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Magnification Error of Femoral Geometry Using Fan Beam Densitometers

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Abstract. Hip axis length (HAL) has been reported as an independent risk factor for hip fracture. DEXA machines using fan beam techniques have become increasingly available. Errors in calculated hip axis length may be expected because of different degrees of magnification by the fan beam. The magnitude of this error on measurement of hip geometry was studied, using an anthropomorphic femur phantom with both fan beam (Lunar Expert and Hologic QDR-2000) and pencil beam (Lunar DPXL) densitometers. The clinical relevance of these findings was also examined using patient measurements of buttock soft tissue thickness.

Femoral neck axis length (FNAL), which correlates well with HAL, was used as a measurement of hip geometry. There was a linear increase or decrease of FNAL with increasing distance of the phantom above the scanning table, when measured with the Lunar Expert or Hologic QDR-2000, respectively. There was no significant difference in FNAL at different heights using the pencil beam densitometer. The maximal difference in buttock soft tissue thickness in 30 women studied was 8.7 cm. From the equations, derived from the phantom studies, this difference would result in an 8.2% (1.4 SD) increase, or an 11.4% (1.9 SD) decrease in FNAL in the largest woman as compared with the smallest woman when measured using the Lunar Expert or Hologic QDR-2000, respectively.

We conclude that there may be unpredictable degrees of magnification of FNAL in vivo, caused by differences in buttock thickness, when measured using a fan beam densitometers. Until these problems are resolved. FNAL, or related parameters of femoral geometry, should be measured using pencil beam instruments.

Key words: Osteoporosis — Hip axis length — Fan beam — DEXA.

Dual energy X-ray absorptiometry (DEXA) using a pencil beam design has been used for quantitation of bone mineral and bone mineral area density (BMD). DEXA measurements may also be used to obtain quantitative measurements of the geometry of the proximal femur. Hip axis length (HAL), defined as the length along the femoral neck axis from below the greater trochanter through the femoral neck to the inner pelvic brim, has been reported to be an independent risk factor for hip fracture [1]. Each standard deviation increase in HAL led to a 1.8-fold increase in the age-adjusted risk of hip fracture. Femoral neck axis length (FNAL) is a similar measure, but extends from the lateral cortex of the trochanter to the cortex of the femoral head and does not include more proximal structures. FNAL correlates well with HAL [2].

DEXA machines, using fan beam techniques, have become increasingly available. Because of the shape of the X-ray fan beam, there is an inherent magnification of scanned structures in the medial–lateral direction, as the distance from the X-ray tube and, hence, from the apex of the fan beam, decreases. This magnification does not occur in the craniocaudal direction. Conversely, as the distance from the X-ray tube increases there is a corresponding diminution in the apparent dimension of scanned structures in the medial-lateral direction. These changes in bone dimensions do not appear to have marked effects on calculated BMD. Estimations of BMD using these new scanners correlate well with measurements from the pencil beam machines [3–6], although magnification by the fan beam may result in systematic differences of up to 2%–3% between absolute BMD measurements. These differences in BMD may be reduced with appropriate calibration [5].

Faulkner et al. [7] reported that HAL measurements using fan beam scanners were significantly larger (7.5%) than the measurements from pencil beam machines and there was a larger observed variation in HAL from the fan beam scans. A systematic difference in measurements of hip geometry between pencil beam and fan beam scanners, on the order reported by Faulkner et al. (7), might be solved by an appropriate conversion factor [7]. However, if differences in hip magnification caused by interpatient variation in buttock thickness and, hence, height of the proximal femur above the scanning table is a significant factor in HAL determination in fan beam machines, unpredictable large errors in the results may occur. This could affect the calculated relationship of individual patients to the normal range with resultant errors in the corresponding standard deviations.

There are no published studies addressing the variation in magnification of hip geometry that may occur between individuals as a result of the variability in buttock soft tissue thickness and, hence, of the height of the femoral neck above the scanning table. We addressed this question by performing studies using two fan beam densitometers from different manufacturers on an anthropomorphic femur phantom placed at varying heights above the scanning table to simulate variations in buttock thickness. These results were compared to scans performed on the phantom using a pencil beam DEXA scanner from one of the manufacturers of the fan beam machines. We also examined the clinical rel-

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evance of these findings by measuring buttock soft tissue thickness in a group of women volunteers and used this data to calculate the magnification error in FNAL that would occur in DEXA fan beam scans on these subjects.

Methods

DEXA scanning of an anthropomorphic femur phantom (Wahner–Hahn Anthropomorphic Femur Phantom, Hologic Inc., Waltham, MA) was performed using two fan beam, dual energy X-ray absorptiometers (Lunar Expert, Lunar Corporation, Madison, WI, and Hologic QDR-2000 Hologic Inc., Waltham, MA). The X-ray tube in the Lunar machine is situated above the subject whereas in the Hologic scanner the X-ray tube is under the subject. The scanning tables were kept at their default vertical height for all scans. The anthropomorphic femur phantom was also scanned on a pencil beam, dual energy X-ray absorptiometer (Lunar DPXL, Lunar Corporation, Madison, WI). The femur phantom consists of a synthetic proximal femur model, containing 38.5 g of calcium hydroxyapatite, embedded in perspex. The distance from the base surface of the perspex to the phantom femoral neck, in the scanning position, is 7 cm, which approximately equals the minimum buttock soft tissue thickness we observed in vivo. The phantom was scanned on each machine, placed on the surface of the scanning bed, as well as at elevations above the bed of 2.5, 5, 10, and 20 cm. Five scans were performed at each level for all three machines. The positioning in a correct plane at each height was verified using a spirit level.

Femoral neck axis length (FNAL), defined as the length along the femoral neck axis from below the greater trochanter through the center of the femoral neck to the cortical rim of the femoral head, was used as a measure of hip geometry. FNAL was used rather than HAL since the latter cannot be measured in available DEXA anthropomorphic femur phantoms because of the absence of the pelvis. FNAL was measured separately on all scans independently by two operators who were blinded to the height of the phantom above the scanning bed. These measurements were performed in the Lunar fan beam and pencil beam scans using the software ruler available in the hip analysis program, which provides the results in centimeters. Manual measurements of FNAL were made in the Hologic fan beam scans from the DEXA printouts, and the results at different heights were expressed as a percentage of the baseline measurement.

The in vivo variation in height of the proximal femur above a scanning table, because of differences in buttock soft tissue thickness, was quantitated in 30 female volunteers who were aged 32 to 65 years. These subjects, who were attending the department for unrelated radionuclide bone scans, had an additional lateral hip image that was obtained, after the subjects gave their consent, in a supine position with the hip rotated internally 25° to replicate the positioning used in standard DEXA hip scans. Buttock soft tissue thickness was measured from the center of the femoral neck to the buttock skin surface using the computerized ruler of the gamma camera. The ratio of soft tissue thickness, anterior to the femoral neck, to buttock soft tissue thickness was also calculated.

Results

The FNAL in the Lunar fan beam scans was 2% larger than in the corresponding pencil beam scans at scanning table height (10.0 cm and 8.9 cm, respectively). The mean FNAL at different scanning heights, expressed as a percentage of the baseline measurement, are shown for both fan beam and for the pencil beam scanners in Figure 1. There was a linear increase in FNAL with increasing distance of the phantom above the scanning table when measured using the Lunar fan beam machine. This was as expected because of its anteroposterior scanning mode. The observed magnification was 0.94% cm^{-1}. There was no significant difference in

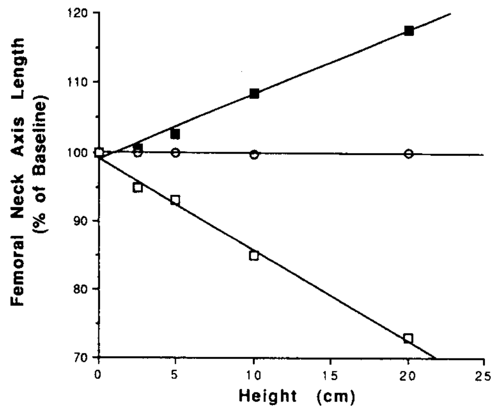

Fig. 1. Femoral neck axis length (FNAL), expressed as a percentage of the baseline measurement, at different heights (cm) of an anthropomorphic phantom above the scanning table for a pencil beam DEXA scanner (○, Lunar DPX-L) and for two fan beam DEXA scanners (■, Lunar Expert and □, Hologic QDR-2000. The lines of best fit are shown. The equations for the lines of best fit for the fan beam scanners are:

Lunar: FNAL % baseline = 98.8 + 0.93 height (r = 0.99)
Hologic: FNAL % baseline = 99.2 – 1.33 height (r = 0.99).

FNAL at the different scanning heights from measurements performed on the Lunar pencil beam densitometer (Fig. 1). There was a linear decrease in mean FNAL with increasing distance of the phantom above the scanning table when measured using the Hologic fan beam machine (Fig. 1). This was as expected due to its posteroanterior scanning mode. The observed magnification was –1.34% cm^{-1}.

The mean buttock soft tissue thickness in the 30 women studied was 11.2 cm (range 7.1–15.8 cm). The distance from the phantom femoral neck to the base surface of the perspex block (7.0 cm) closely approximates the minimum thickness observed (7.1 cm). The normal range and standard deviation of FNAL in our department, determined from measurements performed on 100 women using a pencil beam DEXA scanner, is 9.30 ± 1.12 cm (mean ± 2 SD). Using these values and by applying the equations derived from the phantom studies, the observed maximal difference in buttock thickness between two women in the group studied (8.7 cm), would result in a spurious magnification of FNAL in the Lunar Expert of 0.81 cm (8.2% or 1.4 SD; $P < 0.0001$) in the larger woman as compared with the smaller, because of the increased distance of the proximal femur above the scanning bed. Conversely in the Hologic QDR-2000, caused by the posteroanterior scanning mode, the increased buttock thickness would result in a spurious decrease of FNAL of 11.4% (1.9 SD; $P < 0.0001$) in the larger woman as compared with the smaller.

The feasibility of correcting for variation in body habitus from measurements of pelvic girth was assessed by calculating the ratio of soft tissue thickness anterior to the femoral neck to buttock soft tissue thickness. This ratio was found to be variable, with a range (mean ± 2 SD) of 0.6–1.6 indicating that simple measurements of pelvic girth could not provide a reliable correction factor for variation in buttock soft tissue thickness.

Discussion

The results of this study confirm earlier data [7] demonstrating that FNAL measurements on fan beam densitometers may be significantly different from measurements performed on pencil beam scanners. As expected, based on the shape of the X-ray beam, this difference in FNAL using fan beam instruments is not a systematic difference, but does vary with the height of the hip above the scanning table. These findings are in agreement with fan beam DEXA phantom studies of Blake et al. [8] and Eiken et al. [9], who reported similar, although slightly larger, changes in BMC and projected area with variation in height above the scanning table. Our patient data also demonstrate for the first time that observed differences in buttock thickness in vivo would result in significant magnification errors of hip geometry by fan beam DEXA. This difference in buttock soft tissue thickness could be as large as 8.7 cm, as observed in the female patients evaluated by lateral radionuclide bone scans. Thus DEXA fan beam scans of proximal femora in individuals of different buttock size could result in a spurious increase in FNAL of up to 1.4 SD or a spurious decrease in FNAL of up to 1.9 SD in the Lunar Expert and Hologic QDR 2000 fan beam instruments, respectively. Potential errors of this magnitude indicate that measurements of hip geometry using fan beam scanning may be an unreliable index if used to help predict fracture risk.

The current study used FNAL rather than HAL as a measure of hip geometry, since the latter can not be measured in currently available DEXA anthropomorphic femur phantoms because of the absence of the pelvis. However, FNAL correlates well with HAL [2] and the magnification errors affecting FNAL, caused by variation in buttock soft tissue thickness, would equally apply to measurements of HAL.

The problem of magnification by fan beam densitometers could, in theory, be overcome by a correction factor based on the patients' pelvic dimensions. Our patient data, however, indicate that the ratio of soft tissue thickness anterior to the femoral neck to buttock soft tissue thickness is variable and, hence, precludes a reliable correction factor from simple measurements of pelvic girth. A measure of buttock soft tissue thickness would allow a suitable correction factor to be applied. These data, however, are not readily available in most patients undergoing DEXA scans. It is possible that a lateral DEXA scan of the hip, in addition to the standard scan, could provide a reliable measurement of buttock soft tissue thickness that would allow a correction factor to be applied to measurements of hip geometry. Further studies are required to address this question.

In summary, this study has shown that there may be unpredictable errors of FNAL, when measured using fan beam densitometers, because of differences in buttock thickness. This raises difficulties in the use of such machines for geometric measurements of the proximal femur in assessment of fracture risk. Until these problems are resolved, measurements of FNAL or related parameters of femoral neck size should be performed using pencil beam DEXA scanners.

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