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An evaluation of sex and body weight determination from the proximal femur using DXA technology and its potential for forensic anthropology

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Abstract

Dual energy X-ray absorptiometry (DXA) is a rarely used technology in forensic anthropology. These densitometers quantify bone mineral density (BMD) and bone mineral content (BMC) and thus introduce new variables which are important for the application of forensic anthropology. This study investigates the importance of these variables and of this technology using bone scans of the proximal femur in sex and body weight determination. Two data sets from studies conducted at the University of Alabama at Birmingham were examined. The first study had 41 White patients, of which there were 17 males and 24 females, ranging in age from 61 to 79 years and in weight from 99 to 242 lb. The following variables were utilized from the DXA scans: BMD in the femoral neck, greater trochanter and in Ward's triangle. A manual ruler in the software facilitated measurements on the minimum neck diameter and shaft diameter just below the lesser trochanter from each scan. The second study had 128 female patients, 71 of which were Black and 57 were White. They ranged in age from 23 to $47\frac{1}{2}$ years and they weighed between $31\frac{1}{2}$ and $98\frac{1}{4}$ kg. The same variables were examined on these DXA scans as in the first study, with the addition of BMC of the femoral neck and the deletion of the minimum shaft diameter below the lesser trochanter. The first study showed statistically significant sex determination relationships ($p < 0.02$, t-tests for equality of means) at the supero-inferior femoral neck and lesser trochanter diameters, and from BMD at the femoral neck, trochanter, and Ward's triangle. Discriminant function analysis correctly classified sex over 92% of the original grouped cases using these variables. Multiple regression analysis using body weight as the dependent variable and various measures of the proximal femur as independent variables shows that while they are statistically significant and they have reasonably high R^2 values up to 0.49; nevertheless, their standard errors of the estimates are too wide to be of much forensic use. The second study examined ethnic differences, Blacks and Whites, and body weight relationships in a larger, all female data set. Statistically significant differences between Blacks and Whites of BMD were found at Ward's triangle. Multiple regression analyses were again run on body weight and various measures of the proximal femur. The results were also broken down by ethnicity. Some body weight relationships were again statistically significant such as between the BMC of the femoral neck and the BMD of the greater trochanter and the BMC of the neck and the minimum neck diameter, but again, the standard error of the estimate is too wide to be of much use. In addition, the square of the correlation coefficient (R^2) is very low, for example, below 0.1 in all cases. Thus, there is very little variability in weight that can be accounted for with these variables. DXA technology offers the potential of a living skeletal data bank and of variables that are useful in cause–effect relationships between bone mineralization and skeletal loads.

Keywords: Forensic science; Dual energy X-ray absorptiometry; Femoral neck; Sex and weight determination

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1. Introduction

Dual energy X-ray absorptiometry (DXA) is rarely used in forensic anthropology. There is only one previous report of its utilization in the literature and that report used single energy X-ray absorptiometry on the taphonomic implications of bone density variation [1]. DXA is a bone scanner that quantifies bone mineral content (BMC) in grams and bone mineral density (BMD) expressed in grams per square centimeter. The use of two low-energy photon energies yields a two-dimensional image, increasing accuracy and decreasing errors, compared to earlier machines that utilized one photon. DXA is now the most widely applied method of bone densitometry—the 'gold standard' in pharmaceutical trials assessing the efficacy of therapeutic interventions in osteoporosis. The femoral neck is one of the major sites for osteoporosis and DXA studies.

There are many advantages of this technology that go a long way towards meeting some of the alleged deficiencies in forensic anthropology [2]. First, it utilizes the extensive clinical literature. Second, it offers the possibility of longitudinal analysis of individuals. Third, it offers a so-called 'bone geometric' quantitative analysis. Bone mineral density, for example, is said to be the single best predictor of trabecular bone strength, although it alone may explain only 49–93% of the variance of mechanical properties such as, the modulus of elasticity or compressive strength [3]. Fourth, it can be used in conjunction with more traditional caliper measurements (on computer images) as is done here. Fifth, it provides data on variables often difficult to obtain from skeletal collections such as, body weight or handedness. Last, it presents the opportunity to modernize or assemble pre-mortem or living skeletal data banks rather than work only from post-mortem data banks.

Examples of sex, ethnicity and body weight determination that show the application of DXA are presented. The proximal femur and neck are weight-bearing sites that have well-known relationships with BMD and body weight. This region supports a load and is subject to various stresses that influence bone remodeling and density (Wolff's law). Sex and body weight are linked because males tend to be heavier and stronger than females and this relationship can be shown quantitatively. DXA technology may also be more relevant for some determinations such as body weight determination because maceration and cooking, for example, can cause as much as 10% loss of BMD [1]. Body weight estimates would not only be forensically useful for individual identification but also for other purposes such as body transport and decomposition rates. Body weight estimates are also valuable in the reconstruction of many life style variables relating to fossils.

2. Materials and methods

The DXA scans of patients were from two studies conducted at the Department of Human Studies in the Nutrition Sciences Laboratory at the University of Alabama at Birmingham. The first study has a total of 41 White patients, 17 males and 24 females, ranging in age from 61 to 79 years and in weight from 99 to 242 lb. Patients were weighed on a scale when their scans were taken. There were no diseases or fractures in the patients measured.

The first study used a bone densitometer (Lunar Corporation, model DPX-L), along with their software program with a manual ruler that facilitated measurements in millimeters on the proximal femur. The bone scans selected for measurement were those that gave good visibility at the femoral neck and the lesser trochanter. The following variables were recorded for each patient: age, sex, height, weight in pounds, scan date, bone mineral density of the neck, Ward's triangle, and the greater trochanter, and the minimum diameter of the femoral neck and the diameter of the femoral shaft just below the lesser trochanter. Ward's triangle is half the width of the femoral neck that is bounded by the principal and secondary compressive and the principal tensile groups of trabeculae. Two measurements were also taken from the scans: the minimum diameter of the neck and the diameter of the shaft just below the lesser trochanter. The minimum diameter of the femoral neck is similar to the 'supero-inferior femoral neck diameter' (SID) mentioned in [4]. The diameter of the lesser trochanter was measured at the base. Each scan was measured three times and the modal measurement was recorded. Any white outline of bone showing on the scan was considered bone and was measured.

The second study has a total of 128 female patients, 71 of which are Black and 57 of which are White. They ranged in age from 23 to $47\frac{1}{2}$ years and they ranged in weight from $31\frac{1}{2}$ to $98\frac{1}{4}$ kg.

These patients were scanned with a Lunar, model Prodigy DXA scanner that uses encore 2002 software. An additional variable, bone mineral content of the femoral neck was added to this study. The only measurement taken from the scan was minimum neck diameter as the location of the lesser trochanter was difficult to find. The Prodigy DXA scanner outlines the bone surface of the femoral neck in blue, making it easy to determine the measurement sites. For additional ease of measurement, all scans were magnified by 300%.

A standard protocol is used to position each patient prior to the DXA scan in both studies. The legs, for example, are rotated inward and the shoes are strapped securely using an anterior brace and attached to a stand. Data for this paper came from measurements made on the left femur. All of the patients were also weighed on a scale at the time of their scans. There were no patients with injuries or diseases. All statistics used in this study were calculated using SPSS 10.0.

3. Results

The patients in the first study were divided by sex and *t*-tests for equality of means and Mann–Whitney *U*-tests were