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Reproducibility of Lateral Spine Scans Using Dual Energy X-Ray Absorptiometry

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Summary. Reproducibility of lateral spine dual energy X-ray absorptiometry (LAT DEXA) scans using a Lunar DPX-L scanner was assessed in a cadaveric phantom and in patients. One hundred phantom measurements over 7 months demonstrated a longitudinal stability of 1.7% (coefficient of variation, CV). Additional scans were performed with the phantom rotated by up to 20° in each of the three orthogonal planes to assess the effects of variable patient positioning. Horizontal and vertical rotation of the spine had little effect on the estimated bone mineral density (BMD), however, axial rotation of greater than 8° led to errors in the BMD measurement. One hundred consecutive patients had two lateral scans performed within 1 month. BMD (range 0.10–1.6 g/cm^2) was determined for each scan by one operator. Significant overlap from ribs and pelvis was often seen with L2 and L4 vertebrae but one vertebra (L3) could be measured in every case. Intraoperator and interoperator variability was assessed by three experienced operators, each analyzing 10 patients' scans on five separate occasions, and was found to be less than 1.1% for a single vertebra. BMD estimation of vertebral bodies and midslices by lateral DEXA scans (CV% of 3.8% and 4.6%) have a 95% confidence interval of 0.074 g/cm^2 and 0.096 g/cm^2, respectively for two vertebrae. This variability is due mainly to axial rotation, with operator variability, horizontal rotation, and vertical rotation having little effect on BMD estimation.

Key words: Bone – Densitometry – Dual energy X-ray absorptiometry – Lateral spine scanning – Reproducibility.

Osteoporosis is a major health problem and various treatments and preventive regimens are currently under intensive investigations. Changes in bone mass induced either by natural bone loss or by therapeutic interventions are relatively small, and measurements of high reproducibility are essential [1]. It is now possible to evaluate the peripheral skeleton, the central skeleton, as well as the trabecular and cortical bone envelopes, with a high degree of accuracy and precision using either dual photon absorptiometry (DPA) or quantitative computed tomography [2]. Dual energy X-ray absorptiometry (DEXA) replaces the gadolinium-153 radionuclide source used in DPA instruments with a constant potential X-ray tube, which provides substantially improved precision compared with DPA [3]. In particular, spine bone mineral density (BMD) measurements using DEXA have a precision error half the value calculated for DPA [4].

The anteroposterior (AP) projection commonly used for DEXA measurements of BMD measures both the cortical and trabecular components of the vertebral body and posterior facet joint processes. Demineralization in the trabecular compartment of the vertebra is more rapid than that observed in the cortical bone of the posterior processes [5]. The AP projection is thus susceptible to overestimation of vertebral body BMD and thus less reliable in detecting minor changes in the vertebral body. The presence of a moderate osteoarthritis or calcification of the aorta will also induce a significant overestimation of the BMD when taken from the AP projection. Recently, newer technologies have permitted estimation of BMD in the lumbar vertebral body itself by obtaining a lateral scan of the vertebrae which allows the vertebral body to be measured independently of the posterior processes [6]. As the need for lateral scanning is increased, quantitative assessment of instrument precision will be essential for the diagnosis of spinal osteopenia and for the longitudinal evaluation of therapy or prophylaxis against osteoporosis.

Preliminary studies [7] have demonstrated that lateral spine (LAT) DEXA measurements of the vertebral body on a small population of similar BMD illustrate good precision. The aim of this study was to evaluate the reproducibility of BMD measurements of the lumbar vertebral body using LAT DEXA, on a large population of varying BMD, and to investigate the factors that will affect the precision, namely, the instrument stability, inter- and intraoperator variability, and patient positioning.

Methods

Bone Mineral Density

BMD, which was expressed as an area density in g/cm^2, was measured with a LUNAR DPX-L (LUNAR Corp, WI, USA) bone densitometer using acquisition software version 1.1. This instrument uses a Cerium k-edge filter and a constant-potential of 75 kV to produce X-rays in two broad bands with effective energies of 40 and 70 keV. The instrument operates at a current of 4.75 mA, requiring only 4 minutes to scan three vertebrae, for a skin radiation dose of 70 μSv [8]. BMD values were calculated for two vertebral bodies using software-defined region of interest boxes (ROI) positioned over the vertebra but specifically excluding the endplates (Fig. 1). In addition, BMD values for the vertebral midslices were also calculated from the ROIs of exactly half the height of the body ROIs. For the purpose of this study, with the exception of the determination of interoperator variability, the analysis of every scan was performed by one experienced operator.

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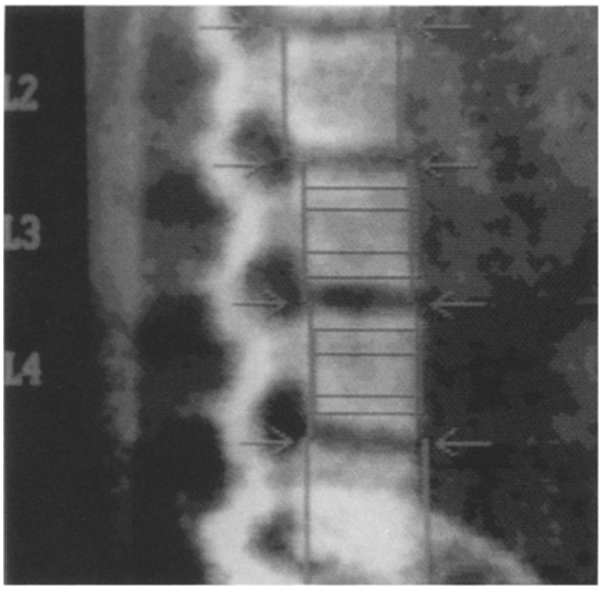

Fig. 1. A lateral spine scan demonstrating the vertebral body and midslice ROI boxes in position for analysis of L3 and L4.

Phantom Studies

Instrument Stability. To monitor the stability of the DPX-L system over time, an aluminium phantom [9] with an established BMD value for the L2 to L4 region, was scanned daily for 12 months. In addition, a phantom (LUNAR Corp) composed of cadaveric vertebrae (0.92 g/cm^2 in the AP projection) set in a square perspex block, representing a uniform soft-tissue layer, was scanned 100 times over 7 months in both the AP and the lateral positions. The X-ray source and detector were calibrated daily according to the manufacturer's instructions.

Positioning. The effects of variable patient positioning was assessed by performing lateral scans with the cadaveric phantom, rotated by up to 20° in each of the three orthogonal planes. Rotation was performed with spacing and the support of perspex blocks. Soft tissue uniformity only varied when rotating phantom axially, however, DPX software accounted for this parameter.

Patient Studies

Patients. One hundred and five consecutive patients referred to the department for bone mineral assessment were initially entered into the study. Five patients were excluded due to obvious compression fractures of the lumbar spine. The remaining 100 patients consisted of 83 females and 17 males between the ages of 20 and 80 years, with a mean age of 42.6 years. The average weight and height of both sexes was 61 kg, 158 cm and 74 kg, 173 cm, respectively. LAT BMD for the population ranged from 0.1 to 1.6 g/cm^2.

The patient was positioned according to the manufacturer's instructions: using a patient positioner, the patient was restrained lying on his/her left side so that the spine was in the true lateral position.

Lateral Scan Study. Reproducibility, *in vivo*, of the lateral spine scan was determined by performing two measurements in each of the 100 patients. Eighty-four of the patients were rescanned on the same day and 16 within a month of the first scan. In each case the patient was repositioned for the second scan. The study covered a 9-month period, the scans being acquired by four experienced operators.

Two methods of analysis were used. The first method assessed the reproducibility between the first and second scans independently analyzed on separate occasions. The second method calculated the reproducibility between the original first scan and the second scan re-analyzed using the first scan as a template for intervertebral spaces. In each case the coefficient of variation (CV%) for the vertebral body and midslices was calculated from the BMD of (1) one vertebra and (2) two vertebrae.

Operator Variability. Intra- and interoperator variability was assessed by three experienced operators, each analyzing 10 patients' lateral scans on five separate occasions. The BMDs of the patient scans ranged from 0.25 to 0.94 g/cm^2. The CV% for the overall mean BMD of one and two vertebrae was calculated for each operator.

AP Spine Study. A pilot study was carried out to determine the reproducibility of two AP spine measurements in 30 successive patients who also underwent a dual lateral spine scan. The interval between measurements was 30 minutes, and the study covered a period of 2 months. The patient was positioned according to the manufacturer's instructions.

Statistical Methods

The reproducibility was given as the coefficient of variation. For the phantom measurements and for the operator variability study, this was expressed as the ratio of the standard deviation of the measurements to their mean, expressed as a percentage. For the paired patient results, CV% was calculated using the following formula:

$$\mathrm{CV\%} = \frac{\sqrt{\sum \frac{d^2}{2n}} \times 100}{\frac{\bar{x}_1 + \bar{x}_2}{2}}$$

where n is the number of paired observations and d the difference between two paired measurements, x_1 and x_2 [10]. The CV% was calculated for both the standard method and the template method. In addition, the standard error of the estimate (SEE) from linear regression was calculated for the paired patient results. The paired *t*-test was used to compare the differences observed between the standard and template method of analysis.

Results

Phantom Studies

The long-term reproducibility was determined by repeated scans of the aluminium phantom in the AP projection, over 12 months and of the cadaveric phantom, in the lateral position, over 7 months. The coefficient of variation value for two vertebrae using the aluminium phantom was 0.8% and 1.7% using the cadaveric phantom.

Measuring two vertebral bodies, the vertical and horizontal rotation had similar reproducibility of 1.5 and 1.4%, respectively, comparable to the instrument stability. Figure 2 shows the affects of rotation of the phantom about the axis of the spine. Little change in measured BMD is noted until a rotation of 8°, after which the measured value increased sharply due to the inclusion of the posterior processes in the lateral projections. The coefficient of variance for 0°–8° was 1.2% as compared with 5.3% for 0°–10°. The angle at which axial rotation becomes significant will be dependent on the vertebral size of the individual patient.

Patient Studies

Ribs overlapped L2 vertebral body in 52% of the 100 lateral

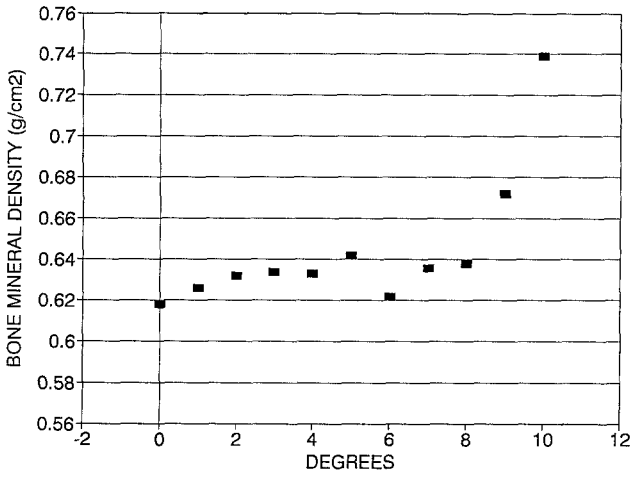

Fig. 2. The relationship between bone mineral density (g/cm^2) of a cadaveric phantom measured in the lateral position and the degree of axial rotation. The CV% for 0°–8° was 1.2%, and 5.3% for 0°–10°.

scans, and the pelvis overlapped L4 in 79% of the cases. In 64% of the patients, at least two vertebral bodies (L2-L3 or L3-L4) could be measured without obvious interference. However, L3 vertebral body was available for analysis in 100% of the scans. The reproducibility *in vivo* was assessed using the whole vertebral body and the midslice section of L3 alone and for two vertebral bodies (L2-L3 or L3-L4) (Table 1 and Table 2). The SEE for lateral scanning of body L3 and mid-L3 was 0.05 g/cm^2 and 0.06 g/cm^2, respectively when a template was used for analysis of the second scan. The SEE for lateral scanning when two vertebrae were taken into consideration was 0.037 g/cm^2 and 0.048 g/cm^2 for the body and midslice section, respectively.

Interoperator variability (Table 3) for two vertebral bodies was 0.9–1.1%, and intraoperator variability (Table 4) was 0.7–0.9%, indicating a high level of reproducibility. Interoperator and intraoperator variability increased slightly for the midslice analysis.

The pilot study, demonstrated that in 30 patients, the coefficient of variation for the AP position (for L2-L4) was 1.7% and the SEE was 0.027 g/cm^2.

Discussion

Noninvasive BMD measurement has gained widespread interest in recent years for identifying patients at risk for osteoporosis [11]. BMD estimation of lumbar vertebrae using the AP projection has been shown to be reliably reproducible. Our small series of 30 patients indicate good reproducibility of the DPX-L system, and are consistent with published results [12]. However, previous investigators [4] have established the deficiency of AP DEXA to discriminate between normal and osteoporotic patients. Lateral spine scanning allows a selective measurement of the trabecular compartment of the vertebral body, an area that is more sensitive to the changes caused by osteoporosis and free of other interfering conditions. The precision of BMD using LAT DEXA was investigated in this study.

In 100 scans of a cadaveric phantom measured over 7 months, the CV% of LAT DEXA was 1.7%, which was considerably greater than the value of 0.8% found when the phantom was scanned in the AP position which reflects the

Table 1. *In vivo* reproducibility results for vertebral bodies obtained in 100 patients

Method 1 Vertebral body	CV %	SEE (g/cm^2)
1 vertebra	6.4	0.057
2 vertebrae	5.1	0.047
Method 2 (template) Vertebral body	CV %	SEE (g/cm^2)
1 vertebra	5.4	0.050
2 vertebrae	3.8	0.037

The results were calculated from the BMD measurements obtained when using both method 1 (independent analysis of both scans) and method 2 (re-analyzing the second scan using the first scan as a positional template)

Table 2. *In vivo* reproducibility results from midslices obtained in 100 patients. The results were calculated from the BMD measurements obtained when using both method 1 and method 2

Method 1 Midslices	CV %	SEE (g/cm^2)
1 vertebra	9.4	0.064
2 vertebrae	5.9	0.055
Method 2 (template) Midslices	CV %	SEE (g/cm^2)
1 vertebra	7.0	0.059
2 vertebrae	4.6	0.048

lower BMD values for vertebral body as compared with the entire vertebra.

Patient positioning was also evaluated as a potential source of variability in LAT DEXA. A patient's lumbar spine cannot be rotated more than 20° either horizontally, vertically or axially, without being obvious to the operator. The effect of patient positioning was assessed using a phantom, with axial rotation of greater than 8° producing significantly elevated values due to inclusion of the posterior processes of the vertebrae within the ROIs. Horizontal or vertical rotation could be adequately corrected by the appropriate positioning of the ROIs.

LAT DEXA allowed two vertebrae to be measured in 64% of the cases due to overlap of the vertebra, from ribs on L2 and pelvis on L4. L3 estimation was possible in all cases. The assessment of inter- and intraoperator variability demonstrated that LAT DEXA was independent of the operator performing the analysis. The precision error for an individual vertebra as compared with when two vertebrae were analyzed suggested an improvement with the latter, although this was not shown to be statistically significant. The 'template' method demonstrated superiority ($P < 0.025$) over the individual analysis technique suggesting that this method is preferred for follow-up scans. When LAT DEXA duplicate measurements could be made for two vertebrae, the 95% confidence interval was 0.074 g/cm^2 for the vertebral body and 0.096 g/cm^2 for midslice calculation. In 36% of the patients only one vertebra was free of artifacts, resulting in a 95% confidence interval of 0.1 and 0.12 g/cm^2 for the vertebral body and midslice, respectively. The vertebral body results were significantly ($P < 0.005$) more reproducible than the midslice calculation, thus allowing a more sensitive measure of changing BMD of the lumbar spine.

Measurements of the lateral spine reduces the influence

Table 3. Inter-operator variability for the vertebral bodies and midslices for 10 patients assessed by three experienced operators on five separate occasions

Inter-operator variability	Vertebral body 3	Vertebral body 2–3	Vertebral midslice 3	Vertebral midslice 2–3
CV %	0.81–1.09	0.68–0.91	1.04–1.26	1.09–1.28

Table 4. Intra-operator variability for the vertebral bodies and midslices of 10 patients with BMD measurements ranging from 0.25 g/cm^2 to 0.94 g/cm^2

Intra-operator variability	Vertebral body 3	Vertebral body 2–3	Vertebral midslice 3	Vertebral midslice 2–3
CV %	0.54	0.49	0.35	0.62

of posterior artifacts most often seen in osteoporotic patients. The aging bone loss for lateral spine bone mineral density is about twice that of the AP projection [13]. Potential advantages of LAT DEXA over AP scans are offset by the lower precision (3.8% versus 1.7%). Intrapopulation variation will also offset the inherent diagnostic advantage of lateral scanning.

The reproducibility of lateral BMD measurements are predominantly effected by the difficulty in (1) positioning patients reproducibly, (2) eliminating the incidence of iliac crest overlying L4 and ribs overlying L2, and (3) vertebral identification. Initial results suggest these limiting factors may be overcome by performing supine lateral scanning, whereby the patient remains flat on the back thus minimizing angulation error [14]. Although these initial results are encouraging, only limited reproducibility data on normal individuals has been presented using this technique and further work is required in a clinical population before the true precision of this instrument is established.

From the present study, the reproducibility of LAT DEXA is considerably larger than the reproducibility seen with AP DEXA [10, 12], and the clinical utility of LAT DEXA in the longitudinal assessment of osteoporotic patients may be questionable. It has been reported [13], however, that the age-related diminution in BMD in the lumbar spine measured in the lateral view is approximately double that found in the AP view. In this way the relatively poor reproducibility of LAT DEXA may be offset by the larger changes seen when using the lateral scan. Clearly, further work in this area is needed.

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