DUAL-ENERGY X-RAY ABSORPTIOMETRY

Lynn Ansley Fordham, MD, FACR, FAIUM, FAAWR
DUAL-ENERGY X-RAY ABSORPTIOMETRY

Other names

DXA
DEXA
Bone densitometry

Applications

Bone mineral density
Body composition
Vertebral fracture risk assessment
Trabecular bone score
Aortic calcification
ALTERNATES TO DXA

QCT

Ultrasound of calcaneus

MRI for body composition
WHO World Health Organization
- 1993 development conference
- 1994 study group created definition for T score

ISCD International Society for Clinical Densitometry
- 2003 created official position, expanded technique to men ≥50 and perimenopausal women
- Updated approximately every 3 years
  - Adult 2023
  - Pediatric 2019
- ACR American College of Radiology
- Practice parameter
- Appropriateness criteria
SCANNER DESIGN

DEXA scanner - low-dose x-ray tube with two energies for separating mineral and soft-tissue components and a high-resolution multidetector array.

Two designs:
- alternating tube current high (140 kVp) and low (70–100 kVp)
- a constant x-ray beam with a rare-earth filter and energy-specific absorption, which separates photons of higher (70 keV) and lower (40 keV) energy

Radiation exposure from a DXA scan is minimal (0.1–6 μSv)
Contraindications to DXA

- Pregnancy
- Oral administration of a contrast agent within 5 days prior to a planned study
- Performance of a nuclear medicine study within 2 days prior to a planned study.

Prep

- Avoid ingesting calcium supplements the day of the study.
- Remove metal objects, if possible
SITES SCANNED

Adults (>20 yo)
- Lumbar spine (L1-4) (trabecular bone)
- Total hip (cortical bone)

Pediatric (5-20 yo)
- Total body less head (TBLH) (cortical)
- AP lumbar spine

Infants -5 yo
- AP lumbar spine
- (Total body ≥3 yo)

Alternate sites
- Distal 1/3 radius
  - Spine/femur w hardware, hyperparathyroidism (cortical bone), patient weight>table limit
  - Distal lateral femur (cortical, UNC)
WHY TOTAL BODY LESS HEAD?

• The skull comprises a relatively large portion of the skeleton

• Bone mineralization at the skull is not affected by nutritional or environmental factors such as weight-bearing activity that impact BMD throughout the rest of the body

• Skull fractures do not represent true osteoporotic fractures
QUALITY

Measurements unique to scanner and software
- Reliably schedule patients on same scanner

Positioning important

Artifacts
- Enteric contrast
- Tubes and lines
- Soft tissue calcification
  - Dermatomyositis
- Liver iron deposition
- Bone lesions/bone graft
- Umbilical jewelry
- Motion
Lumbar spine positioned with hips flexed

Correct level of lumbar spine

- See 12th ribs, iliac crest
- Exclude abnormal vertebral bodies, may need radiograph
- Contour excludes transverse processes
- Need at least two levels for analysis
- Largest transverse processes are L3
- Vertebral area values increase from L1 to L4
- BMD increases from L1 to L3
- BMD of L4 is similar to L3.

(Lorente-Ramos, Azpeitia-Armán et al. 2011)
**HIP**

- Hip positioned with internal rotation
- Should not see lesser trochanter
- Femoral neck ROI placement is the greater trochanteric notch

(Lorente-Ramos, Azpeitia-Armán et al. 2011)

(Khalatbari, Binkovitz et al. 2021)
1/3 DISTAL RADIUS

Non dominant arm

Most important ROI is one-third (1/3) radius

Image should include 2 cm of diaphysis over one third of forearm and part of carpal bones.

Can include separate analysis for ultradistal radius

(Lorente-Ramos, Azpeitia-Armán et al. 2011)
DISTAL LATERAL FEMUR

Used for non ambulatory patients
Utilize 1/3 radius software tool
Region 1 trabecular bone
Region 3 cortical bone

(Henderson, Lark et al. 2002)
<table>
<thead>
<tr>
<th>Region</th>
<th>Area</th>
<th>BMC</th>
<th>BMD</th>
<th>Fat</th>
<th>Lean</th>
<th>Lean + BMC</th>
<th>Total</th>
<th>% Fat</th>
<th>T-score</th>
<th>PR (Peak Reference)</th>
<th>Z-score</th>
</tr>
</thead>
<tbody>
<tr>
<td>L Arm</td>
<td>109.98</td>
<td>52.88</td>
<td>0.481</td>
<td>451.5</td>
<td>988.0</td>
<td>1040.9</td>
<td>1492.4</td>
<td>30.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R Arm</td>
<td>99.22</td>
<td>48.88</td>
<td>0.493</td>
<td>498.6</td>
<td>965.8</td>
<td>1014.6</td>
<td>1513.2</td>
<td>32.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L Ribs</td>
<td>81.29</td>
<td>36.91</td>
<td>0.454</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R Ribs</td>
<td>90.46</td>
<td>39.33</td>
<td>0.435</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T Spine</td>
<td>76.11</td>
<td>41.19</td>
<td>0.541</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L Spine</td>
<td>32.68</td>
<td>22.47</td>
<td>0.688</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pelvis</td>
<td>127.12</td>
<td>94.99</td>
<td>0.747</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trunk</td>
<td></td>
<td></td>
<td></td>
<td>234.89</td>
<td></td>
<td>2907.4</td>
<td>8968.6</td>
<td>9203.5</td>
<td>12110.9</td>
<td></td>
<td>24.0</td>
</tr>
<tr>
<td>L Leg</td>
<td>221.16</td>
<td>154.65</td>
<td>0.699</td>
<td>2044.4</td>
<td>2919.5</td>
<td>3074.1</td>
<td>5118.5</td>
<td>39.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R Leg</td>
<td>224.75</td>
<td>150.85</td>
<td>0.671</td>
<td>2098.1</td>
<td>3005.0</td>
<td>3155.9</td>
<td>5254.0</td>
<td>39.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subtotal</td>
<td>1062.75</td>
<td>642.16</td>
<td>0.604</td>
<td>8000.1</td>
<td>16846.9</td>
<td>17489.0</td>
<td>25489.1</td>
<td>31.4</td>
<td></td>
<td></td>
<td>-1.7</td>
</tr>
<tr>
<td>Head</td>
<td>188.09</td>
<td>229.38</td>
<td>1.220</td>
<td>947.6</td>
<td>2003.1</td>
<td>2232.5</td>
<td>3180.2</td>
<td>29.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1250.86</td>
<td>871.54</td>
<td>0.697</td>
<td>8947.7</td>
<td>18850.0</td>
<td>19721.6</td>
<td>28669.3</td>
<td>31.2</td>
<td></td>
<td></td>
<td>-1.9</td>
</tr>
</tbody>
</table>
ARTIFACTS

Umbilical jewelry overlying spine

Posterior spinal fixation

(Lorente-Ramos, Azpeitia-Armán et al. 2011)
DEXA RESULTS

DXA measurements
- BMC: bone mineral content, measured in grams
- Projected area of bone (measured in cm²) outlined from reference scan

DXA analysis
- BMD areal bone mineral density: $\text{BMC/area}= \text{aBMD g/cm²}$
- Pitfall- 2-dimensional technique

- (BMAD) bone mineral apparent density: calculated correction to create 3D bone density
T- and Z-Scores

T-score is the standard deviation (SD) difference between the adult patient’s (post and perimenopausal women and men ≥50) current BMD measurement and the mean BMD of a young adult reference population, 20- to 29-year-old Caucasian women (peak bone mass).

Z-score, defined as the standard deviation difference between the patient’s (pediatrics and “young” adults) BMD measurement and the mean BMD of an age- and gender-matched (and if available, race) reference population.

(Khalatbari, Binkovitz et al. 2021)
**T AND Z SCORES**

**Peds and “Young” adults**

Z-score ≤ −2.0 is defined as below the expected range for age

Z-score above −2.0 is defined as within the expected range for age

**Peri/Post Menopausal women and men ≥ 50**

T-score ≤ −2.5 osteoporosis

T-score between −1 and −2.5 osteopenia

T-score > −1 normal bone mineral density
Short stature is defined as height ≤2 SD below the mean for children of the same gender and chronological age.

TBLH: Adjustments for height age, i.e. the age at which a child's measured height is at the 50th percentile height on the Centers for Disease Control and Prevention (CDC) growth chart are made by substituting the height age for the chronological age when generating Z-scores.

No correction for infants and children ≤ 5.

Spine: Height adjusted z score or BMAD bone mineral apparent density calculated correction to create 3D bone density.

When adjustments are made, short for age children are compared to younger children of similar height who are at an earlier stage of sexual maturation.

https://zscore.research.chop.edu/
# Adjusting Z Score for Height Age

11 Year Old with Height of 7 Year Old

![Stature-for-age percentiles: Boys, 2 to 20 years](image1.png)

### Table 1: Body Composition Analysis

<table>
<thead>
<tr>
<th>Region</th>
<th>Area[cm²]</th>
<th>BMC[g]</th>
<th>BMD[g/cm³]</th>
<th>Z-score</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>7.84</td>
<td>2.94</td>
<td>0.375</td>
<td>-1.7</td>
</tr>
<tr>
<td>L2</td>
<td>8.06</td>
<td>3.69</td>
<td>0.458</td>
<td>-1.4</td>
</tr>
<tr>
<td>L3</td>
<td>9.79</td>
<td>4.66</td>
<td>0.476</td>
<td>-1.4</td>
</tr>
<tr>
<td>L4</td>
<td>9.90</td>
<td>5.24</td>
<td>0.529</td>
<td>-0.4</td>
</tr>
<tr>
<td>L1-L4</td>
<td>35.59</td>
<td>16.52</td>
<td>0.464</td>
<td>-1.3</td>
</tr>
</tbody>
</table>

| Subtotal | 1022.53 | 617.22 | 0.604 | 8751.7 | 17424.7 | 18041.9 | 26793.6 | 32.7 | -0.1 |
| Head     | 206.82  | 255.24 | 1.234 | 1067.1 | 2258.8  | 2514.0  | 3581.1  | 29.8 | -0.1 |
| Total    | 1229.35 | 872.46 | 0.710 | 9818.7 | 19683.5 | 20555.9 | 30374.7 | 32.3 | -0.4 |

### Table 2: Body Composition Analysis

<table>
<thead>
<tr>
<th>Region</th>
<th>Area[cm²]</th>
<th>BMC[g]</th>
<th>BMD[g/cm³]</th>
<th>Z-score</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>7.84</td>
<td>2.94</td>
<td>0.375</td>
<td>-2.6</td>
</tr>
<tr>
<td>L2</td>
<td>8.06</td>
<td>3.69</td>
<td>0.458</td>
<td>-2.4</td>
</tr>
<tr>
<td>L3</td>
<td>9.79</td>
<td>4.66</td>
<td>0.476</td>
<td>-2.4</td>
</tr>
<tr>
<td>L4</td>
<td>9.90</td>
<td>5.24</td>
<td>0.529</td>
<td>-1.6</td>
</tr>
<tr>
<td>L1-L4</td>
<td>35.59</td>
<td>16.52</td>
<td>0.464</td>
<td>-2.3</td>
</tr>
</tbody>
</table>

| Sex: Male | Ethnicity: Pediatric | Height: 49.0 in | Weight: 66.0 lb | DOB: 2012 | Age: 7 |

| Subtotal | 1022.53 | 617.22 | 0.604 | 8751.7 | 17424.7 | 18041.9 | 26793.6 | 32.7 | -0.1 |
| Head     | 206.82  | 255.24 | 1.234 | 1067.1 | 2258.8  | 2514.0  | 3581.1  | 29.8 | -0.1 |
| Total    | 1229.35 | 872.46 | 0.710 | 9818.7 | 19683.5 | 20555.9 | 30374.7 | 32.3 | -0.4 |

(Khalatbari, Binkovitz et al. 2021)
USING CHOP Z-SCORE CALCULATOR

RESULTS:

Patient's Height: 50 in
Patient's Gender: Female

https://score.research.chop.edu/scoliosisscore.php

1/8/24, 2:31 PM

Please select whether the patient is black or non-black: Non-black

Patient's Date of Birth: 1/13/2013
Patient's Date of Office Visit: 2/21/2023
Age (in months) at Time of Visit: 121.3
Age in years: 10.1
Age in years (rounded): 10
Body part: Lumbar Spine (BMD)
Body part value: 0.414
Height Z-Score: -1.76
Lumbar Spine (BMD) for Age Z-Score: -3.06
Lumbar Spine (BMD) for Age Z-Score Adjusted for HAZ: 2.18
(a) presence of one or more vertebral compression fractures in the absence of local disease or high-energy trauma

or (b) presence of a clinically significant fracture history and BMD Z-score of $\leq -2.0$.

A clinically significant fracture history is defined as two or more long-bone fractures by the age of 10 years or $\geq 3$ long bone fractures at any age up to age 19 years.
VFA VERTEBRAL FRACTURE ASSESSMENT

DXA lateral spine imaging can be performed to detect vertebral fractures. ISCD Adult Positions and Pediatric Positions identify indications for obtaining a lateral spine radiograph or vertebral fracture assessment in adults as well as recommendations for Genant semiquantitative scoring and additional spine imaging.

(Khalatbari, Binkovitz et al. 2021)
BASELINE DXA REPORT: ISCD

- 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
- Tanner Stage or Bone age results, if available
- Technical quality
- BMC and areal BMD
- BMC and/or areal BMD Z-score
- Source of reference data for Z-score calculation
- Adjustments made for growth and interpretation
- Recommendations for the necessity and timing of the next DXA study are optional
Serial DXA reports should include the same information as for baseline testing.

Additionally, indications for follow-up scan, technical comparability of studies, changes in height and weight, and change in BMC and areal BMD Z-scores should be reported.

Low bone mineral mass or bone mineral density is the preferred term for pediatric DXA reports when BMC or areal BMD Z-scores are less than or equal to -2.0 SD.
ISCD NOMENCLATURE

DXA – not DEXA.

• T-score – not T score, t-score, or t score
• Z-score – not Z score, z-score, or z score
**PREFERRED NUMBER OF DECIMAL DIGITS FOR DXA REPORTING:**

<table>
<thead>
<tr>
<th>Metric</th>
<th>Example</th>
<th>Digits</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMD: (example, 0.927 g/cm²)</td>
<td>3 digits</td>
<td></td>
</tr>
<tr>
<td>T-score: (example, -2.3)</td>
<td>1 digit</td>
<td></td>
</tr>
<tr>
<td>Z-score: (example, 1.7)</td>
<td>1 digit</td>
<td></td>
</tr>
<tr>
<td>BMC: (example, 31.76 g)</td>
<td>2 digits</td>
<td></td>
</tr>
<tr>
<td>Area: (example, 43.25 cm²)</td>
<td>2 digits</td>
<td></td>
</tr>
<tr>
<td>% reference database: (example, 82%)</td>
<td>Integer</td>
<td></td>
</tr>
</tbody>
</table>
UNC PEDIATRIC DXA

124 Pediatric DXA in 2023 (121 patients)
- 70 Main campus
- 27 Imaging and spine center
- 19 Eastowne
- 7 Hillsborough

Age range 2-18
- 9 patients ≤ 5 years old

Data courtesy of Jay Allen Cannady-Kelderman

https://iscd.org/learn/official-positions/pediatric-positions/

https://www.acr.org/-/media/ACR/Files/Practice-Parameters/dxa.pdf


https://zscore.research.chop.edu/

http://www.lateraldistalfemur.org/