leg	0.7065	0.6390	0.7095	0.6753	0.5428
Right leg	0.6967	0.6186	0.7006	0.6681	0.5305

[a] All correlations were significant ($P < 0.001$)

Table 7. Correlations[a] of fat and lean parameters of the total body scan (SB)

	Fat left arm	Lean left arm	Fat right arm	Lean right arm	Fat trunk	Lean trunk	Fat left leg	Lean left leg	Fat right leg	Lean right leg
Fat left arm	1.000	0.6792	0.9778	0.6727	0.9137	0.7176	0.8864	0.7196	0.8910	0.7181
Lean left arm	0.6792	1.000	0.6630	0.9935	0.7363	0.9663	0.7294	0.9722	0.7334	0.9667
Fat right arm	0.9778	0.6630	1.000	0.6665	0.9100	0.7114	0.8964	0.7128	0.8936	0.7129
Lean right arm	0.6727	0.9935	0.6665	1.000	0.7360	0.9658	0.7322	0.9724	0.7353	0.9689
Fat trunk	0.9137	0.7363	0.9100	0.7360	1.000	0.7828	0.8947	0.7854	0.8945	0.7835
Lean trunk	0.7176	0.9663	0.7114	0.9658	0.7828	1.000	0.8119	0.9844	0.8158	0.9831
Fat left leg	0.8864	0.7294	0.8964	0.7322	0.8947	0.8119	1.000	0.8106	0.9953	0.8078
Lean left leg	0.7196	0.9722	0.7128	0.9724	0.7854	0.9844	0.8106	1.000	0.8144	0.9951
Fat right leg	0.8910	0.7344	0.8936	0.7353	0.8945	0.8158	0.9953	0.8144	1.000	0.8147
Lean right leg	0.7181	0.9667	0.7129	0.9689	0.7835	0.9831	0.8078	0.9951	0.8147	1.000

[a]All correlations were significant ($P < 0.001$)

related better with the right and left leg than with thoracic and lumbar spine in both scan modes, probably the result of more common cortical bone in that field. This corresponds also to the results of Rico et al. [13] using SB techniques only. BMD total of the hip or the trochanteric region showed highly significant correlations with BMD total of the total body, with r-values reported for the relationship of lumbar spine and hip. As expected, best correlations were found in the lumbar spine area of the total body and the separate spine scans.

Evaluating soft tissue parameters, short-and mid-term precision errors were greater than the corresponding BMD errors, but excellent correlations between bilateral corresponding parameters were found. Our data indicate not only a dose relationship of subregional scan values with BMD total of the total body but also with lumbar spine and hip. However, differences in fan beam design and precision errors of soft tissues should be kept in mind if effects of treatment and exercise on bone density or soft tissues are evaluated [14].

BMD of the arms was significantly correlated with the subregions of the total body scan, being best for the legs, lumbar spine, and pelvis area and the right forearm.

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