Interchangeability of pencil-beam and fan-beam dual-energy X-ray absorptiometry measurements in piglets and infants

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ABSTRACT

Background: Compared with the older pencil-beam (PB) dual-energy X-ray absorptiometry (DXA), the newer fan-beam (FB) DXA has the advantage of faster scan acquisition and greater accuracy of body-composition measurement in small subjects. However, no data exist on the relation between the measurements obtained with these techniques.

Objective: The objective of the study was to investigate whether PB and FB DXA measurements in small subjects are interchangeable.

Design: PB and FB DXA scans were performed on 26 piglets and 54 infants to examine the relation between the measurements obtained by using the 2 techniques.

Results: The correlation between all PB and FB DXA measurements of variables (total weight, bone area, bone mineral content, bone mineral density, and lean and fat masses) approached 1.0, but there were significant differences in absolute values. The extent of the differences varied according to the variable; with the lowest value for total weight (mean difference: ≈1% for both piglets and infants) and the highest value for bone mineral content (mean difference: 35.3% and 36.7% for piglets and infants, respectively). PB and FB DXA measurements were strongly predictive of each other after adjustment ($r^2 = 0.927–1.000$ for the piglet data and $0.939–0.999$ for the infant data).

Conclusion: In small subjects, DXA measurements from PB and FB techniques were strongly predictive of each other, although their absolute values differed. Thus, group comparison of PB and FB DXA data is possible after adjustment of the data from either technique. It is advisable to generate normative data for each technique and to use the same technique throughout longitudinal studies.


KEY WORDS    Dual-energy X-ray absorptiometry, pencil-beam, fan-beam, body composition, piglets, infants

INTRODUCTION

Dual-energy X-ray absorptiometry (DXA) is now generally accepted as the standard for the measurement of bone mass and is the preferred means of measuring soft-tissue composition in small subjects such as human infants (1). Extensive data are available on the older pencil-beam (PB) DXA technique for measuring bone mass and body composition throughout infancy, because its use was independently validated by several research groups who used instruments from the same manufacturer, the same scan acquisition technique with the use of an infant platform, and the same analytic algorithm with infant whole-body software (version 5.64 or later; Hologic Inc, Waltham, MA) (2–5).

Advances in DXA technology resulted in the development of a new generation of densitometers in which the PB X-ray source and the single detector of the first-generation instruments were replaced by a fan-beam (FB) X-ray source and a multiple detector array. The new densitometers offer increased scan speed and improved spatial resolution; both attributes have recently been confirmed in a study of piglets (6). These attributes enhance the ability of DXA to measure bone mass and body composition because of the FB technique’s faster scan acquisition and improved accuracy in small subjects compared with the PB technique, and they offer the potential for increased use in studies of infants and young children.

Instrument effect, as indicated by systematic differences among measurements from instruments based on the same DXA technique (7) and those from instruments based on different DXA techniques (8–13), supports the critical need for cross-calibration studies during the transition from first-generation to second-generation DXA instrumentation, such as that which occurs with the addition of new equipment or the replacement of old equipment. This information is needed to eliminate or at least minimize the potential discrepancies or errors that may exist between 2 instruments using different DXA techniques. Furthermore, this information is critical to appropriate interpretation of new data and comparison with the existing data generated from older instruments, in particular with regard to whether new normative data should be generated and whether it is feasible to use these instruments interchangeably during a longitudinal study.

In adults and older children, the bone, lean mass (LM), and fat mass (FM) measurements with FB DXA show a systematic relation with data from the PB DXA (8–13). In some reports, equivalency of bone mineral density (BMD), LM, and FM measurements with FB DXA has been confirmed by cross-calibration with other criterion methods including PB DXA, the 4-compartment

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4 Received July 18, 2002.
5 Accepted for publication March 6, 2003.

model, and multislice computed tomography scans (10, 12). However, a recent study in adults who had a mean (±SD) change in body weight of 5.7 ± 4.5 kg found that both PB and FB DXA measured changes in body composition that were similar to changes measured with the use of total body water, but the data from PB and FB DXA are not interchangeable (13). Whether such similarity exists between PB and FB DXA measurements in infants and in young children is not known, because the body composition of small subjects differs substantially from that of adults and older children, and different software algorithms are needed for scan acquisition and analysis. We therefore aimed to ascertain the relation between the older-generation PB DXA measurements and the newer-generation FB DXA measurements in small subjects and to determine whether it is feasible to cross-calibrate the measurements obtained with the use of these 2 techniques.

SUBJECTS AND METHODS

Piglets

Twenty-six domestic piglets (J&M Farms, Lansing, MI) with a mean (±SD) body weight of 8359 ± 5914 g (range: 640–21 100 g) were studied as part of a comprehensive protocol to determine the various aspects of body-composition measurements in a piglet model. Each animal was weighed on an electronic scale (Seca; Toledo Scale Co, Toledo OH) immediately before DXA scanning and then killed at completion of the in vivo study procedures. DXA scans were obtained with FB and PB whole-body densitometers (QDR 4500A and 2000+, respectively; Hologic Inc). Scan acquisition was performed by using the infant whole-body mode according to the manufacturer’s recommendations. A 2-platform system (aluminum platform overlying a foam table pad) and an external calibration standard were used in conjunction with the PB densitometer. Each piglet was placed on a cotton blanket in the prone position with the front and hind limbs extended. The long axis of the animal was positioned at the midline of the platform with the snout ≈ 5 cm from the cranial end of the platform (2, 6). Each piglet was covered with a cotton blanket and a disposable diaper was used in larger piglets to prevent soiling. The same coverings were used for all scan acquisition. The mean weights of the piglets including coverings were 8803 ± 5861 g (range: 760–21 310 g). The piglets were sedated with sodium pentobarbital and sodium thiopental and kept in the same posture for all scan acquisitions. Scan analysis used software vKH6 validated for the PB DXA measurement of small subjects (6) and software v5.7.1p validated for the PB DXA measurement (2, 4, 5). All scans were checked for movement artifacts during scan acquisition and analysis. Details of all DXA procedures were reported elsewhere (2, 3, 6). With our densitometer, the typical entry radiation exposure during an infant whole-body scan was a maximum dose of 3 μSv (1 μSv = 0.1 mrem) for the PB DXA with the infant platform and of 7 μSv for the FB DXA. The radiation scatter at 66 cm from each densitometer did not differ significantly from background during 10 min of measurement. The animal study was approved by the Human Investigation Committee at Wayne State University.

Infants

Fifty-four infants with a mean naked body weight of 7285 ± 3310 g (range: 1790–13 080 g) were studied at 216 ± 160 d (range: 1–500 d). Each infant underwent one scan with the use of each densitometer to determine the relation between the data generated by these 2 techniques. This is a cross-sectional design with data from subjects in 4 clinical studies at the same institution during the transition phase in which the DXA measurements were switched over from the PB technique to the FB technique. Each infant wore a diaper and was swaddled in a cotton blanket; a cross-calibration scan was done if the infant remained asleep, and the infant’s covering and position were kept as similar as possible for both scans. In older infants, the wearing of lightweight underwear was allowed. All coverings, including a diaper and any clothing, were weighed separately, and the mean total weight at DXA measurement was 7506 ± 3358 g (range: 1920–13 245 g). A parent and the technician were present during the study. Scan acquisition used the infant whole-body mode and scan analysis with the same software as that used for piglet studies (2, 3, 6). All clinical studies were approved by the Human Investigation Committee at Wayne State University, and written informed consent was obtained from the parent of each subject.

Statistical analysis

Paired t tests were used to ascertain differences between each specific DXA measurement (bone area, bone mineral content, BMD, FM, LM, and total weight) obtained with the use of the PB and FB techniques. Regression analysis was used to determine the extent of the relation between PB and FB DXA measurements. Given the high precision of the PB (14–16) and FB (6) DXA measurements, a sample size of 30 subjects should be sufficient to determine the true relation between these measurements (17), although reports of previous clinical studies indicated that a much larger group of subjects was needed to better reflect the wide range of body composition in vivo and to optimize the ability to determine the true relation between PB and FB DXA measurements (8–12). Data analyses were performed separately for piglets and infants. All statistical tests were performed with the use of SPSS for WINDOWS (version 10.0; SPSS Inc, Chicago), and P = 0.05 indicated significance. Unless otherwise stated, all values are means ± SDs.

RESULTS

There was near-perfect consistency between the measurements by these 2 techniques in each subject with respect to the position in the distribution—ie, the r values approached 1.0 for all variables measured—but the location of the distributions—ie, r values obtained from comparisons of the means—differed significantly. The extent of difference between PB and FB measurements varied according to the specific variable. PB DXA showed slightly greater total weight and LM for the piglets and greater total weight for the infants than did FB DXA. However, there was a difference of >30% between the PB and the FB techniques in the measurements of some components of body composition, eg, bone mineral content (Tables 1 and 2).

In contrast, DXA measurements obtained with the PB technique were highly predictive of those obtained with the FB technique with adjusted r² between 0.927 and 1.000 for the piglet data and between 0.939 and 0.999 for the infant data (Figures 1 and 2).

DISCUSSION

One of the major advantages of the FB DXA over the PB DXA in the measurement of bone mass and body composition...
in infants and young children is the significant difference in scan acquisition time, ie, a reduction from 15 min to <3 min in older infants (6). This shorter scan acquisition time results in less potential for movement artifact with the FB DXA (3). The FB DXA algorithm also corrected the underestimation of carcass ash content and the overestimation of fat content that were reported for the PB DXA measurement in small subjects (2, 4, 5) and maintained adequate precision for clinical needs (6). With the gradual withdrawal of industry support for the PB DXA instrument, the newer FB technique will inevitably become the only available DXA technique for body-composition measurement in subjects of all ages and body masses. Thus, every investigator will face at some point the necessity to transition from the PB DXA to the FB DXA technique and to determine the relation between the data generated from the current PB DXA measurements and those from the future standard FB DXA measurements, particularly for ongoing longitudinal studies.

We considered the use of phantoms for this cross-calibration study, but it has been shown that the use of a small number of phantoms results in unacceptably large residual variability around the regression line (8), and the use of a large number of phantoms to cover the full range of expected body-composition data would be impractical. The domestic piglet has many similarities to the human infant and is frequently used as a model for data coupling with the consistency between the animal and human data support the adequacy of our study design for a meaningful interpretation of the data generated from these 2 DXA techniques, ie, our study design achieved an adequate sampling of heterogeneous subjects in vivo and contributed to a meaningful cross-calibration study during instrument transition. The radiation exposure from FB DXA scan is the same as that from the PB DXA scan obtained without using the infant platform (2, 18–23) or from a repeat PB DXA procedure if the initial scan was unsatisfactory (22). In any case, the extent of radiation exposure is well within the range of natural background radiation (24). This approach is similar to that in reports from multiple investigators on the use of duplicate DXA scans as a quality-control procedure critical to any clinical study (14, 15, 25–31).

In this study, the differences between mean PB and FB DXA-measured total weights were quite small at ≈1% for both piglets and infants. However, there were greater differences between other DXA measurement obtained with these techniques: a difference of ≈5% in mean LM and much greater differences in bone and fat measurements. The large differences between PB and FB DXA-measured bone and fat reflect the correction by FB DXA for the PB DXA underestimation and overestimation of these variables in small subjects (2, 4, 5). The differences in bone area and BMD in part reflect the magnification effect of the FB technique and the different software algorithm used by the PB and FB DXA systems for measurements in small subjects. The homogeneity of FM in piglets explains the lack of difference in absolute values of FM between the 2 techniques.

Our data showed that all PB DXA measurements are significantly predictive of the corresponding FB DXA measurements.

### TABLE 1

Pencil-beam (PB) and fan-beam (FB) dual-energy X-ray absorptiometry (DXA) measurements of weight and body composition in 26 piglets

<table>
<thead>
<tr>
<th></th>
<th>PB</th>
<th>FB</th>
<th>Percentage difference: (PB−FB)/PB</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>DXA total weight (g)</td>
<td>8499 ± 6017 (^2)</td>
<td>8283 ± 5728</td>
<td>1.0 ± 2.4</td>
<td>1.000</td>
</tr>
<tr>
<td>Bone area (cm(^2))</td>
<td>503 ± 298</td>
<td>661 ± 358</td>
<td>−35.3 ± 9.1</td>
<td>0.993</td>
</tr>
<tr>
<td>Bone mineral content (g)</td>
<td>150 ± 117.6</td>
<td>203 ± 147.6</td>
<td>−42.6 ± 13.3</td>
<td>0.992</td>
</tr>
<tr>
<td>Bone mineral density (g/cm(^2))</td>
<td>0.259 ± 0.073</td>
<td>0.271 ± 0.073</td>
<td>−5.2 ± 5.0</td>
<td>0.986</td>
</tr>
<tr>
<td>Fat mass (g)</td>
<td>674 ± 498</td>
<td>684 ± 511</td>
<td>−0.3 ± 16.2</td>
<td>0.964</td>
</tr>
<tr>
<td>Lean mass (g)</td>
<td>7675 ± 5418</td>
<td>7397 ± 5081</td>
<td>1.8 ± 3.1</td>
<td>1.000</td>
</tr>
</tbody>
</table>

\(^1\) \(P \leq 0.001\) for all comparisons (paired t test), except fat mass (\(P = 0.71\)).

\(^2\bar{x} \pm SD.\)

### TABLE 2

Pencil-beam (PB) and fan-beam (FB) dual-energy X-ray absorptiometry (DXA) measurements of weight and body composition in 54 infants

<table>
<thead>
<tr>
<th></th>
<th>PB</th>
<th>FB</th>
<th>Percentage difference: (PB−FB)/PB</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>DXA total weight (g)</td>
<td>7620 ± 3457 (^2)</td>
<td>7502 ± 3354</td>
<td>1.2 ± 1.3</td>
<td>1.000</td>
</tr>
<tr>
<td>Bone area (cm(^2))</td>
<td>553 ± 207</td>
<td>690 ± 255</td>
<td>−25.3 ± 5.0</td>
<td>0.994</td>
</tr>
<tr>
<td>Bone mineral content (g)</td>
<td>159 ± 86.7</td>
<td>214 ± 114.1</td>
<td>−36.7 ± 8.6</td>
<td>0.996</td>
</tr>
<tr>
<td>Bone mineral density (g/cm(^2))</td>
<td>0.266 ± 0.065</td>
<td>0.288 ± 0.066</td>
<td>−9.2 ± 6.7</td>
<td>0.969</td>
</tr>
<tr>
<td>Fat mass (g)</td>
<td>2262 ± 1437</td>
<td>1824 ± 1147</td>
<td>19.2 ± 9.1</td>
<td>0.984</td>
</tr>
<tr>
<td>Lean mass (g)</td>
<td>5198 ± 2170</td>
<td>5463 ± 2256</td>
<td>−5.1 ± 4.6</td>
<td>0.993</td>
</tr>
</tbody>
</table>

\(^1\) \(P \leq 0.001\) for all comparisons (paired t test).

\(^2\bar{x} \pm SD.\)
Given an almost perfect linear relation between each variable measured by the two techniques, it is expected that the critical ratios and the corresponding P values would be equivalent, whether the data were generated from PB or FB DXA. It is therefore possible to compare the existing PB data with those increasingly being generated by the newer FB DXA technique. Our data from measurements in small subjects suggest that, on a group basis, there is adequate interchangeability between the 2 DXA techniques, although the data from one of these techniques will have to be adjusted. This finding is in contrast with that from a report in adults that changes in body composition associated with a small change in body weight as measured by PB and FB DXA techniques are not interchangeable (13). This difference in findings presumably reflects the differences in the software for adult and infant DXA measurements, with the latter having a better capability for discrimination at low body mass.

The acceptability of a conversion factor in the standardization of DXA measurement from PB to FB values, ie, the clinical relevance of this systematic relation, would depend on the magnitude of the residuals associated with the conversion, which varies with the value being compared and with the changes in these values expected under different circumstances. For infants, the consistently excellent predictive ability of PB DXA for FB DXA measurements is reflected in the adjusted \( r^2 \) values of 0.999, 0.993, 0.986, and 0.967 for the prediction of total weight, bone mineral content, LM, and FM, respectively. Conversely, the SEE for the respective FB DXA measurements is extremely small. However, the absolute values from these 2 techniques are not directly interchangeable. Thus, to minimize any errors in the conversion of data between these 2 techniques and to optimize the ability to detect small differences or changes in body-composition measurement, it seems preferable to generate normative data specifically for each DXA technique and to maintain the use of the same technique, whether PB DXA or FB DXA, throughout longitudinal studies. The same conclusions can be drawn for bone area and BMD measurements, although these variables have little clinical relevance because bone area is subjected to changes in the posture of the subject at scan acquisition, and DXA BMD is not recommended for use as a measurement in small growing subjects (32, 33).

We conclude that, in growing piglets and infants, there is a systematic relation between PB and FB DXA measurements, although there are significant differences in the absolute values obtained with the use of the 2 techniques. The extent of the differences varies with the DXA variable. Other potential errors due to instrument effect, operators, and techniques of scan acquisition and analysis (3, 7, 34, 35) also must be considered. Thus, to optimize the interpretation of the data obtained from both instruments, it is incumbent on the investigator to generate a cross-calibration equation from a subset of subjects on the specific instruments in use during the transition from the PB DXA technique to the FB DXA technique.

MH participated in the study design, data collection, and preparation of the manuscript; EMH participated in the study design, data analysis, and preparation of the manuscript; and WWKK participated in all aspects of this study.
None of the authors had any financial or contractual conflict of interest associated with this study.

REFERENCES


