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Section III: Quality Issues

Errors in Dual-Energy X-Ray Scanning of the Hip Because of Nonuniform Fat Distribution

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Abstract

The variable proportion of fat in overlying soft tissue is a potential source of error in dual-energy X-ray absorptiometry (DXA) measurements of bone mineral. The effect on spine scanning has previously been assessed from cadaver studies and from computed tomography (CT) scans of soft tissue distribution. We have now applied the latter technique to DXA hip scanning. The CT scans performed for clinical purposes were used to derive mean adipose tissue thicknesses over bone and background areas for total hip and femoral neck. The former was always lower. More importantly, the fat thickness differences varied among subjects. Errors because of bone marrow fat were deduced from CT measurements of marrow thickness and assumed fat proportions of marrow. The effect of these differences on measured bone mineral density was deduced from phantom measurements of the bone equivalence of fat. Uncertainties of around 0.06 g/cm^2 are similar to those previously reported for spine scanning and the results from cadaver measurements. They should be considered in assessing the diagnostic accuracy of DXA scanning.

Key Words: Dual-energy X-ray absorptiometry; fat; hip.

Introduction

It is well established, but not always appreciated, that the accuracy of dual-energy X-ray absorptiometry (DXA) bone scanning is influenced by the relative fat and lean proportions of soft tissue. This is because the 3 main components have different X-ray attenuation coefficients and only 2 energies are used. The fat proportion overlying bone cannot be determined, and assumptions have to be made about its relationship to the fat proportion in adjacent tissue. The DXA scanner manufacturers do not reveal what assumptions they make, but they cannot be universally valid. This potential error is usually ignored, although authors of previous studies have suggested that it may seriously affect the clinical utility of bone mineral density (BMD) results from DXA *(1)*. It is therefore important to examine the magnitude of the possible errors.

The extent of the errors in spine scanning has been examined by studies on cadavers, which can include both intra- and extraosseus fat. These studies have been summarized by Blake and Fogelman *(2)*. The results agree that the mean fat thickness overlying the vertebra is less than that over the adjacent soft tissue, leading to accuracy errors of a mean 5–10% and a comparable spread in the results. The mean deviation is not serious, as it would apply equally to the results used to define reference ranges. The dispersion of the results is more important, and Blake and Fogelman *(2)* estimate that the 95% confidence interval for T-score accuracy error is around 0.95. Cadaver studies have involved relatively few subjects and a limited range of body shapes and sizes.

An alternative approach is to examine the adipose tissue (AT) distribution apparent in computed tomography (CT) scans, including those performed for clinical diagnosis. A number of studies have used this technique to study the possible errors in DXA spine measurements *(3–6)*. The findings are similar to those from cadaver studies. Hip scanning has received much less attention, although Svendsen et al *(7)* included the proximal femur in their cadaver studies, and Kuiper et al *(8)* considered the femoral neck. We are not

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aware of any previous application of CT scans to the fat error problem in hip scanning, so we have undertaken such an investigation.

Methods

Phantom Measurements

It was necessary to determine the (negative) bone equivalence of a given fat thickness. We had previously measured this for spine scanning by performing DXA measurements of a slab of bone-equivalent material with and without layers of fat-equivalent material on top, with the assembly placed in a water bath *(3)*. A similar arrangement was used for the hip. As the bone equivalent, an aluminum slab was cut in the shape of the proximal femur plus a section of the pelvis, approximating to the region of interest (ROI) used in hip scanning (Fig. 1). This was fixed in the middle of a water bath, depths 12, 16, and 20 cm, respectively, and scanned with and without slabs of paraffin wax cut to the same shape overlying the phantom. A Hologic Discovery-A scanner (Hologic Inc, Bedford, MA) was used, with software version 12.6.2. The thickness of paraffin wax was varied between 14 and 42 mm. The bone equivalence was derived from the gradient of the linear regression of BMD vs thickness of wax. The fat equivalence of paraffin wax was determined from previous experiments *(3)*.

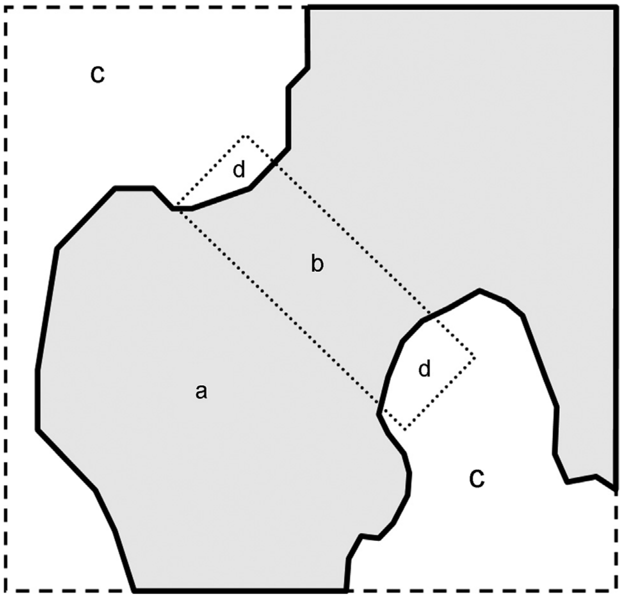

Fig. 1. Illustration of region-of-interest (ROI) positioning for adipose tissue thickness estimation. The main rectangular ROI is denoted by the dashed line, bone is denoted by the shaded area, and the rectangular femoral neck ROI is denoted by the dotted line. We define ''whole bone'' to comprise regions a and b, and ''background'' to comprise regions c and d.

In Vivo

The study was deemed as not requiring NHS ethical review by the National Research Ethics Service. The local Radiology Information System was examined to find diagnostic pelvic CT scans. The results were sorted to find patients with repeat CT scans. This list was used to examine the local Picture Archiving and Communications System (PACS) and identify suitable scan data sets for analysis. The inclusion criteria for each hip were (1) absence of hip prosthesis, (2) absence of hip fracture, (3) CT field of view sufficient to include all peripheral body fat, extending at least 5 mm past the lateral edge of the greater trochanter, and (4) scan coverage to at least the inferior extent of the lesser trochanter. The rotation of the pelvis was also measured, using the PACS angular measurement tool, taken as the deviation from horizontal of the line drawn between the center of the femoral heads. The DICOM images were downloaded and anonymized to protect patient confidentiality before analysis. The CT scans from 52 subjects were selected. To investigate reproducibility, 36 scans were chosen from subjects who had 2 scans, mostly with an interval of less than 25 d, but some with intervals of up to 30 mo. The former were chosen to study the reproducibility, as a real change of fat proportion would be unlikely. Both left and right hips were examined. In total, 176 hip scans were available for analysis from 126 women and 50 men. All the scans were analyzed by 1 operator, and a subset of 55 hips also by 2 other operators. There was a wide range of fat thickness in the women and less in the men. The mean age was 66 ± 12 yr, typical of a population examined by DXA scanning.

Image analysis was performed using a custom software tool written in IDL (Exelis Visual Information Solutions, Boulder, Colorado). Within each transaxial CT slice, voxels in each column with density greater than 250 Hounsfield units (HU) were counted as bone. Voxels with $-150 < \text{HU} < -50$ were counted as AT, consistent with previous work *(3)*. This process yielded bone and AT thickness profiles for each slice. Repeating this process on a slice-by-slice basis generated AT and bone thickness maps in coronal projection. The bone thickness maps were then used to produce a bone mask and position DXA-like ROIs that could be mapped onto the AT thickness image. The DXA manufacturers do not reveal which areas of soft tissue they use to estimate the fat tissue thicknesses over bone. We therefore made our own choice of possible regions. A main rectangular ROI was defined by the superior and medial limits of the femoral head and the lateral edge of the greater trochanter, with margins of 5 mm on each side, as recommended for the analysis of DXA scans. The effect of moving the lateral ROI edge was also investigated for a subset of patients. A default ROI length of 105 mm was used, taken from the average ROI length used in clinical DXA scans. The operator drew a chord bisecting the femoral neck, and the software positioned a rectangular femoral neck ROI perpendicular to the chord at its midpoint. The operator adjusted the position and length of the femoral neck ROI such that 1 corner was in the notch of the greater trochanter and the other 3 corners were outside the bone (Fig. 1). The