Pediatric DXA: Bone Mineral Density and Body Composition

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Objectives

• To understand the technical aspects of DXA performance
• To be knowledgeable regarding pediatric DXA indications
• To become proficient in pediatric DXA interpretation
• To be knowledgeable of the pitfalls of pediatric DXA interpretation.
Objectives

- To understand the technical aspects of DXA BCA performance
- To be knowledgeable regarding pediatric DXA BCA indications
- To be familiar with the uses of DXA BCA in childhood obesity and anorexia nervosa.

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Increasingly, pediatricians are recognizing that low bone mineral density, BMD, can result from a wide variety of childhood diseases or be due to the effects of their treatment. Complications of osteoporotic fractures that occur late in life can be delayed or prevented by optimizing bone mineral during childhood and adolescence.
Introduction

Pediatric specialists are increasingly requesting evaluation of BMD and imagers are expected to be knowledgeable in the technique, interpretation and clinical applications of DXA.
Is the result of a DXA examination a number or a diagnosis?
Both!

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Introduction

Clinical pathologist monitoring the technical aspects of the DXA acquisition.

Statistician knowledgeable in the concepts of Z-scores and least significant change.

Bone specialist providing a meaningful clinical context for the numeric result.
Technique

How was the number obtained?

DXA = Dual energy X-ray absorptiometry

Differential absorption of photons based on radiologic density.

Source, Detector, Computer, Standards
Technique

How was the number obtained?

Bone mineral content, BMC(g)
Bone area, BA(cm$^2$)

$\text{BMC g} / \text{BA cm}^2 = \text{BMD g/cm}^2$
Because DXA uses bone area (a 2-D projection of a 3-D object, i.e. planar image), the BMD generated with DXA is termed areal BMD, aBMD, as opposed to the volumetric BMD generated with CT where a true 3-D bone volume is obtained.
Areal BMD and Bone Size

Because of this, smaller bones will appear to have lower BMD than larger bones.

This is a major challenge of pediatric DXA.
Why Bone Size Counts

vBMD = 1 gm/cm³

<table>
<thead>
<tr>
<th></th>
<th>1x1x1cm</th>
<th>2x2x2cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 cm³</td>
<td>8 cm³</td>
<td></td>
</tr>
</tbody>
</table>

The DXA bone area will reflect only one side of the cube.
Why Bone Size Counts

\[ \nuBMD = 1 \text{ gm/cm}^3 \]

<table>
<thead>
<tr>
<th></th>
<th>(a)</th>
<th>(b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMC</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>BA</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>(aBMD)</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

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Areal BMD and Bone Growth

A child’s bones grow over time and the growth of individual bones is not uniform in three dimensions. This further introduces errors with aBMD and can make comparison of follow up and baseline studies more challenging to interpret in pediatric patients. This is a second major challenge in pediatric DXA.
Bone Growth, X-ray Source Design and Magnification Effects

The design of the X-ray source can give rise to magnification effects which may introduce another technical challenge to pediatric DXA.

Fan-beam sources result in magnification artifacts which increase with increasing body size (growth) and decrease with marked weight loss (lap band for morbid obesity).
Bone Growth, X-ray Source Design and Magnification Effects

Hologic scanners use a wide fan beam source and cover the region of interest in a single sweep.

GE scanners use narrow fan beam sources and multiple overlapping sweeps to minimize magnification effects.
Transverse Fan Beam

...Use of Overlapping Beams
Image Fidelity

Triangulates on bone using multiple angles – similar to tomographic reconstruction

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Technique

Was meticulous technique used?

Patient positioning and region of interest selection is performed by the technologist and requires precision. This needs to be evaluated by the radiologist for each study.
Technique

Artifacts, including enteric tubes, orthopedic hardware, and jewelry, should be excluded from the image if possible. Vertebral segments with overlying artifacts should be excluded from BMD analysis.
Lumbar Spine

The lumbar spine should be straight and centered in the image with visualization of the last rib pair and the upper sacrum.

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The femoral shaft should be parallel to the long axis of the image with only a small amount of the lesser trochanter visualized. No overlap of the trochanters and femoral neck.
Total Body

Whole body scanning provides total body BMC and BMD but also allows for sub-regions with appropriately drawn regions of interest.
Statistics

What are the statistical limitations of the DXA numerical result?

DXA provides accurate and precise bone mineral data. Accuracy refers to how closely a measured value is to the true value determined by a “gold standard” technique. Precision is a measure of reproducibility of a measurement and is expressed in terms of coefficients of variation, %CV.
Technique

**Accuracy:** For DXA measurements of BMC are within approximately 7-9% of gold standard measurements.

**Precision:** Both short and long term precision are important in performing DXA examinations.
Precision

Short term precision:

Imprecision of the equipment reported to be less than 1% for DXA scanners.

Imprecision of the technologist is due to variation in patient positioning and processing and motion effects. The %CV is suggested to be < 3% for the spine, <5% for the hip, and <2% for the whole body.
Long term precision:

Long-term precision is a measure of machine drift. It is normally well below 1% and the radiologist should review the daily quality control scans of phantoms graphed over a period of weeks in order to detect this.
Why is Precision Important?

For any numeric result in medicine, the decision as to how long to wait to until a follow up study is performed depends on the least significant change of the measurement and the expected rate of change of the variable measured.
Least Significant Change

What is the minimum change in the numeric result that is statistically significant?

This is termed the least significant change, LSC, and is equal to 2.8 x %CV for the 95% confidence limit.
If the %CV were 1.5, a change from the baseline measurement of 4.2% (2.8 x 1.5%) would be required in order for it to be statistically significant.
What are appropriate follow up intervals?

The LSC can also be used to suggest the timing of follow up measurements. If the LSC is 4.2% and the expected annual rate of change in the BMC or BMD is 2%, a follow up study before 2 years would likely result in a value not statistically different than baseline.
What are appropriate follow up intervals?

The annual rate of change in BMC and BMD varies considerably during childhood with dramatic acceleration of bone accrual during the early pubertal years, especially in females.

For most pediatric conditions, follow up examinations are obtained between 6 and 12 months.
Indications for DXA

The NOF lists the following indications for DXA in children:

systemic long-term steroids, chronic inflammatory conditions, hypogonadism, prolonged immobilization, osteogenesis imperfecta, idiopathic juvenile osteoporosis, recurrent low trauma fractures, and apparent osteopenia on radiographs.
The NIH and the ISCD has suggested that any child being treated or considered for treatment of osteoporosis should undergo a DXA examination.
Indications for DXA

DXA would be inappropriate for skeletal pain, chronic disease or traumatic fractures, without any of the additional risk factors listed above.
Pediatric DXA Interpretation

To give more meaning to the DXA result, it is compared to normals and a standard deviation score, termed Z-score, is given. It represents the number of SD from the mean a measure value is.
Pediatric DXA Interpretation

Much of the research in pediatric DXA has focused on determining which factors most influence BMD and should be accounted for in the development of normative data sets. The factors of age, gender, ethnicity, and physiologic maturity have been extensively studied but may not be included in normative data sets provided by manufacturers.
Pediatric DXA Interpretation

There are numerous pediatric normative data sets obtained on a variety of scanners and processing software and are based on various combinations of demographic and physiologic patient variables.
Pediatric DXA Interpretation

Rather than simplifying pediatric DXA interpretation, the sheer number of available normal databases has made interpretation complex, confusing, and at times erroneous.
Pediatric DXA Interpretation

To report the numeric result generated from the manufacturer’s automated processing without consideration of factors specific to the patient being studied is unacceptable. This often will lead to misdiagnoses and may result in inappropriate therapy.
Pediatric DXA Interpretation

For DXA, the disease being “diagnosed” is osteoporosis and is defined for adults in terms of the T-score. The T-score is a measure of bone density loss since early adulthood; its use in children whose BMD has yet to peak will always yield a low result. It should not be included in the pediatric DXA report.

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Pediatric DXA Interpretation

Because the WHO’s DXA-based definitions of osteopenia and osteoporosis are in terms of T-scores, $T < -1.0$ and $T < -2.5$, respectively, a different terminology is needed for pediatric patients. It is recommended that the phrase “low bone density” be used in DXA reports.
A different terminology is needed for pediatric patients. It is recommended that the phrase “low bone density” be used in DXA reports.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Z Score Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Osteopenia</td>
<td>$&lt;-1.0 &lt; Z \leq -2.5$</td>
</tr>
<tr>
<td>Osteoporosis</td>
<td>$Z &lt; -2.5$,</td>
</tr>
</tbody>
</table>

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Pediatric DXA Interpretation

The diagnosis of osteoporosis in a child based on a DXA results is most often due to a misinterpretation of the scan data. The most common causes for misdiagnosis are the use of T-scores, inappropriate normative data sets, inadequate ROIs, and inattention to short stature.

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A methodical evaluation of the results should be undertaken in order to minimize the risk of misdiagnosis. The imager needs to review all input data including patient age, gender, ethnicity, weight, height, and Tanner stage (if provided).
DXA Interpretation

Patient positioning should be evaluated and the regions of interest need to be analyzed for artifact and appropriateness. Comparison should be made to previous studies to insure consistency of positioning and ROI selection. Changes in patient height, weight, and Tanner stage should be noted.
DXA Interpretation

An appropriate database for comparison purposes is selected. Ideally, this is based on data generated locally using the same equipment and technologists but this is rarely possible. Normative data provided by the DXA manufacturers can be used but historically these data sets do not include the parameters currently thought to be most important for interpretation.
DXA Interpretation

At a minimum, patient body size (height or weight) and physiologic maturity (Tanner stage, gynecologic or bone age) should be factors included in the normative data set. Ethnicity and gender are also frequently included in the generation of normative data and are generally thought to affect BMD significantly.
Molgaard’s Technique

- Height/Age: Are the bone long or short?
- Height/BA: Are the bones narrow or wide?
- BMC/BA (BMD): Are the bones heavy or light?
BMD is related to body size

TB BMC is strongly related to bone area

Height is strongly related to age

TB bone area is strongly related to height

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Lean Mass Ratios

Lean mass for height

Female Lean for Height

\[ y = -0.0193x^3 + 10.812x^2 - 1412.9x + 63855 \]

\[ R^2 = 0.8867 \]

Male Lean for Height

\[ y = 0.0113x^3 + 0.1188x^2 - 192.56x + 19527 \]

\[ R^2 = 0.9146 \]

BMC for lean mass

Female BMC for Lean

\[ y = 0.0708x - 410.52 \]

\[ R^2 = 0.9002 \]

Male TBBMC for Lean

\[ y = 0.0572x - 217.03 \]

\[ R^2 = 0.9512 \]
Hogler’s Technique

- There is a strong correlation between LTM and BMC and between Height and BMC.
- Incorporation of body stature into the DXA interpretation can give a more accurate assessment of bone status than simply comparing BMD to age.
Hogler’s Technique

- BMD/Age or BMD/Height
- Height/Age: Are the bones long or short?
- Height/LTM: Is there sufficient muscle mass for body size?
- BMC/LTM$_h$: Have the bones responded to the muscle force upon them?
Hogler’s Technique

- **Primary bone disorder**: Low BMC/LTM with normal LTM/Ht indicates a decrease in the bone’s adaptation to mechanical stress and insufficient bone deposition.

- **Secondary bone disorder**: Normal BMC/LTM with low LTM/Ht indicates normal bone adaptation to reduced mechanical stress.

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Lean Mass Assessment

LM ratios for two different disorders

Children on Growth Hormone

- Low BMD and BMC for age
- Low Ht/Age (short stature)
- Normal LM/Ht (adequate muscle mass)
- Normal BMC/LM (bone mineralized normally)

Anorexic Girls

- Low BMD and BMC for age
- Normal Ht/Age
- Low LM/Ht (muscle mass not adequate for skeletal size)
- Low BMC/LM (mixed bone defect)

Hogler’s Technique: Validation

Crabtree Bone (2004)

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Hogler’s Technique: Pitfall

BMC/LTM$_h$ ratios can be misleading in post puberty children with very short stature who would be compared to pre-pubertal children based on their height. Correction for age rather than height (BMC/LTM$_a$) may be appropriate in this situation.
Pediatric Assessment Tools

- **Body Size Assessment**
  - Height for Age
    - short/long bones
  - BMC for Bone Area
    - light/heavy bones
  - Bone Area for Height
    - thin/fat bones

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Pediatric Assessment Tools

- Lean Mass Assessment
  - LM for Height
    Muscle development
  - BMC for LM
    Muscle-bone imbalance/adaptation
Reference Data

**Challenge**

- Provide useful comparison to reference during period of age-related variable growth

**Solution**

- Age-specific standard deviation (SD)
- Sub-cranial BMD
- Comparison to skeletal age

![Graph showing BMD changes with age](image)

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Age-specific Pediatric SD’s

Recent studies show BMD SD’s vary considerably with age.

Age-specific SD provides better estimate of Z-score.

Largest SD’s occur at adolescent growth – gender specific.

Barden et al. (2005) Presented at the ISCD Meeting, New Orleans

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Sub-cranial BMD

- Skull contributes high percentage of total BMD in younger children
- Exclude head region for more sensitive total body assessment

Landoll et al. (2004) Presented at the ASBMR, Seattle, WA

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Sub-cranial Assessment

Total Body: $Z = -1.7$  Sub-cranial: $Z = -3.2$

- Boy with Duchenne Muscular Dystrophy

Landoll et al. (2004) Presented at the ASBMR, Seattle, WA
Clinical Case 1

Clinician would like to perform DXA on a 4 week old rib fractures to exclude OI.

Is the exam feasible?

Will the results be definitive?
Clinical Case 1

DXA can be performed on neonates and has been validated in premature infants and term neonates. Normative data has been published (Salle, Koo).
Clinical Case 1: OI

Genetic disorders of collagen synthesis

Fracture occurrence and DXA findings vary with subtype: normal or near normal in type I, more frequent fractures and marked reductions in BMD in types III and IV. Type II typically results in perinatal demise.

Up to 40% of patients with OI will have normal BMD and BMC, a normal DXA study does not preclude the diagnosis of OI or distinguish cases of OI from non-accidental injuries.
Clinical Case 2

Are levels appropriately drawn?
When lumbar segmentation is in doubt, the lowest segment is assumed to be sacrum and is excluded.
Clinical Case 3

Is there a way to get meaningful data from the follow up DXA scan?
At least 2 levels are needed for DXA study.
Clinical Case 3

Follow up DXA on young teenager with steroid dependent Crohn's disease. Was Tanner stage 2 at baseline and is now Tanner stage 3..
Table 1: Effect of Pediatric vs. Adult Software Analysis on Bone Area and Bone Mineral Content Results

<table>
<thead>
<tr>
<th>Region</th>
<th>Pediatric Area cm²</th>
<th>Pediatric BMC g</th>
<th>Pediatric BMD g/cm²</th>
<th>Adult Area cm²</th>
<th>Adult BMC g</th>
<th>Adult BMD g/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lt arm</td>
<td>201</td>
<td>93</td>
<td>0.465</td>
<td>114</td>
<td>71</td>
<td>0.622</td>
</tr>
<tr>
<td>Rt arm</td>
<td>196</td>
<td>97</td>
<td>0.497</td>
<td>116</td>
<td>76</td>
<td>0.655</td>
</tr>
<tr>
<td>Lt ribs</td>
<td>79</td>
<td>40</td>
<td>0.507</td>
<td>75</td>
<td>39</td>
<td>0.511</td>
</tr>
<tr>
<td>Rt ribs</td>
<td>98</td>
<td>51</td>
<td>0.525</td>
<td>92</td>
<td>48</td>
<td>0.525</td>
</tr>
<tr>
<td>T-spine</td>
<td>85</td>
<td>48</td>
<td>0.569</td>
<td>83</td>
<td>48</td>
<td>0.524</td>
</tr>
<tr>
<td>L-spine</td>
<td>49</td>
<td>28</td>
<td>0.50</td>
<td>33</td>
<td>20</td>
<td>0.599</td>
</tr>
<tr>
<td>Pelvis</td>
<td>179</td>
<td>136</td>
<td>0.760</td>
<td>115</td>
<td>95</td>
<td>0.829</td>
</tr>
<tr>
<td>Lt leg</td>
<td>353</td>
<td>269</td>
<td>0.76</td>
<td>228</td>
<td>199</td>
<td>0.873</td>
</tr>
<tr>
<td>Rt leg</td>
<td>338</td>
<td>245</td>
<td>0.724</td>
<td>226</td>
<td>187</td>
<td>0.829</td>
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<tr>
<td>Subtotal</td>
<td>1577</td>
<td>1008</td>
<td>0.639</td>
<td>1081</td>
<td>782</td>
<td>0.723</td>
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<tr>
<td>Head</td>
<td>233</td>
<td>367</td>
<td>1.572</td>
<td>233</td>
<td>367</td>
<td>1.572</td>
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<tr>
<td>Total</td>
<td>1810</td>
<td>1375</td>
<td>0.759</td>
<td>1315</td>
<td>1149</td>
<td>0.874</td>
</tr>
</tbody>
</table>

Table 1 Legend:

Total body DXA from a 13 year old patient processed using pediatric and adult software analysis. Note decreased BA (1315 cm²) and BMC (1149 g) but increased BMD (0.874 g/cm²) with the adult technique. Low density portions of the bone are included using the pediatric technique and thus a larger BA (1810 cm²) with a greater BMC (1375 g) are obtained but the BMD (0.759 g/cm²) is lower because of the inclusion of low density “bone pixels.”
Clinical Case 5

Can these patients have a meaningful DXA exam?
Clinical Case 5

For patients with severe contractures of extensive lumbar and hip metallic devices, a lateral of the distal femur is an alternative site (Henderson, Harcke)
Clinical Case 6

Is LS DXA possible in this patient?
Clinical Case 6
Clinical Case 7

Due to table weight limits (300 lbs), markedly obese children can not have routine DXA views (LS, hip, TB). FA DXA is used but there is limited pediatric data.
Clinical Case 8

15 year old male with juvenile idiopathic osteoporosis. LS DXA was normal. Is there more that should be done?
Clinical Case 8

Because of high risk of osteoporotic compression fractures, a lateral thoracic scanogram was performed with DXA.
Clinical Case 8

Identification of a thoracic compression fracture in the setting of normal DXA BMD is not unusual and strongly predicts additional future fractures.
Makitie found compressive thoracic deformities in eleven of 32 children suspected of having secondary osteoporosis who were studied with DXA. Eight of these 11 children had normal lumbar DXA and the demonstration of a thoracic compressive deformity was felt to be an important diagnostic and prognostic finding. The addition of vertebral morphologic assessment may be an important adjunct in the diagnosis of pediatric osteoporosis.
Clinical Case 9

4 year-old white female with nutritional rickets and multiple low trauma fractures. She was Tanner stage 1 and weighed 19 kilograms. Her baseline lumbar BMD was 0.399 g/cm².
**Patient Information:**

- **Patient ID:** 1321865
- **Postal Code:**
- **Sex:** Female
- **Ethnicity:** White
- **Height:** 108.0 cm
- **Weight:** 19.0 kg
- **DOR:** 07/28/1999
- **Age:** 4
- **Menopause Age:**
- **Referring Physician:** MAHAN, J 4360

**Scan Information:**

- **Scan Date:** February 24, 2004 - A02240401D
- **Scan Type:** Lumbar Spine
- **Analysis Date:** 02/24/2004 14:49
- **Report Date:** 02/24/2004 14:58
- **Institution:** Columbus Children's Hospital
- **Operator:** AL
- **Model:** Delphi A (SN 70754)
- **Comment:** BASELINE/ TANNER 1
- **Software version:** 11.2

**Results Summary:**

<table>
<thead>
<tr>
<th>Region</th>
<th>Area [cm²]</th>
<th>BMC [g]</th>
<th>BMD [g/cm²]</th>
<th>T-Score</th>
<th>PR (Peak Reference)</th>
<th>Z-Score</th>
<th>AM (Age Matched)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>6.58</td>
<td>2.64</td>
<td>0.402</td>
<td>-4.8</td>
<td>43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L2</td>
<td>7.30</td>
<td>2.58</td>
<td>0.354</td>
<td>-6.1</td>
<td>34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L3</td>
<td>7.95</td>
<td>2.94</td>
<td>0.370</td>
<td>-6.5</td>
<td>34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L4</td>
<td>8.81</td>
<td>4.05</td>
<td>0.459</td>
<td>-6.0</td>
<td>41</td>
<td></td>
<td></td>
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<tr>
<td>Total</td>
<td>30.65</td>
<td>12.22</td>
<td>0.399</td>
<td>-5.9</td>
<td>38</td>
<td>-2.1</td>
<td>76</td>
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</table>

**Physician's Comment:**

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Clinical Case 9

Using our normal database that corrects for Tanner stage and weight, the patient’s LS BMD was very low (Z score < -2.3). The manufacturer’s database yielded low Z score of -2.1. The total body BMC was 543g with a Z score of -2.3. The patient was reported as having markedly reduced lumbar bone density and reduced total body BMC.
Clinical Case 10

13 year-old black female with lupus. Baseline DXA LS BMD was 0.719 g/cm², equivalent to a Z score of 1.6 using our local database and considered to be a high normal value for a 33 kg and Tanner stage 1 patient. The total body bone mineral content was 1280 g, equivalent to a Z score of 1.5 and also thought to be a high normal value.
<table>
<thead>
<tr>
<th>Region</th>
<th>Area [cm²]</th>
<th>BMC [g]</th>
<th>BMD [g/cm²]</th>
<th>T-Score</th>
<th>PR (Peak Reference)</th>
<th>Z-Score</th>
<th>AM (Age Matched)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>6.10</td>
<td>4.01</td>
<td>0.657</td>
<td>-3.3</td>
<td>65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L2</td>
<td>7.52</td>
<td>5.19</td>
<td>0.690</td>
<td>-4.0</td>
<td>61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L3</td>
<td>8.59</td>
<td>6.19</td>
<td>0.724</td>
<td>-4.2</td>
<td>61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L4</td>
<td>10.14</td>
<td>7.85</td>
<td>0.774</td>
<td>-4.1</td>
<td>63</td>
<td></td>
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<tr>
<td>Total</td>
<td>32.45</td>
<td>23.34</td>
<td>0.719</td>
<td>-3.9</td>
<td>63</td>
<td>-1.6</td>
<td>82</td>
</tr>
</tbody>
</table>

Total BMD CV 1.09%, ACF = 1.035, BCF = 1.003

Fracture Risk: High, WHO Classification: Osteoporosis

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After 15 months treatment with steroids, she gained 15 kg and progressed to Tanner stage 2. A follow up DXA then measured the lumbar BMD to be 0.723 g/cm², Z-score = -0.67.
She is still in the well within normal range. Do you report her DXA as normal?
Clinical Case 10

The lumbar BMD of 0.723 g/cm² corresponds to the 25th percentile and a Z score of -0.67. This is a slight decrease in lumbar BMD at a time when rapid bone mineral accrual is expected; her Z score, decreased from 1.5 to -0.67. This is definitely abnormal and is reported as a substantial decline in BMD.
Clinical Case 11

16 year-old white female with Turner Syndrome and of small stature (150cm, 1st percentile, Z score of -2.3).
Clinical Case 11

Manufacturer’s database LSBMD Z score -3.0, but it does not take into account height or weight.

For Tanner 3 and 50 kg, Z score of -1.3

Results Summary:

<table>
<thead>
<tr>
<th>Region</th>
<th>Area [cm²]</th>
<th>BMC [g]</th>
<th>BMD [g/cm²]</th>
<th>T Score</th>
<th>Z Score</th>
<th>AM (Age Matched)</th>
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<tbody>
<tr>
<td>L1</td>
<td>11.17</td>
<td>6.41</td>
<td>0.375</td>
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<td></td>
</tr>
<tr>
<td>L2</td>
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<td>7.31</td>
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<td>8.35</td>
<td>0.678</td>
<td>-3.7</td>
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Total BMD CV 1.09%, ACF = 1.05%, BCF = 1.009
Fracture Risk: High, WHO Classification: Osteoporosis

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Clinical Case 11

Low LS BMD Z-score is likely due to the short stature, (Z-score -2.3). Correction for weight our normal database incorporates partially accounts for her short stature and gives a more meaningful interpretation of the numeric DXA result. This patient’s bone age was 13 years (Z score = -2.3) and using this rather than herchronologic age of 16 years with the manufacturer’s normal database would result in a Z score of -1.0.
Clinical Case 11

This value would better reflect the patient’s actual bone status. Some researchers suggest corrected DXA values for bone age. Because our database corrects for weight and Tanner stage, each patient is weighed and has a Tanner stage determination made by the referring clinician prior to the DXA study. Thus we do not use the patient’s bone age in DXA interpretation.
Baseline Follow up

Clinical Case 12

Results Summary:

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<th>Region</th>
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<th>BMC [g]</th>
<th>BMD [g/cm²]</th>
<th>T-Score</th>
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<td>0.562</td>
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Results Summary:

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<tr>
<th>Region</th>
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<th>BMC [g]</th>
<th>BMD [g/cm²]</th>
<th>T-Score</th>
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Clinical Case 12

Dramatic increases in BMD suggest pharmacologic interventions with bisphosphonates. These are anti-resorptive drugs, which are given cyclically and result in a series of bone deposition lines.
Summary

- Areal BMD means bone size counts
- Growing bones add special challenges for DXA interpretation
- Meticulous technique and best precision
- No T-scores
- Know your normal database
- Don’t monkey around
Clinical Applications of DXA
Gastrointestinal Diseases

- Decreased calcium intake: Milk allergy
- Decreased calcium absorption: Celiac disease, IBD
- Reduced lean tissue mass: IBD
- Therapy with corticosteroids: IBD
Milk Allergy

- Calcium intake: Directly correlates with LS BMD.
- Calcium supplements: Effectively to correct bone density deficits in childhood even with severe dietary dairy restrictions.
IBD

- Low LS and TBBMD is multi-factorial: CS, diarrhea, mal-absorption and inflammatory cytokines.
- Correction for height, Tanner stage or LTM, normalizes DXA results.
Celiac Disease

- Low LS BMD universal in untreated patients
- Early diagnosis (<4 years) and treatment with GFD will normalize BMD
Liver Disease

- Vitamin D absorption and activation reduced in cholestatic disorders (atresia, Alagille)
- Liver Tx normalizes BMD w/in 1 year
Renal Diseases

- Vitamin D activation reduced
- Altered calcium and phosphate handling
- Elevated PTH
- Reduced GH low LTM)
- Chronic anemia
Renal Diseases

- Low DXA values will be found in majority of patients
- With adequate vitamin D and calcium supplementation and corrected for height, DXA values normalize
- BMD reductions found up to two years Post-Tx due to CS therapy.
Renal Diseases

- Hypercalciuria: Low LS BMD found in children and adults with HC and defects thought to persist into adulthood.
- Deficits independent of urolithiasis or urinary uric acid levels.
Endocrinologic Diseases: GH

- Numerous complex hormonal interaction involved in reduced BMD in children with endocrine disorders.
- Correction for short stature essential in DXA interpretation.
- Reduced GH levels correlate with reduced LTM.
- GHRT results in robust increase in LTM, height, and TBBMC.
- Increases in BMD occur even after growth plate closure.
Endocrinologic Diseases: DM

- Mechanism of reduced BMD and BMC despite normal stature unclear
- HgA1C levels inversely correlated with BMD and TBBMC
Endocrinologic Diseases: CS

- Adverse effects on BMD due to pharmacologic CS therapy well-documented.
- Physiologic replacement, as in CAH, does not adversely effect BMD if there is no evidence of androgen suppression.
- Cushing disease associated with severe BMD reductions due to increased osteoclastic activity as well as reduced GH and sex hormones.
- These reductions tend to persist if hypercortisolism was present in adolescents.
Endocrinologic Diseases: Reproductive Hormones

- Estrogen is protective against post-menopausal osteoporosis
- Hormonal contraception which suppresses estrogen levels associated with reduced BMD
- The lower the level of estrogen in OCP, the lower the BMD
- Estrogen supplementation of progesterone-mediated contraception blunts osteopenic effects
Endocrinologic Diseases: Anorexia Nervosa

- Multi-factorial causes of low BMD include hormonal, nutritional and mechanical factors.
- Decreased BMD at multiple sites
- Defects most severe in early onset AN
- Low BMD persists into adulthood
- Estrogen supplementation and exercise program blunt osteopenic effects of AN on BMD
Respiratory Diseases: Cystic Fibrosis

- Multi-factorial causes of low BMD include decreased absorption of Ca and vitamin D, reduced sex steroids, reduced LTM, CS, chronic inflammatory cytokines.

- LS BMD Z scores correlate well with overall pulmonary function which in turn reflects disease duration.

- Treatment with IV or oral bisphosphonates has proved beneficial in CF patients.
Respiratory Diseases: Asthma

- Multi-factorial causes of low BMD include decreased chronic hypoxia, reduced LTM and CS use
- Correction for height essential in DXA interpretation
- Oral, but not inhaled CS, detrimental to LS BMD
Hematologic Diseases: Anemias

- Chronic anemia alters bony architecture with expansion of the medullary space, trabeculare coarsening and cortical thinning.
- Bone infarction is also a factor for altered BMD in SCD patients
- Decreased LTM and physical activity
- Endocrine dysfunction of thalassemia
- Low BMD correlates with disease severity
- Persists despite transfusion/chelation therapy

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Hematologic Diseases: Hemophilia

- Low BMD largely due to decreased axial loading exercise
- Is found even with correction for stature
- Low BMD correlates with disease severity (joint scores)
- Abnormalities persist into adulthood
Oncologic Diseases

- Effects on BMD related to type and location of cancer, therapy, age of diagnosis

- With changing therapy over time (whole brain radiation for ALL) or newer lower toxicity chemotherapy or reduced radiation therapy, conclusions regarding BMD changes in these patients are evolving.
Oncologic Diseases: ALL

- Vast majority of patients with childhood ALL survive their disease
- Long term effects of disease and treatment important
- Reduced BMD found during treatment and shortly after
- Recuperative capacity is great and in the disease free state, with normal physical activity, nutrition and hormonal status, normal BMD is expected
Oncologic Diseases: Other Malignancies

• Little data regarding BMD in survivors of other childhood malignancies

• Gonadal dysfunction due to pelvic irradiation, limb deformities associated MSK tumors, and radiation doses for primary brain tumors all will play important roles in BMD results.

• In general, diagnosis and treatment during puberty will have more severe and long-lasting effects.
Neurologic Diseases: CP

- Reduced LTM and mobility
- Contractures make DXA difficult
- Direct measurement of distal femur BMD recommended: easier and better correlated with fracture risk than LS or hip BMD
- Bisphosphonates increase BMD acutely and have prolonged protective effect against fracture

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Neurologic Diseases: MMC

• Low FA BMD despite normal upper extremity function in children
• Mechanical and systemic factors result in reduced BMD
• LS but not hip BMD preserved in upright non-ambulatory adult patients
• Forearm BMD recovers with increased upper extremity loading
Connective Tissue Diseases: JRA and SLE

- In JRA patients, joint disability and CS therapy are determinants of decreased BMD
- Disease duration inversely correlates with LS BMD
- In SLE, BMD more likely to be preserved but immobility, CS and reduced sunlight exposure can result in reduced BMD
Musculoskeletal Diseases: DMD

- BMD directly correlates with motor function
- Rapidly progressive BMD reductions following loss of ambulation or use of CS
- Bisphosphonates have been shown to increase BMD, especially when started at a young age
Musculoskeletal Diseases: OI

- Spectrum of genetic disorders of collagen synthesis results in low BMD, increased fragility and fractures.
  - Type I: Often normal BMD
  - Type II: Perinatal demise
  - Types III and IV: More frequent fractures and low BMD
  - 40% of patients with OI will have normal BMD
Musculoskeletal Diseases: OI

- Bisphosphonates increase BMD and reduce pain and immobility
- Fracture incidence may increase due to increased activity
- No detrimental impact on height
Body Composition Analysis

Analysis of regional and total body fat, lean and calcium.

- requires no additional radiation exposure, hardware, software or training
- ideally suited for children with respect to alternative techniques for BCA
- highly reproducible and accurate
- provides valuable information to clinicians
Body Composition Analysis

Ideally suited for pediatrics

Minimally invasive

- Radiation dose approximately 5-10uSv
- Five - 10 minute scan time
- No sedation needed
- No injection, blood sampling, breath holding or submersion as is needed for alternative techniques
Body Composition Analysis

Highly reproducible: %CV = 1-2% for FM and LTM
Very accurate: Error = 1-3% FM and 3% LTM
Body Composition Analysis

Highly reproducible: %CV = 1-2% for FM and LTM

Very accurate: Error = 1-3% FM and 3% LTM
Body Composition Analysis

To provide valuable information to clinicians, there must be a well-established normal database for comparison purposes.
Body Composition Analysis

What is normal body composition?

Is average normal?

Is average healthy?
Normal Body Composition

Analysis

The terms average, normal and healthy are not interchangeable.

Average has not been stable.

Average weight and height in developed countries have increased over time: 3.4 and 5.7 kg increase in US children 5-14 yrs and 15-17 yrs, respectively, between 1973 and 1994. Further increases since have been documented.
A functional definition would be the weight range/distribution that is associated with the least long-term health risks.

In terms of BMI (Kg/cm²):

- 25  normal,
- 25-30 overweight low risk
- >30  obese, moderate risk
- >40  morbid obesity, high risk, anti-obesity surgical candidate
Body Composition Analysis

What is healthy weight or weight distribution?

A functional definition would be the %body fat that is associated with the normal menses.

Initiation: 17%
Maintenance: 22%
Body Composition Analysis

Gender differences in BC:

Girls have higher %body fat and lower LTM than boys throughout childhood.

Girls have an increasing %body fat throughout childhood reaching approximately 23% in late adolescents.

Boys have fairly stable %body fat from 5 yrs through adolescents averaging approximately 10%.

Gynoid vs android fat distribution: subq and thigh/hip vs visceral fat distribution patterns.

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Body Composition Analysis

Racial differences in BC:

Little difference in BC in newborns regardless of race when appropriate factors are controlled.

White girls accumulate more fat during childhood and adolescents than black girls racial when appropriate factors are controlled.

Black males have lower FM than white males who have lower fat mass than Hispanic males.
Obesity: accumulation of excessive adipocytes and specifically refers to an increase in fat to lean tissue mass ratio.

What is normal %body fat?

10-25% boys
17-32% girls

What is normal fat distribution?
Body Composition Analysis: Obesity

Typically weight or BMI are used to diagnose obesity, not altered FM/LTM ratio

- weight above a given percentile
- BMI above certain value

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BMI: Pitfalls

There are several serious problems with using BMI as a surrogate for BCA:

For any given BMI, there is a wide range of %body fat
An increase in LTM above average will be reflected with an increased BMI: Athletes
A decrease in LTM will be reflected in a low BMI: sarcopenic patients such as CP, OI, DMD etc.
Definition of FTM and LTM: Often both are very elevated
Track fat and lean tissue mass loss following intervention

In general, medical (diet and exercise) or surgical weight loss interventions result in similar ratios of fat/lean tissue loss: 5:1

Surgical techniques, either gastric bypass or laparoscopic vertical banded gastroplasty, are more effective long-term than medical techniques.

LVBG was more effective in reducing visceral fat
Anorexia Nervosa

Eating disorder with abnormal intake, purging and or exercise associated with extreme weight loss, fear of gaining weight, disordered body image and, in females, amenorrhea.

weight < 85% of ideal
BCA in Anorexia Nervosa

Weight reductions extreme: average 26% below average
BMI commonly below 16
%Body fat well below average, often as much as 50-60% reductions from average
BCA in Anorexia Nervosa

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DXA BCA in Anorexia Nervosa

Monitoring interventions with DXA BCA allow for more accurate assessments of body fat/lean tissue rather than simply observing changes in weight.

Allows for meaningful endpoints; restoration of normal %body fat and LTM levels is associated with lower rates of relapse versus clinical endpoints of weight gain or resumption of menses.

Documents altered body fat distribution with recovery: increases visceral (android) fat.
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