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Position Statement

Dual Energy X-ray Absorptiometry Interpretation and Reporting in Children and Adolescents: The 2007 ISCD Pediatric Official Positions

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Abstract

The International Society for Clinical Densitometry Official Positions on reporting of densitometry results in children represent an effort to consolidate opinions to assist healthcare providers determine which skeletal sites should be assessed, which adjustments should be made in these assessments, appropriate pediatric reference databases, and elements to include in a dual energy X-ray absorptiometry (DXA) report. Skeletal sites recommended for assessment are the lumbar spine and total body less head, the latter being valuable as it provides information on soft tissue, as well as bone. Interpretation of DXA findings in children with growth or maturational delay requires special consideration; adjustments are required to prevent erroneous interpretation. Normative databases used as a reference should be based on a large sample of healthy children that characterizes the variability in bone measures relative to gender, age, and race/ethnicity, and should be specific for each manufacturer and model of densitometer and software. Pediatric DXA reports should provide relevant demographic and health information, technical details of the scan, Z-scores, and should not include T-scores. The rationale and evidence for development of the Official Positions are provided. Given the sparse data currently available in many of these areas, it is likely that these positions will change over time as new data become available.

Key Words: Dual energy X-ray absorptiometry; Z-score; bone mineral density; bone mineral content; bone age; maturation; clinical assessment; children; fracture; position; guideline.

Introduction

The foundation of bone health is built during the childhood and teenage years *(1−4)*. Peak bone mass is established by the third decade of life *(2−8)*, a compromise of which may be associated with an increased lifetime risk of osteoporosis and fractures *(9,10)*. A variety of childhood diseases and pharmaceutical interventions can result in bone loss, suboptimal accrual of bone mass, or a combination of both *(11−16)*. Therefore, clinicians have sought to identify tests that best evaluate bone health in young children and adolescents. The goal of bone densitometry is to identify individuals at risk for skeletal fragility, to determine whether bone mass is compromised in children with established bone fragility, and to guide and monitor treatment. Although the rationale for densitometry is the same in children as in adults, performance of

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densitometry and interpretation of bone density results are much more complex in young, growing patients *(3,4,17–19)*.

Dual-energy X-ray absorptiometry (DXA) is the most commonly used bone densitometric technique for children throughout the world, preferred over other techniques because of its speed, precision, safety, low cost, and widespread availability *(3,4,19–21)*. In contrast to adults, there are no internationally recognized guidelines for bone density testing in children. For a given patient, the clinician must consider the need for a bone density evaluation, including both the duration and severity of the chronic illness, and/or frequency and nature of fractures *(19)*. There are significant knowledge gaps in this area, few large representative normative databases from healthy youth, especially for certain ethnic groups, and a lack of consensus as to which adjustments may be needed to interpret densitometric results in children with altered growth or maturity patterns. Appendicular fractures exhibit a bimodal distribution with an initial peak during puberty (at 11 yr in girls and 14 yr in boys) *(22)*. Such fractures were originally attributed to trauma due to increased activity in this age group, although more recent studies have suggested that such fractures may reflect differential changes in bone mineral content (BMC) and bone area during puberty, possibly resulting in transient bone fragility *(23)*. Furthermore, a four-year follow-up study of children with forearm fractures and low bone mass demonstrated a persistently low BMC at several skeletal sites, even after adjustment for bone area, height, weight and pubertal stage, confirming the premise that fractures may indeed represent a marker of skeletal fragility *(24)*. Although still limited, there are mounting data that describe the relationship between DXA measurements and fracture risk in growing children and adolescents. All of the prospective studies completed to date in this area have examined otherwise healthy children or adolescents with fractures, rather than those with chronic disease *(25–43)*.

The following questions regarding the reporting of pediatric densitometry results were addressed at the 2007 International Society for Clinical Densitometry (ISCD) Position Development Conference, held in Montreal, Canada, and the results follow:

- What are the most appropriate and reproducible sites for densitometry in children?
- What is the best method for reporting areal bone mineral density (BMD) in children (what corrections should be made for bone size, height, lean body mass, skeletal age or pubertal stage)?
- What are the most appropriate normative databases for use in childhood?
- What are the elements that should be included in a DXA report for a child or adolescent?

Methodology

The methods used to develop, and grading system applied to the ISCD Official Positions, are presented in the Executive Summary that accompanies this paper. In brief, all positions were rated by the Expert Panel on quality of evidence (Good; Fair; Poor: where Good is evidence that includes results from well-designed, well-conducted studies in representative populations; Fair is evidence sufficient to determine effects on outcomes, but the strength of the evidence is limited by the number, quality, or consistency of the individual studies; and Poor is evidence that is insufficient to assess the effects on outcomes because of limited number or power of studies, important flaws in their design or conduct, gaps in the chain of evidence, or information), strength of the recommendation (A; B; or C: where A is a strong recommendation supported by the evidence; B is a recommendation supported by the evidence; and C is a recommendation supported primarily by expert opinion), and applicability (worldwide = W or variable, according to local requirements = L). Necessity was also considered with a response of ''necessary'' indicating that the indication or procedure is ''necessary'' due to the health benefits outweighing the risk to such an extent that it must be offered to all patients and the magnitude of the expected benefit is not small.

What are the Most Appropriate and Reproducible Sites for Densitometry in Children?

ISCD Official Position

- DXA is the preferred method for assessing BMC and areal BMD.
  Grade: Good-B-W-Necessary
- The posterior-anterior (PA) spine and total body less head (TBLH), are the most accurate and reproducible skeletal sites for performing BMC and areal BMD measurements.
  Grade: Good-B-W-Necessary
- Soft tissue measures in conjunction with whole body scans may be helpful in evaluating patients with chronic conditions associated with malnutrition, such as anorexia nervosa, inflammatory bowel disease, cystic fibrosis, or with both muscle and skeletal deficits, such as idiopathic juvenile osteoporosis.
  Grade: Fair-B-W-Necessary
- The hip (including total hip and proximal femur) is not a reliable site for measurement in growing children due to significant variability in skeletal development and lack of reproducible regions of interest.
  Grade: Fair-B-W-Necessary

Rationale

At the present time, there are relatively sparse data regarding the relationship between a bone density measurement by DXA in young, growing children and fracture risk, peak bone mass, and risk for the development of future osteoporosis. In the absence of these data, information about a site's reproducibility and the clinical information afforded guide the selection of sites for densitometry in children. The sites selected for DXA measurements are generally intended to provide

an evaluation of a child's bone density, and insight into overall skeletal health (18).

Whole Body and Spine. If technically feasible, the pediatric DXA examination should include scans of the lumbar spine and total body (14,18). Both sites are highly reproducible, as evidenced by a coefficient of variation (CV) documented to be 0.64−1.03 at the spine, and 0.66−1.20 at the total body in a recent study of healthy children ages 6−16 yr (44). Studies of adults have reported a similar precision at these sites: 0.7−1.7 at the spine and 0.7 at the total body (45−47). Measurements of the spine and total body provide more information about the status of trabecular and cortical bone, respectively, than standard radiographs (48). The spine is a preferred site in pediatrics because of its speed and precision of measurement, easily identified bony landmarks, and increasing amounts of pediatric normative data (49). The total body is also a recommended site because of excellent precision and fact that this site provides a measurement of total bone mass, as well as measures of body composition, including fat mass and lean body mass (predominantly muscle mass).

Soft tissue evaluations in parallel to bone data may be helpful for clinicians caring for children with chronic conditions. Growth, chronic illness, and specific interventions may affect both bone mass and soft tissue body composition (49). Therefore, scans of the total body may be useful for both ongoing clinical assessments and research purposes as both bone and body composition can be evaluated. Total body measurements have been used in studies of many chronic conditions in pediatrics, including: eating disorders (e.g., anorexia nervosa) (16,50,51); inflammatory diseases (e.g., inflammatory bowel disease, celiac disease, systemic lupus erythematosis, etc.) (52−54); glucocorticoid therapy related to inflammation or transplantation (55); neuromuscular disorders (e.g., spinal cord injuries (56); paralysis or cerebral palsy (57,58); Duchenne muscular dystrophy (59−61); long-term immobilization after injuries (62); and idiopathic juvenile osteoporosis (IJO) (63)). In fact, muscle development plays an important role in bone mineral accrual, and it has been proposed that insight into the mechanisms of reduced bone mass/density can be obtained through an evaluation of the DXA-based 'muscle-bone unit' (64−66). The relationship between muscle force and mass to bone mass and geometry in the developing skeleton can be considered in the context of the 'mechanostat hypothesis' (67). According to this theory, bone mass and geometry are influenced by growth and muscle development in children and adolescents. Thereby, bone adapts to tissue strain secondary to biomechanical forces. The process is further modified by hormonal signals (e.g., estrogens and androgens), which can be altered by a chronic disease (e.g., low estrogens and androgens in an emaciated adolescent girl with anorexia nervosa who has little body fat and muscle tissue, as well as a low bone mass) (50,51). Although normative data for body composition are limited, trends in soft tissue that are noted during the interval between scans can provide important information for areal BMD interpretation.

For total body bone assessments, there is a growing consensus that total body or TBLH measurements should be obtained. Arguments against including the head are that the skull constitutes a substantially greater proportion of the total skeletal mass in younger children compared to older adolescents (approximately 40% vs 20%; unpublished data), and the skull is not responsive to physical activity or other environmental stimuli (68). Ideally, a clinician would have the choice to evaluate both a total body scan with head and less head, the latter option especially useful in a young child. One recent large prospective cohort study examined the relationship between bone mass, assessed as TBLH, and fracture risk in 6213 children over the subsequent 2 yr (43). In children, mean age 9.9 yr, there was a weak inverse relationship between areal BMD and subsequent fracture risk (odds ratio (OR) per standard deviation (SD) decrease = 1.12; 95% CI: 1.02−1.25). Those investigators did not present results for the total body with head so the comparative advantage is not known.

Other Skeletal Sites. The proximal femur region, commonly assessed by DXA in adults, is more challenging to evaluate in children for several reasons (49,69). Skeletal landmarks, which guide proper positioning, may not be well-developed in young children. This can lead to errors in positioning and placement of the region of interest using standard software; these difficulties contribute to lower precision of measurements at the hip. Normative data at the hip for children and adolescents are more limited than at the spine and whole body, but are available for both the proximal femur and total hip regions (20,21,70−73). Reference data are also available for the lateral distal femur, but they were obtained using earlier pencil beam Hologic scanners (74). This site can provide a skeletal measure in children for whom standard DXA measures are difficult to obtain because of skeletal contractures (74). Few pediatric reference data exist for the forearm (20,70,75). In the absence of reference data, value may be obtained only when comparing a baseline measurement for a given child to subsequent studies (18,49). The forearm scan may also be useful for those patients whose weight exceeds the scanner limit (18,49).

BMC Vs. Areal BMD. For total body measurements, total body BMC is considered one of the preferred methods of assessment for bone status because of its reproducibility, and lack of areal density-related errors (76). Some experts contend that this measurement is the most reliable in pediatric patients, especially during the pre-pubertal and early adolescent years (18,76). One study found spinal BMC measurements by axial quantitative computed tomography (QCT) and DXA (77) to be highly correlated ($R^2 = 0.94$). In a recent meta-analysis of 10 pediatric fracture studies, each case-control studies, Clark et al. found BMC by DXA to be a reasonable predictor of fracture in healthy children (standardized mean difference −0.26; 95% CI: −0.40 to −0.11, $p < 0.001$, in those with fractures, compared to controls) (78). Bone area (cm^2), as derived by DXA, can also be monitored separately, in addition to changes in BMC and areal BMD. These

separate assessments enable a clinician to differentiate the effects of either an intervention and/or disease process on bone mineral accrual and bone size, which is especially useful in the context of a research protocol.

Accuracy and Precision. Precision is an indicator of the reproducibility of a measurement. Precision error can be expressed in terms of the least significant change (LSC), equal to 2.8 x % CV (% coefficient of variation) for the 95% confidence limit *(79,80)*, or root mean square standard deviation (RMS SD) in g/cm^2 of a set of measurements *(80)*. The RMS SD is the ISCD-recommended form of expressing precision error. Both short- and long-term precision are important to consider in performing DXA measurements *(18,79)*. Short-term precision may reflect errors in either the acquisition or analysis of DXA data, or those directly related to patients *(81)*. Examples include the imprecision of the scanner itself (manufacturers report this to be less than 1%) *(18)*, and that resulting from variation in patient positioning and motion artifacts (typically less than 2−3% at the spine, up to 5% at the hip, and 1−2% for the total body) *(82−84)*. Short-term precision also varies with each technologist and should be assessed using a repeated measures procedure *(80,85)*. Long-term precision reflects potential machine drift, which can occur with any scanner. As with short-term precision, this type of precision may reflect errors in the acquisition or analysis of data, and patient-related errors. For example, a patient could develop a neurological disease that worsens over time, with motion artifacts introduced on later scans from the inability to remain still. It is important that the technologist regularly review quality control scans of phantoms daily, graphing results over several week periods to monitor for this problem *(86)*. Recent preliminary data showed that the DXA precision of adolescents (expressed as the %CV) is similar to published adult values, but the %CV of young children was higher *(44)*. In adolescents age 14−16, the mean %CV was 0.66, 0.64, and 1.19 at the total body, lumbar spine, and femoral neck, respectively. In the children studied, ages 6−9, the mean %CVs were 1.20, 1.03, and 1.82 at these same skeletal regions, respectively.

Discussion

Many of the same principles apply when obtaining DXA scans in children as those in adults. The clinician interpreting the scans must be knowledgeable about both the process by which the numbers were generated and ensure that meticulous technique was used. The clinician should also be familiar with the precision and accuracy of this technique, and again be familiar with the concept of LSC. The magnitude of change required to be statistically significant varies with the precision of the measurement technique *(79,80,85)*. To interpret serial measurements accurately, a clinician must know the LSC at the facility in which the areal BMD measurements are performed. If the observed change equals or exceeds the LSC, one can be reasonably confident that true bone loss or gain has occurred in a given patient. However, if the LSC has not been equaled or exceeded, the patient can be informed that the changes observed in follow-up measurements are within the error of repeated measurements and may not be significant. These decisions have important implications for clinical care, including dictating whether new therapies are initiated, or ongoing ones discontinued. As detailed below, the application of LSC assessment in children and adolescents is complicated by changes in bone mass due to interval growth. That is, the gain in bone mass may exceed the LSC, even if the gain is less than expected given the interval increase in age or height.

The LSC can also be used to guide the timing of follow-up measurements. Children and adolescents, unlike adults, are growing and the regions of interest (ROIs) will change constantly. The mean growth velocity of a healthy child averages a steady 5−6 centimeters per year (cm/yr) until puberty when peak height velocity occurs, averaging 8.3 cm/yr in girls and 9.5 cm/yr in boys *(87)*. Peak height velocity occurs at a mean age of 11.5 yr in girls and 13.5 yr in boys *(87)*. The most rapid gains in bone mineral occur during the pubertal growth spurt, but lag behind peak growth velocity by several months *(1)*. Chronic illness may significantly inhibit both growth and puberty, thereby compromising the normal building and remodeling of the skeleton, with the potential to compromise peak bone mass *(3,4,88)*. At the present time, as for adults, repeat scans should generally be obtained within 1−2 yr for clinical purposes, and in some settings, such as a patient in a research study and/or who is receiving a therapeutic skeletal agent, every 6 mo *(18,89,90)*. The shorter 6-mo interval may reveal trends in skeletal losses or gains, reflecting variations in bone turnover from either a chronic disease or an intervention, but ones that are not yet clinically significant.

Monitoring time interval (MTI) estimates the duration (yr) between two areal BMD measurements during which 50% of the population changes more than the LSC. This concept is important to consider in planning longitudinal follow-up areal BMD measurements. There are few data from which to estimate the MTI for children. In 1554 healthy children, ages 6−16 yr, Wong et al. showed that the shortest MTIs were at the anterior-posterior (AP) spine (MTI 0.2−1.1 yr), and were longer at the femoral neck and distal third of the radius (0.6−4.3 yr). MTIs at the spine were shortest at any age, a finding seen in both girls and boys *(91)*.

A complete understanding of precision, and the terminologies LSC and MTI, is important for clinicians who order and interpret skeletal assessments by DXA. Familiarity with these terms also leads to a better appreciation of why lumbar spine and total body were chosen as the appropriate sites for skeletal monitoring in children and adolescents.

What is the Best Method for Reporting Areal BMD in Children; What Corrections Should be Made for Bone Size, Height, Lean Body Mass, Skeletal Age, or Pubertal Stage?

ISCD Official Positions

- In children with linear growth or maturational delay, spine and TBLH BMC and areal BMD results should be

adjusted for absolute height or height age, or compared to pediatric reference data that provide age-, gender- and height-specific Z-scores.

Grade: Good-A-W-Necessary

Rationale

The areal BMD Z-score, standardizing bone density with respect to age, is currently the central element used in the interpretation of DXA results *(3,4,49,81,98)*. The Z-score cannot be used for diagnostic classification (as a T-score in adults), but it affords a comparison of a child's DXA result with respect to age-matched peers. Alternatively, the Z-score can be used to express comparison to peers matched for height or other measures. This practice has been suggested because growth and maturation greatly influence bone density results, and many children with chronic medical conditions who are likely to undergo bone density testing have delayed growth and maturation. In general, results must be interpreted in terms of relevant patient factors that influence the numeric DXA result. These variables include gender, ethnicity, height, weight, body composition, and pubertal development *(20,49,97)*. The most appropriate way to express bone densitometry results in growing children will vary depending on the specific clinical profile of the child, and the type and/or number of adjustments used will depend upon reference data available *(65,66,92)*.

Bone Size. The greatest challenge in the interpretation of pediatric DXA measurements is an adjustment for the influence of bone size, as both BMC and areal BMD are highly influenced by skeletal dimensions *(99–103)*. A recent pediatric study, comparing spinal areal BMD measurements obtained by DXA to volumetric measurements by quantitative computed tomography (QCT) (which was considered the gold-standard), highlights the errors that can occur with DXA unless bone size and body composition are considered, especially in subjects below the fifth percentile for height or weight. Wren et al. examined the diagnostic test characteristics of DXA Z-scores, compared with spinal QCT *(104)*. In 400 children, 200 who were healthy and 200 who had a chronic disease, DXA areal BMD Z-scores less than −2.0 SD predicted QCT Z-scores below −2.0 SD with moderate sensitivity (72%), specificity (85%), and negative predictive value (98%), but the positive predictive value was low (24%). That is, among children with DXA areal BMD Z-scores less than −2.0, only 24% had QCT Z-scores less than −2.0. The over-diagnoses of skeletal deficits by DXA were most pronounced in children with chronic disease in whom short stature resulted in an underestimate of BMD. Many more subjects were classified as having a low bone density by DXA than QCT.

To circumvent the confounding effects of bone size, mathematical models have been developed to estimate volumetric BMD in growing children, although there is debate over the validity of their underlying assumptions regarding bone shape *(99–101)*. One of the most commonly used methods is calculation of bone mineral apparent density (BMAD) *(99)*. BMAD of the spine is calculated as BMC (L_1 - L_4) ÷ $Ap^{1.5}$ where Ap is projected area from DXA measurements of areal BMD. This relationship was based on the empiric observation that spine BMC increased as a function of bone area to the 1.5 power in children. Femoral neck BMAD is calculated as BMC $_{(\text{femoral neck})}$ ÷ Ap^2 *(99)*. Validation of Carter's BMAD calculation comes from studies comparing BMAD to volumetric BMD determined by QCT. BMAD was correlated with volumetric BMD measurements by QCT *(104)*, with higher correlations noted among adolescents at Tanner stage 4–5 ($R^2 = 0.56–0.60$) vs Tanner stage 1–3 ($R^2 = 0.13–0.27$). Using the method of Carter et al. *(99)*, BMAD at the spine was moderately correlated with a direct volumetric BMAD measurement by QCT ($R^2 = 0.49 - 0.55$) *(104)*. In another study, Jones et al. examined 321 subjects with upper extremity fractures vs 321 healthy controls and found that the only DXA variables that were consistently associated with fracture risk in both boys and girls were spine areal BMD and BMAD for total upper limb fractures, and spine and hip BMAD for wrist and forearm fractures *(40)*. Kroger et al. *(100)* also proposed a method for the estimation of volumetric BMD using an underlying assumption that bone is a cylinder or ellipse. Estimated volumetric BMD at the femoral neck was calculated as: areal BMD x (4/π x (height of measurement area/measurement area of femoral neck). At the spine, the formula is areal BMD x [4/(π x width of lumbar measurement area)], width defined as the mean width of the second to fourth lumbar vertebral body. Lastly, multiple regression analyses to adjust total body BMC for body size have also been proposed *(65,66,76,92,93,102)*. None of these methods to estimate volumetric density has been tested longitudinally against the outcome of predicting childhood fracture, so the best estimate has not been yet established.

Alternatively, Molgaard proposed a three-step approach which takes into account multiple measures of growth and development, which may have some useful clinical applications *(92)*. This method assesses whether bones are the appropriate size for age by looking at: height for age (short bones); bone area for height (narrow bones); and whether they are appropriately mineralized for their size, BMC for bone area (light bones) *(92)*. This approach is provided as an analysis option on some GE Lunar scanners. However, it was subsequently suggested that a drawback of this approach was ignoring the substantial impact of lean mass on bone mass *(66)*, with significant gender differences noted in this parameter *(20,65,66,97)*. Whereas few studies have shown that correction for bone size parameters normalizes BMC in children with low bone mass, such as children with HIV *(105)* and other chronic illnesses *(106,107)*, it is not clear that such adjustments prove the structural integrity of bone in these children. Indeed, small body frame (i.e., small bones) is a predictor of fractures, at least in adults *(108)*. Therefore, unless there is evidence of structural integrity, such adjustments may be misleading.

There are specific clinical scenarios for which the Molgaard approach could be problematic. An important principle is that in the adjustment of areal BMD for bone area, the

child's height must be considered. Bone area as generated by DXA is a function of two dimensions: width (e.g., periosteal circumference), and length. A tall child with narrow bones will have the same bone area as a short one with broad bones. Thus, it would be inappropriate to expect both children to have the same BMC because they have the same bone area. Data from two studies support this point. First, DXA whole body BMC-for-bone area Z-score has no correlation with cortical volumetric BMD as measured by peripheral quantitative computed tomography (pQCT) *(107)*. Second, Leonard et al. studied obese children who have markedly increased bone area for height ($p < 0.001$), compared to lean children *(109)*. These overweight children were also found to have a markedly decreased BMC relative to bone area ($p < 0.0001$). When an obese child was compared to a lean child with the same bone area, the obese child was compared to a lean child who was significantly taller. Thus, the BMC for bone area in the obese child was low because one was expecting an obese child to have the same BMC as a child who was much taller. Another clinical example is assessing BMC for bone area in a child with chronic illness compared with a healthy control subject. The ill child will be expected to have a low bone area for height (narrow bones). When one then assesses BMC in the ill child, compared to a control with the same bone area, one is comparing the child with the chronic illness to a control who is shorter (i.e., same bone area, but secondary to the shorter height). Clark et al. *(43)* also showed that BMC adjusted for bone area, as well as height and lean mass, provided the best fracture discrimination. These illustrations support the conclusion that consideration of BMC for bone area has value, but only if corrected for height. Given the importance of height in the assessment of whole body BMC and areal BMD, numerous investigators have proposed prediction equations for whole body DXA results that incorporate height *(65,66,76,93)*.

Bone Age. Bone age assessments, in conjunction with measurements by DXA, have been suggested as an approach to adjust for factors related to growth and puberty. Bone age corresponds to pubertal maturation and is closely linked to the adolescent growth spurt, taking into account normal biological maturation in the evaluation of BMC or areal BMD the *(3,4,49)*. However, the expertise of the individual determining the bone age is of critical importance. In addition, it is noteworthy that there are certain conditions where bone age and height are asynchronous, such as genetic short stature or syndromes where children can be extremely short, but bone age is typically normal. Therefore, caution should be used with this maneuver as bone age may not correct for bone size in this setting. DXA-derived bone age films have also recently become available *(110,111)*. Evaluating skeletal maturity via this method appears to involve less radiation exposure than standard radiographs, with results that appear to be comparable to the standard method.

In the United States (US), the Greulich and Pyle method is used most frequently for bone age evaluation *(112)*. Outside of the US, the Tanner-Whitehouse II method is commonly used *(113)*. There are no published BMC or areal BMD reference data relative to bone age for either system, but in healthy children, bone age has been found to predict spine areal BMD by DXA ($r = 0.893$, $p < 0.001$), in 135 healthy Caucasian children, age 1−15 yr *(114)*. Zemel et al. *(115)* have shown that in healthy children, bone age was a better predictor of cortical volumetric BMD as measured by pQCT than chronologic age. In 159 children-studied using pQCT radial and tibial measurements at baseline and 12 mo, R^2 values for cortical volumetric BMD at the tibia increased from 0.19 to 0.31 for males, and from 0.61 to 0.70 for females, when bone age was used rather than chronologic age. R^2 values for cortical volumetric BMD at the radius increased from 0.37 to 0.40 for males and from 0.70 to 0.78 for females when bone age was used. A delayed bone age was shown in another study to be associated with fracture *(36)*. In some clinical conditions associated with a delayed bone age (e.g., multi-hormonal pituitary deficiency), it appears to be reasonable to adjust DXA areal BMD for bone age instead of chronological age *(111)*. In one study, such patients who had low Z-scores (< -1) had a delayed bone age with respect to chronological age. After recalculation of areal BMD data according to bone age, a marked increase in Z-score was noted *(111)*. Ideally, the clinician would have the scanner option to adjust DXA data for skeletal maturation in those clinical scenarios deemed appropriate. An example is a 15 yr-old adolescent boy with a history of a brain tumor who has received craniospinal irradiation after surgical resection of the lesion. He has deficits of multiple pituitary hormones, and a low areal BMD in the setting of short stature and pubertal delay. Interpretation of areal BMD with respect to his delayed bone age in this adolescent avoids an overestimation of his skeletal deficits. If a child has both low bone age and bone mass, the skeletal deficits may be secondary to the compromised bone age. If one adjusts for bone age, the bones will look ''normal,'' but in reality are not. Ideally, one should report the unadjusted bone result to show that the bones are weak, and then use the adjusted result to suggest that the deficit may be related to the maturational deficit. However, it is important to underscore that there remain gaps in knowledge as to whether these adjustments assist in fracture risk prediction.

Problems that arise using an adjustment for skeletal age must be considered. Mora et al., using the Greulich and Pyle method, showed that the variability between skeletal and chronologic age was significant and varied by ethnic group in a sample of healthy American children *(116)*. Zemel et al. noted a significant discrepancy between chronologic age and bone age among a cohort of healthy American boys and girls, concluding that the US standards for bone age are not well-matched to maturation rates of contemporary children *(117)*. These data suggest that the standards need to be revised to incorporate ethnic differences, and a pattern of earlier growth and pubertal development (e.g., earlier pubertal maturation, especially among certain ethnic groups). A clinician must also consider that the distribution of BMC or areal BMD values for bone age is unlikely to be the same as that for chronologic age *(49)*, as accounting for skeletal maturation may decrease the variability. Thus, a one standard

deviation unit change in BMD when scaled to bone age may be smaller than a one standard deviation unit change scaled to chronological age. This is especially important for children with obesity or a chronic disease, scenarios associated with advanced or delayed bone age, respectively *(49,118,119)*. The rising prevalence of overweight and obesity may contribute to the differences that have been recently noted between chronologic and bone age. In contrast, a chronic illness like Crohn's disease can delay bone age. However, when bone age was substituted for chronological age in the calculation of BMD Z-score, one study in children with inflammatory bowel disease found that this approach only affected findings significantly when there was a discrepancy between bone age and chronological age of more than 2 yr *(119)*. When deciding whether it is appropriate to adjust an areal BMD measurement for bone age, these issues should be carefully considered.

Pubertal Stage. Densitometry data can also be adjusted for pubertal status since both growth and puberty influence bone accretion, and both influence body size, skeletal maturation, and bone mineral accrual. Few studies have included Tanner stage or gynecologic age as a primary factor in their normative datasets *(5,21,120–122)*. There are no guidelines regarding how to account for pubertal stage in the evaluation of DXA results, although the presence of advanced or delayed puberty is an important consideration in the interpretation, especially in the case of a chronic disease, which can delay both pubertal maturation and bone accretion *(52)*. Although some studies suggest that pubertal staging by a trained clinician is significantly more accurate than self-assessment by teens *(123)*, self-assessments are nonetheless used in many bone density centers, especially when a full examination is not possible *(124,125)*. At the present time in clinical practice, information on pubertal status can be considered in attempting to understand a bone density measurement or change in areal BMD over a given interval. Actual correction for pubertal stage is generally reserved for research studies.

Height Age. For clinical purposes, substitution of height age for chronologic age is sometimes used in the calculation of areal BMD Z-score. Height age is defined as the age at which the child's height is the median height, and is most readily estimated by determining the age at which the fiftieth percentile on the height-for-age growth curve corresponds to the subject's height. However, this approach can be problematic as use of height age may force a comparison with a developmentally inappropriate age group. This practice is especially worrisome if a short pubertal child is compared to a pre-pubertal child, highlighting the critical role of pubertal development on bone accretion during adolescence *(3)*. This point is underscored in the study of Saland et al. who showed that the prevalence of a low bone mass in pediatric renal transplant recipients varied depending on the method of analysis used *(126)*. When BMD was interpreted with respect to height age rather than chronologic age, the prevalence of ''osteopenia'' was significantly lower. Height age adjustment increased the areal BMD Z-score of the pubertal patients more than pre-pubertal patients (mean increase $= 1.8 \pm 0.9$ vs 0.9 ± 0.7 SD, $p < 0.01$) *(126)*. However, the clinician should be aware that adjusting for absolute height when interpreting the BMD of two adolescents of the same pubertal status, but with different heights, would be an appropriate maneuver.

Body Composition. There are strong associations between indices of body composition and bone mass measures, with a differential impact in the relative effect of lean mass and fat mass on such measures between gender groups *(97,127)*. Several studies have shown that there is a high correlation between muscle mass and bone mass in children *(20,49,66,97,128,129)*, consistent with the functional bone-muscle unit theory, and with the fact that taller children have greater bone mass and muscle mass. There are also gender differences when adjusting for lean mass *(20,49,64,66)*, and lean mass strongly correlates with bone size, height, and pubertal stage.

There are recent studies suggesting the use of total body BMC to lean body mass (BMC/LBM) ratio as a relative bone strength index for fracture risk estimation in children *(49,63,130,131)*. Crabtree et al. proposed a two-step algorithm to investigate the relation between LBM and BMC in child with chronic disease. The first step evaluated LBM for height, and stage 2 BMC for LBM. Children studied with spinal muscular atrophy had a low height Z-score ($Z = -1.8 \pm 1.4$), but mean BMC/LBM Z-score of 1.2 ± 1.3, indicating that sarcopenia was their primary abnormality. In contrast, children with osteogenesis imperfecta had a normal LBM Z-score of $+0.4 \pm 1.7$, but mean BMC/LBM Z-score of -2.5 ± 1.8, confirming a primary bone abnormality *(65)*. The data reported by both Crabtree et al. *(65)* and Pludowski et al. *(63)* support the concept that reduced amounts of BMC for a normal LBM may be associated with increased risk for fracture, at least in children. Crabtree et al. studied a third group of British children with fragility fractures and found that BMC by DXA was lower than expected for the normal LBM noted in this group *(65)*. It was found that British children with fractures of mixed etiology had Z-scores of: -1.9 ± 1.5 for the total body BMC/LBM ratio. Likewise, Pludowski et al. noted BMD Z-scores below -2.0 for the total body BMC/LBM ratio in both boys and girls in a study of children suffering from acute stage of IJO *(63)*. The magnitude of disturbance between bone and muscle tissue was suggested by the correlation between bone pain, and both metaphyseal and vertebral fractures. In contrast, during recovery from IJO, the muscle-bone relationship tended to normalize, yielding improved Z-scores of -1.07 ± 0.99 and -1.15 ± 1.40 for BMC/LBM ratio in girls and boys, respectively. The marked increase in BMC/LBM ratio observed during recovery from IJO coincided with lack of bone pain and new fractures. In contrast, in another study comparing whole body measurements by DXA and tibial strength surrogates by pQCT *(107)*, neither DXA bone area for lean mass nor BMC for lean mass correlated with pQCT cross-sectional area for length or strength-strain index

(SSI) for length. DXA BMC for bone area was weakly associated with pQCT SSI for length, but in females only. DXA BMC normalized for bone area and lean mass were identified as poor indicators of bone strength.

Regression of BMC against lean mass can be carried out in contrast to calculation of the BMC/LBM ratio. Ratios can be problematic especially when comparing variables in which the slope is not 1.0 and the intercept is not 0. A useful approach, especially in studies of children with chronic illness, is to regress BMC against lean body mass. This maneuver has the advantage that height can be included in the regression. A study of patients with Crohn's disease used this approach *(13)*, and prediction equations for total body BMC relative to lean mass and height have been published *(65)*.

Discussion

When considering the most appropriate way to express bone densitometry results in growing children, there is no single adjustment paradigm that fits all scenarios, and the type and/or number of adjustments used will vary depending on the specific clinical profile of the child. The utility of selected adjustments depends upon having appropriate reference data available to serve as a comparison *(65,66,92)*. Lastly, it must be considered whether the adjustment tools are being applied in a chronically ill vs healthy child, and/or whether the tools may afford information on disease-specific factors, as was suggested by a recent algorithm that incorporates age, ethnicity, height, weight, and bone area *(93)*. Consideration should be given as to whether the purpose of the adjustment is to understand the etiology of the low bone mass (e.g. short stature for age, or small bone area), or to assist in the prediction of fractures. A serial approach may be useful in the assessment of bone mass and density to help understanding the etiology of low bone mass and density. However, without validation of such adjustments against a gold standard outcome (e.g., a clinically significant fragility fracture as opposed to the usual fractures of childhood), it is not possible to conclude which adjustments are the most appropriate. Indeed, studies that have measured bone mass in children with fractures, the majority of which were conducted in otherwise healthy children, have not implemented such adjustments *(25–27,32,33,43,94–96)*. As is increasingly becoming apparent, fracture is also highly dependent upon bone size, geometry, architecture, and quality; each a factor that affects bone strength, and may be independent of an areal BMD measurement by DXA.

In general, results must be interpreted in terms of relevant patient factors that influence the numeric DXA result. There is a lack of consensus regarding which combination of these factors provides the most accurate assessment of skeletal status. A major limitation is lack of reference data that adjusts for different patient factors. Use of bone age or height age instead of chronological age may be useful in situations of growth and maturational delay in the absence of reference data to account for height or maturation. Information on pubertal stage is most useful for aiding the clinician in interpretation of results rather than for standardizing measurements. The utility of BMAD measurements again depends upon having suitable reference data.

There is need for more research regarding the interactions between body composition and bone, and how these interactions differ in an ill vs healthy child. Contradictory conclusions of studies in this area must be resolved before a recommendation regarding use of BMC/LBM can be endorsed. As discussed, inclusion of lean body mass in regression models can be a useful maneuver that also allows for concurrent adjustment for height. In general, an adjustment for LBM may help a clinician understand the etiology of skeletal deficits. For example, if a child has both low muscle and bone mass, the skeletal deficits may be secondary to the compromised muscle mass and/or bone. If one adjusts for muscle, the bones will look "normal," but in reality are not. One should report the unadjusted bone result to show that the bones are weak, then use the adjusted result to suggest that the deficit may be related to the muscular deficits. However, it is important to underscore that there remain gaps in knowledge as to whether these adjustments assist in fracture risk prediction.

What are the Most Appropriate Normative Databases for use in Childhood?

ISCD Official Positions

- An appropriate reference data set must include a sample of the general healthy population sufficiently large to characterize the normal variability in bone measures that takes into consideration gender, age and race/ethnicity.
  Grade: Good-A-W-Necessary
- When upgrading densitometer instrumentation or software, it is essential to use reference data valid for the hardware and software technological updates.
  Grade: Good-A-W-Necessary

Rationale

There is a lack of consensus regarding the demographic and physiologic factors that should be incorporated into a normative database. "Ideal" characteristics of reference data were considered, including what constitutes an ideal sample and how the data would be modeled in the statistical analysis *(132)*. Some characteristics of the ideal sample include: sample of healthy youth (normal growth and development, and free of illness, medication, or lifestyle limitations); representative of the general population; multi-regional, to address local differences in ethnicity and lifestyle; and sufficiently large to capture variability due to gender, age, and race/ethnicity.

How reference data are modeled mathematically is important in order to capture the nonlinearity of gains and the increased variability with increasing age (heteroscedasticity) *(132)*. The most common approach to characterize reference data is to define the mean and a standard deviation. However, when the distribution of values for a given age are skewed, it is inappropriate to use the standard deviation to characterize the variability. Furthermore, variability is not fixed and

increases with age and puberty. Some statisticians recommend transforming bone mineral data using parametric regression modeling *(76,133)* as has been used previously *(134)*. This technique becomes particularly important when a large data set is not available for more data intensive techniques. The LMS method *(135)* has also been proposed and is more appropriate when data are both skewed and heteroskedastic. The LMS method uses a power transformation to normalize data. The optimal power to obtain normality is calculated, and the trend is summarized by a smooth curve (L). Smoothed curves for the mean (M) and coefficient of variation (S) by age are acquired, and these three measures are used to describe the data distribution. The disadvantages of the LMS approach are that it requires large amounts of data, and that multiple adjustments (e.g., age and height) cannot be made simultaneously.

At the present time there are few DXA reference data sets in children that capture all of the above characteristics. The Bone Mineral Density in Childhood Study funded by the US National Institutes of Health was designed to meet the majority of these ''ideal'' characteristics and has obtained longitudinal data on a multi-ethnic cohort of 1554 children in the US *(70)*. Reference data for children 7−17 yr of age are available for several skeletal sites. The sample was selected to include a large number of healthy children using a common protocol. Given the paucity of pediatric reference data to date, results from this study are an important contribution to the densitometry field. However, its applicability to children and adolescents outside of the US will have to be monitored. Another limitation is that these data were derived solely using Hologic scanners. These data show the age-related changes in BMC and areal BMD, especially variability and skewness that will be critical for designing studies on other manufacturers DXA devices. How and if these data can be extrapolated for other types of DXA systems (e.g., using conversion equations) deserves consideration and potential investigation.

Basic points that need to be considered when choosing a reference database include using normative data collected with the same model and software version as that being used for the patient, and the importance of gender-specific norms as the BMC and areal BMD of girls and boys differ, especially at different ages and stages of puberty *(136)*. Because the absolute value for areal BMD is lower in young children compared to that of a healthy adult, software analysis has been modified for children to improve edge detection of lower-density bone at some sites *(18,98,132)*. The ability to measure these parameters using standard adult analysis software may be problematic. As such, the manufacturers have developed specific analysis algorithms for edge detection in young patients, specifically children with low areal BMD. These algorithms have been validated in healthy, obese, and chronically ill children for assessment of spinal areal BMD *(137)*. It has been suggested that normative pediatric data be collected using the low-density analysis routinely in children, with the DXA report stating which algorithm (pediatric or adult) was used *(81)*. Newer low-density software, Hologic Auto-Low, uses an algorithm that detects bony landmarks and gives a much more complete picture of the spine. Auto-Low software for the whole body uses a different algorithm for the detection of bone, based on the subject's weight. As shown by Shypailo et al., if the child's weight is greater than 40 kg, results are not significantly different from those generated using adult software *(138)*. However, this group illustrated the large magnitude of the effect in smaller children who are below this weight threshold: among children weighing 10 kg, the new software resulted in a 25% lower total body BMC compared with the prior version *(138)* (Figure 1). In selecting reference data, it is essential to use norms collected on DXA equipment from the same manufacturer because of systematic differences between scanners *(18,132,139)*. In addition, data should be collected using the same software version for a given patient. Errors may arise if reference normative data from one type of scanner are used to interpret areal BMD data from a machine of a different manufacturer. Furthermore, it is important to use the same norms when doing serial studies. It is noteworthy that many software revisions do not appreciably impact the bone and body composition results. However, revisions, such as the implementation of the auto-low spine and whole body software algorithms, resulted in dramatic changes in results, especially in smaller and younger children. Therefore, it is important to ensure that reference data remain appropriate when instrumentation or software changes occur.

Pediatric software for GE Lunar scanners have the ability to make corrections using the Molgaard method and the lean body mass method *(92)* directly by the scanner. Owners of machines from other manufacturers can apply either the method of both Molgaard *(92)* or Carter *(99)*, but the calculation has to be performed manually.

Discussion

The ISCD Official Positions regarding appropriate reference databases for pediatrics include new criteria and expand upon other concepts considered in prior positions for adults. Most important is the need to recognize differences and changes in machine specific software used to analyze pediatric DXA scans. This issue is critically important for pediatrics as the range of BMC and areal BMD results is large. As a consequence, different thresholds historically have been used to detect the bone edge in pediatric scans to ensure that all of the bone is included. However, this has caused problems in situations when scans analyzed with one software version have been compared to reference databases that have used scans analyzed with a different software version. Clinicians interpreting scans must be cognizant of the software version used, and monitor the impact of future changes on BMC and areal BMD results.

Use of locally collected norms that reflect the genetic potential and environmental exposure of patients is often thought to be ideal. However, collecting sufficient numbers of children to adequately characterize the variability in bone mass and density is difficult and costly. Thus, many clinicians depend on normative data collected by others. There are several existing databases that include children and adolescents from differing geographic regions and of varying ethnicities. Table 1 represents a recent compilation of pediatric reference

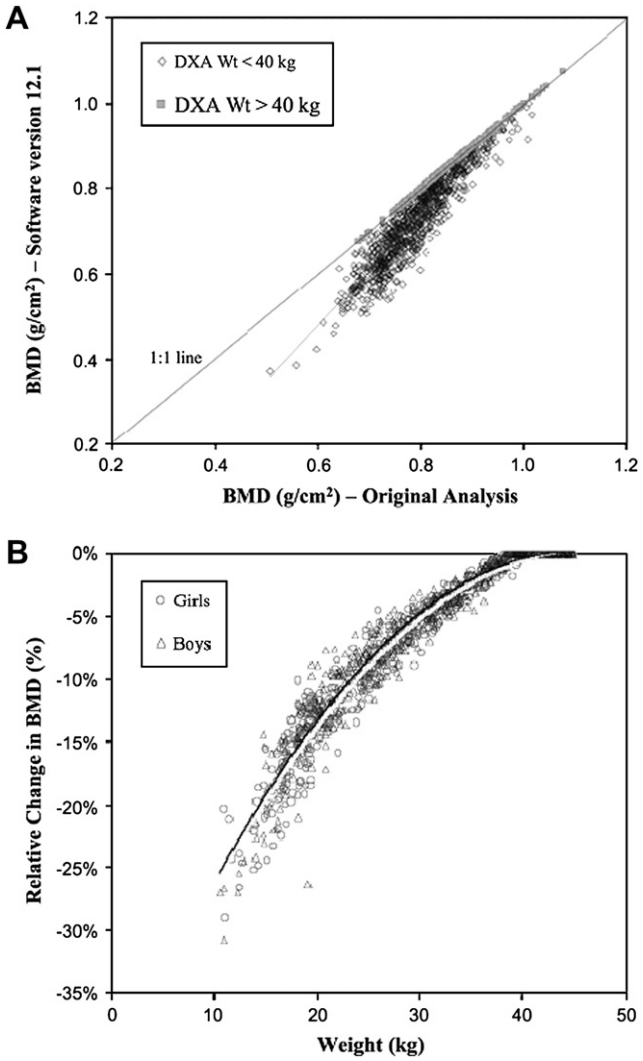

Fig. 1. The newer whole body software (Hologic, Inc., version 12.1) results in significantly lower estimates of whole body BMC compared with an earlier version 11.2 among subjects less than 40 kg body weight. Part (**A**) illustrates that BMD data from the two software versions are similar in subjects greater than 40 kg, whereas BMD results from version 12.1 are lower than those from version 11.1 among subjects weighing less than 40 kg. Part (**B**) illustrates that the percent decrease in BMD estimates with the newer software (compared with the original software) are progressively larger in children of smaller body weight. (From Shypailo RJ, Ellis KJ. 2005 Bone assessment in children: comparison of fan-beam DXA analysis. J Clin Densitom 8(4):445−453).

data sets available from the literature and the three primary DXA manufacturers *(5,20,21,65,66,70,71,73,74,76,92,93,97, 134,140−156)*. Data sets obtained in 150 or more children or adolescents are highlighted, excluding infants and toddlers. Outstanding pediatric reference databases include: the NIH database, ''Bone Mineral Density in Childhood Study,'' using a Hologic system, as mentioned *(70)*; the Dutch reference database *(154)* using a Lunar DPXL-PED system; the British pediatric reference data *(155)* using a Lunar Prodigy system; and the Argentina reference data *(156)*, using a Norland system. Thus, clinicians have several choices among reference databases to find one that is optimal for their patient population and type of DXA scanner.

What are the Elements That Should be Included in a DXA Report for a Child or Adolescent?

ISCD Official Positions

Baseline DXA testing

- Baseline DXA reports should contain the following information:
  - DXA manufacturer, model and software version
  - Referring physician
  - Patient age, gender, race/ethnicity, weight and height
  - Relevant medical history including previous fractures
  - Indication for study
  - Bone age results, if available
  - Technical quality
  - BMC and areal BMD
  - BMC and areal BMD Z-score
  - Source of reference data for Z-score calculations
  - Adjustments made for growth and maturation
  - Interpretation
  - Recommendations for the necessity and timing of the next DXA study are optional

Grade: Good-C-W-Necessary

Serial DXA testing

- Accurate interpretation of serial DXA results requires knowledge of the LSC for all sites measured and for all technologists at the DXA testing facility.
  Grade: Good-A-W-Necessary
- Should be done only when the expected change in areal BMD equals or exceeds the least significant change.
  Grade: Fair-B-W-Necessary
- Serial DXA reports should include the same information as for baseline testing, but additionally include:
  - Indications for follow-up scan
  - Comparability of studies
  - Interval changes in height, weight
  - BMC and areal BMD Z-scores adjusted or unadjusted for height or other adjustments
  - Percent change in BMC and areal BMD, and interval change in Z-scores
  - Recommendations for the necessity and timing of the next DXA study are optional

Fair-C-W-Necessary

Terminology

- T-scores should not appear in pediatric DXA reports
  Grade: Good-C-W-Necessary

Table 1
Normative Data for DXA in Pediatric Subjects[a]

Year of publication (Ref.)	DXA	Number	Age	Ethnicity	Sites
1991 (*5*)	Hologic 1000	207	9−18	White (Swiss)	Femoral neck, Spine (L2-4)
2002 (*74*)	Hologic 1000/2000	256	3−18	White, black, other	Spine, proximal and distal femur
1999 (*134*)	Hologic 1000 Pencil beam	423[b]	9−25	Asian, Black, Hispanic, White	Femoral neck, total hip, total body, Spine (L2-4)
1997 (*92*)	Hologic 1000 Pencil beam	343	5−19	White (Denmark)	Total BMD, BMC, BA
1993 (*140*)	Hologic 2000 FB	234	8−16	White (Canada)	Lumbar and total BMC and BMD
1996 (*141*)	Hologic 2000 (array)	234[b]	8−17	White (Canada)	Femoral neck, total body, Spine (L1-4)
2001 (*76*)	Hologic 2000	982	5−18	White, Black, Hispanic	Total body (corrected for size)
2002 (*142*)	Hologic 4500	231	5−22	Mostly white	Total body BMC (tibial pQCT)
2004 (*97*)	Hologic 4500A	363	10−17	Arab/Lebanese	Spine, total body, femoral neck, distal third of radius
2004 (*20*)	Hologic 4500A	363	10−17	Arab/Lebanese	Spine, total body, femoral neck, distal third of radius (volumetric)
2004 (*73*)	Hologic QDR 4500 W	422[c]	12−18	White, black (USA)	Spine L2-L4, femoral neck BMD
2005 (*143*)	Hologic 4500	>1000	3−20	Unknown (USA)	Spine, total hip, whole body
2006 (*150*)	Hologic QDR 4500	345	2−18	Turkish	Spine, Femur BMD, BMDvol
2007 (*21*)	Hologic QDR Discovery	442	6−17	British	Spine, hip, total body
2007 (*70*)	Hologic QDR 4500	1554	7−17	White, black, Hispanic	Spine, hip, total body, forearm
2007 (*152*)	Hologic 4500A + Discovery A	179	3−18	Canadian	Whole body BMC + body composition
2007 (*153*)	Hologic 4500 A + Discovery	179	3−18	Canadian	Whole body, spine, proximal femur
1994 (*145*)	Lunar DPX-L	471	3 mo−21 yr	White (Spain)	Spine (L2-4)
1996 (*144*)	Lunar DPX	209	5−27	White (Australia)	Spine (L1-4), femoral neck, mid-shaft femur
1997 (*146*)	Lunar DPXL/PED	500	4−20	Dutch white, black, Asian	Spine, total body, BM, BMDvol
2001 (*147*)	Lunar DPX	255	6−14	White (Brazil)	Spine BMC and BMD
2002 (*154*)	Lunar DPXL/PED	444	4−20	White (Netherlands)	Total body, Spine (L1-4) body composition, BMAD, Tanner stages
2003 (*66*)	Lunar DPX	459	3−30	White	Total body (corrected for lean body mass)
2004 (*65*)	Lunar DPX-L Pencil beam	646	5−18	Unknown (UK)	Spine, total body (corrected for lean body mass)
2004 (*93*)	Lunar DPX, DPX-L	1218	6−18	White, black, Asian, Hispanic	Total body BMC, BMD
2005 (*155*)	Lunar DPX-L/GE or Prodigy	1508	5−18	White/Black/Asian	Spine, total body BMD and BMAD
2005 (*151*)	Lunar DPX -L	562	5−18	Polish	Spine, total body
1995 (*156*)	Norland XR-26	778	2−20	White (Argentina)	Whole body, spine, femoral neck, radius, trochanter
1998 (*148*)	Norland XR-26, Norland 278	179	12−13	Chinese	Spine L2-L4 BMD, distal radius (BMC)
2004 (*150*)	Norland XR-35	102	3−15	Turkish	Spine, femoral neck BMD

[a]The sex of all subjects is male and female, unless indicated otherwise.
[b]The number of scans included in these data bases exceeds the number of subjects because individuals were scanned repeatedly in these longitudinal studies.
[c]All subjects female.

- The term ''osteopenia'' should not appear in pediatric DXA reports
  Grade: Good-A-W-Necessary
- The term ''osteoporosis'' should not appear in pediatric DXA reports without knowledge of clinically significant fracture history.
  Grade: Good-A-W-Necessary
- ''Low bone mineral content or bone mineral density for chronologic age'' is the preferred term when BMC or areal BMD Z-score are less than or equal to −2.0.
  Grade: Fair-C-W-Necessary

Rationale

An appropriate pediatric DXA report should include information that identifies the patient, assists the interpreter in evaluating the scan, conveys the validity of the scan, and provides both clear scan interpretation and recommendations, where appropriate *(157)*. Questionnaires administered to patients at the time of scanning can provide valuable clinical information that will allow for a more accurate areal BMD interpretation. As there are sparse data regarding the relationship between a given areal BMD measurement by DXA and fracture risk in pediatric patients, caution should be used in making recommendations. Longitudinal changes in both bone measures (e.g., BMC and areal BMD) and Z-scores are important to highlight.

Items that should not be included in a DXA report

- Wording such as the ''patient has osteoporosis.'' The term ''osteopenia'' must also not be used as these two terms generate confusion when used in children, and the WHO criteria apply only to postmenopausal women. ''Low BMC or areal BMD for chronologic age'' (defined as BMC or areal BMD Z-score less than or equal to −2.0 SD) is a more appropriate term until more information is available.
- Never use T-scores in children and adolescents.

Discussion

The recommended elements of the DXA report represent a significant change from the standard reports generated by DXA machines historically. Importantly, inclusion of these elements better enables a clinician to interpret the results appropriately. Information on the technical aspects of the DXA scan is generally the same for adults and children. However, information on growth and maturation, processes unique to the pediatric age group, need to be considered to prevent erroneous interpretation that may results from either growth or maturational delay. The terminology ''T-scores'' and ''osteopenia'' cannot be used for children or adolescents since the WHO diagnostic classification was based on studies done on postmenopausal women. The use of T-scores in children, which compares the areal BMD of a child to that of a young adult, is particularly problematic and may result in severe clinical mismanagement of a child's bone health. Thus, they should never be used in a pediatric DXA report.

Additional Questions for Future Research

- Which DXA sites and various adjustments for lean mass, pubertal stage, height, and bone size (BMAD) best predict fracture in healthy children and children with chronic disease?
- How can available pediatric reference databases be kept up to date? How often should they be updated? What adjustments can be made when newer software versions become available?
- Is there a need to consider ''universal DXA units,'' considering the variability among scanners from differing manufacturers and that normative data is generally derived from one scanner type?
- What are the relationships between DXA measures of BMC and areal BMD in children and adolescents, peak bone mass, and the future risk of osteoporosis?
- Will revised bone age standards that incorporate ethnic differences and contemporary patterns of growth and pubertal development improve the interpretation of DXA results in children?
- Will the development of longitudinal pediatric DXA reference data improve the identification of children with impaired bone mineral accrual rates and risk of fracture?

Summary

The ISCD Official Positions on the interpretation and reporting of densitometry in children and adolescents represents an effort to consolidate opinions on which skeletal sites should be assessed, which corrections should be made in these assessments, appropriate pediatric reference databases, and the important elements to include in a DXA report. Opinions from pediatric bone health experts from around the world were elicited and a systematic literature search performed. Given the sparse data that are currently available in many of these areas, it is likely that these positions will evolve and change over time as new data become available. Further research is needed to expand upon and confirm many of the opinions cited in this position statement.

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