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The Official Positions of the International Society for Clinical Densitometry: Acquisition of Dual-Energy X-Ray Absorptiometry Body Composition and Considerations Regarding Analysis and Repeatability of Measures

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Abstract

In preparation for the International Society for Clinical Densitometry Position Development Conference of 2013 in Tampa, Florida, Task Force 2 was created as 1 of 3 task forces in the area of body composition assessment by dual-energy X-ray absorptiometry (DXA). The assignment was to review the literature, summarize the relevant findings, and formulate positions covering (1) accuracy and precision assessment, (2) acquisition of DXA body composition measures in patients, and (3) considerations regarding analysis and repeatability of measures. There were 6 primary questions proposed to the task force by the International Society for Clinical Densitometry board and expert panel. Based on a series of systematic reviews, 14 new positions were developed, which are intended to augment and define good clinical practice in quantitative assessment of body composition by DXA.

Key Words: Body composition; dual-energy X-ray absorptiometry; guidelines; official positions; whole body.

Background

Task Force 2 was charged with the research and analysis of the published literature covering questions related to the performance and calibration of the dual-energy X-ray absorptiometry (DXA) systems in relationship to body composition measurements. A total of 8 literature searches were performed in PubMed, with major key words related to DXA whole-body phantoms, fat tissue accuracy and precision, lean tissue accuracy and precision, region definition and analysis procedures, artifacts, and measurement frequency

(Appendix A). The searches yielded approximately 200 citations, and all these papers were downloaded and distributed to the task force for review and assessment of relevance to the questions at hand. On the basis of short summaries of the information from the relevant papers, the recommendations were formulated and appropriately supported with citations.

The following sections are grouped into 3 major areas: (1) calibration for body composition measurements, (2) acquisition of DXA body composition measures in patients, and (3) considerations regarding analysis and repeatability of measures. Each section first lists the questions to be addressed, followed by some introductory information, which then leads to the various recommendations. Every recommendation is accompanied with a rationale and a discussion section; where appropriate, suggestions for future research also are provided. Explanations as to the process of adopting the various recommendations as well as the grading of the

strength and applicability can be found in an accompanying article *(1)*.

## Accuracy and Precision Assessment

Questions

- What phantoms and procedures should be used for quality control (QC) monitoring and cross-calibration for whole-body outcomes?
  - What phantoms should be used to assure a DXA system is working within specifications and with stable calibration over time?
  - How can measures be cross-calibrated between systems from different manufacturers?
  - How to cross-calibrate measures between systems of the same manufacturer?
- How should the accuracy of percent fat, fat mass, and lean mass be ascertained in the clinical setting?
  - What phantoms are available to ascertain absolute accuracy?

Introduction

The comparability of DXA parameters involves the principles of radiation physics involved in the image-forming process as well as image segmentation to define the relevant regions of interest (ROIs). Because the ultimate goal is to compare patient results over time and across scanners, an appropriate phantom would have to be anthropometric, reflecting the range of body compositions encountered in actual patients, and provide a geometric arrangement of these compositions in an adequate anthropomorphic configuration, at least to mimic an in vivo scan in the anterior-posterior view. Only under these circumstances is it possible to obtain phantom results reflecting actual patients if scanners from different manufactures are used, which are based on different dual-energy approaches using different X-ray energies. If any of these principles are not fulfilled, a comparison determined by phantom measurements has to be limited to scanners that use identical radiation-physical approaches.

Assuming that identical approaches have been used to generate the images, there is still the issue of creating ROIs for the extraction of relevant clinical parameters. The extraction of these regions involves, to some extent, computer-based algorithms, and different manufacturers tend to use different region definitions, which implies that a phantom would have to be anthropometric to provide useful results for patient comparisons. Thus, in the absence of adequate anthropometric and anthropomorphic phantoms, phantom measurements are restricted to scanners of the same make and model, where the physics of image generation and the analysis approach are identical (Fig. 1).
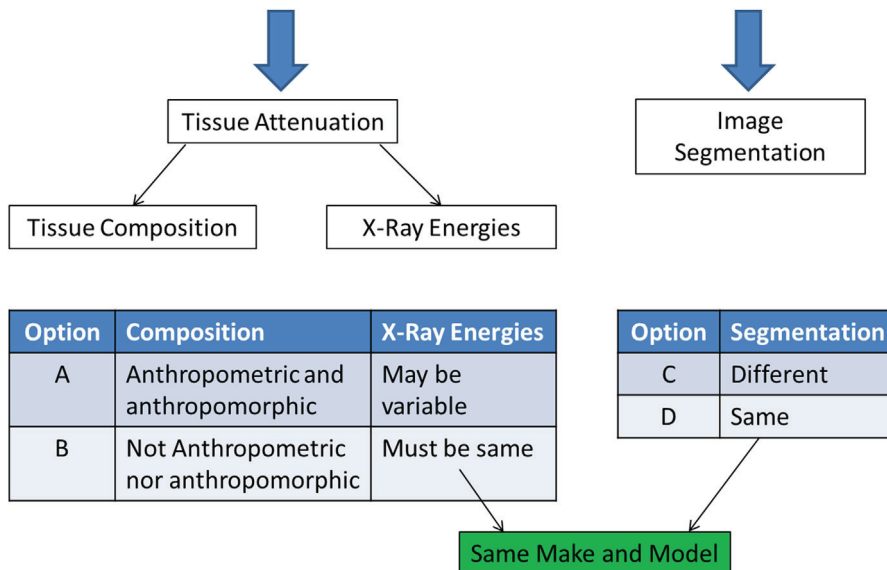
Fig. 1. Considerations for phantom-based comparisons of DXA scanners. Because of the differences between manufacturers in the radiation-physical approach of generating images, an ideal phantom would have to be anthropometric in composition and anthropomorphic in projected shape to adequately reflect a patient (**A**). Although simplifications are possible in the phantom shape for the calibration of soft tissue, such simplifications would have to be thoroughly investigated. A lack of appropriate phantoms restricts the comparison to scanners of the same make and model (**B**). This lack of an appropriate phantom also impacts the image analysis, where the different approaches by different manufacturers (**C**) create different results in phantoms as compared to patients. Thus, the use of currently available phantoms requires identical analysis procedures, again restricting phantom cross-calibrations to scanners of the same make and model (**D**).

International Society for Clinical Densitometry (ISCD) Official Position

- No phantom has been identified to remove systematic difference in body composition when comparing in vivo results across manufacturers.

Grade: Good-B-W

Rationale

To validate a phantom to remove systematic, in vivo differences between DXA systems for body composition, subjects with a range of body composition values must be scanned on both systems along with the phantom (Fig. 2). In this way, phantom cross-calibration relationships can potentially be derived that assure the removal of in vivo differences. Several studies of this kind have been performed over the years. The commercial phantoms used include the Variable Composition Phantom (VCP, previously Bio-Imaging Technologies, Inc., West Trenton, NJ, now BioClinica, Newtown, PA) *(2)*, the Hologic Whole-Body Phantom (HWBP; Hologic, Inc. Bedford, MA) *(3)*, and the BioClinica Whole Body Phantom *(4)*. Some pictures of available commercial phantoms are shown in Fig. 3. There were also a few custom phantoms, including Picaud et al's pediatric phantom *(5)*, Tothill et al's water-filled cylindrical phantom *(6)* and Braillon et al's anthropomorphic pediatric phantom *(7)*.
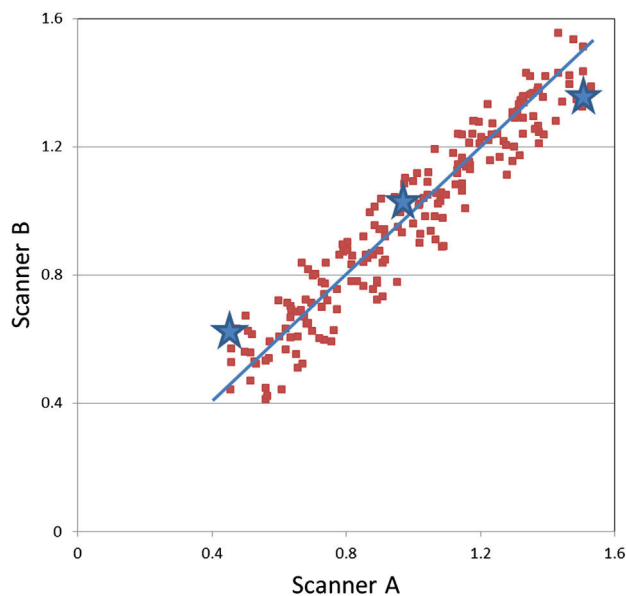
Fig. 2. An adequate phantom for scanner cross-calibration would have to show a similar range of relevant values as the patient cohort of interest (squares) and overlay the regression line generated by the patient parameters. In the illustrated hypothetical data, the phantom values (stars) cover the appropriate range, but they do not appropriately overlay the regression line.

Only a few studies fulfilled the criteria for validating a phantom for cross-calibration between different makes of DXA systems. Diessel et al *(2)* found that the VCP provided a fairly good approximation of the calibration differences between a Hologic QDR 4500 and a Lunar DPX-IQ (GE Lunar, Madison, WI). However the slopes varied substantially, a = 0.81 and 0.97, for patients and phantom, respectively, where the equation was Hologic %fat = a * Lunar %fat + b. Pearson et al *(8)* also compared the percent-fat relationships of the Hologic QDR 2000 with the GE Lunar Prodigy by using a VCP on 21 subjects. They concluded that the VCP did not provide an adequate cross-calibration of percent fat compared with in vivo data.

Discussion

Not having a phantom that will cross-calibrate between DXA systems of different makes is a definite limitation to the field. In theory, construction of such a phantom is possible, but it would have to be made with materials that are representative of biological tissues at the wide range of X-ray energies used for DXA.

Additional Questions for Future Research

It would be valuable to develop an adequate phantom, useful for scanner cross-calibration, which will then need to be validated as described previously.

ISCD Official Position

- An in vivo cross-calibration study is necessary when comparing in vivo results across manufacturers.

Grade: Fair−B−W

Rationale

The question of the use of an in vivo cross-calibration study for comparing results of bone densitometry measurements across manufacturers has been addressed in previous Position Development Conferences *(9)*. It is not surprising, then, that the physics of dual-energy absorptiometry, the different approaches used by the various manufacturers in regards to energy selection, beam shape and orientation, as well as edge detection algorithms, which make in vivo cross-calibration necessary for bone densitometry, equally apply to the determination of lean mass and fat mass across these same systems.

Discussion

This position parallels the 2007 ISCD Official Positions for the need of cross-calibration of systems for the determination of bone mineral density (BMD) and bone mineral content (BMC) *(3)*. Previously Tothill et al *(10)* noted substantial differences between pencil-beam scanners of different manufacturers (Hologic 1000 W, Lunar DPX-IQ, and 2 Norland Mark II devices) for body-composition parameters and concluded that they were sufficiently different as to not be interchangeable for body-fat indices in individuals or clinical trials. Others have shown that these significant differences are still present in newer fan-beam devices of different manufacturers
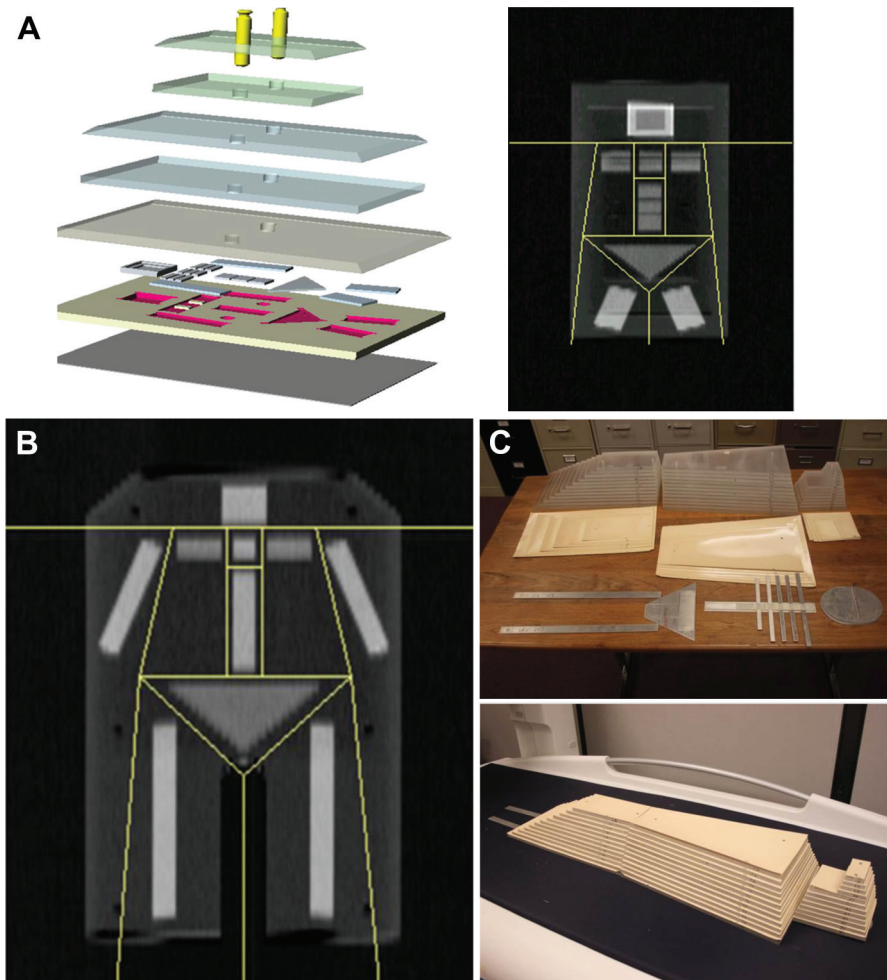
Fig. 3. Examples of available whole-body phantoms. (**A**) Hologic; (**B**) BioClinica; (**C**) Norland.

(2,11−13), between different models of the same manufacturer *(12,14−16)*, the same densitometer with different analysis software *(5,10)*, and even using different scan modes and geometries on the same device *(17)*.

Most differences between scanners are proportional, and linear regression formulae have most often been generated to describe the relationships between devices, with Bland-Altman verification. However, Malouf et al *(13)* demonstrated that a more sophisticated mathematical approach via the use of fractional polynomial equations, which also included weight, height and sex, provided better postcorrection agreement over standard linear regression.

Given the major differences in approach to dual-energy absorptiometry between manufacturers, it appears reasonable to require an in vivo cross-calibration study that provides the specific equations needed for comparison across scanners from different manufacturers.

Additional Questions for Future Research

Again, the development of an adequate anthropometric and anthropomorphic phantom would be valuable.

ISCD Official Position

- Cross-calibrating systems of the same make and model can be performed with an appropriate phantom.

Grade: Fair-A-W

Rationale

Systems of the same make and model use identical basic hardware and analysis procedures. Differences arise from residual discrepancies in calibration. Such differences can be assessed by phantom measurements, particularly the type of phantom that consists of simple, geometric structures that lend themselves to robust, automatic analysis, eliminating operator interaction as much as possible. It is important to note that some DXA devices need to have representative bone material in the phantom; otherwise, spurious results will occur. The safest approach is to use an anthropomorphic phantom with both bone and soft tissue that represent nominal density values. Some examples of phantoms that approach these appropriateness criteria are the HWBP *(3)*, the BioClinica

Whole Body Phantom *(4)*, and the Orthometrix WB phantom Oscar Jr. *(18)*. They are useful for monitoring stability of body composition parameters as well as cross-calibration between similar makes and models.

Discussion

Few published data are available to show the validity of using any of the aforementioned anthropomorphic phantoms for cross-calibration. Investigators from the National Health and Nutrition Examination Survey (NHANES) study have used the HWBP for the past 14 years to cross-calibrate their 3 mobile examination centers using Hologic A-series scanners (J. Shepherd, personal communication). Other simpler, non-anthropomorphic phantoms have been used with mixed results. The Lunar variable body-composition phantom has been used to assess differences between scanners of the same and of differing makes and models *(2)*. However, this phantom must be used with the bone ''head'' piece to fulfill the appropriateness criteria listed previously. Even then, this phantom has no distinct ROIs that would be considered anthropomorphic. Whereas the percent fat variability between makes and models, which included Hologic QDR 4500, Hologic QDR 1500, and Lunar DPX-IQ, was $-.3.4 \ldots +3.7\%$ (absolute difference to fat standard), the variability between the 4 Hologic QDR 4500 scanners was only $\pm 0.8\%$. In another investigation, custom-made bottle phantoms representing lean tissue and fat were used to assess the differences between a Lunar DPX-L and 2 Lunar Prodigy scanners *(19)*. At the slow scanning speed for all scanners, the differences between scanner models were 0.6−1.3 percent fat, 15−83 g of fat mass, and 96−209 g of lean mass. In comparison, the differences between the 2 Lunar Prodigy scanners were 0.5−0.6 percent fat, 26−28 g of fat mass, and 63−84 g of lean mass. These differences are approximately half of those observed between scanner models.

Additional Questions for Future Research

Although the phantom measurements presented show smaller variability between scanners of the same make and model compared with scanners of different makes or models, the link between in vivo cross-calibration and phantom measurements has not been well described in the literature.

ISCD Official Position

- Changes in body composition measures can be evaluated between 2 different systems of the same make and model if the systems have been cross-calibrated with an appropriate total-body phantom.

Grade: Fair-B-W

Rationale

Differences in total and local BMC, lean tissue mass, and fat mass can be great when 2 nonidentical systems, even from the same manufacturer, are used. For example, differences of 7.3% in BMC, 5.0% in fat mass, and 1.5% in lean tissue mass have been found for in vivo measurements performed with

a QDR 4500 and a Discovery system from Hologic *(16)*. It could be expected that interdevice differences are not so large when measurements are made with DXA systems of the same brand and same model. However, even in this more-favorable situation, highly significant differences for BMC, lean tissue mass, and fat mass measured values were found (P. Braillon, unpublished data).

Discussion

Good maintenance, ensuring correct cross-calibration for spine BMD between different DXA systems, is not sufficient to assess changes in body composition with confidence. Therefore, an appropriate whole-body phantom should be used to make cross-calibrations. However, this phantom should mimic as closely as possible the human subjects to be measured. This means that the ideal phantom(s) should be anthropomorphic and be made of materials with X-ray absorption coefficients close to those of bone, lean tissue, and fat to obtain the most accurate results possible for bone area, BMC, BMD, lean tissue mass, and fat mass for the entire body as well as for any subregion.

Additional Questions for Future Research

Lean tissue mass and fat mass values measured with different DXA systems of the same make and model could be significantly different. These differences are mostly due to residual calibration errors. Different manufactures have different tolerance levels for factory calibration and scanner drifts. It would be useful to establish these tolerances and assess how well the systems in use conform to the established limits.

ISCD Official Position

- When changing hardware, but not the entire system, or when replacing a system with the same technology (make and model), cross-calibration should be performed by having one technologist do 10 phantom scans, with repositioning, before and after hardware change. If a >2% difference in mean percent fat, fat mass, or lean mass is observed, contact the manufacturer for service/correction.

Grade: Fair-B-W

Rationale

During the lifetime of a DXA system, minor and major repairs will be the norm. In addition, improvements in DXA technology will provide options to upgrade specific hardware components until, at some point, the system is replaced (Fig. 4). These major breakpoints will influence the calibration of the scanner, and it is important to measure the differences in the relevant parameters to be able to apply the necessary corrections to longitudinal data if indicated.

The recommended procedure is the same as currently stipulated for BMD and BMC *(20)*. The restriction to same manufacturer and model excludes major differences in beam geometry and analysis algorithm, both of which are major reasons for potential between-scanner differences. The recommendation of most manufacturers deal exclusively with
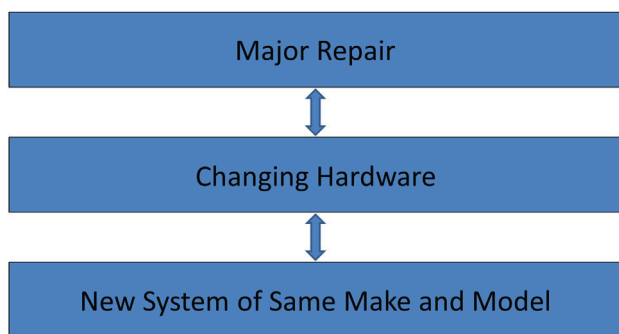
Fig. 4. Events in the life cycle of a dual-energy X-ray absorptiometry scanner that require careful assessment of potential differences in all relevant parameters.

bone values on a spine phantom when validating a system after repair. However, Norland does have a soft tissue–specific validation procedure. It is recommended to scan their Composition QC Phantom, provided with the system, a minimum of 16 times. Differences between subsequent QC studies must not exceed 2% for lean mass or fat mass *(21)*. Some scanner operators may also choose to use the Norland Anthropometric Whole Body Phantom, which can be used to assess combinations of bone, lean tissue, and fat *(22)*.

Discussion

The justification for the 2% threshold stems from longitudinal quality-control phantom measurements (Table 1), which show long-term precision values between 0.3% and 5.5%. Assuming the lean mass precision of 5.5% to be an outlier, the upper limit of the range of precision values is 2.0%. If 10 phantom measurements are performed before and after a service event, the error of the mean is reduced by sqrt(10), resulting in 0.63%. A difference between the means of 10 measurements before and after a service event would have

Table 1
Precision Values of Hologic Whole-Body and BioClinica Body Composition Phantoms Measured on Lunar Prodigy, Hologic Delphi-W, and a Nonspecified Hologic Scanner

Parameter	Precision, %	Min. diff.	Reference
%Fat	0.3 … 0.9	0.26 … 0.79	*(4)*
	0.6	0.53	*(11)*
	1.6	1.40	*(11)*
	1.4	1.22	*(23)*
Fat mass	0.3 … 0.9	0.26… 0.79	*(4)*
	0.7	0.61	*(11)*
	1.3	1.14	*(11)*
	1.7	1.49	*(23)*
Lean mass	0.1 … 0.6	0.09 … 0.53	*(4)*
	0.7	0.61	*(11)*
	5.5	4.82	*(11)*
	1.1	0.96	*(23)*

to be 1.96 * sqrt(2) = 2.77 times the error of the mean to be considered significant at the 95% confidence level. Based on the upper limit of 0.63%, this difference would have to be 1.8% to be significant. This value rounds to 2%.

Additional Questions for Future Research

The paper by Gotfredsen et al *(22)* as well as the Norland procedure for soft-tissue calibration are good examples of what should be done in an ideal environment. However, these procedures are quite long and difficult to implement with the proposed phantoms. Nowadays, specific polymer materials could be used to mimic body tissues for DXA applications.

ISCD Official Position

- No total-body phantoms are available at this time that can be used as absolute reference standards for soft-tissue composition or bone mineral mass.

  Grade: Good–A–W

Rationale

The algorithms used by DXA systems to quantify body composition make many assumptions to get repeatable measures. To fully test a DXA system's accuracy for fat, lean, and BMC masses, one must use a phantom that is in the same total mass, fat mass, and lean mass range as the patients of interests. In addition, a reasonable phantom geometry simulating human whole-body anatomy must be used to ensure that the region-specific assumptions are being used appropriately. There are only a few semianatomically correct phantoms available: The HWBP *(3)* and the Bioclinica Whole Body Phantom *(4)*. Both of these phantoms have aluminum bars to represent bone mineral and layers of low-density polyethylene and polyvinyl chloride to represent varying compositions of soft tissue. However, the materials themselves are not stable representations of percent fat when imaged at different X-ray energies. Thus, they cannot be used as an absolute reference standard. There are materials available that mimic the X-ray properties of adipose and muscle tissues over a wide range of energies. The Oscar phantom *(18)* is an anatomical phantom made from these materials but, to our knowledge, has not been used in a DXA cross-calibration study or to calibrate DXA systems to absolute accuracy.

Stearic acid and saline water (0.6% NaCl) may be appropriate calibration materials because of their biological equivalency to human lipids and water *(24)*. However, these materials are not durable enough for general field calibration use. Also, tests have been performed with machinable wax, Delrin (DuPont, Wilmington, DE), and solid water that show theoretical equivalence to a standardized stoichiometry of human lipid, protein, and water *(25)*.

Discussion

Initially, DXA systems were calibrated to known reference standards such as stearic acid for fat, water for lean soft tissue, and hydroxyapatite for bone mineral *(24,26)*. Norland systems are still currently tied to these materials *(22)*.

However, it was found that Hologic systems, which were used in the NHANES study, were underestimating body fat as represented by the 4-compartment model, and the reason was thought to be related to the absolute calibration. Schoeller et al *(27)* showed in a quasi-meta-analysis that the Hologic Delphi system overestimated lean soft-tissue mass by 5%. Thus, the Hologic systems were recalibrated to reduce the lean mass by 5%. This recalibration became known as the NHANES correction because the study was commissioned by the Center for Disease Control and Prevention's NHANES study group. To the task force's knowledge, GE and Norland have not altered their calibration of fat and lean mass in the past 20 years. However, few details exist on what these systems are calibrated to. In short, there is no specific phantom that would allow for an absolute in vivo calibration to be established in the field.

There are numerous publications that compare DXA parameters to results from other methods like chemical analysis *(27−36)*, computed tomography (CT) *(37,38)*, or magnetic resonance imaging (MRI) *(38,39)*. Whereas the chemical analysis creates a relationship to patient measurements, there is no phantom involved to aid in calibrating the scanner. Comparisons with other imaging methods are no more useful in attaining accuracy because these other methods have not been calibrated to absolute standards either.

Additional Questions for Future Research

It is difficult to make progress in the absolute calibration of DXA systems when they are calibrated to other models of body composition that may be even less accurate. A series of studies are needed that relate homogenized human tissue samples to stable polymer materials that are representative of these tissues over a wide range of X-ray energies, followed by the creation of life-sized anatomical phantoms made from these materials. These phantoms could then serve as reference phantoms for many generations of DXA systems to come.

ISCD Official Position

- The quality control (QC) program at a DXA body composition facility should include compliance with manufacturer guidelines for system maintenance. In addition, if not recommended in the manufacturer protocol, the following QC procedures are advised:
  - perform periodic (at least once per week) body composition QC scans for any DXA system as an independent assessment of system calibration;
  - plot and review data from calibration and body composition QC scans;
  - verify the body composition phantom mean percent fat mass and tissue mass after any service performed on the densitometer;
  - establish and enforce corrective action thresholds that trigger a call for service;
  - maintain service logs; and
  - comply with radiation surveys and regulatory government inspections, radiation surveys, and regulatory requirements.

Grade: Fair-B-W

Rationale

This recommendation follows the 2004 ISCD recommendation for a QC process for BMD on DXA scanners. Regular phantom scanning verifies system performance, and it is the main method by which one can monitor the stability of DXA results over time. Phantom scanning can detect both long-term and short-term drifts and help determine when a DXA system is out of calibration and requires service. Phantom scanning does not calibrate the system but rather allows monitoring of the system to identify problems with calibrations. A regular QC program requires use of a phantom of stable percent fat and tissue mass. When a densitometer is installed, the installation technician should scan a phantom with soft-tissue equivalents numerous times with repositioning. The manufacturer's recommendations for phantom scanning should be followed *(21,40,41)*.

Discussion

Manufacturer's guidelines for system maintenance vary by make and model. Newer DXA systems require basic daily QC scans as part of normal operating procedures. On most current scanners, the QC scans used for checking soft-tissue results have automatic checks to trigger service and prevent subsequent patient scans until service is complete. On older systems that do not require daily or regular QC scanning procedures, a tissue phantom should be scanned regularly, and if any of the measured parameters are out of range ($\pm1.5\%−2\%$ from the mean, to be established based on the first 30 scans), then the operator should run the phantom scan again. If the results are out of range twice in a row, then the operator should stop scanning patients and call the manufacturer for service. The phantom can also be used to detect whether changes have occurred in the tissue calibration after software and hardware changes and repairs.

Additional Questions for Future Research

The frequency of phantom measurements for DXA body composition would ideally be daily as is stipulated for the BMD QC program on most scanners. However, the time necessary to perform whole-body scans creates a sufficient additional burden to warrant a lower frequency, recommended to be no less than once per week. If a simplified phantom could be created that measures the relevant soft-tissue parameters and is small enough to shorten the measurement time, such a phantom could be used daily between the scans of the large whole-body phantom.

Acquisition of DXA Body Composition Measures in Patients

Questions

- What is the optimal way to prepare and position a patient for whole body scans?
  - How should the hands, arms, legs, and feet be positioned?

- How should very obese or patients that do not fit within the scan limits be positioned?

Introduction

Parameters derived from whole-body scans are dependent on the status of the patient, including position in the scanner, hydration status, and food intake. The following recommendations aim to address some of these issues and include suggestions on how to minimize the variability of the evaluation parameters.

ISCD Official Position

- Consistent positioning and preparation (e.g., fasting state, clothing, time of day, physical activity, empty bladder) of the patient are important for precise measures.

Grade: Fair-B-W

Rationale

Body composition is influenced by body hydration as well as stomach and intestinal content. To keep variability as low as possible, standardized measurement conditions, including time of day, premeasurement diet, and activities need to be defined.

Discussion

A careful study of 31 physically active participants, who were measured 5 times over a 2-day period, was carried out under different conditions of diet and physical activity *(42)*. The measurements included duplicate scans after an overnight fast, a scan after 8 hours of normal daily activities, and further scans the following day before and after a simple breakfast. Using the initial duplicate measurements as the baseline variability, total mass varied by <300 g, lean mass by <180 g, and fat mass by <150 g. The measurements at the end of the day showed an increase in total mass by 500 g and in lean mass by 560 g as well as a decrease in fat mass by 120 g for the female participants. The differences for the male participants were similar, although the total mass increase was lower. The differences due to breakfast consumption were, for males, an increase in total body mass by 1110 g, in lean mass by 900 g, and in fat mass by 280 g. Although the females showed a smaller total body mass increase of only 530 g, their increase in fat mass was similar at 210 g.

This is an exceptionally well-designed and executed study, and the measurement errors have been kept to a minimum. Normal daily activities and regular food intake show a major influence on the body composition parameters. It appears that a scan after an overnight fast provides the best condition for a reproducible measurement.

The variability viewed as the result of confounding lifestyle parameters are consistently larger than the least significant change (LSC) as calculated from the initial duplicate measurements for total mass and lean mass but not for fat mass. These LSCs are, for men and women, respectively, 400 g and 290 g for total mass, 380 g and 410 g for lean mass, and 290 g and 350 g for fat mass. Even with a lesser precision than published here, a difference in total body mass of 1 kg is easily observable. Considering potential scanner drift over longer periods of time, it appears reasonable to require special attention to patient preparation if differences of less than 2 kg in total body mass are to be evaluated.

ISCD Official Position

- Positioning of the arms, hands, legs, and feet whenever possible should be according to the NHANES method (palms down isolated from the body, feet neutral, ankles strapped, arms straight or slightly angled, face up with neutral chin).

Grade: Fair-B-W

Rationale

Given that the NHANES reference database is being recommended for DXA body composition results, the patient positioning from the NHANES manual *(43)* is advised (Fig. 5). Most of the DXA manufacturers have similar requirements for patient positioning for whole-body DXA scans *(21,40,41)*.

Discussion

Positioning recommendations, which are common across manufacturers and the NHANES guidelines, include the following. For all scanners, the patient is positioned lying supine with the head at the top end of the table just below the upper scan margin. The necessity of having the entire body, including all soft tissue, within the table scan margins is critical for accurate total body tissue results. The NHANES cohort excluded those that were too tall for the scan (taller than 6'5"). The patient should be centered within the sides of the table scan margins. Please refer to hemi-scan statement (following recommended position) if the entire total body will not fit within the table scan margins.

Positioning recommendations that vary between the manufacturers and the NHANES guidelines include the way to position the hands and the use of positioning devices. All DXA manufacturers and the NHANES guidelines agree on placing the arms straight at the patient's sides with a space between the patient's arms and sides. Hand positioning does vary between manufacturers; some recommend hands prone and others vertical with palms facing the hips. The consistency of hand placement is important because a deviation could result in tissue (primarily bone area) changes. NHANES and Lunar recommend the use of a Velcro strap to secure the ankles to keep the legs together and reduce movement. NHANES also allows the option to use radiolucent pillows/blocks/wedges for the head or knees for subjects who cannot lay flat. Most DXA systems assume a flat body without positioning aids, as elevation of head or limbs could cause magnification errors. In addition, if the positioning device material is not radiolucent, it may be detected as soft tissue. The placement of analysis ROIs for the accurate delineation of whole-body subregions is challenged by any overlapping tissue (i.e., hands tucked under hips, arms over breast, or chin over neck).
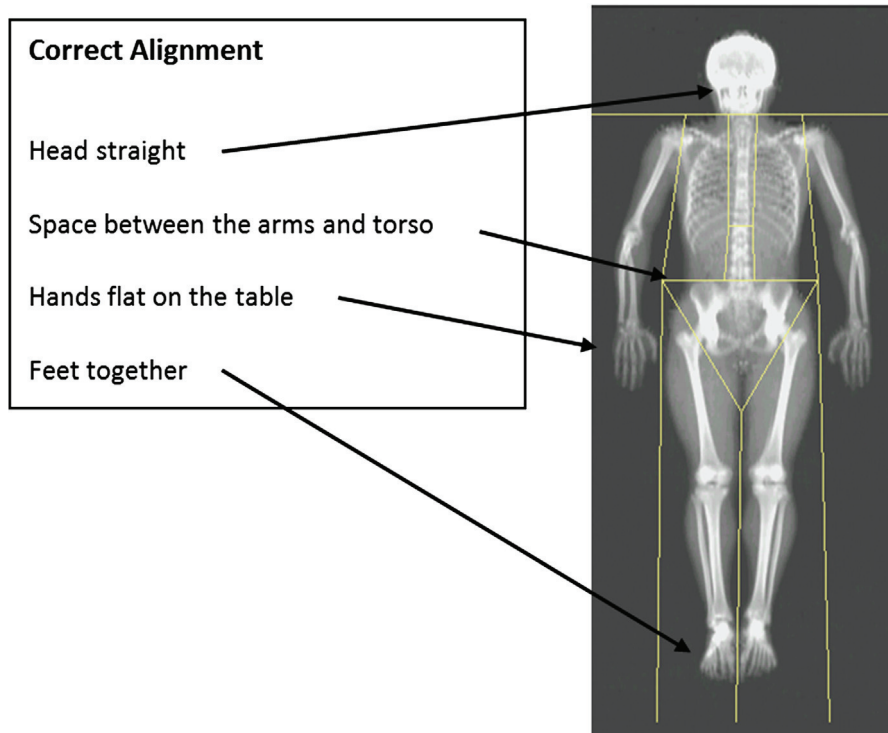
Fig. 5. Recommended positions of head, arms, hands, and legs based on National Health and Nutrition Examination Survey.

If DXA whole-body data are to be compared with NHANES normal values the same patient positioning as used for the NHANES studies is indicated. The specific NHANES guidelines *(43)* are as follows:

- The legs should be positioned together with the feet relaxed. Use a piece of double-sided Velcro around the ankles to support the legs in this position and to reduce movement.
- The patient should lie flat on the table without a pillow. If the patient has trouble lying flat as the result of back problems or difficulty breathing when lying flat, use the radiolucent pillow to support the head. If the pillow does not provide sufficient support, use the radiolucent block or wedge. These may also be used under the knees. If the patient continues to have difficulty lying flat or with the head slightly supported, exclude him/her from the examination.
- The patient's feet should be within the scan limit border. Position the legs and feet, then place Velcro around the ankles to maintain the position.
- Place the patient's arms straight at their sides, palms down, with a separation from the thighs. Verify that the arms are within the scan border. A large patient can place the hands vertically next to the thighs to ensure that hands and arms remain within the limits. Do not tuck the hands under the body. There must be a space between the patient's arms and sides.

Additional Questions for Future Research

To what degree do radiolucent positioning devices impact DXA whole body composition results?

ISCD Official Position

- ''Offset scanning'' should be used in patients who are too wide to fit within the scan boundaries, using a validated procedure for a specific scanner model.

Grade: Fair−B-W

Definition and Rationale

Offset scanning is a generic description of a technique whereby patients, whose body width exceeds the scanning field of the table, are positioned where the midsagittal line of the patient is offset from the midline of the table to allow complete scanning of either the right or left limbs and trunk, even if the contralateral corresponding upper or lower limbs are incompletely visualized (Fig. 6). The software is then allowed to ''mirror'' the results of the completely imaged side and replace the incompletely visualized limb values as needed. Because of the design of most scanners and the interference of the vertical portion of the c-arm, this typically means replacing incomplete left upper and/or lower extremity values with values derived from the right upper and lower limbs.

Whole body lean and fat indices such as total BMC, percent body fat, as well as lean and fat mass require assessment

Fig. 6. Example of a whole-body scan in which the patient did not completely fit into the scanning field. The data for the missing left arm can be reproduced from the available data of the right arm.

of a whole person for their calculation and comparison to normative data charts. When direct measurement of the entire body is not possible, the offset scanning technique with mirroring of right limb values onto the left is more accurate and reproducible than ignoring the nonimaged portions of the limbs outside the field of view. This technique is also less time-consuming and associated with less radiation dose to the patient than performing two offset scans to measure both left and right extremities separately.

Three studies on almost 300 patients combined, using Lunar DPX-L *(44)*, Lunar iDXA *(45)*, and Norland XR-36 scanners *(46)* evaluated mirroring of a half scan to obtain appropriate values for the whole body. They have shown small left/right differences of 0.1 … 0.7% for %fat, 0.04 … 1.1 kg for lean

mass and 0.04 … 1.0 kg for fat mass. Considering the weight of obese patients, these errors are less than 1.7% for percent fat (coefficient of variation [CV]), 2.1% for lean mass, and 2.5% for fat mass. In comparison, these errors are similar to the precision errors listed in Table 2: 0.6 … 2.4% for percent fat, 0.4 … 2.2% for lean mass, and 0.7 … 3.4% for fat mass. It is, thus, reasonable to conclude that offset scanning does not add any major errors to the evaluated parameters.

Discussion

Early in the development of DXA scanners, the issue of patients too wide for the scanner field was not as common as it is today. Most notably, the first model scanners had rather modest table weight limits, as low as 118 kg (260 pounds), and with these limits it was extremely rare to encounter subjects too wide to fit in the scan field. As manufacturers began to address the issues of an increasingly obese population, the table weight limits in their latest designs have increased so that, today, many scanners can safely support patients up to 180 kg (400 pounds) and more. Thus, the likelihood of encountering patients that cannot be completely imaged is much more likely today, especially as interest in monitoring body composition in obese subjects and those undergoing weight loss continues to gain interest.

Two of the aforementioned studies *(44,45)* list left/right errors; the third study *(46)* is an abstract and lists only regression equations. All regression slopes, which relate the half-scan to the full scan, have values less than 2 (1.79 … 1.88) but show positive intercepts. Using average values for lean mass (50 kg) and fat mass (40 kg), the given regression equations result in the following differences between full scan and half-scan values, calculated separately for the right and left half scan; lean mass: 1.6 and 4.4 kg (3.2% and 8.8%); fat mass: 1.0 and 3.7 kg (2.5% and 9.3%).

Another method, used by Hologic, consists of replacing only the extremities outside the scanning field with the contralateral extremities. Evaluation of this method on 434 subjects showed that the precision of duplicate scans is worse by only 0.1%, although there were systematic differences between full measurement and reflected extremities of 0.2%−0.9% *(47)*.

The development and distribution of validated automated approaches by manufactures in their latest iterations of body-composition software, which takes into account the asymmetry between left and right limbs and performs the calculations automatically, has simplified image evaluation. This technique may also be of value in amputees, allowing the comparison to total-body normative data in these patients.

Additional Questions for Future Research

The quality of the half-scan inference for whole-body data appears to be scanner dependent. The 2 published references involving Lunar scanners *(44,45)* provide good performance for this approach. The data from the Norland scanner are less convincing. Hologic scanners support replacing only the extremities (arms and/or legs) of one side of the body.

Table 2
Precision for the Various Body Composition Parameters

Measure	Scanner	Population	Precision [CV]	Reference
Percent fat	Norland XR-36	51 college athletes	2.4%	(56)
Percent fat	Various	review article	0.6 … 1.2%	(31)
Percent fat	Lunar iDXA	52 subjects	0.9%	(50)
Percent fat	Lunar DPX-L	20 subjects	1.9%	(51)
Fat mass	Lunar Prodigy	30 male subjects; 22–61 yr	1.1%	(57)
Fat mass	Norland XR-36	51 college athletes	2.5%	(56)
Fat mass	Various	review article	0.7 … 1.3%	(31)
Fat mass	Hologic QDR 4500 A	165 female and 136 male subjects	2.1 … 3.2% (obese … lean)	(52)
Fat mass	Lunar iDXA	52 subjects	0.8%	(50)
Fat mass	Lunar Prodigy	Lunar Prodigy; 81 subjects	1.6%	(58)
Fat mass	Lunar DPX-L	76 subjects.	3.4%	(59)
Fat mass	Hologic QDR 4500 A	20 women, 40–70 yr	1.2%	(54)
Fat mass	not given	17 volunteers	2.6%	(60)
Fat mass	Lunar Prodigy	9 subjects	2.4%	(61)
Fat mass	Hologic QDR 4500 W and Discovery Wi	42 subjects	2.0%	(16)
Fat mass	Lunar DPX-L	20 subjects	2.0%	(51)
Fat mass regional	Hologic QDR 2000 fan-beam mode	113 subjects, 30—70 yr	3.4 … 10.9%	(62)
Fat mass lower ex.	Lunar Prodigy	30 male subjects; 22–61 yr	2.7%	(57)
Fat mass upper ex.	Lunar Prodigy	30 male subjects; 22–61 yr	4.1%	(57)
Lean mass	Lunar Prodigy	30 male subjects; 22–61 yr	2.2%	(57)
Lean mass	Norland XR-36	51 college athletes	1.0%	(56)
Lean mass	Various	Review article	0.4 … 1.3%	(31)
Lean mass	Hologic QDR-4500 A	165 female and 136 male subjects	1.5 … 2.2% (lean … obese)	(52)
Lean mass	Lunar iDXA	52 subjects	0.5%	(50)
Lean mass	Lunar DPX-L	76 subjects	2.2%	(59)
Lean mass	Hologic QDR 4500 A	20 women, 40–70 yr	1.1%	(54)
Lean mass	Not given	17 volunteers	0.9%	(60)
Lean mass	Lunar Prodigy	9 subjects	1.1%	(61)
Lean mass	Hologic QDR 4500 A	41 subjects	0.6%	(14)
Lean mass	Hologic QDR 4500 W and Discovery Wi	42 subjects	1.6%	(16)
Lean mass	Lunar DPX-L	20 subjects	1.1%	(51)
Lean mass regional	Hologic QDR 2000 fan-beam mode	113 subjects, 30–70 yr	1.2 … 10.9%	(62)
Lean mass lower ex.	Lunar Prodigy	30 male subjects; 22–61 yr	4.8%	(57)
Lean mass upper ex.	Lunar Prodigy	Prodigy; 30 male subjects; 22–61 yr	9.1%	(57)

Considerations Regarding Analysis and Repeatability of Measures

Questions

- How should whole body scans be analyzed?
  - How should arms, legs, and head be sectioned from the trunk?
  - If observed in the scan at the time of analysis, how should removable artifacts be addressed?
  - If observed in the scan at the time of analysis, how should nonremovable artifacts be addressed?
- How should precision be assessed for body composition measures?
- What is the minimum precision acceptable for a DXA site?
  - What is the minimum precision for fat tissue assessment?
  - What is the minimum precision for lean tissue assessment?

Introduction

Consistent patient positioning and analysis are the most important aspects of keeping the measurement errors low. Recommendations on how to achieve and assess repeatability errors have been published for bone assessment before *(20)*. Here, we are concentrating on soft-tissue assessment from whole-body scans, and the literature review as well as the recommended performance values are based on data published since 2000. Scanner technology and analysis procedures have likely improved during this time period, which should have a positive impact on scan repeatability.

ISCD Official Position

- Every technologist should perform an in vivo precision assessment for all body composition measures of interest using patients who are representative of the clinic's patient population.

Grade: Fair−B−W

Rationale

The concept of precision and of the LSC for the assessment of BMD has been covered in a previous Position Development Conference *(20)*, and the phenomenon and sources of imprecision and its measurement are well established *(48)*. The imprecision of measures of body composition, especially in subregions, can be much larger and more variable than that for regional BMD scans. Thus, knowledge of the LSC for body composition indices is required before any quantitative statement of change can be made for body composition measures and is no different in approach and calculation than for bone density measurements, which have already been established.

Discussion

All measurements have reproducibility errors (imprecision), and bone densitometers are no exception. This imprecision in body composition measurements is well documented in the literature and will vary by device and scan mode *(10,19,31,49)*, subregion and compartment *(50,51)*, body habitus, and age *(52−54)*.

Because the physiologic range of body composition values is much greater than that of BMD and precision varies with the size of the patient, it is even more important to select a population of subjects for the calculation of the in vivo precision and LSC values for body composition that match the typical patient population in a given clinic. If one deals with more than one population of extremes, for example an eating disorder clinic seeing both morbidly obese and anorexic/bulimic patients, it may be reasonable to perform separate precision assessments for each group.

ISCD Official Position

- The minimum acceptable precision for an individual technologist is 3%, 2%, and 2% for fat mass, lean mass, and percent fat, respectively.

Grade: Fair-B-W

Rationale

Table 2 summarizes identified literature regarding body composition precision. At least one paper was available for Norland, GE-Lunar, and Hologic systems. Several general statements can be made. First, lean mass precision is generally greater (better) than fat mass precision. Second, precision varies by body size with precision in general being lower (worse) for adults with greater body mass index values. However, few data were available for individuals at the extreme end of underweight and the morbidly obese. Third, there was a trend for greater precision for more recent models of Hologic and GE systems. Toombs et al *(31)* found that the GE iDXA has better precision on most body composition measures than the Prodigy on the same individuals scanned the same day. Fan et al *(55)* found that the precision of the more recent Hologic APEX software was significantly better than the older Delphi software but only for central DXA measures. No statement can be made regarding Norland. With the exception of one 10-yr-old Norland study, reported precision values as coefficients of variation for percent fat were <2%, for fat mass <3%, and for lean mass 2%.

Statistical analysis for the precision values pertaining to percent fat, fat mass, and lean mass of the whole body, excluding data from subregions, are illustrated in Fig. 7. The discrepancy between the median and mean values illustrates the non-normal distribution of the data. Considering the 75th percentile for each of the parameters, we obtain 1.4% for percent fat, 2.7% for fat mass, and 1.8% for lean mass. These numbers support the recommended minimum performance standards of 2% for percent fat, 3% for fat mass, and 2% for lean mass.

Discussion

It is clearly a complex question to ask how precise should DXA body composition values be for a given technologist, DXA system, and patient population. The data available are usually in the form of a reported value for a group of individuals and their mean statistics. Training in performing body composition studies has always been very limited until the introduction of the ISCD body composition course. Finally, there has been little standardization on how a patient should be positioned with respect to legs, arms, and hands. Unlike bone density measures, body composition precision is most likely on the road to improving over the next few years based on standardization guidelines like those presented here.

Precision data for subregions are available in the literature, and some are listed in Table 2. However, there is not enough information available right now to make firm recommendations for subregion precision values.

Additional Questions for Future Research

A meta-analysis of available data from the papers as listed in Table 2 would allow for a further refinement of our knowledge of how precise DXA body composition values are and how covariates impact the nominal precision values.

ISCD Official Position

- Consistently use manufacturers' recommendations for ROI placement.

Grade: Fair-B-W

Rationale

Most DXA software provides a semiautomated placement of ROIs for whole body subregions. In most cases these automated subregions will require some revision by the technologist. Consistency in placing these by use of bony landmarks is critical to the reproducibility of subregion soft-tissue results. Although there are slight differences between the DXA manufacturers' analysis software regarding the movement and segmentation of subregion ROI markers, the recommendations for the positioning of the subregion ROIs are comparable between manufacturers. What is most important is consistency in ROI placement.

Fig. 7. Histograms and statistical analyses of precision data from Table 2 for percent fat, fat mass and lean mass. The 75th percentile values were taken as an indicator for establishing the recommended performance expectations of 2% for percent fat, 3% for fat mass, and 3% for lean mass.

Discussion

Differences in patient positioning can challenge the user's ability to consistently place the ROI markers. As recommended and enabled by the manufacturers, compare to the base-line scan during analysis of follow-up scans to ensure reproducibility. Although duplication of the baseline ROIs does not ensure that all ROIs will be placed correctly, it does provide another opportunity to review and check the patient positioning and how it may have changed between scans. The best way to check that ROIs are precisely positioned is to use simple anatomical landmarks such as the gleno-humeral joints, the top of the iliac crests, the middle of the femoral necks, etc. As expected, the ROI markers are used to delineate soft tissue between anatomical landmarks, yet one must be careful to include all soft tissue in the corresponding subregions for subregion results to be accurate and reproducible.

Caution should be used when considering soft-tissue results from novel subregions of whole-body scans. Some have investigated special abdominal subregions *(37,63,64)* and found the precision to be good (R = 0.89−0.97). Others have defined additional subregions to differentiate upper and lower arms or legs *(65)* with less precision (CV = 4% −6.5%). With smaller ROI size and increased complexity in ROI positioning, the ability to reproduce tissue results is compromised.

In some cases of bone deformities or limb paralysis, especially found in orthopedic studies, the usual bony landmarks cannot be used properly. In these cases, a good assessment of the total BMC and global body composition in fat mass and lean tissue mass can be obtained by using an ROI that includes the entire body.

Additional Questions for Future Research

The assessment of abdominal fat by DXA is a new field of research, which has interesting clinical applications in overweight and obesity as well as in fat deficit (anorexia nervosa, AIDs, etc.). As previously noted, several studies have been performed to compare DXA results with those of CT *(37,63)* or MRI *(66)*. However, in these studies the size and position of abdominal ROIs were not standardized, although in the DXA analysis they were chosen to fit as well as possible the corresponding CT or MRI ROI. Therefore, the methodology is not clearly defined, and several ROIs could be used. Whatever the patient's sex, it could be suggested that one use an ROI limited in height by the last ribs (bottom of L1) as upper limit and the top of the iliac crests or the bottom of the ischium as lower limit.

ISCD Official Position

- Consistently use manufacturers' recommendations for artifact removal.

  Grade: Fair-B-W

Rationale

There are many possible sources of artifacts in DXA whole-body composition scans. The sources of artifact may be internal or external. Sources of internal artifacts include implanted hardware *(67)* and residual contrast media from a previous imaging study *(68)*. Many of the more dense artifacts would be estimated as bone pixels by DXA unless otherwise resolved during analysis. The best approach is to remove any potential sources of artifacts whenever possible. In cases where external artifacts are not removable, it is important to maintain consistency for longitudinal reproducibility. Motion artifacts are usually prevented by ensuring the subject is comfortably positioned, is provided with clear instructions and is reminded not to talk or move. If motion artifacts are detected during the scan, the scan can be stopped and restarted.

Discussion

Madsen et al *(67)* showed that the soft-tissue parameters can be affected by high-density orthopedic implants. Scans performed with and without an external, overlaying femoral prosthesis were analyzed with and without the high-density detection (HDD) option. The external prosthesis increased lean mass by 12.4% without HDD and by 3.7% with HDD; fat mass was decreased by 15.8% without HDD and by 7.0% with HDD. Analysis of a cohort with endogenous hip implants with and without HDD showed similar differences as the cohort with overlying implants.

Nonremovable sources of artifacts should be documented, and the artifacts should be consistent for accurate, longitudinal comparison. Soft-tissue results may be less impacted by implanted hardware, given the density typically is greater than that of soft tissue, and most of the manufacturers' software programs have HDD algorithms that identify and resolve the influence of implanted hardware.

Some DXA software enables users to assist in identifying artifacts on the image and allow them to extract or neutralize the relevant pixels during analysis. Because the degree to which artifacts may impact results is not clearly defined and not all DXA software enables extraction of artifacts during analysis, it is critical that all removable sources of artifacts be eliminated from the patient and DXA table whenever possible.

Additional Questions for Future Research

All manufacturers should provide a method for extracting tissue data points that include artifacts. Further research is needed to better characterize the impact of artifacts on whole-body tissue results.

Acknowledgments

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Appendix A

ISCD TF-2 Search Strategy

DXA Body Comp Base

((((((((DXA OR DEXA)) AND (((((body composition)) OR percent body fat) OR percent fat) OR lean body mass))) AND ("1986/1/1"[Date - Create] : "3000"[Date - Create]))) AND "english"[Language]) AND "humans"[Filter]

Q1 Phantoms

(((((((((DXA OR DEXA)) AND (((((body composition)) OR percent body fat) OR percent fat) OR lean body mass))) AND ("1986/1/1"[Date - Create] : "3000"[Date - Create]))) AND "english"[Language]) AND "humans"[Filter])) AND phantom.

Q2 Position and Preparation

((((((((((DXA OR DEXA)) AND (((((body composition)) OR percent body fat) OR percent fat) OR lean body mass))) AND ("1986/1/1"[Date - Create] : "3000"[Date - Create]))) AND "english"[Language]) AND "humans"[Filter])) AND position)) OR (((((((((((DXA OR DEXA)) AND (((((body composition)) OR percent body fat) OR percent fat) OR

lean body mass))) AND ("1986/1/1"[Date - Create] : "3000"[Date - Create]))) AND "english"[Language]) AND "humans"[Filter])) AND preparation).

Q3a Accuracy: Fat

(((((((((((DXA OR DEXA)) AND (((((body composition)) OR percent body fat) OR percent fat) OR lean body mass))) AND ("1986/1/1"[Date - Create] : "3000"[Date - Create]))) AND "english"[Language]) AND "humans"[Filter])) AND accuracy)) AND fat.

Q3b Accuracy: Lean

(((((((((((DXA OR DEXA)) AND (((((body composition)) OR percent body fat) OR percent fat) OR lean body mass))) AND ("1986/1/1"[Date - Create] : "3000"[Date - Create]))) AND "english"[Language]) AND "humans"[Filter])) AND accuracy)) AND lean.

Q3c Precision: Fat

(((((((((((DXA OR DEXA)) AND (((((body composition)) OR percent body fat) OR percent fat) OR lean body mass))) AND ("1986/1/1"[Date - Create] : "3000"[Date - Create]))) AND "english"[Language]) AND "humans"[Filter])) AND precision)) AND fat.

Q3d Precision: Lean

(((((((((((DXA OR DEXA)) AND (((((body composition)) OR percent body fat) OR percent fat) OR lean body mass))) AND ("1986/1/1"[Date - Create] : "3000"[Date - Create]))) AND "english"[Language]) AND "humans"[Filter])) AND precision)) AND lean.

Q4a Region and Analysis Procedure

(((((((((((DXA OR DEXA)) AND (((((body composition)) OR percent body fat) OR percent fat) OR lean body mass)))

AND ("1986/1/1"[Date - Create] : "3000"[Date - Create]))) AND "english"[Language]) AND "humans"[Filter])) AND analysis procedure)) AND ((((((((((DXA OR DEXA)) AND (((((body composition)) OR percent body fat) OR percent fat) OR lean body mass))) AND ("1986/1/1"[Date - Create] : "3000"[Date - Create]))) AND "english"[Language]) AND "humans"[Filter])) AND region).

Q4b Artifact

(((((((((((DXA OR DEXA)) AND (((((body composition)) OR percent body fat) OR percent fat) OR lean body mass))) AND ("1986/1/1"[Date - Create] : "3000"[Date - Create]))) AND "english"[Language]) AND "humans"[Filter])) AND artifact)) OR ((((((((((DXA OR DEXA)) AND (((((body composition)) OR percent body fat) OR percent fat) OR lean body mass))) AND ("1986/1/1"[Date - Create] : "3000"[Date - Create]))) AND "english"[Language]) AND "humans"[Filter])) AND artifact).

Q5 Frequency

(((((((((((DXA OR DEXA)) AND (((((body composition)) OR percent body fat) OR percent fat) OR lean body mass))) AND ("1986/1/1"[Date - Create] : "3000"[Date - Create]))) AND "english"[Language]) AND "humans"[Filter])) AND time interval)) OR ((((((((((DXA OR DEXA)) AND (((((body composition)) OR percent body fat) OR percent fat) OR lean body mass))) AND ("1986/1/1"[Date - Create] : "3000"Date - Create]))) AND "english"Language]) AND "humans"[Filter])) AND measurement frequency)) OR (((((((((((DXA OR DEXA)) AND (((((body composition)) OR percent body fat) OR percent fat) OR lean body mass))) AND ("1986/1/1"[Date - Create] : "3000"[Date - Create]))) AND "english"[Language]) AND "humans"[Filter])) AND frequency)) AND assessment).