Body composition by DEXA in older adults: accuracy and influence of scan mode

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This is a non-final version of an article published in final form in:

Clasey, J.L., Hartman, M.L., Kanaley, J., Wideman, L., Teates, D.C., Bouchard, C. and Weltman, A. 1997. Body composition by DEXA in older adults: accuracy and influence of scan mode. *Medicine & Science in Sport & Exercise* 29(4): 560-567. PMID: 9107641

Abstract:

Dual energy x-ray absorptiometry (DEXA) measures bone mineral content(BMC), bone mineral density (BMD), fat-free mass (FFM), and provides estimates of percent body fat. Changes in scan mode geometry (pencil beam vs array) may impact these measures and body composition estimates using multi-compartment models. Forty-one adults, ages 59-79 yr, were scanned in each mode and also underwent hydrostatic weighing and measurement of total body water (tritiated water dilution). The effect of scan mode on measurement of DEXA BMC, BMD, FFM, and percent body fat (DEXA%Fat) was examined. The effect of scan mode on percentage body fat determined by a 4-compartment body composition model (4 Comp%Fat) and comparison of DEXA%Fat and 4 Comp%Fat were also examined. BMC and DEXA%Fat were greater (1.3% and 3.9%, respectively, $P < 0.01$), and BMD and FFM were lower (1.1% and 1.9%, respectively, $P< 0.01$) with the array scan mode. The 4 Comp%Fat was significantly greater(0.2%) when the array scan mode measurements of total body bone mineral were used; however, these differences were physiologically inconsequential. Comparison between DEXA%Fat and 4 Comp%Fat measures revealed a total error of± 5.0% in the older adults examined. These results indicate significant scan mode differences in total body BMC, BMD, FFM, and DEXA%Fat measurements and demonstrate the importance of using a single DEXA scan mode for clinical investigation, particularly with longitudinal studies. For all investigations with DEXA, the scan mode should be reported. Furthermore, the error associated with using DEXA alone to estimate percent fat in an older population suggests that this technique is unacceptable in a research setting.

Keywords: DEXA | bone mineral content | bone mineral density | fat-free mass | percent body fat

Article:

The advent of dual-energy x-ray absorptiometry (DEXA) has allowed for rapid, noninvasive bone measurements and body composition estimates with minimal radiation exposure for both

clinical practice and research. Several DEXA models, software versions, and technological advances have been introduced in recent years. Although upgrades of DEXA devices are designed to improve and expand the measurement capabilities of the technique, these technological advances may influence the precision and accuracy of data obtained during longitudinal studies or comparison of data between studies(4). Van Loan et al. (15) recently reported that a change in software version (Lunar Corp., Madison, WI) produced significantly different estimates of bone mineral content, bone mineral density, and soft tissue distribution.

Another recent technological advance in hardware, available using the Hologic QDR 2000 (Hologic, Inc., Waltham, MA), is the selection option for scan mode. The pencil beam scan mode option allows total body and regional measurements to be performed using a traditional highly collimated x-ray source coupled with a single detector. The alternate array scan mode uses a fan beam x-ray source coupled with multiple detectors, which allows for an increase in scan speed (10,14). However, it is possible that the scan geometry changes required for data acquisition may alter the resulting bone and/or body composition measurements in a systematic or random fashion. In addition to its use for measuring BMC and BMD, software has been written to estimate regional and whole body fat-free mass (FFM) and percent fat using DEXA (13). DEXA incorporates a three-compartment body composition model and makes the assumption that the hydration of the mineral-free lean tissue (FFM-bone) is constant at 0.73 $ml \cdot g^{-1}$(9). When this assumption was previously evaluated in older adults, it was shown to be erroneous(1,8). Therefore, it can be hypothesized that use of DEXA to estimate percent fat in an older population may result in total error values that are unacceptable in a research setting.

Thus, the purposes of the present study were: 1) to determine whether scan mode significantly altered estimates of total body bone mineral content (BMC), bone mineral density (BMD), fat-free mass (FFM), and percent body fat(DEXA%Fat) in older individuals using the Hologic QDR 2000 DEXA; 2) to determine whether using the BMC measurements obtained with the array and pencil beam scan modes resulted in significantly different estimations of percentage body fat using a 4-compartment body composition model (4 Comp%Fat); and 3) to compare DEXA%Fat and 4 Comp%Fat measurements in a group of older men and women.

TABLE 1. Physical characteristics of the 41 older adult subjects.

Variable	Mean (±SD)	Range
Age (yr)	67.0 (5.1)	59–79
Height (cm)	170.8 (9.8)	152.0–190.0
Weight (kg)	79.6 (15.0)	50.2–102.9
BMI (kg/m^2)	27.0 (3.5)	20.7–34.7
4-Compartment Model Percentage body fat (%)*	33.2 (9.6)	9.5–49.3

* DEXA pencil beam estimates of total body bone ash used; $N = 28$.

MATERIALS AND METHODS

Subjects. Forty-one healthy adults (23 men and 18 women), 59-79 yr of age served a subjects. All subjects underwent a detailed medical history and physical examination and provided written informed consent in accordance with the guidelines established by the Human Investigation

Committee of the University of Virginia. The physical characteristics of the subjects are shown in Table 1. None of the subjects were taking medications known to affect bone or body composition measures, including postmenopausal use of estrogen replacement therapy.

DEXA scans and analysis. DEXA scans were performed in both the pencil beam and array modes using a Hologic QDR 2000 (Hologic, Inc.) bone densitometer. The subjects were instructed to remove all objects such as jewelry or eyeglasses and wore only a standard hospital gown during the scan procedures. The subjects were scanned in the pencil beam mode followed by the array scan mode during a single testing session and were not removed from the scan table between measurements. The alignment of subjects on the scan table was checked between scans to ensure that positioning was consistent. All scans were subsequently analyzed by a single trained investigator (J.L.C.) using the Hologic enhanced whole body software version 5.64. DEXA total body BMC (g), BMD (g/cm^2), FFM (kg), and DEXA%Fat (%) were assessed. DEXA total body bone and body composition analyses were performed twice for each mode to determine intra-analysis variability. Because the results were consistent ($r \geq 0.99$) and no mean differences were found for bone, lean, and fat measurements, a single scan analysis was used to represent the pencil beam and array scan mode measurements.

Body composition assessment (4-compartment model). To determine if the scan mode influenced the estimation of percentage body fat using a 4-compartment body composition model and to provide a comparison between 4 Comp%Fat and DEXA%Fat, the technique proposed by Heymsfield et al.(8) was employed. This requires the measurement of body density, total body water, and total body bone ash for each subject. Body density was determined by hydrostatic weighing (11) corrected for residual lung volume (16). Total body water was measured by a tritiated water dilution technique modified for use with plasma samples (7). The total body bone ash was computed using BMC results from both scan modes with BMC corrected for the addition of non-osseous mineral using the proposed computation of Heymsfield et al. (8).

Statistical analysis. Paired *t*-tests were used to determine if scan mode affected the measurement of BMC, BMD, FFM, DEXA%Fat, and 4 Comp%Fat. In addition, DEXA%Fat measures were compared with 4 Comp%Fat measures. Linear regression analyses were used to determine if the slope and the intercept of the regression line generated from the comparison of the bone and body composition measurements differed significantly from 1 and 0, respectively. The correlation between the scan mode measurements and the SE(total error) from the line of identity were determined for the BMC, BMD, FFM, and percent body fat measurements.

To examine further the effect of scan mode on bone and body composition measurements and to compare DEXA%Fat and 4 Comp%Fat, the analysis technique described by Bland and Altman (3) was employed. This statistical analysis appropriately assesses the agreement between two methods of measurement using graphic techniques and simple calculations of mean differences between scan mode methods (3).

RESULTS

Mean comparisons for estimates of BMC, Area, BMD, FFM, DEXA%Fat, and 4 Comp%Fat by pencil beam and array scan modes are shown in Table 2. The findings demonstrate small, but

significantly greater, BMC, Area, and DEXA percent body fat measurements by the array scan mode compared with the pencil beam scan mode. Measurements of BMC, Area, and DEXA%Fat were 1.3%, 2.4%, and 3.9% greater, respectively, with the array scan mode ($P < 0.01$). Using the array scan mode also resulted in small (0.2%) but significantly greater 4 Comp%Fat ($P< 0.2\%$) measurements. Measurements of BMD (BMD = BMC/Area) and FFM were 1.1% and 1.9% lower, respectively, with array than with pencil beam scan mode($P < 0.01$).

TABLE 2. Dual energy x-ray absorptiometry measurements: comparison of pencil beam and array scan mode measurements in older adults ($N = 41$).

Variable	Pencil Beam Scan Mode Mean (±SD)	Array Scan Mode Mean (±SD)	Mean Difference	% Difference
BMC (g)	2677.0 (677.5)	2711.6 (669.3)	−34.6*	1.3
Area (cm^2)	2245.4 (279.0)	2300.5 (287.2)	−55.1*	2.4
BMD ($g \cdot cm^2$)	1.175 (0.168)	1.163 (0.157)	0.013*	1.1
FFM (kg)	52.63 (13.26)	51.67 (13.22)	1.02*	1.9
DEXA % Fat	33.6 (10.2)	34.9 (10.1)	−1.3*	3.9
4 Comp % Fat	33.2 (9.6)	33.3 (9.6)	−0.06#	0.2

* Denotes paired *t*-test significant differences ($P < 0.01$).
\# Denotes paired *t*-test significant differences ($P < 0.02$).
BMC, DEXA bone mineral content; Area, DEXA bone area; BMD, DEXA bone mineral density; FFM, DEXA Fat-free mass; % Fat, DEXA percent Fat; 4 Comp % Fat, 4 compartment model percentage fat using DEXA BMC measurements ($N = 28$).

Figure 1 displays the relationship between pencil beam and array beam measurements for BMC (Fig. 1A), BMD (Fig. 1B), FFM (Fig. 1C), and DEXA%Fat (Fig. 1D). The line of identity and the SE around the line of identity are shown on each graph, with the slope and intercept from the actual regression line reported. Regardless of the variable examined, the slope and intercept of the regression line generated from the scan mode comparisons did not significantly differ from 1 and 0, respectively. Figure 1E shows the relationship between 4 Comp%Fat results using the pencil beam and the array scan mode BMC to estimate total body bone ash. All other values (body density and body water) used to compute the 4 Comp%Fat remained constant, thus allowing for determination of the influence of DEXA scan mode alone on this multi-compartment model method of assessing percent fat. The number of subjects included in this portion of the analysis decreased by seven men and six women because the total body water measures required for the 4-compartment model computation of percent body fat were not available. The line of identity and the SE from the line of identity are shown, with the slope and intercept from the actual regression line reported. The slope and intercept of the regression line generated from this comparison did not significantly differ from 1 and 0, respectively.

Figure 2 illustrates the difference between the pencil beam and array scan mode bone and body composition measurements plotted against the mean of the scan mode variable measurements, thus showing the degree of agreement between method for each variable measured(3). Figure 2A demonstrates the bias of the BMC scan mode measures estimated by the mean difference of the measurement methods and computation of the limits of agreement (-34.6 ± 126 g). This type of analysis is also shown for BMD (0.013 ± 0.0536 g/cm^2) (Fig. 2B); FFM (1.02 ± 2.16 kg)(Fig. 2C); and DEXA%Fat (-1.3 ± 2.4%)(Fig. 3D). Figure 2E demonstrates the small bias between the

4 Comp%Fat measures (-0.06 ± 0.26%) when the pencil beam and array scan modes were used to measure BMC for the total body bone ash estimates.

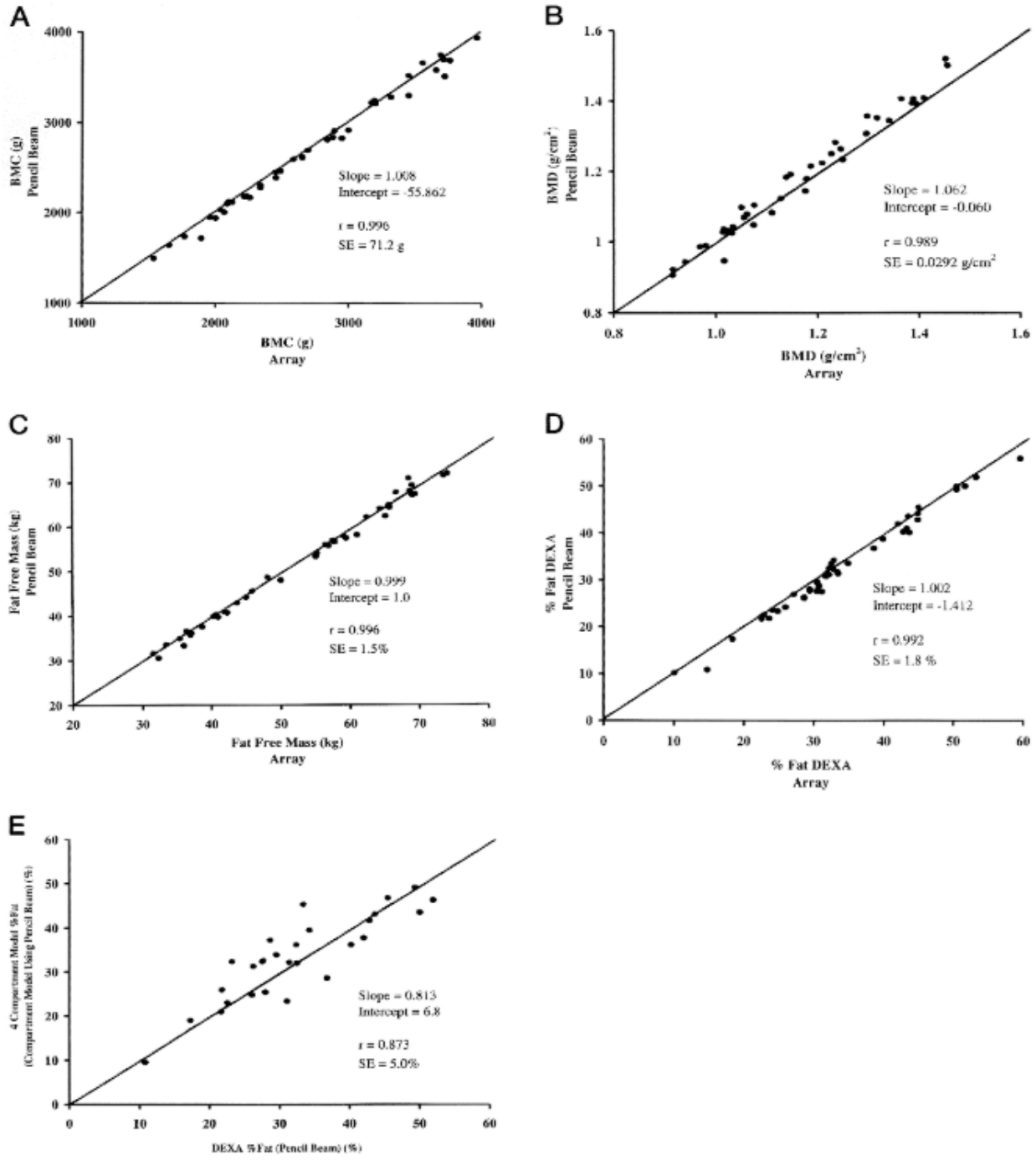

Figure 1. Effects of DEXA pencil beam and array scan modes on the measurement of: A) bone mineral content (BMC); B) bone mineral density (BMD); C) fat-free mass (FFM); D) DEXA percent body fat (DEXA%Fat); and E) 4-compartment model percent body fat (4 Comp%Fat). The slope, intercept, and correlation coefficient (r) are reported from the actual regression. The SE = about the line of identity depicted.

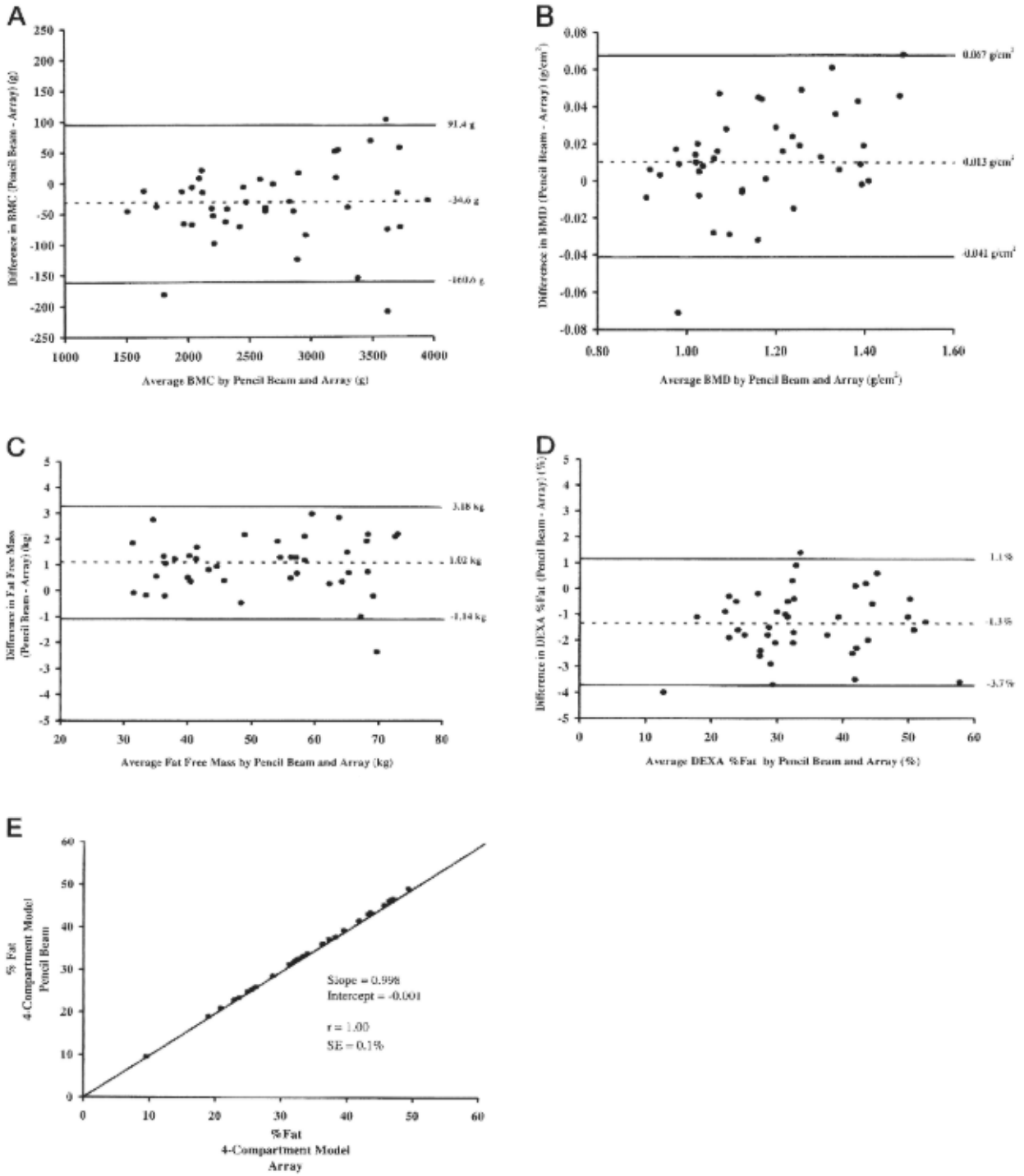

Figure 2. Plots of the difference between the pencil beam and array scan mode measurements against the mean of the scan mode measurements for: A) bone mineral content (BMC); B) bone mineral density (BMD); C) fat-free mass(FFM); D) DEXA percent body fat (DEXA%Fat); and E) 4-compartment model percent body fat (4 Comp%Fat). ---- Mean measurement difference (Pencil beam - Array scan mode); — ± 2 SD of the mean measurement difference.

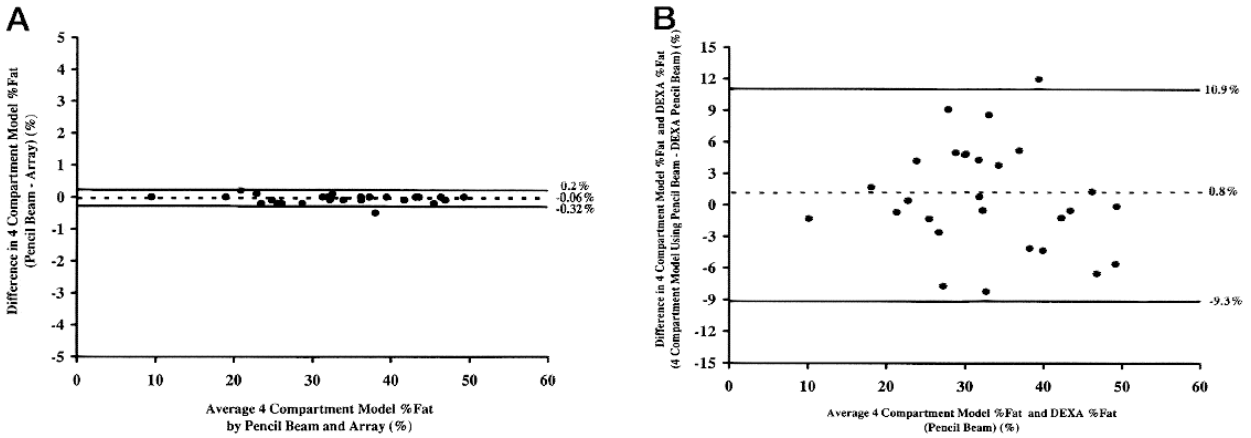

Figure 3. A) Relationship between 4-compartment model percent body fat (4 Comp%Fat) using DEXA pencil beam scan mode BMC measurements and DEXA percent body fat (DEXA%Fat) using pencil beam scan mode measurements. The slope, intercept, and correlation coefficient (r) are reported from the actual regression. The SE = about the line of identity depicted. B) Plot of the difference between the 4-compartment model percent body fat (4 Comp%Fat) using DEXA pencil beam scan mode BMC measurements and DEXA percent body fat(DEXA%Fat) using pencil beam scan mode measurements against the mean of 4 Comp%Fat and DEXA%Fat measurements. ---- Mean%Fat difference (4 Comp%Fat - DEXA%Fat); — ± SD of the mean%Fat difference.

Figure 3A displays the relationship (r = 0.873) between the 4 Comp%Fat measures using the pencil beam BMC to estimate total body bone ash and the DEXA%Fat measures using the pencil beam scan mode. The line of identity and the SE around the line of identity (SE = ± 5.0%) are shown, with the slope and intercept from the actual regression line reported. The slope and intercept of the regression line generated from the percent fat measures did not significantly differ from 1 and 0, respectively. Figure 3B shows the degree of agreement between the two methods (4 Comp%Fat and DEXA%Fat) of measuring percent fat in older adults. The mean difference of the measurement methods (4 Comp%Fat - DEXA%Fat) was 0.8% and the limits of agreement were ± 10.1%.

DISCUSSION

Few investigations have been performed to examine the effect of scan mode on DEXA bone measurements. Most studies evaluated differences between densitometer models, not specifically scan mode measurement differences within a single densitometer (2,5,6). For example, Blake et al. (2) performed *in vivo* studies of the lumbar spine and left proximal femur of 20 volunteers (ages 23-45 yr) to determine the effect of the change in scan beam configuration on DEXA BMD measurements. Regression analyses showed significant differences between the SEE in all lumbar spine (L1-L4) measurements when the Hologic QDR 1000W pencil beam mode was compared with the Hologic QDR 2000 array scan mode. Lumbar spine BMD differences were similar to the reported precision of DEXA measurements. Although Blake et al. (2) did not report the BMC and area of the femoral neck, greater trochanter, and Ward's triangle regions, the BMD of these proximal femur sites did not differ between the two scan modes. The authors concluded that scan mode had negligible effects on clinically important BMD measurements.

However, their study did not report on the effect of scan mode on BMC or percentage fat measurements.

Two other studies have compared results between the Hologic QDR 1000W and QDR 2000 densitometers using regional measures of BMD and BMC. Faulkner et al.(6) scanned the spine and proximal femurs of 69 women(ages 46-75 yr) participating in several different pharmaceutical intervention studies examining the effects of treatment on bone mass. Significant mean differences in the proximal femur and all hip subregional (femoral neck, trochanter, intertrochanter, and Ward's triangle) measurements were observed when the Hologic QDR 1000W pencil beam mode was compared with the Hologic QDR 2000 array scan mode. Lumbar spine area, BMC, and BMD measurements did not differ between scan modes and a strong relationship was observed between scan modes ($r > 0.99$). The authors suggested that although the findings of small systematic and directional significant differences owing to scan mode change may not be clinically significant, caution should be exercised when direct comparisons of investigative results are desired. Similarly, Eiken et al.(5) reported statistically significant mean differences when the Hologic QDR 2000 pencil beam and array scan mode phantom spine BMC and BMD measurements were compared with the same measurements performed in the pencil mode using the QDR 1000W densitometer model. In contrast, results of patient spine scans revealed no significant mean differences between the pencil beam and array scan modes. This finding was consistent when the Hologic QDR 1000W pencil scan mode was compared with the Hologic QDR 2000 array scan mode and when the QDR 2000 pencil beam versus QDR 2000 array scan modes were compared. However, when individual data were examined more closely, the authors suggested that both BMC and BMD measurements of the spine were different between and within DEXA model scan modes. These studies suggest that although the difference in BMC and BMD measurements between the QDR 1000W and QDR 2000 densitometers are small, longitudinal comparisons should be made with a single densitometer model.

The present study is the first to compare pencil beam and array scan mode measurements of total body BMC, BMD, FFM, and estimates of percentage body fat using a single DEXA instrument (Hologic QDR 2000). These data indicate that pencil beam and array scan modes on the same densitometer yield significantly different measurements of BMC, BMD, FFM, DEXA%Fat, and 4 Comp%Fat (Table 2). In this sample of older men and women, scanning in the array mode resulted in 1.3% and 3.9% greater estimate of BMC and DEXA%Fat, respectively, compared with the pencil beam scan mode. The array scan also resulted in a 1.1% and 1.9% lower estimate of BMD and FFM, respectively, compared with the pencil beam scan mode. DEXA is increasingly being used to measure percentage body fat in clinical investigation(13). In the present study, the mean difference of the percentage body fat measurements demonstrated significantly greater measures when the array scan mode was compared with the pencil beam scan mode. Of the DEXA variables examined, DEXA percent body fat demonstrated the greatest relative differences (3.9%) when scan mode measurements were compared(Table 2). These results support previous data reported on scan mode differences between different devices at regional sites.

The choice of scan mode depends on the particular application since both scan modes have advantages. Whereas the array scan mode may be suitable for routine clinical practice because of its faster scan speed, the pencil beam may be superior for clinical investigation, particularly if

changes in body depth are anticipated. For example, in one study increasing distance from the DEXA scan table to a phantom spine from 0 to 12 cm during array mode scanning resulted in a decrease of 3.1% cm^{-1} for BMC, 2.8% cm^{-1} for area, and 0.2% cm^{-1} for BMD measurements. Height variations resulted in decreases of less than 0.1% cm^{-1} when the same measurements were performed in the pencil beam mode (2). In a second study, decreasing the distance (0 to 3 cm) between a phantom spine and the scan table using array mode resulted in an increase of 2.8% cm^{-1} for both BMC and area, with no effect on BMD measurements (4). The magnification effect of the array scan mode geometry during data acquisition likely accounts for these differences. In the present study the magnification effect of the array scan mode geometry was further demonstrated when the bone area measurements in the pencil beam and array scan modes were compared (Table 2). In this sample of older men and women, scanning in the array mode resulted in a 2.4% greater estimate of bone area. DEXA BMD (g/cm^2) measures are generated by dividing the BMC (g) by the bone area (cm^2); therefore, the greater relative change of the bone area (2.4%) compared with the relative change of the BMC (1.3%) scan measures explains why the BMD measures were greater in the pencil beam compared with the array scan mode. If the BMC and area measures had changed by the same relative amount using the two scan modes, the BMD measures would have likely been unaffected. Since losses or gains in body weight (far or lean tissue) change the distance between the scan table surface and the site of the patient being measured, larger errors in measures of BMC, Area, and perhaps BMD can be expected with the array scan mode in longitudinal studies when changes in body weight occur.

We are unaware of any other research comparing the influence of different DEXA scan modes of total body BMC on resulting estimates of percentage body fat using a 4-compartment body composition model. The present data indicate that although a statistically significant difference in 4 Comp%Fat existed when pencil beam and array BMC measurements were employed, this difference was clinically and physiologically inconsequential. This was not surprising since variations in the aqueous fraction are reported to be the most significant contributor to the differences in percentage body fat estimated by 3-compartment (DEXA) and 4-compartment body composition models in an older adult population (1).

Although scan mode does not affect the measurement of 4 Comp%Fat, the present data suggest that estimates of percent body fat by DEXA alone is not valid for use in older adults. In the present study, DEXA estimates of percentage body fat were not significantly different with both the pencil beam(33.6 ± 9.6%) and array (34.9 ± 10.1%) scan modes compared with that obtained with a 4-compartment (using BMC by pencil beam scan mode) body composition model (33.2 ± 9.6%). However, the total error associated with DEXA pencil beam and array scan modes was unacceptably large (± 5.0% and ± 5.2%, respectively). Figure 3B further emphasizes the magnitude of the error generated when the DEXA%Fat (pencil beam scan mode) was used to estimate the percent fat of the older subjects. While the mean difference between the 4 Comp%Fat and the DEXA%Fat was relatively small (0.8%), the limits of agreement (95% confidence interval) between the two measures of percent fat was unacceptably large (±10.1%). This suggests that the use of DEXA alone to measure percentage body fat in older adults cannot be advocated at the present time.

The need for further evaluation of the accuracy and precision of DEXA soft tissue measures in several populations, including older adults, has been recognized (13). We are aware of only one

published study that has compared DEXA soft tissue results to multi-compartment body composition models, exclusively in adults of similar age to those in the present study (12). Nelson et al.(12) demonstrated that DEXA measures were not sensitive enough to pick up significant changes in muscle mass and changes in the constituents of FFM resulting from strength training in older women. The disparity of the DEXA%Fat and 4 Comp%Fat measures in the present study were likely a result of a violation in the assumption made by DEXA software that the hydration of the FFM is consistent and stable over time. Roubenoff et al.(13) regard the constancy of FFM hydration as the most important assumption of body composition determination. The wide range of fat-free mass hydration measures of the adults in the present study (mean± SD = 78.7 ± 5.8 $l \cdot kg^{-1}$) may account for the greatest portion of the error when reporting the DEXA%Fat of this population.

We conclude that DEXA scan mode influences measurements of bone and body composition even when the same densitometer is employed. Although the differences in BMC, BMD, and FFM using different scan modes are small and may be interpreted as clinically insignificant from a screening standpoint, in longitudinal or intervention studies requiring precise measurements small sources of variability may have a meaningful impact on the interpretation of the effectiveness of the intervention or appreciation of the changes over time. In addition, the present data indicate that the use of DEXA to estimate percent fat in older adults results in a variable error(Figs. 3A and 3B) that makes it an unacceptable method for use in a research setting. Based on these data, we recommend the use of a single scan mode (pencil beam) for clinical investigation and urge caution in the use of DEXA for measuring percentage body fat in older adults.

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