Pediatric DXA: A Review of Proper Technique and Correct Interpretation

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Accurate assessment of bone density in the pediatric patient differs significantly from bone density assessment in adults and is essential for preventing misdiagnosis and unnecessary treatment. This article reviews current indications, technique, and accurate interpretation of pediatric dual energy x-ray absorptiometry (DXA). Specifically, current methodology for acquisition of pediatric DXA, guidelines for precise and meaningful interpretation of results, and the most comprehensive pediatric normative database compiled to date, as well as its implications for DXA interpretation, will be discussed. Case reports will be provided for further study.

Introduction

The medical approach to assessing and managing low bone mineral density in pediatric patients is consistent with the osteopathic philosophy of treating the whole patient. Knowledge of the individual’s overall health, particularly with respect to chronic illnesses and/or risk factors that may predispose to impaired bone health and specific history of fractures, is essential for diagnosing and treating low bone density. Physicians, including radiologists who interpret pediatric DXA, must apply two major concepts: (1) identify current DXA indicators of pediatric bone health; and (2) accurately interpret these indicators for correct description of pediatric bone health. The radiologist’s knowledge of pediatric bone health indicators and accurate and informed interpretation of pediatric DXA results can contribute significantly to the bone health of young individuals over their lifespan.

DXA has traditionally been used to measure pediatric bone mineral density (BMD) and bone mineral content (BMC) and is still considered the gold standard for assessing and monitoring of pediatric bone health. The measurement of BMD

and BMC in growing subjects, however, presents a unique set of challenges, both technical and theoretical. Technical challenges relate to the patient’s positioning, the performance of the bone scan, and the analysis of data. Theoretical challenges are related to the identification of a suitable control population for the growing skeleton and to the interpretation of results to determine whether the patient’s bone status can be considered “normal.” The interpreting clinician must be aware that reportable measures and description of pediatric bone density differ significantly from adult DXA measures and reporting, as will be discussed in more detail, and that the diagnosis of osteoporosis in children and adolescents cannot be made based on densitometric data alone. This article reviews pediatric DXA and its measures as summarized at the 2007 Pediatric Position Development Conference (PDC), held in Montreal, Quebec, Canada, by the International Society for Clinical Densitometry (ISCD). 1

Indications

According to the ISCD, DXA is an appropriate tool for the monitoring of bone health in apparently healthy children with “clinically significant” fractures and as a part of the comprehensive skeletal health assessment in children and adolescents with disease states associated with an increased risk of fracture (Table). 1 The definition of a “clinically significant fracture” is as follows: long bone fracture of the lower extremities, vertebral compression fracture, or two or more long bone fractures of the upper extremities. 1

Epidemiologic studies indicate that the incidence of fractures, particularly forearm fractures, has shown an upward trend in children 2-5 with 27-40% of girls and 42-51% of boys sustaining
at least one fracture during growth. Of these individuals, up to one-third will sustain more than one fracture. Pediatric fractures occur most commonly in the peripheral skeleton, with some reports that forearm and wrist fractures are associated with low bone density in children. Still, these epidemiologic studies and other similar reports are insufficient for reliable or conclusive stratification of how BMD relates to fracture risk in growing children based on DXA bone density measurement alone. Though evidence does support the relationship between lower bone mass and increased fracture risk in apparently healthy children, there is less direct correlation between DXA results and fracture risk in pediatric patients than in adults. Consequently, the ISCD has concluded that in children and adolescents neither a diagnosis of osteoporosis nor associated fracture risk can be made on the basis of densitometric data alone, in contrast to how DXA data is utilized in the adult population.

### Disease States Associated with Increased Risk of Low BMD and/or Fracture

<table>
<thead>
<tr>
<th>Primary Bone Disease</th>
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<tr>
<td>Osteogenesis Imperfecta (OI)</td>
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<td>Idiopathic Juvenile Osteoporosis</td>
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<th>Secondary Bone Disease</th>
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<td>Chronic Illness / Inflammatory Diseases</td>
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<td>Cystic Fibrosis</td>
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<td>Gastrointestinal disease (IBD, celiac disease)</td>
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<td>Juvenile idiopathic arthritis</td>
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<td>Endocrine disorders (e.g., diabetes mellitus)</td>
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<th>Medical Therapies</th>
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<td>Glucocorticoids</td>
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<td>Anti-epileptic drugs</td>
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<td>Chemotherapeutic agents</td>
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<th>Immobilization States</th>
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<tbody>
<tr>
<td>Cerebral palsy</td>
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<td>Muscular dystrophy</td>
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<td>Other neuromuscular disorders</td>
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<th>Inadequate Nutrition</th>
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<td>Anorexia Nervosa</td>
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Table. Disease States Associated with Increased Risk of Low BMD and/or Fracture.

### Technical Aspects

#### Principles of operation.
DXA technique relies on the differential absorption of x-rays of two different energy levels to distinguish tissues of different radiographic density. At low energy (30-50keV), bone attenuation is greater than soft tissue attenuation, whereas at high-energy (greater than 70keV), bone attenuation is similar to soft tissue attenuation. Utilizing this data and a mathematical algorithm, bone mass, soft tissue mass, and bone mineral content can be quantified. DXA quantifies (in grams) the BMD and BMC at various body sites. Unlike other density measurements, however, the DXA-derived BMD is not a true volumetric measure, as it is based on the two-dimensional x-ray projected area of a three-dimensional structure (i.e., areal BMD). The third dimension, depth, is not directly measured because it is in the same direction of the x-ray. This fact contributes to inherent error in the DXA process (Fig. 1). In addition, growth of individual bones over time is not uniform in 3 dimensions. Consequently, inherent error caused by serial measurements of aBMD in the growing pediatric skeleton makes comparison of follow-up with baseline DXA studies more challenging to interpret in pediatric patients.

![Figure 1](image). Impact of bone size on DXA scan results. Smaller bones (e.g. cube A) will have lower areal BMD (aBMD) despite being equal in volume to larger bones (e.g. cube B). BMC, bone marrow content; BA, bone area; vBMD, volumetric bone mineral density.
DXA performance. Positioning the patient and selecting regions of interest (ROI) require precision by the technologist performing the scan and careful evaluation by the radiologist interpreting DXA results.\textsuperscript{15,18} The ISCD Official Position for DXA performed on children and adolescents (males and females 5-19 years) indicates that when technically feasible, the lumbar spine (LS) and whole body (WB) aBMD and BMC should be performed, as these measures are the most accurate and reproducible skeletal sites for performing aBMD and BMC.\textsuperscript{1} The lumbar spine should be straight and centered in the image, with the last rib pair and the upper sacrum visualized (Fig. 2). The ROIs are generated automatically using edge-detection software and are selected for the L1 to L4 vertebral segments. Artifact, including enteric tubes, orthopedic hardware, and jewelry should be excluded from the image if possible, as artifact contributes to false elevation especially of aBMD numeric results and Z-score for any ROI that includes such objects.

In contrast, the BMC value is not felt to be as affected by the presence of artifacts. If the artifact cannot be removed and obscures the spine, one vertebral body can be excluded and aBMD of the lumbar spine still considered a reliable measure. If evaluation of the spine is not feasible because of extensive orthopedic hardware or patient positioning issues, DXA of the forearm or distal femur may be performed and serve as a surrogate measure of aBMD.\textsuperscript{1,15} In growing children, the hip is not a reliable site for measurement of aBMD given the significant variability in skeletal development and lack of reproducible ROIs.\textsuperscript{1}

Pediatric DXA Interpretation. Z-score vs T-score: As with other laboratory tests, the numeric aBMD and BMC values generated are meaningless without comparison to the appropriate normal controls.\textsuperscript{15} Once a comparison is made to the normative database, as performed by software analysis, the reported pediatric DXA value is given as a percentile or a standard deviation score, the Z-score (Fig. 2). A Z-score of zero is equivalent to the mean, whereas Z-scores of -1 and +1 are equivalent to one standard deviation below and above the mean, respectively. It is important to understand, however, that the normative databases utilized for generation of Z-score vary according to DXA manufacturer. The largest database is that of Hologic systems, in which the most current software includes the normative database for children ages 5 through 23 years, as obtained during the Bone Mineral Density in Childhood Study (BMDCS).\textsuperscript{19}

The T-score that is used in adult interpretation of DXA should not be included in the pediatric DXA report. Because T-score reflects comparison to peak aBMD and BMC in adults, as based on the NHANES III study that incorporates normal values for adults within the age range of 20-85, and provides an indication of bone density loss since early adulthood, its use in children who have not yet reached peak aBMD is meaningless and may result in an inaccurate diagnosis of low BMD and/or unnecessary medical intervention.

Definition of Osteoporosis. As mentioned previously, the diagnosis of osteoporosis in childhood cannot be made, and associated fracture risk cannot be extrapolated, from the pediatric aBMD, BMC or their associated Z-scores as measured by DXA. The 2007 ISCD Official Position Statement dictates that the diagnosis of osteoporosis in children and adolescents cannot be made on the basis of densitometric criteria alone, unlike DXA interpretation in the adult.\textsuperscript{1} Because the World Health Organization’s DXA-based definitions of osteopenia and osteoporosis in adults are based on T-scores, T<-1.0 and T<-2.5, respectively, a different terminology is required for children. The preferred descriptive terminology is as follows. When aBMD or BMC Z-scores are between -1.0 and -1.9, “at risk for low bone mineral density or bone mineral content for chronologic age” is suggested. When aBMD or BMC Z-scores are less than or equal to -2.0, “low bone mineral density or bone mineral content for chronologic age” is suggested.\textsuperscript{1} The term “osteopenia” should never appear in pediatric DXA reports, and the term “osteoporosis” should not appear in pediatric DXA reports without knowledge of clinically significant fracture history. In the
pediatric population, osteoporosis is a clinical diagnosis and is reserved for those patients with an aBMD Z-score less than or equal to -2.0 in combination with a clinically significant fracture.¹

Limitations. In addition to the fact that DXA does not yield a true volumetric measure of bone density, limitations of DXA include (1) different normative reference databases for each manufacturer, which restricts cross comparison between systems and facilities in the case of patient care transfer; (2) the relative contribution of the head and skull to whole body bone density; and (3) limitations of the existing manufacturer normative reference curves that may not account for patient population homogeneity. The different DXA manufacturers (Hologic, Norland, and GE) utilize different pediatric normative database for generation of Z-scores.² Software upgrades within one system may incorporate newer and more up-to-date normative reference data, so it is prudent for the interpreting radiologist and clinician to know which DXA system and software are installed within the facility and which normative reference database is current for the software type. Since normative reference databases vary according to DXA manufacturer and software, data from two different systems cannot be simply interchanged in the case of patient care transfer to or from another facility (i.e., site specific aBMD and its interpretation as measured by Hologic may vary compared to aBMD as measured by Norland). There are, however, software programs with calculators available for purchase that can convert site specific aBMD from one DXA scanner to the next.

Though LS and WB aBMD and BMC are considered the gold standard measures for initial assessment and follow-up of bone density, the current ISCD Position prefers total body less head (TBLH) aBMD or BMC. Using this technique, the calvarium is excluded from whole body measures due to (1) the high contribution of the relatively static head to WB aBMD and BMC during growth of the remainder of the axial and appendicular skeleton and (2) the importance of the postcraniale skeleton in fracture risk assessment. Current reference data curves utilized by Hologic, however, are from the BMDCS, a large national cohort of children for whom standardized DXA measurements were obtained and from which standardized normative reference curves for aBMD and BMC of the total body to include head, lumbar spine, forearm, and proximal femur for children aged 7-17 years were generated. Therefore, although TBLH aBMD and BMC are suggested as the gold standard whole body measures, most software versions currently in use reflect inclusion of the head in total body aBMD and BMC Z-scores.

Another limitation of current DXA relates to the homogeneity of current normative reference curves, from which the Z-score is extrapolated from age matched controls based only on age and sex. There is, however, ongoing effort to further stratify normal reference curves based on height and ethnicity. For example, as greater aBMD and BMC levels in black versus non-black adults and children have been reported in prior studies using DXA, Zemel et al most recently generated extended black versus non-black normative reference curves for aBMD and BMC of the total body to include TBLH, LS, hip, and forearm following a multicenter longitudinal study.¹⁹ These new reference curves provide the most robust normative databases to date, provide some adjustment factors for height status, and are sure to be incorporated into next generation DXA software upgrades. Current studies are underway and future work remains to be done with reference to ethnicity and disease specific reference curves in order to facilitate improved characterization of pediatric bone health in specific populations.

Future Directions for DXA/Comparison to Other Modalities

The future of DXA includes expansion of reference curves not only for ethnicity and height but also to include larger normative databases for site specific measurement and for specific disease states. Currently, normative reference curves are available for the distal 1/3 radius and at the distal lateral femur for bone assessment in non-weightbearing patients such as those with cerebral palsy, muscular dystrophy, severe scoliosis in whom LS aBMD cannot be reliably measured, and spinal or body orthopedic hardware that falsely
elevates WB aBMD and limits accuracy of the data.\textsuperscript{15,21,22} When distal 1/3 radius or the distal lateral femur is measured in these patient populations, a Z-score is generated that can be used to infer risk for low aBMD and BMC at these locations.

Once primarily an investigational tool, peripheral quantitative computed tomography (pQCT) is a low dose CT measure of bone density being used increasingly in clinical practice for more accurate assessment of BMD and BMC. Benefits of pQCT include its ability to provide a true volumetric measurement since it is a three dimensional technique and its ability to distinguish cortical from trabecular bone, the latter of which is eight times more metabolically active.\textsuperscript{23} Disadvantages include the relative paucity of normative reference data for pQCT, as compared to the more comprehensive DXA reference databases, and the higher radiologic dose administered. pQCT also requires specific software algorithms for incorporation into standing CT systems that are not yet widely available. Though normative reference data are available for pQCT measurements of the appendicular skeleton in children, reference data for the axial skeleton are lacking. Radiologic dose of pQCT, though decreased by use of low dose CT, should still be expected to be higher than that delivered by standard DXA. The general estimated effective dose delivered to L1-L3 by pQCT is 1.0-1.5mSv\textsuperscript{21} versus an estimated total effective dose of 1 to 10 uSv for an entire DXA exam including lumbar spine and whole body scanning. In comparison, natural background radiation delivers approximately 5-8 uSv per day,\textsuperscript{15} a PA and lateral chest X-ray approximately 50-150uSv, and a diagnostic CT of the neck, chest, abdomen and pelvis in oncologic follow-up approximately 12-14mSv.

Peripheral quantitative ultrasound (pQUS) is less expensive, portable, and relatively easy to use. Although initially promising because it lacks radiation exposure, it is rarely used as a single modality for assessing skeletal health. Normative pediatric databases are even more limited than those for pQCT, and precision and reproducibility of pQUS may never reach that of DXA or pQCT due to much greater operator variability.

Clinical Case Studies
The following case studies are brief examples of common DXA examinations performed at Nationwide Children’s Hospital and illustrate the principles used in DXA interpretation:

**Patient 1** is a 14 year old male with myelomeningoceles, scoliosis, and a history of femur fracture. His WB aBMD was measured as 1.156 g/cm\textsuperscript{2} with a corresponding Z-score of 1.5. According to the manufacturer’s database, which accounts for age and sex, the patient’s WB Z-score indicates normal bone mineral density for chronologic age (Fig. 3a). Given extensive spinal hardware, however, which contributes to false elevation of aBMD and its corresponding Z-score, a distal forearm (FA) study was performed (Fig. 3b). The distal FA aBMD value of 0.408g/cm\textsuperscript{2} can be followed longitudinally to evaluate for interval change. Its corresponding Z-score of -1.7 more accurately reveals increased risk for low bone mineral density for chronologic age for this patient.

**Patient 2** is a 3 year old non-weight bearing male with a diagnosis of mitochondrial disorder and fracture. Technician notes identify the patient’s G-tube which overlies the left lateral margin of the L4 vertebral segment (Fig. 4 a). As the child is just 3 years of age, only a lumbar spine (LS) image was obtained. Because the patient’s G-tube partially obscures the L4 segment, the technician redrew ROIs to exclude this segment (Fig. 4b). Although the patient’s LS Z-score is markedly low both with and without inclusion of L4, note that exclusion of G-tube artifact does alter the Z-score value. Recall that it is acceptable practice to exclude one vertebral body segment in the case of confounding artifact in order to increase accuracy of data.

Example scanning technique
**Nationwide Children’s Hospital DXA Examination.** The typical scan includes the lumbar spine, total left hip, and total body for all patients. For children younger than 12 years, the hip is not scanned because of lack of well-controlled norms; in these patients, only scans of the whole body and lumbar spine are performed. In patients less than 4 years
Figure 2. DXA Performance. Frontal view of the lumbar spine demonstrates appropriate regions of interest (ROIs) along the margins of the L1 through L4 vertebral bodies. The lumbar spine is straight and centered within the image. The lowest rib pairs and upper aspect of the sacrum are within the field of view.
Figure 3. 14-year-old boy with myelomeningocele. Initial DXA image (A) demonstrates pronounced bony deformities as well as significant hardware throughout the thoracolumbar spine, which falsely elevates the aBMD and corresponding Z-score. Therefore, a distal forearm study (B) was performed, which shows increased risk for low BMD for chronological age.
Figure 4. 3-year-old non-weight-bearing boy with G-tube. Initial DXA (A) reveals a G-tube projecting over the left lateral margin of the L-4 vertebral body. Repeat analysis with exclusion of the affecting segment (B) results in a more accurate measure of BMD with a markedly decreased Z-score for age.
of age, only the lumbar spine is scanned. The manufacturer’s database (Hologic version 12.7.3) includes normative data that extends down to 3 years of age. In patients younger than 3 years of age and in patient populations for whom there is no reference database for generation of a Z-score, the aBMD and BMC of the lumbar spine are reported as absolute values for clinicians to use as baseline measurements and to follow longitudinally over time. For patients with an increased risk of vertebral compression fracture, including those with osteogenesis imperfecta, and patients with known low bone mineral density and known vertebral body fractures, a vertebral morphologic assessment is performed with a lateral scanogram. The distal 1/3 forearm scan is performed in patients with spinal hardware, as well as in non-weight bearing and sarcopenic patients who may have movement disorders such as cerebral palsy complicated by contractures, Duchenne Muscular Dystrophy, and Rett syndrome. The distal lateral femur scan is currently being integrated into our practice for the same patient populations, with current consideration given to the future incorporation of pQCT and pQUS.

Sample DXA Report
Note: the following can be used as a template for voice dictation.

TECHNIQUE
Utilizing Hologic Delphi technique and pediatric software analysis, regions of interest were drawn about L1 - L4, the total left hip, and the total body. [He or she] is [x] years of age. Additional technician notes include [e.g., presence of G-tube, VP shunt tubing, spinal or orthopedic hardware].

FINDINGS:
The bone mineral density of the lumbar spine is [x] g/cm2. The corresponding Z-score for this value is given as [z]. (Report T-score if given for patients >20 years of age)

The total body bone mineral density is [x] g/cm2. The corresponding Z-score for this value is given as [z]. (Report T-score if given for patients >20 years of age)

The total body bone mineral content is [x] grams.

(IF distal 1/3 radius or distal lateral femur values are given, report in same fashion).

(Report lateral scanogram findings, if performed)

The patient has [x]% body fat.

IMPRESSION:
1. Compared to the manufacturer’s database which accounts for age and sex, the patient’s bone mineral density is ...
2. When compared to the prior study, absolute values for bone mineral density as measured at [x] site have ...
3. When compared to the prior study, absolute value for the patient’s whole body bone mineral content have ...

Final Recommendations
Radiologists are assuming a more prominent role in pediatric DXA performance, interpretation and research, necessitating expertise with DXA as a radiologic procedure, a numeric result, and a clinical diagnostic examination. The radiologist who interprets pediatric DXA can be an advocate for children’s bone health and, by ensuring the appropriate clinical use of DXA, can contribute significantly to the bone health of young individuals over their lifetime.

References