Bone Densitometry Notes

**NOMENCLATURE: DXA (NOT DEXA), T-score and Z-score. VFA—vertebral fracture analysis (not DVA, LVA, IVA, RVA, etc.), FRAX**

Spine: approx 66% trabecular/cancellous bone on PA view, remainder cortical/compact bone. L1 usually lowest BMD, BMC and area progressively increase from L1 to L4. BMD tends to increase from L1 to L3. BMD of L4 similar or less than L3. If difficulty numbering due to rib variability and transitional vertebrae, count from below, with L4-L5 considered at iliac crests if possible. 1 in 6 patients have variants, so if uncertain, count from below, usually L4-5 at iliac crest or slightly below. L3 usually has longest transverse processes.

Hip: 25% trabecular at neck and 50% trabecular at trochanter

**Forearm:** use 33% radius = 1/3 radius: almost entirely cortical bone and only 1% trabecular bone.

Hyperparathyroidism primarily affects cortical/compact bone, that’s why forearm must be scanned in patients with hyperparathyroidism.

Bone density on average: M>F and Blacks>Whites. Peak bone mass achieved in teens or early 20's. Relative plateau until 35 years old, then age-related bone loss occurs at a rate of 0.5%-1.0%/year. Bone loss accelerates with menopause (1.0-2.0%/year) and accelerated phase lasts 5-10 years. Age-related bone loss continues, with bone loss eventually going back down to pre-adolescent levels.

Cancellous or trabecular bone accounts for 20% of skeleton but 80% of surface area. More vascular and higher turnover, with 25% renewed each year. Cancellous bone loss is rapid in early menopause so ↑ frequency of wrist fxes first, then as cancellous bone loss continues, ↑risk of vertebral fxes.

Cortical or compact bone makes up about 80% of the skeleton, but is only about 20% of surface area and about 3% of cortical bone is renewed each year. About 10% of the skeleton is being remodeled at any one time. Cortical bone loss is
more gradual, but also more persistent. Risk of hip fractures increases as a result of loss of both cancellous and cortical bone, especially later ages, 80's. Hip and spine have a similar rate of osteoporosis in patients' 70's.

In females, incidence of clinical vertebral fxs increases age 55-60 y/o and rises \textit{linearly} thereafter. Men's risk begins to rise 5-10 yrs later (60-65 y/o). \textit{2/3 of vertebral fractures are clinically silent (morphometric, seen on x-ray)! Only 25-30\% of fxs seen on x-ray are dx'd clinically.}

Hip fxs: In women incidence begins to rise about age 65 and increases \textit{exponentially} thereafter. In men, incidence rises 5-10 yrs later. Complications of hip fx (especially nursing home pts): 24-30\% excess mortality within 1 year, 50\% of survivors are permanently incapacitated and 20\% of survivors require long-term nursing home care.

Central DXA = current gold standard for DIAGNOSTIC CLASSIFICATION of BMD and osteoporosis, excellent reproducibility, low radiation dose (1-10 µSv), most epidemiologic studies and clinical pharmaceutical trials. However, multiple other techniques are well-validated for \textit{fracture risk assessment (not diagnosis of osteoporosis)}. \textbf{Radiation Dose:} 1-10 µSv, 1/10th the dose of a CXR, approximately the equivalent of natural daily background exposure (5-8 µSv per day). Boston to Chicago flight approx. 30 µSv.

\begin{itemize}
\item \textbf{INDICATIONS FOR BONE MINERAL DENSITY (BMD) TESTING}
\item Women ≥ 65 y/o.
\item Postmenopausal women (natural or surgical) < 65 y/o with risk factors for fx
\item Women during the menopausal transition (perimenopausal) with clinical risk factors for fx, e.g. low body weight, prior fx, or high-risk medication use.
\item Men ≥ 70 y/o.
\item Men < 70 y/o with clinical risk factors for fx.
\item Adults with a fragility fx*.
\item Adults with a disease or condition assoc'd with low bone mass or bone loss.
\item Adults taking medications associated with low bone mass or bone loss.
\item Anyone being considered for pharmacologic therapy.
\item Anyone being treated, to monitor treatment effect.
\item Anyone not receiving therapy in whom evidence of bone loss would lead to treatment.
\end{itemize}

\*\textbf{Fragility Fx = fx from falling from standing height or lower at walking speed or slower, often vertebral, hip or wrist. Fx occurring in the absence of obvious trauma or minimal trauma not usually expected to cause a fracture. Excludes pathologic fxs, and fxs of digits, hands & ankles/feet, and skull fxs.}

\**Although not part of the WHO classification, the presence of a fragility fx--\textit{regardless of T-score}--should be considered diagnostic of osteoporosis (provided other causes for the fracture have been excluded.)

\begin{itemize}
\item \textbf{Reference Database for T-scores}
\item Use a uniform Caucasian/white (non-race adjusted) female normative database for women of all ethnic groups.
\item Use a uniform Caucasian/white (non-race adjusted) male normative database for men of all ethnic groups.
\item Use the NHANES III database for T-score derivation at the hip regions.
\end{itemize}
Transgender individuals, use BIRTH gender.

**DDX of low T-score: Osteoporosis and Secondary Causes of Osteoporosis:**

Osteoporosis: skeletal disorder characterized by compromised bone strength predisposing to an increased risk of fracture. Bone strength reflects the integration of two main features: bone density and bone quality. There are no symptoms from low bone mass unless fracture occurs.

Bone marrow disorders: osteomalacia, genetic e.g. osteogenesis imperfecta, Gaucher's disease, mastocytosis, multiple myeloma, marrow infiltrative process e.g. skeletal metastases. Hemolytic anemia, hemoglobinopathies, myelo- and lympho-proliferative disorders.

GI tract disorders: Gastrectomy, inflammatory bowel disease, celiac disease/sprue, intestinal bypass surgery, primary biliary cirrhosis, pancreatic insufficiency

Endocrinopathies (hypercalciuria, hypogonadism, hyperprolactinemia, hyperparathyroidism, hyperthyroidism, Cushing's syndrome, ?acromegaly)

Drugs (excess glucocorticoids/steroids, excess thyroid hormone, anticoagulants/heparin, GnRH agonists, anticonvulsants, aluminum-containing antacids, aromatase inhibitors e.g. Arimidex and Femara, thiazolidinediones e.g. Avandia, cyclosporine, rifampicin, exchange resins, methotrexate, alcohol, ?loop diuretics.

Vitamin D Insufficiency and Deficiency: lack of sun exposure and lack of dietary Vit D, age-related decline in cutaneous prod'n, GI disease, liver disease, renal disease, drugs (phenytoin, phenobarbitol)

In one study of 664 women: 53% of peri/postmenopausal women with T-score ≤ -2.5 had secondary osteoporosis by history!!

**T-score:** number of standard deviations the patient's BMD is above or below average peak BMD of young adult reference population.

**Z-score:** number of standard deviations the patient's BMD is above or below age- and sex-matched mean reference value. Z-score should be population specific where adequate reference data exist, including **ethnicity**.

**Z-scores are used instead of T-scores for children, pre-menopausal women and men younger than age 50!** A Z-score ≤ -2.0 is defined as "below the expected range for age." Z-score > -2.0 is "within the expected range for age."

**Osteoporosis cannot be dx'd in MEN under age 50 on the basis of BMD alone. However, the WHO diagnostic criteria may be applied to women in the menopausal transition=perimenopausal (and younger surgically post-menopausal patients).**

**DIAGNOSIS:** Use lowest T-score of spine, femoral neck OR total hip or (nondominant) forearm. Even if two sites have normal BMD and one site osteoporotic, dx is still osteoporosis. Do not give two separate diagnoses! Do not say borderline osteoporosis. In certain circumstances the 33% (1/3) radius may be utilized.

**FOLLOW-UP monitoring:** Use spine or total hip (total proximal femur) preferred over mean hip. Do not state percentage change or any actual BMD numbers if there is NOT a significant increase or decrease. Just simply state there is no significant change at sites. Follow-up serial BMD measurements can be used to determine whether tx should be started, is effective or if tx needs to change due to non-response. Interval between BMD testing should be determined according to each pt's clinical status: e.g. 1 year after initiation or change of tx, with longer intervals once therapeutic effect is established. **Follow-up should be performed when the expected change in BMD equals or exceeds the least significant change (LSC)!”
Increases in BMD are encouraging, stable BMD is okay. Significant decreases in BMD are worrisome (if on appropriate therapy and patient is compliant)--consider evaluation for secondary causes of osteoporosis.

**WHO CLASSIFICATION**

Normal T-score ≥ -1.0

**Low bone mass/low bone density terminology preferred over osteopenia for T-score between -1.0 and -2.5**

Osteoporosis T-score ≤ -2.5

Severe or established osteoporosis with T-score ≤ -2.5 WITH Hx of fragility fx

**SPINE ROI**

- use PA L1-L4 & use all evaluable vertebrae and only exclude vertebrae that are affected by structural change or artifact.
- **exclude vertebrae if clearly abnormal and nonassessable within resolution of the system or prior surgery OR**
- there is > 1.0 T-score difference between the vertebra in question and adjacent vertebrae **AND VISIBLe CAUSE such as sclerosis.**
- Assess for cause, often increased T-score due to subtle fx or increased degenerative change & sclerosis (so **usually drop high T-score vertebra**) or may occasionally see spurious decrease T-score due to interval surgery or laminectomy (drop low T-score). {e.g. L1 T-score 2.9, L2 -0.1, L3 1.1 and L4 0.7 --you would drop L1 as it is spuriously increased by degenerative change/fx, also, L3 is > 1.0 T-score higher than adjacent L2 vertebra and it has degenerative sclerosis, so it is dropped as well. Evaluate only L2 and L4 in this instance.} "Art of medicine“ may be invoked on challenging cases. e.g. if dropping a vertebra doesn't change diagnosis may not want to drop it, especially if it is outlying lower than the rest. If lots of variation between vertebral bodies, likely need additional imaging of hips/dominant forearm today, or in the future. Careful about dropping vertebra on baseline exam. Remember, lose statistical significance when drop vertebrae. **Must have at least two or more assessable vertebrae to use L-spine BMD. If only one assessable lumbar vertebra, CANNOT use spine, instead use hips and forearm.**

- use remaining vertebral BMDs to derive the T-score and make certain comparison study is also modified to reflect change in vertebrae included i.e. "Trend" or comparison also reflects only assessable vertebrae.
- Best precision and most responsive to therapy.

**HIP ROI** Consider doing bilateral hip! in case of interval surgery or fx, still have comparison site.

- for diagnosis, use femoral neck or total proximal femur, whichever is lowest. Either hip may be used.
- mean hip (average of R/L hips) BMD may be used for monitoring but total hip is preferred for monitoring/follow-up because of better precision. But mean hip may also be used. Femoral neck only as a final alternative site for monitoring/follow-up.

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FOREARM ROI

- use if another site is not evaluable (e.g. hip replacements, spinal surgery, significant degenerative change/scoliosis, obesity exceeding table weight limit, etc.) or if patient has hyperparathyroidism.*
- only 33% radius (1/3 radius) technique of non-dominant forearm is recommended for diagnosis. If history of fracture of nondominant wrist or forearm as an adult, then use dominant forearm.
- does not respond well to therapy

*Hyperparathyroidism targets cortical bone so also perform 33% or 1/3 radius in this instance.

INDICATIONS FOR VERTEBRAL FRACTURE ASSESSMENT (VFA)

-Postmenopausal women with low bone mass PLUS
  any ONE of the following: ≥ 70 y/o, historical loss of height > 4 cm (1.6"), prospective loss of ht of > 2 cm (0.8"), self-reported vertebral fx not previously documented,
  OR
  TWO or more of the following: 60-69 y/o, self-reported non-vertebral fx, historical height loss of 2-4 cm, chronic systemic diseases assoc'd with increased risk of vertebral fxs (e.g. COPD, rheumatoid arthritis, Crohn's disease)

-Men with low bone mass PLUS
PLUS any ONE of the following: ≥ 80 y/o, historical height loss > 6 cm (2.4"), prospective ht loss > 3 cm (1.2"), self-reported vertebral fx not previously documented,
  OR
  TWO or more of the following: 70-79 y/o, self-reported prior non-vertebral fx, historical height loss of 3-6 cm, on pharmacologic androgen deprivation tx or following orchiectomy, chronic systemic diseases assoc'd with increased risk of vertebral fxs (e.g. COPD, rheumatoid arthritis, Crohn's disease)

-Women or men on chronic glucocorticoid tx (equivalent to ≥ 5 mg of prednisone daily for ≥ 3 months. Glucocorticoids/steroids especially affect trabecular (cancellous) bone.

-Postmenopausal women or men with osteoporosis by BMD criteria if documentation of one or more vertebral fxs will alter clinical management.

Vertebral fxs may be wedge, biconcave or crush (see diagram at end of document) Mild = grade 1 approx 20-25% loss of ht, moderate = grade 2 approx 25-40% and severe fx = grade 3 > 40% loss of height. On VFA be conservative with dx of grade 1 fxs, especially T-spine. Also check VFA for other bony findings and aortic calcification!!

Indications for following VFA with another imaging modality (if not already performed), also must be based on each patient's overall clinical picture:

- two or more mild (grade 1) deformities without any moderate or severe deformities
- lesions in vertebrae that cannot be attributed to benign causes
- vertebral deformities in a pt with known hx of relevant malignancy
- equivocal fxs
- unidentifiable vertebrae between T7-L4
- sclerotic or lytic changes or findings suggestive of conditions other than osteoporosis.

BMD values of different manufacturers are NOT comparable due to different methods of dual-energy production, calibration, detectors, edge detection software, ROIs and databases. Even same manufacturer/model/software
Must monitor technologists' precision error and coefficient of variation to determine the significance of change between serial measurements. If less precise, then greater change must be documented to be considered significant. Need to calculate Least Significant Change (LSC). Also need QA/QC checks, phantom scans and calibration, maintenance, review, etc. Precision analysis: 15 patients measured 3 times or 30 patients measured 2 times, repositioning the patient after each scan (off the table between scans). Minimal acceptable precision: L-spine 1.9% (LSC 5.3%), Total Hip: 1.8% (LSC 5.0%), Femoral Neck: 2.5% (LSC 6.9%). Precision assessment should be standard clinical practice. See ISCD website, Precision Calculator Tool.

INTERPRETATION AND REPORTING:

Technique

- **Spine:** use positioning block. (GE One-Scan not optimal) centered & straight & not tilted or leaning, both iliac crests visible, mid T12-mid L5 included? excluding large osteophytes? too narrow and excluding bone? look at raw data and histograms to confirm disk levels? exclude vertebrae with fx (check VFA too!) or hardware, vertebroplasty or kyphoplasty (=vertebral augmentation) or laminectomy. Other artifact, stent grafts, surgical clips, barium, calcification, f.b., external to patient? Careful because DXA does subtract soft tissue! Appropriate and consistent numbering? Same vertebrae measured as on prior exam?
  
  Check for > 1.0 difference in T-score between adjacent vertebrae and associated visible abnormality like sclerosis!

- **Hip:** positioning of hip, foot in positioning device? femoral neck centered in the image, very little lesser trochanter apparent (internally rotated)? vertical orientation of diaphysis? total hip includes ischium and greater trochanter? verify bone margins! Have patient retract panniculus every time!
  
  appropriate ROI box placement--slightly different by manufacturer e.g. femoral neck rectangular ROI should not include ischium if possible (usually can auto-subtract "neutralize" ischium vs. 2nd option narrow the box or 3rd option, move the box)--

  GE Lunar: finds narrowest point of femoral neck and all 4 corners in soft tissue, vs

  Hologic: anchors it to the superomedial edge of greater trochanter with 3 corners in soft tissue, one corner touches/anchors to greater trochanter

  neither neck box should include greater trochanter or ischium (neutralize ischium if necessary).

  Lower inferior margin GE auto selects it based on greater trochanter triangle and Hologic supposed to find inferior margin of lesser trochanter and go 1 cm inferior.

  Check for artifacts, surgical clips, metal, calcification, objects external to patient. Exclude if prior fx or surgery.

- **Forearm:** nondominant forearm. Centered? radius & ulna straight, parallel to long axis of table? distal cortex of radius & ulna and proximal carpal row visible? artifacts? Do not use forearm if hx of prior fracture as an adult as tends to increase BMD. If patient has history of nondominant forearm fx as an adult, use dominant forearm. Radius 1/3 or radius 33% is the only value used.

  - Compare ROIs, consistent year to year?
  - Check BMD vs. BMD and T-score vs. T-score as well.
  - If can't do spine, do bilateral hips (or unilateral hip) and nondominant forearm.
  - Pediatric DXA- NEED dedicated pediatric software program. Scan whole body then ignore head during analysis. Scan PA spine too but NOT hip. Follow manufacturer's guidelines for positioning.

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BASELINE DXA REPORT minimum requirements include:

- Pt demographics, provider, indications
- MANUFACTURER AND MODEL of instrument used
- Technical quality and limitations of the study—stating why a specific site or ROI is invalid or not included
- BMD in g/cm² for each site (3 units past the decimal point e.g. 0.993 g/cm²)
- Skeletal sites and ROI (R/L) scanned
- T-score and/or Z-score where appropriate (tenths e.g -2.3)
- WHO criteria for dx in postmenopausal females and in men ≥ 50
- Risk factors, previous non-traumatic fx
- Statement about fx risk—any statement about relative fx risk must specify the population of comparison (e.g. young-adult or age-matched).
- A general statement that a medical evaluation for secondary causes of low BMD may be appropriate.
- Recommendations for the necessity and timing of the next BMD study

FOLLOW-UP DXA REPORT:

- Statement regarding which previous study or baseline study and ROI is being used for comparison.
- **Statement about the Least Significant Change (LSC) at your facility and the statistical significance of the comparison. Subtract patient's current BMD from the one you are comparing with and if value is ≥ LSC, then report change as significant.
- Report any significant change, if any, between the current and prior study or studies in g/cm² (which ISCD prefers) AND percentage. (If no significant change, do not give numeric values!)
- Comments on any outside study including manufacturer and model on which previous studies were performed and the appropriateness of comparison. Cannot compare between different machines due to different dual energy methods, different calibration and LSC, different detectors, different edge detection software and different data bases and ROI techniques, etc.
- Recommendations for the necessity and timing of the next BMD study

OPTIONAL ITEMS:

- Recommendation for further non-BMD testing, e.g. X-ray, MRI, CT, etc.
- Recommendations for pharmacological and non-pharmacological interventions.
- Addition of the percentage compared to a reference population.
- Specific recommendations for evaluation of secondary osteoporosis.

DXA REPORT SHOULD NOT INCLUDE:

- a statement that there is bone loss without knowledge of previous bone density
- "mild", "moderate" or "marked" osteopenia or osteoporosis
- separate dx for different ROI skeletal sites (e.g. osteopenia at the hip and osteoporosis at the spine)
- expressions such as "she has the bones of an 80 y/o" if the pt is not 80 y/o
- results from skeletal sites that are not valid
- actual change in BMD if it IS NOT a significant change based on the precision error and LSC.

Pediatric DXA  (ages 5-19)

Pediatric DXA- Requires dedicated pediatric software program. Scan whole body then ignore head during analysis. Scan PA spine too but NOT hip. Follow manufacturer's guidelines for positioning.

The diagnosis of osteoporosis in children and adolescents should NOT be made on the basis of densitometric criteria alone. The diagnosis of osteoporosis requires the presence of both a clinically significant fracture hx and low bone mineral content or bone mineral density.
A clinically significant fx hx is ONE or more of the following: long bone fx of the lower extremities, vertebral compression fx, two or more long-bone fxs of the upper extremities.

Low bone mineral content or bone mineral density is defined as a BMC or areal BMD Z-score that is ≤ -2.0, adjusted for age, gender and body size, as appropriate.

DXA measurement is part of a comprehensive skeletal health assessment in pts with increased risk of fx.
Therapeutic interventions should not be instituted on the basis of a single DXA measurement.
When technically feasible all patients should have spine and total body less head (TBLH) BMC and areal BMD measured (prior to initiation of bone-active tx and to monitor tx in conjunction with other clinical data).
In pts with primary bone disease or potential secondary bone diseases (e.g. due to chronic inflammatory diseases, endocrine disturbances, hx of childhood cancer or prior non-renal transplantation), spine and TBLH BMC and areal BMD should be measured at clinical presentation.
In pts with thalassemia major, spine and TBLH BMC and areal BMD should be measured at fx presentation or age 10, whichever is earlier.
In children with chronic immobilization (e.g. cerebral palsy) spine and TBLH BMC and areal BMD should be measured at fx presentation. DXA should not be performed if contractures prevent the safe and appropriate positioning of the child.
The minimum time interval for repeating a bone density measurement to monitor treatment with a bone-active agent or disease processes is 6 months.
DXA is the preferred method for assessing BMC and areal BMD.
PA spine and TBLH are the most accurate and reproducible skeletal sites for performing BMC and areal BMD measurements. The hip is NOT a reliable site for children.
Soft tissue measures in conjunction with whole body scans may be helpful in evaluating patients with chronic conditions associated with malnutrition or with both muscle and skeletal deficits.
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.

PEDIATRIC DXA REPORT should include:

- Pt demographics (AGE, GENDER, WT, HT, RACE/ETHNICITY), provider, indications
- MANUFACTURER AND MODEL AND SOFTWARE VERSION of instrument used
- Technical quality
- Relevant medical hx including prior fxs
- Bone age results if available
- BMC (hundredths e.g. 31.76 g) and areal BMD (hundredths e.g. 43.25 cm²)
- Z-score (tenths e.g. 1.7), source of reference data for Z-score calculations
- Adjustments made for growth and maturation
- A general statement that a medical evaluation for secondary causes of low BMD may be appropriate.
- Recommendations for the necessity and timing of the next BMD study are optional

T-scores should NOT appear in pediatric DXA reports.
The term "osteopenia" should NOT appear in pediatric DXA reports.
The term "osteoporosis" should NOT appear in pediatric DXA reports without knowledge of clinically significant fx history.

"Low bone mineral content or bone mineral density for chronologic age" (or below the expected range for age) is the preferred wording when BMC or BMD Z-scores are ≤ -2.0. A Z-score > -2.0 is "within the expected range for age."

FOLLOW-UP PEDIATRIC DXA REPORT:

-should be done only when the expected change in areal BMD is ≥ the LSC.
Serial DXA reports should include the same info as baseline PLUS:
- Indications for follow-up scan
- Comparability of scans
- Interval change in height & weight
- BMC and areal BMD Z-scores adjusted or unadjusted for height or other parameters
- Percent change in BMC and areal BMD and interval change in Z-score
- Recommendations for the necessity and timing of the next BMD study are optional.

![Bone Fracture Diagram]

**References and Sources:**

International Society for Clinical Densitometry (ICSD) 2007 Official Positions and Pediatric Official Positions
ICSD Bone Densitometry Course for Clinicians 2012
Osteoporosis Essentials: Densitometry, Diagnosis and Management 2013 (ISCD and IOF)
Bone Densitometry in Clinical Practice: Application and Interpretation 3rd Ed. 2010 by Sydney Lou Bonnick, MD

**FRAX**

Main use is to help determine if treatment is necessary in cases of osteopenia. If $\geq 20\%$ risk of major osteoporosis related fx or $\geq 3\%$ risk of hip fx then treatment recommended!

FRAX is not performed if there is normal bone mineral density or osteoporosis based on the lowest T-score or if there is known vertebral or hip fracture or if patient is being treated for osteoporosis.