Bone Density Update

Southwest Chapter Meeting

SNMMI

4/14/2016
Disclosures

• No Financial disclosures
• Member of the International Society of Clinical Densitometry’s Certification Council
• No bias for any particular scanner, software product, or certification body
Objectives

• Pathophysiology Underlying Bone Loss
  – in Normal Aging
  – in Osteoporosis
  – Molecular Mediators

• Comparison of Current Methods to assess bone density

• Best Practices for DEXA Measurement and Reporting
  – ISCD Guidance
Bone Mass Change From Peak Bone Mineral Density

Hendrickx et Nat Rev Rheumatol, 11:462, 2015
Bone Density Changes in Aging

Red: Pre-meno F; Blue: Post-meno Fem; Black: Men

Values for vBMD (mg/cm3) of cortical bone at the distal radius and vertebral body in a population sample of Rochester, Minnesota women and men between the ages of 20 and 97 years.
Bone Modeling and Remodeling: Building, Repairing or Losing Bone through Coordinated Ob, Ocy, Oc Action

Baron and Kneissel Nat Med 19: 179, 2013
Multi-factorial Pathogenesis of Primary Osteoporosis

• Age-associated factors
  – **Sex steroid deficiency**
  – Oxidative stress
  – Apoptosis
  – Macroautophagy
• Life-style related Factors
  – Inadequate intake of calcium and vitamin D
  – Smoking
  – Physical Inactivity
  – Excessive Alcohol intake
• Genetic
  – Monogenic forms: e.g. Type I collagen in Osteogenesis Imperfecta, LRP5 in Osteoporosis-Pseudoglioma syndrome, Runx2 in cleidocranial dysplasia
  – Polygenic trait: many contributors each with small effects
Age Associated Factors Contributing to Bone Fragility and Loss: ROS buildup, Cell Death

20–30 years of age

- Antioxidant systems: SOD, GPx, GSH, CAT, FOXO
- p66Shc
- ROS: $O_2^-$, $HO^-$, $H_2O_2$
- Sex steroids
- Mitochondria
- Oxidative stress: Controlled
- Apoptosis: Controlled
- Autophagy

Ageing

>55 years of age

- Antioxidant systems: SOD, GPx, GSH, CAT, FOXO
- p66Shc
- ROS: $O_2^-$, $HO^-$, $H_2O_2$
- Sex steroids
- Mitochondria
- Oxidative stress: Damage to macromolecules
- Apoptosis: Uncontrolled
- Cell senescence
- Autophagy

- Increased osteoblast and osteocyte apoptosis
- Micropetrosis
- Unbalanced bone remodelling
- Low BMD and deteriorated bone microarchitecture
- Increased fracture risk

Hendrickx et Nat Rev Rheumatol, 11:462, 2015
Wnt Signaling Pathways in Bone Regulation

Note Connection to:
Hormones, e.g. PTH
Therapies e.g. anti-DKK1, anti-SOST
Working Model of Estrogen Regulation of Bone Turnover

Evidence for Critical Role of Estrogen Deficiency in Male Skeletal Health

- Estrogen (E) receptor alpha deficient males have high E but low BMD
  - NEJM 331:1056, 1994
- Aromatase Deficient Males have low bone mass
  - JCEM 80:3689, 1995
- In the Osteoporotic Fracture in Older Men Study (MrOS), bio-available E not bio-T was associated with increased risk of non-spine fracture
  - JCEM 94:3337, 2009
  - Similar observation for hip however low bio-T was also associated with increased fracture risk and faster bone loss
    - JCEM 95:4314, 2010
  - Note that estrogens are made from androgens

Reviewed in Cauley, Steroids 99:11, 2015; SAM Question
Osteoporosis

• The most common bone disease in humans
• Systemic Disease characterized by low bone mass, deterioration of bone tissue and disruption of bone architecture, compromised bone strength and an increase in the risk fracture
• Note this definition involves bone quantity and bone quality
Types of Bone Density Tests

- RA: Radiographic Absorptiometry
- SPA: Single Photon Absorptiometry
- SXA: single x-ray absorptiometry
- DPA: Dual Photon Absorptiometry
- DXA: dual energy x-ray absorptiometry
- pDXA: peripheral dual energy x-ray absorptiometry
- QUS: quantitative ultrasound
- QCT: Quantitative Computed Tomography
- pQCT: peripheral quantitative computed tomography
Bone Density Assessment: Nuclear Medicine Roots

- **SPA**
  - Introduced in the 1960's
  - I-125 source radionuclide source
    - Gamma emitter, ~28keV
    - 60 day half-life
    - Worked best in areas of uniform thickness
    - Precision and accuracy very good; longest fracture trials published to date, demonstrating the ability of a single bone mass measurement to predict fracture, were performed using SPA measurements of the radius
  - Superseded by SXA

- **DPA:**
  - Introduced to overcome the limitations of SXA in sites with variable soft tissue thickness and composition such as axial skeleton, hip or whole body
  - Gd-153 radionuclide source
    - Gamma emitter, 42 and 102keV
    - ~240d half-time
  - Superseded by DXA*
    - Shorter exam times
    - Greater accuracy and precision
    - Fewer errors due to source decay corrections
    - Most widely used method of measuring BMD

* Fogelman and Blake JNM 41:2015
Comparison of Available Modalities for Bone Status Assessment**

<table>
<thead>
<tr>
<th>Technique</th>
<th>Precision Error (%)</th>
<th>Accuracy Error (%)</th>
<th>Effective Dose (µSv)</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>RA Phalanges/metacarpal</td>
<td>1-2</td>
<td>5</td>
<td>~5</td>
<td>Low cost per test/equipment</td>
<td>Limited to the hands</td>
</tr>
<tr>
<td>SXA/pDXA Radius/calcaneus</td>
<td>1-2</td>
<td>4-6</td>
<td>&lt;1</td>
<td>Low cost per test/equipment</td>
<td>Limited to hands, wrist or heel Area density</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Equipment mobile</td>
<td>Limited correlation to spine/hip</td>
</tr>
<tr>
<td>DXA PA spine</td>
<td>1-1.5</td>
<td>4-10</td>
<td>~1</td>
<td>Multiple sites capability</td>
<td>Limited Mobility</td>
</tr>
<tr>
<td>Lat spine</td>
<td>2-3</td>
<td>5-15</td>
<td>~3</td>
<td>Low radiation exposure</td>
<td>Areal density</td>
</tr>
<tr>
<td>Probimal femur</td>
<td>1.5-3</td>
<td>6</td>
<td>~1</td>
<td></td>
<td>Moderate cost of equipment</td>
</tr>
<tr>
<td>Forearm</td>
<td>~1</td>
<td>5</td>
<td>&lt;1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole body</td>
<td>~1</td>
<td>3</td>
<td>~3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>QCT spine trabecular/integral</td>
<td>2-3</td>
<td>5-15</td>
<td>~50</td>
<td>Volumetric density</td>
<td>High radiation exposure</td>
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<tr>
<td>hip trabecular/integral</td>
<td>2-3</td>
<td>4-10</td>
<td>~50</td>
<td></td>
<td>&quot;Limited access&quot;</td>
</tr>
<tr>
<td>pQCT radius trabecular</td>
<td>1-2</td>
<td>?</td>
<td>~1</td>
<td>Volumetric density</td>
<td>Limited to wrist</td>
</tr>
<tr>
<td>radius total</td>
<td>1-2</td>
<td>2-8</td>
<td>~1</td>
<td>Equipment mobile</td>
<td>Limited correlation with spine/hip</td>
</tr>
<tr>
<td>QUS SOS calcaneus/radius/phalanges</td>
<td>0.3-1.2</td>
<td>?</td>
<td>0</td>
<td>Radiation free</td>
<td>Limited to peripheral sites</td>
</tr>
<tr>
<td>BUA calcaneus</td>
<td>1.3-3.8</td>
<td>?</td>
<td>0</td>
<td>Low cost per test/equipment</td>
<td>Limited correlation to the spine/hip</td>
</tr>
</tbody>
</table>

*Dose for annual background ~2,000 µSv, for abdominal radiograph ~500µSv and for abdominal CT ~4000µSv, Semin Nucl Med 27(3):210-218
** After Genant HK et al JBMR 11(6): 707, 1996
WHO Operational Definition of Osteoporosis Based on DXA

- Import slides from Oz DXA lecture
- Import slide on DXA guidelines from lecture on PMH NM
DXA Indications

• Women aged 65 and older
• For post-menopausal women younger than age 65 a bone density with a risk factor for low bone mass
  • Low body weight
  • Prior fracture
  • High risk medication use
  • Disease or condition associated with bone loss
• Women during the menopausal transition with clinical risk factors for fracture
  • Low body weight
  • Prior fracture
  • High-risk medication use
DXA Indications: Males

• Men aged 70 and older
• For men < 70 years of age a bone with a risk factor
  • Low body weight
  • Prior fracture
  • High risk medication use
  • Disease or condition associated with bone loss.
Other Indications

- Adults with a fragility fracture.
- Adults with a disease or condition associated with low bone mass or bone loss.
- Adults taking medications associated with low bone mass or bone loss.
- Anyone being considered for pharmacologic therapy.
- Anyone being treated, to monitor treatment effect.
- Anyone not receiving therapy in whom evidence of bone loss would lead to treatment.
- Women discontinuing estrogen should be considered for bone density testing.
<table>
<thead>
<tr>
<th>Patient’s T-Score</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.5 T</td>
<td>Normal</td>
</tr>
<tr>
<td>-1.0 T</td>
<td>Osteopenia</td>
</tr>
<tr>
<td>-1.5 T</td>
<td>Osteoporosis</td>
</tr>
<tr>
<td>-2.0 T</td>
<td>Severe Osteoporosis (with fragility fractures)</td>
</tr>
</tbody>
</table>
Young Adult T-score

- $1T = 1$ Standard Deviation (SD)
- Compares patient’s result to average Young Adult reference
- Example:
  
  If T-score = -2.3, then subject’s BMD is 2.3 SD below average Young Adult BMD

Age-Matched Z-score

- $1Z = 1$ Standard Deviation (SD)
- Compares patient’s result to Age-Matched reference
Gradient Relationship between T-score and Fracture risk: Approximates Hip-Fracture Risk and Hip BMD Relationship
WHO Fracture Risk Assessment Tool (FRAX)

- Fracture risk assessment developed by the World Health Organization
- Complex computer algorithm designed to compute 10-year fracture risk
- Based on meta-analysis of multiple studies
- Used to help predict those untreated patients at high risk for fracture who might benefit from therapy
- Country-specific threshold assigned to the risk depending on the economic model the country uses to calculate most cost-effective time to intervene
- A guide not a substitute for clinical judgment and acumen
- Our clinicians tend to follow NOF guidelines on treatment
- May incorporate FN BMD data but not absolutely necessary
WHO Fracture Risk Assessment Tool (FRAX)

N.B. Does not include fall history; SAM Question

https://www.shef.ac.uk/FRAX/tool.jsp
FRAX: Accepts Mindways CT Derived Femoral Neck BMD

For USA use only

Consider FDA-approved medical therapies in postmenopausal women and men aged 50 years and older, based on the following:

- A hip or vertebral (clinical or morphometric) fracture
- T-score ≤ -2.5 at the femoral neck or spine after appropriate evaluation to exclude secondary causes
- Low bone mass (T-score between -1.0 and -2.5 at the femoral neck or spine) and a 10-year probability of a hip fracture ≥ 3% or a 10-year probability of a major osteoporosis-related fracture ≥ 20% based on the US-adapted WHO algorithm
- Clinicians judgment and/or patient preferences may indicate treatment for people with 10-year fracture probabilities above or below these levels
Trabecular Bone Score (TBS)

- Textural index that evaluates pixel gray-level variations in the lumbar spine DXA image
- Not a direct physical measurement of microarchitecture but correlates but is related to 3D measures such as Tb.N, Tb.S, and connectivity density
- Principle: Dense architecture yields image with small variations in pixel values, porous architecture yields image with low number of pixel variations of high amplitude
- Elevated TBS appears to represent strong, fracture resistant microarchitecture
- Low TBS reflects weak, fracture prone microarchitecture
- Predicts Fracture risk independent of BMD
- TBS can differentiate microarchitecture from 3D objects with the same density but different microarchitecture
- Generally derived from re-analysis of lumbar spine BMD, hence papers are accumulating rapidly and it represents an opportunity for NM DXA labs
TBS Proposed Normal Range for Post-menopausal Women

- **Normal:**
  - TBS ≥ 1.350

- **Partially Degraded Microarchitecture**
  - TBS > 1.200 and < 1.350

- **Degraded Microarchitecture**
  - TBS ≤ 1.200

- **Normal range for men not yet proposed**
TBS Principles and Example Cases with same BMD but Different TBS

<table>
<thead>
<tr>
<th>BMD</th>
<th>Illustration of Well-structured trabecular bone</th>
<th>Experimental variogram</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.972</td>
<td>![Image of well-structured trabecular bone]</td>
<td>![Experimental variogram]</td>
</tr>
<tr>
<td></td>
<td>Normal</td>
<td></td>
</tr>
<tr>
<td>0.969</td>
<td>![Image of altered trabecular bone]</td>
<td>![Experimental variogram]</td>
</tr>
<tr>
<td></td>
<td>Partially degraded</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TBS</th>
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<tbody>
<tr>
<td>1.459</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Normal</td>
</tr>
<tr>
<td>1.243</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Partially degraded</td>
</tr>
</tbody>
</table>
TBS in Aging and Medications

- Normative reference curve

- Healthy Aging
  - Little change between 30 and 45y/o, thereafter progressive decrease with advancing age
  - %Decrease with age similar to that of lumbar spine aBMD as is short term reproducibility

- Improved fracture discrimination

- Anti-resorptives: Degrades

- PTH and Ibandronate: Improves or preserves

- Aromatase inhibitors: Degrades
TBS and Diseases

• Diabetes:
  – Type I
  – Type 2

• Hyperparathyroidism:


• Treatment of Breast Cancer Patients with Zoledronic Acid:

• Others: Crohn‘s Disease, HIV patients
Some clinicians are using the TBS adjusted FRAX score to make treatment decisions.
TBS Adjusted Fracture Risk in Osteopenia

- Fracture risk assessed by BMD alone:

  Based on minimum hip or spine BMD T-score

<table>
<thead>
<tr>
<th>Normal</th>
<th>Osteopenia</th>
<th>Osteoporosis</th>
</tr>
</thead>
<tbody>
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</tbody>
</table>

  Adapted from Table 3 in Hans et al. J Bone Miner Res. 2011 Nov;26(11):2762-9

- Fracture risk assessed by the combination of TBS + BMD:

  Based on minimum hip or spine BMD T-score

<table>
<thead>
<tr>
<th>Normal</th>
<th>Osteopenia</th>
<th>Osteoporosis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

  Based on Spine TBS

<table>
<thead>
<tr>
<th>≥ 1.300</th>
<th>Osteopenia</th>
<th>Osteoporosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.200 &lt;-&gt; 1.300</td>
<td>Osteopenia</td>
<td>Osteoporosis</td>
</tr>
<tr>
<td>≤ 1.200</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

  Adapted from Table 3 in Hans et al. J Bone Miner Res. 2011 Nov;26(11):2762-9

Figure 1. Prediction of fractures with bone mineral density (BMD) and trabecular bone score (TBS). The upper table shows fracture risk levels based on BMD alone. In the lower table, the combination of TBS with BMD shows an increased fracture risk in osteopenic patients with a low TBS level, while a high TBS level has a relatively protective effect.

Lewiecki et al., Endocr Res, Early Online: 1–14, 2015

E. Michael Lewiecki, *,1 Neil Binkley, 2 Sarah L. Morgan, 3 Christopher R. Shuhart, 4 Bruno Muzzi Camargos, 5 John J. Carey, 6 Catherine M. Gordon, 7 Lawrence G. Jankowski, 8 Joon-Kiong Lee, 9 and William D. Leslie 10 on behalf of the International Society for Clinical Densitometry
Recommendations: DXA Acquisition, Analysis and Interpretation and Reporting

Box. DXA Best Practices

Scan Acquisition and Analysis
1.1. At least one practicing DXA technologist, and preferably all, has a valid certification in bone densitometry.
1.2. Each DXA technologist has access to the manufacturer’s manual of technical standards and applies these standards for BMD measurement.
1.3. Each DXA facility has detailed standard operating procedures for DXA performance that are updated when appropriate and available for review by all key personnel.
1.4. The DXA facility must comply with all applicable radiation safety requirements.
1.5. Spine phantom BMD measurement is performed at least once weekly to document stability of DXA performance over time. BMD values must be maintained within a tolerance of ±1.5%, with a defined ongoing monitoring plan that defines a correction approach when the tolerance has been exceeded.
1.6. Each DXA technologist has performed in vivo precision assessment according to standard methods and the facility LSC has been calculated.
1.7. The LSC for each DXA technologist should not exceed 5.3% for the lumbar spine, 5.0% for the total proximal femur, and 6.9% for the femoral neck.

Interpretation and Reporting
2.1. At least 1 practicing DXA interpreter, and preferably all, has a valid certification in bone densitometry.
2.2. The DXA manufacturer and model are noted on the report.
2.3. The DXA report includes a statement regarding scan factors that may adversely affect acquisition/analysis quality and artifacts/confounders, if present.
2.4. The DXA report identifies the skeletal site, region of interest, and body side for each technically valid BMD measurement.
2.5. There is a single diagnosis reported for each patient, not a different diagnosis for each skeletal site measured.
2.6. A fracture risk assessment tool is used appropriately.
2.7. When reporting differences in BMD with serial measurements, only those changes that meet or exceed the LSC are reported as a change.

BMD, bone mineral density; DXA, dual-energy X-ray absorptiometry; LSC, least significant change.
<table>
<thead>
<tr>
<th>Organization</th>
<th>Description</th>
<th>Weblink</th>
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</thead>
<tbody>
<tr>
<td>American Bone Health</td>
<td>Limited permit X-ray technician</td>
<td><a href="https://americanbonehealth.org/limited-permit-x-ray-technician-school-bone-densitometry">https://americanbonehealth.org/limited-permit-x-ray-technician-school-bone-densitometry</a></td>
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<tr>
<td>American College of Radiology</td>
<td>Practice parameter for the performance of DXA</td>
<td><a href="http://www.acr.org/~/media/eb34da2f786d4f8e96a70b75ee035992.pdf">http://www.acr.org/~/media/eb34da2f786d4f8e96a70b75ee035992.pdf</a></td>
</tr>
<tr>
<td>American Society of Radiologic Technologists</td>
<td>Training and certification for technologists</td>
<td><a href="http://www.asrt.org/events-and-conferences/event-calendar">http://www.asrt.org/events-and-conferences/event-calendar</a></td>
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<td><a href="http://www.asrt.org/docs/default-source/educators/">http://www.asrt.org/docs/default-source/educators/</a> bonedensitometrycurriculum.pdf</td>
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<td>Auntminnie.com</td>
<td>Bone densitometry course for technologists</td>
<td><a href="http://www.auntminnie.com/(F(AiaAhFYYF2NIpZ-LQYAK9zBSaE53uNbrdw8TMEotZJ4C_auBzpJsK51OZTxmuNjXb903JuUqAs9rhc5QxVyVpLxTkY0MGovcJoYPYoY40DAE80cW6r0WGxQ0rgHkOA557w2)/index.aspx?sec=lin&amp;sub=def&amp;erd=83">http://www.auntminnie.com/(F(AiaAhFYYF2NIpZ-LQYAK9zBSaE53uNbrdw8TMEotZJ4C_auBzpJsK51OZTxmuNjXb903JuUqAs9rhc5QxVyVpLxTkY0MGovcJoYPYoY40DAE80cW6r0WGxQ0rgHkOA557w2)/index.aspx?sec=lin&amp;sub=def&amp;erd=83</a></td>
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<td>DEXA Solutions</td>
<td>Link to training and certification</td>
<td><a href="http://www.dexasolutions.com/Resources/Certification.aspx">http://www.dexasolutions.com/Resources/Certification.aspx</a></td>
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<td>Hologic</td>
<td>DXA training</td>
<td><a href="http://www.hologic.com/training/dxa-101-basics-bone-densitometry">http://www.hologic.com/training/dxa-101-basics-bone-densitometry</a></td>
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<tr>
<td>International Society for Clinical Densitometry</td>
<td>Training courses for DXA certification for clinicians and technologists, facility accreditation</td>
<td><a href="http://www.iscd.org/education/cmece-live-courses/osteoporosis-essentials/">http://www.iscd.org/education/cmece-live-courses/osteoporosis-essentials/</a></td>
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<td>Medical Technology Management Institute</td>
<td>Bone densitometry training course</td>
<td><a href="http://www.mtmi.net/courses/reg_BD.php">http://www.mtmi.net/courses/reg_BD.php</a></td>
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<td>OAR</td>
<td>OAR Canadian Bone Mineral Densitometry Facility Accreditation</td>
<td><a href="http://cbmd.ca/">http://cbmd.ca/</a></td>
</tr>
<tr>
<td>Study.com</td>
<td>Bone density technician training and degree program options</td>
<td><a href="http://study.com/articles/Bone_Density_Technician_Training_and_Degree_Program_Options.html">http://study.com/articles/Bone_Density_Technician_Training_and_Degree_Program_Options.html</a></td>
</tr>
</tbody>
</table>

**Note:** This is not an all-inclusive list. Other organizations in other countries may have excellent resources as well. Inclusion of programs in this table does not represent an endorsement of the ISCD; the quality of training in preparation for certification and/or accreditation may vary.

**Abbr:** DXA, dual-energy X-ray absorptiometry; CAR, Canadian Association of Radiologists; CME, continuing medical education; OAR, Ontario Association of Radiologists.
Reporting

- ISCD Recommendations
- Automated
- Manufacturer’s Reporter
- Pre-populating software
  - iMorgan
  - EPIC based workflow tool developed in-house
Drop Smart Menus in EPIC

RAD DEXA BODY REGIONS:15040
- lumbar spine
- bilateral hips
- right hip
- left hip
- right forearm
- left forearm

RAD DEXA FINDINGS:15042: no confounding issues
- no confounding issues
- degenerative change of the lumbar spine and hips
- degenerative change of the lumbar spine
- degenerative change of the hips

RAD DEXA FINDINGS: 2:15044
L1
L2
L3
L4

RAD DEXA FINDINGS: 3:15045:
were not used based on standard T-Score exclusion criteria.
was not used based on standard T-Score exclusion criteria.

Change:15167

In our facility changes greater than the following are considered significant: Hip 2.8%, Femoral neck 5.4%, and Lumbar spine 3.7%

Impressions:15110
1. Bone mineral density is within expected range for age.
2. Bone mineral density is below expected range for age.
   1. Osteopenia. Fracture risk analysis was not given secondary to ***.
   2. Osteopenia. 10 year fracture risk is calculated to be ***% for major osteoporotic fracture and ***% for hip fracture.
   1. Osteoporosis.
   2. No comparison exams.
   2. (Sig:15190) (inc/dec:15191) in bone mineral density since the baseline exam.
   2. (Sig:15190) (inc/dec:15191) in bone mineral density since the baseline exam. (Sig:15190) (inc/dec:15191) in bone mineral density since the most recent prior.

Attestation:15125
Resident Preliminary Report.
I Personally reviewed the study and the report above and concur.
CLINICAL HISTORY: 64-year-old postmenopausal female for screening bone densitometry.

TECHNIQUE: The bone mineral density of the lumbar spine and hips was evaluated with a GE Lunar Prodigy Advance (PA+41705) scanner equipped with software version 13.6. The bone mineral density at the sites was compared to the manufacturer's installed database. The T-scores are standard deviations above or below the Caucasian young adult mean. The Z-scores are standard deviations above or below the age, race, and gender matched mean.

COMPARISON: None

FINDINGS:

The available images show degenerative changes of the L3 and L4 vertebra which can exaggerate BMD values. Therefore, these levels were excluded from analysis.

In the region of:
- Lumbar spine L1-L2 vertebral bodies
  - Bone mineral density: 1.080 g/cm², T-score: -0.7, Z-score: 0.9
- Left femoral neck
  - Bone mineral density: 1.120 g/cm², T-score: 0.6, Z-score: 2.1
- Total left hip
  - Bone mineral density: 1.096 g/cm², T-score: 0.7, Z-score: 1.9
- Right femoral neck
  - Bone mineral density: 1.134 g/cm², T-score: 0.7, Z-score: 2.2
- Total right hip
  - Bone mineral density: 1.129 g/cm², T-score: 1.0, Z-score: 2.2

WHO CRITERIA:

WHO criteria are applied to peri-/post-menopausal females and males 50 years of age or older. For those groups, normal bone mineral density is defined by T-scores greater than or equal to -1.0; Osteopenia is defined by T-scores between -1.0 and -2.5; and Osteoporosis is defined by T-scores equal to or lower than -2.5.

Result Impression

1. Normal bone mineral density.

I personally reviewed the image(s) and the report above and concur.
Decreased Report Turn-around time with Machine to Machine Communication and EPIC Driven WorkFlow
Cost

Our solution
- $6175 install, no yearly maintenance cost
- $2500 for vendor modality HL7 interface
- $1675 for vendor install support
- $2000 for internal implementation (45 man hours)

Commercially available solution
- Known from associated institution
- $80,000 install and $80,000 for 5 year maintenance
- $65,000 for software and license
- $15,000 for implementation project
- $20,000 for annual service and support
Opportunistic Bone Mass Screening

- Refers to
- FDA approved software
- Figures from dual modality scan
- Peel off Nuc scan
- Show CT in axial projection
- Show Jim’s analysis and a report
- Show DXA equivalent from Mindways software
- Show FEA modeling
- Conclusion: Dual modality scanning puts us in prime position to assess in one setting bone mass and bone mechanical competence
Sagittal F-18 PET-CT
Dual Use of CT: QCT from Dual Modality Scans

• QCT was introduced prior to DXA at the end of the 1970s
• Originally bone mineral density of the spine by 2D analysis
• Early CT scanners had limited availability
• With the development of DXA, QCT lost ground

• May be performed on any CT system
• Calibration used to convert HU to BMD.
• Newer systems enable volumetric (3D) analysis of spine and hip measurement
Volumetric 3D-QCT

- Helical scan
- 20–24 thin (3mm) slices
- 2 vertebra imaged
- Gantry not angled
- Software produces excellent precision

Courtesy Keenan Brown, Mindways Software
QCT BMD Phantom Based Calibration

- Phantom found automatically in image
- Calibration of image grey values (HU) to mg/cm³
- Vertebrae (or hip) found automatically

Courtesy Keenan Brown, Mindways Software
QCT Spine Region of Interest

- **Elliptical Cylinder ROI**
- **Trabecular Bone**
  - No cortical bone
  - No extraosseous mineral
  - Higher metabolic rate
- **Measurement precision:** CoV of 0.7%

Courtesy Keenan Brown, Mindways Software
Analysis and Reporting

Analysis

Reporting

Courtesy Keenan Brown, Mindways Software
QCT Reporting

- Should not be interpreted using WHO T-Score guidelines for fracture-risk categorization
- The American College of Radiology Guidelines on the use of QCT has the following fracture risk categories for Spine BMD equivalent to DXA T-score categories:
  - BMD > 120 mg/cm³ “Normal”
  - 80 mg/cm³ ≤ BMD ≤ 120 mg/cm³ “Osteopenia”
  - BMD < 80 mg/cm³ “Osteoporosis”

Courtesy Keenan Brown, Mindways Software
1. Series of axial images through proximal femur
2. Remove soft-tissue pixels from axial images and sum mineral mass, bone volume along rays.
3. Result is synthesized bone projection image.
QCT & DXA: Hip Areal Density

- Both technique give essentially equivalent results when the same bone is measured with both techniques.

- Same subject
- QCT & DXA
- Essentially same T-scores
- 0.012 g/cm² long term precision

Courtesy Keenan Brown, Mindways Software
Correlation of BMD derived from virtual non-contrast CT Using Asynchronous Calibration

Figure. Linear regression of BMD from non-contrast scans and VNC of contrast scans.
HR-pQCT

- 40-80 um resolution
- Wrist and Distal Tibia
- Research Tool

Link, Can Assoc Radiol Journal, 2016
Atypical Subtrochanteric Fractures

- Associated with long term bisphosphonate use (>3y)
- Maybe genetic
- Very Rare (<1.0%)
- Look for cortical beaked thickening
- Do bone scan or MRI if focal pain but negative radiograph
Summary

- Bone loss is multi-factorial with aging, sex steroids, oxidative stress, and Wnt signaling being strong contributors.
- DXA is the number one clinical tool for diagnosis of osteoporosis, treatment response, and monitor age-related changes.
- TBS is a rapidly evolving tool that uses lumbar spine DXA data for enhanced fracture risk assessment and response to diseases, medications, and aging.
- Best Practice Guidelines have been published by ISCD.
- Explore in-house solutions for “automated” reporting of DXA values to avoid high costs and to decrease reporting errors.
- BMD from dual use of CT from hybrid dual modality (PET/CT), SPECT, CT) scanning offers Nuclear Medicine an opportunity to expand its role in bone health assessment.
- Nuclear Medicine is uniquely suited for bone health assessment since we have the tools to measure bone mass and turnover.
1. Which of the following steroids is the major regulator of bone metabolism in men and women and low levels of which are associated with low bone density and fracture risk?
   A. Vitamin D
   B. Estradiol (KEY)
   C. Testosterone
   D. Dehydroepiandrosterone

Correct Answer: B.

2. What is the most commonly used diagnostic imaging method to assess bone density for osteoporosis?
   A. Dual Photon Absorptiometry
   B. Single Photon Absorptiometry
   C. Dual Energy X-ray Absorptiometry (DXA) (KEY)
   D. Quantitative Computed Tomography?

Correct answer: C.

3. Which of the following is a recommended DXA best practice?
   A. Use the manufacturer's scanner precision as the least significant change for serial BMD measurements
   B. Only two-thirds of the technologists need to perform an in vivo precision assessment
   C. At least one practicing DXA technologist and one practicing DXA interpreter should have valid certification in bone densitometry (KEY)
   D. Spine phantom BMD measurements should be performed quarterly

Correct answer: C.
Source: J Clin Densitometry: Assessment and Management of Musculoskeletal Health http://dx.doi.org/10.1016/j.jocd.2016.03.003.

4. The Fracture Risk Assessment Tool, FRAX, algorithm includes:
   A. Glucocorticoid Use
   B. Smoking History
C. Fracture History
D. Fall History
E. All of the above
F. A-C \textbf{(KEY)}
G. B-D

\textbf{Correct Answer: F.}

5. The Trabecular Bone Score is?
   A. A parameter obtained from the trabecular compartment of a vertebral body
   B. A parameter that is derived from DXA scans
   C. Independent of bone mineral density and FRAX risk variables in fracture prediction
   D. A and B are true
   E. B and C are true \textbf{(KEY)}

\textbf{Correct Answer: E.}