DXA Basics

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UAB

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IBJI

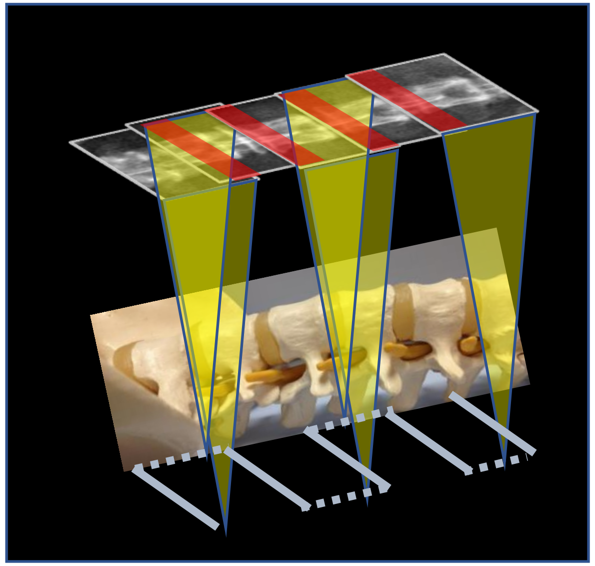
COI Disclosures:

- Sarah Morgan: MD, RD, CCD : None
- Lawrence Jankowski CBDT: None

Course Objectives

- Describe the technology behind Dual-energy X-ray Absorptiometry (DXA) and its strengths and weaknesses as a diagnostic test: a technical quality perspective.
- Describe the three uses of DXA in the clinical setting (diagnosis, fracture risk, and monitoring changes).
- Provide clinicians techniques for determining the accuracy of DXA scans and reports before incorporating them into patient management.
- Case studies for review.

Dual-Energy X-ray Absorptiometry



Absorptiometry:

- Measurement of absorption

Dual-energy X-ray:

- Two different energy Xray beams passed through the patient
- Equations solve for bone density and soft-tissue at each point in the image
- Results are in grams (ash-weight) of mineral per square centimeter.

$$\sigma_b(x) = \frac{(\mu_s^L / \mu_s^H)\ln\left[I^H(x) / I_0^H\right] - \ln\left[I^L(x) / I_0^L\right]}{\mu_b^L - \mu_b^H\left(\mu_s^L / \mu_s^H\right)}$$

$$\sigma_s(x) = \frac{\ln\left[I^L(x) / I_0^L\right] - \left(\mu_b^L / H\mu_b^H\right)\ln\left[I^H(x) / I_0^H\right]}{\mu_s^H\left(\mu_b^L / \mu_b^H\right) - \mu_s^L}$$

Bone Densitometry by DXA

Blessing

- DXA doesn't measure bone density
- DXA uses T-scores for diagnosis
- DXA has exceptional precision
- DXA scan interpretation seems very straightforward
- DXA uses extremely low doses of radiation

Curse

- DXA doesn't measure bone density
- DXA uses T-scores for diagnosis
- DXA can have atrocious precision
- DXA scan interpretation seems very straightforward
- DXA uses extremely low doses of radiation

DXA Doesn't Measure Bone Density

Blessing:

- Area BMD (g/cm^2) correlates better with bone strength than volumetric BMD (g/cm^3) .
- A toothpick and the birch log it was made from has the exact same volumetric density
- The BMD of the log on a DXA scanner would read manyfold higher density reflecting its inherently greater strength.

DXA Doesn’t Measure Bone Density

Curse:

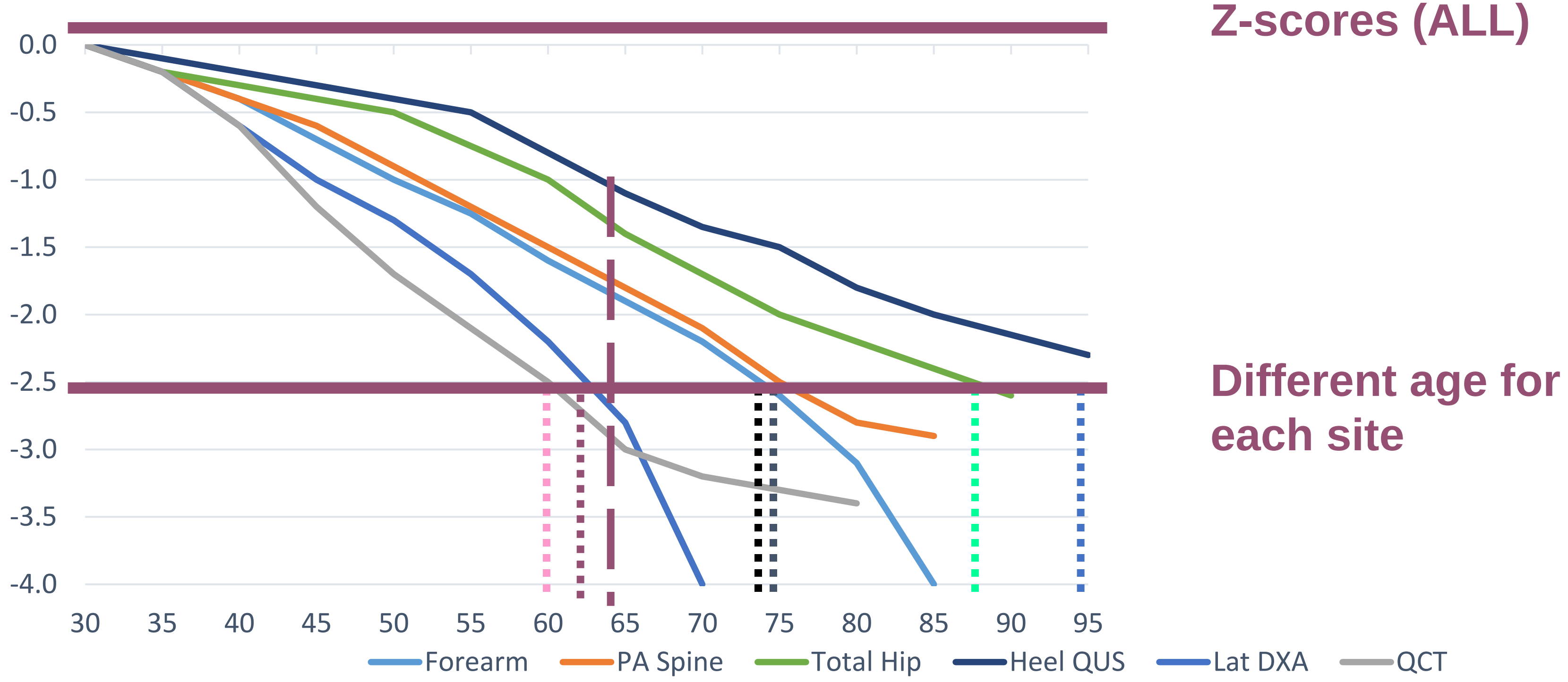
- BMD is highly dependent on orientation of X-ray beam as it passes through the anatomy
- Largest source of precision error is inability to carefully reproduce patient anatomy between visits

DXA scan interpretation seems very straightforward

- T-score below -2.5 is osteoporosis.
- T-score above -1.0 is normal
- The scan printouts are the report.

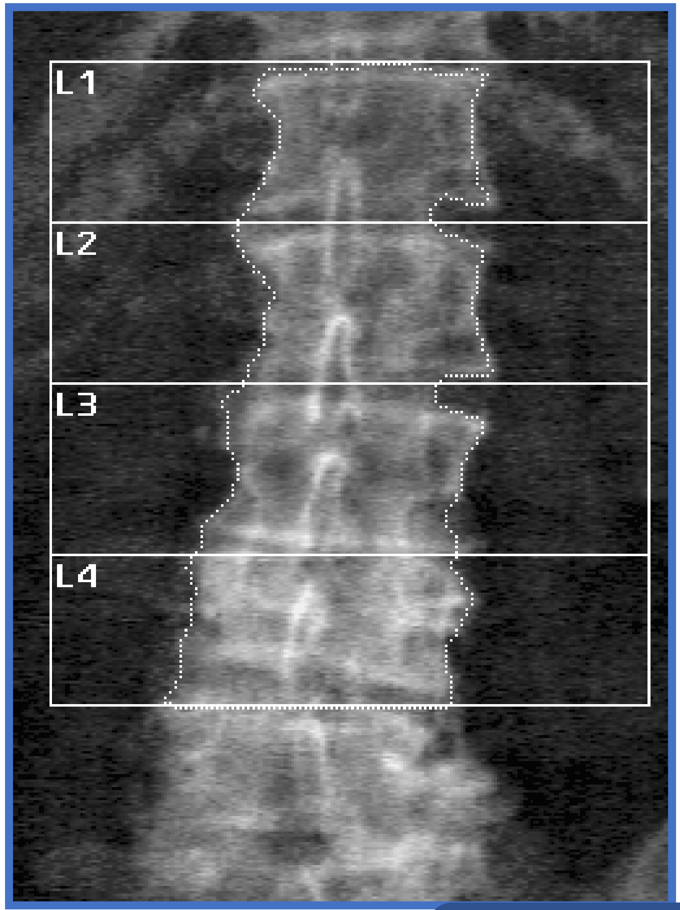
How hard can this be?

DXA Uses T-scores for Diagnosis
The T-Score Dilemma



Adapted from Faulkner KG, et al. J Clin Densitom 1999; 2:343

Discordance – PA vs. Lateral 82y female

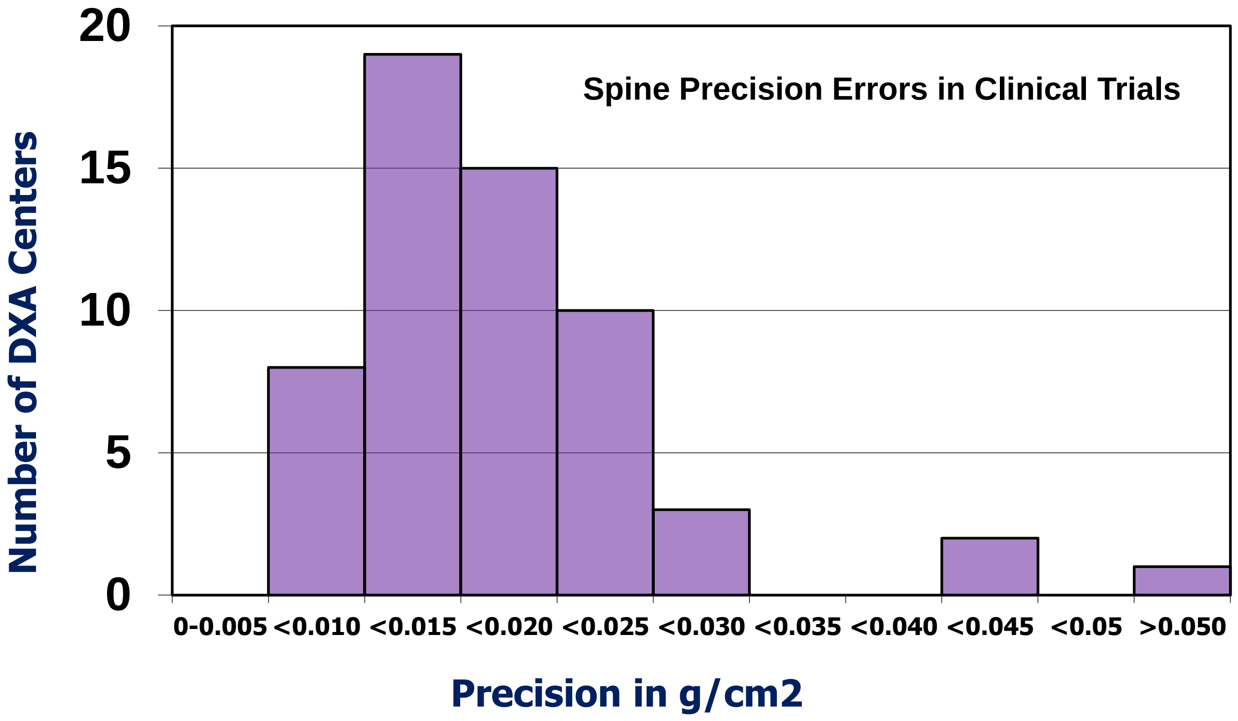


L1-L3 BMD 0.721 g/cm2 T:-2.7, Z: -0.2

L2-L3 BMD 0.0.491 g/cm2, T:-4.2, Z: -0.3

DXA has exceptional precision?

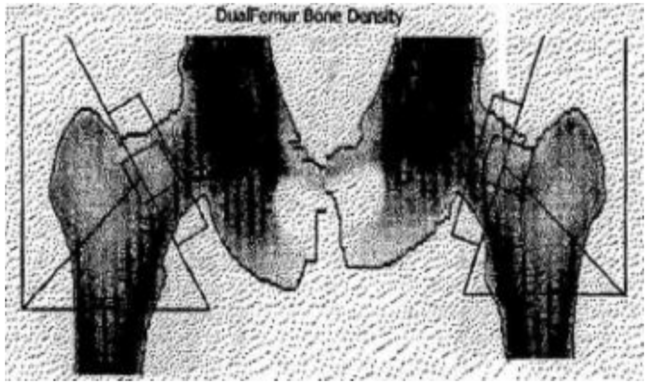
- Blessing



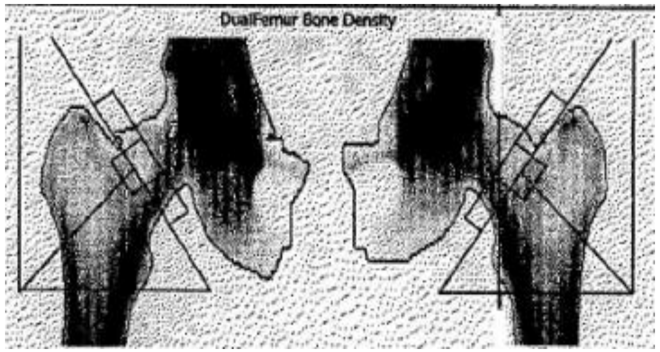
Unpublished data – Courtesy Tom Fuerst, PhD, Synarc

- Curse

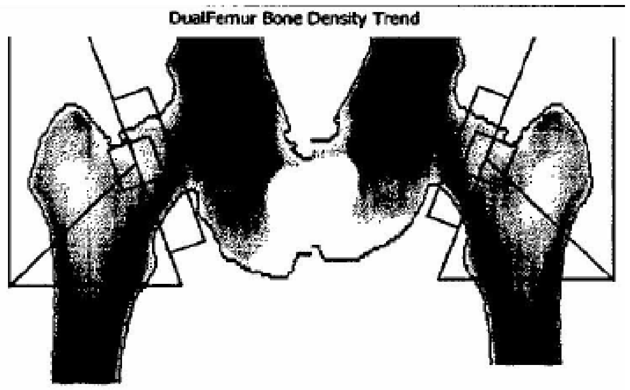
2013



2015



2018



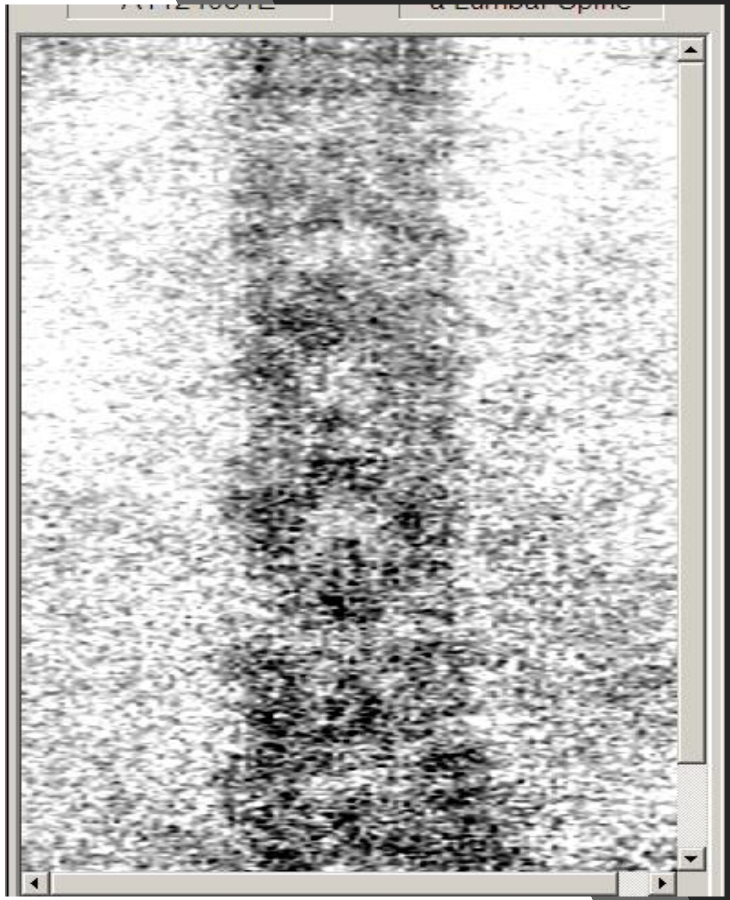
DXA uses extremely low doses of radiation

Blessing:

- Background: 5-8 µSv/day
- DXA: 1-5 µSv
- QCT: 50-60 µSv
- pQCT: 1- µSv
- QUS:- none
- Maximal permissible dose is 1,000 µSv per year (general public excluding diagnostic testing or radiation therapy)*
- Lumbar Spine x-ray: 700 µSv

*Title 10, Part 20, of the *Code of Federal Regulations* (10 CFR Part 20), "Standards for Protection Against Radiation,"

DXA uses extremely low doses of radiation



60.2”   257lb,
BMI=49.9

- Curse:
  Low radiation is a limitation in obese patients
  - Poor counting statistics increases precision error
  - Fat causes artifactual increase in measured BMD

Uses of Bone Densitometry

- Diagnosis
- Estimate of fracture risk
- Monitor the effectiveness of therapy

WHO T-score Diagnosis Guidelines

- -1 or above – Normal bone mineral density
- -1 to >-2.5 - Low bone mass (osteopenia)
- -2.5 or below – Osteoporosis
- -2.5 or below plus fracture – Severe (established) osteoporosis

- Caveats:
  - Use T-scores in postmenopausal women and men $\geq$ age 50
  - Use only Z-scores in premenopausal women and younger men
  - Valid only for Spine (L1-L4), Femur neck, total hip, and 1/3 distal radius

T-score*

$$T-score = \frac{BMD_{(patient)} - \bar{x}_{(peak\_reference)}}{SD_{(peak\_reference\_population)}}$$

- There really is no such thing as a T-score (in statistics)
- Hologic was first DXA manufacturer to use this term.
  - Technically it is a "young-normal reference *z*-score"
  - Units are in standard deviations

Tom Kelly – Hologic

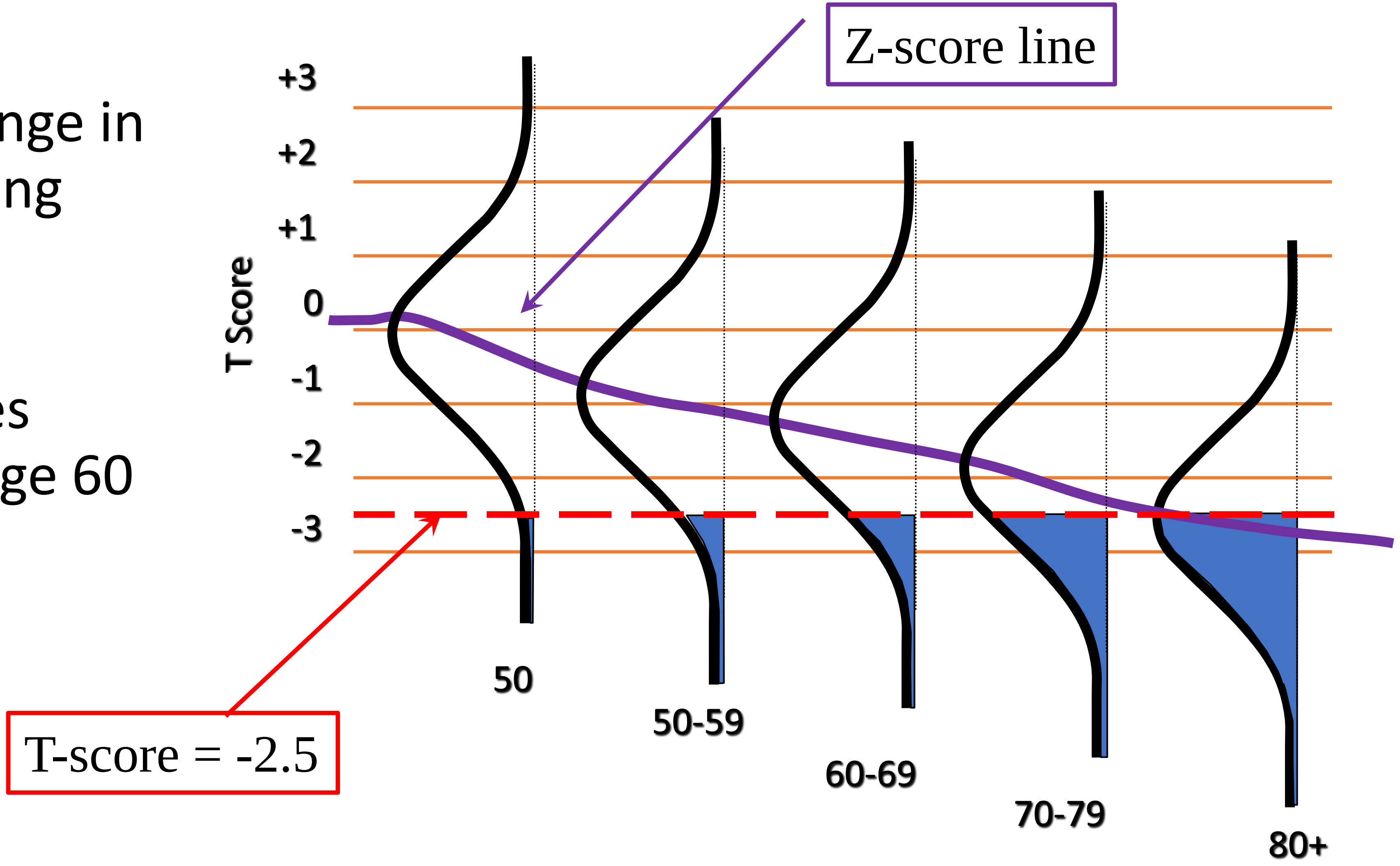
Z-score

$$Z - score = \frac{BMD_{(patient)} - \bar{x}_{(age\_matched\_reference)}}{SD_{(peak\_reference\_population)}}$$

- Age-(and race and sex and even weight) matched z-score
- The unit is in standard deviations
- Used in patients prior to age of peak bone mass

Age-related Decline in BMD

- Z-scores do not change in older patients if losing bone mass at age-expected rate
- Fracture risk doubles each decade after age 60 at same BMD



Reference Curves

- Estimates of true populations (unless the entire population is sampled)
  - Larger samples are a better estimate of the whole population
  - NHANES* is better than manufacturer databases
  - Most curves assume a normal (bell-curve) distribution – SD scores
  - In skewed curves (e.g. % body fat) percentiles are more appropriate

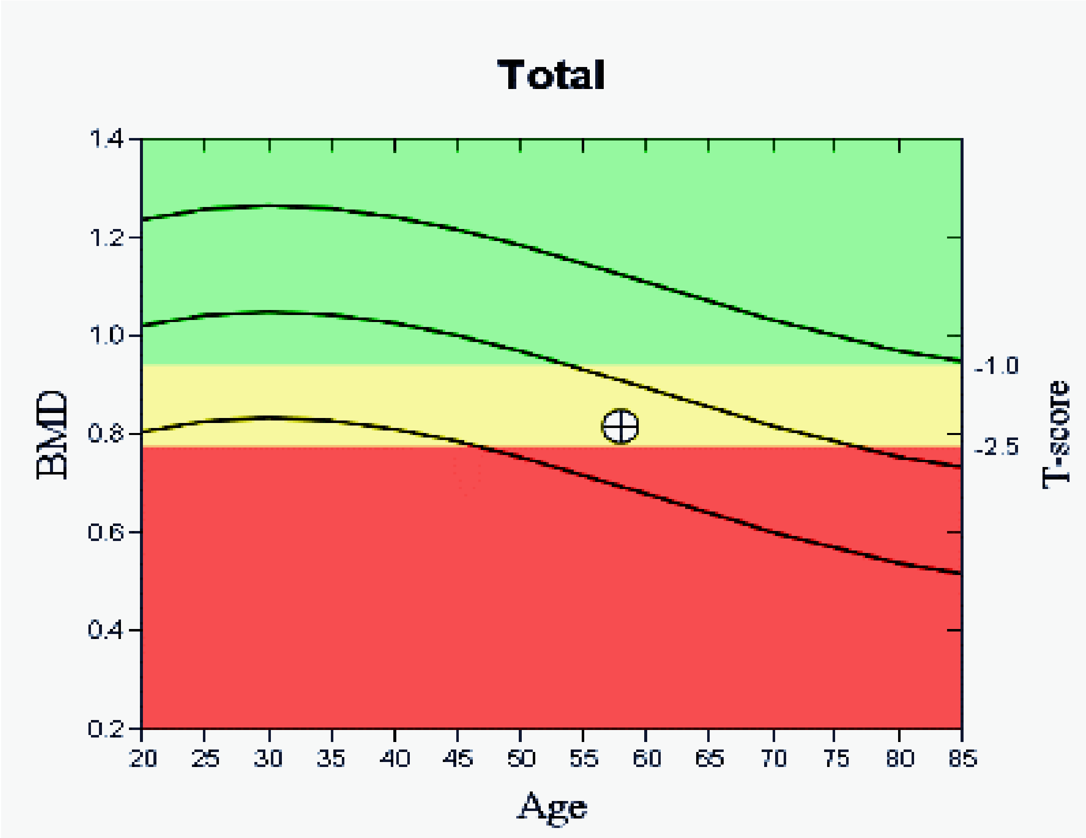
*National Health and Nutritional Evaluation Survey – US Census Bureau

NHANES DATABASE

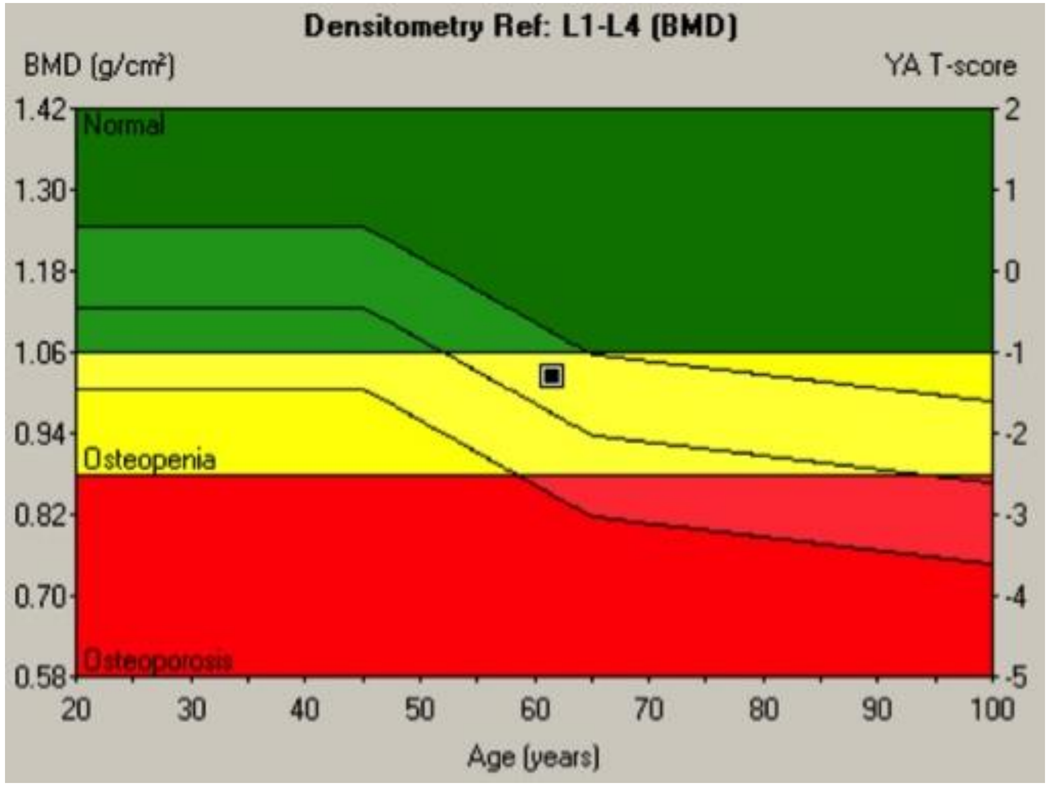
- National Health and Nutrition Evaluation Survey
  - National (USA) Census Bureau conducted at 5 year offset to population census
  - Hologic DXA scanners
  - Random sample of US population (converted to other scanner brands also)
- Universal database for all men and women (and NGC) of all races for T-scores and FRAX*

Normative Data Graphs are Different

- GE
  - Limit lines are +/- 1 SD (68%)
  - Females assume linear periods of stable, PMP loss age 45-65
- Hologic
  - Limit lines are +/- 2SD (95%)
  - Loss varies continuously with age (Cubic spline smoothing)



Hologic

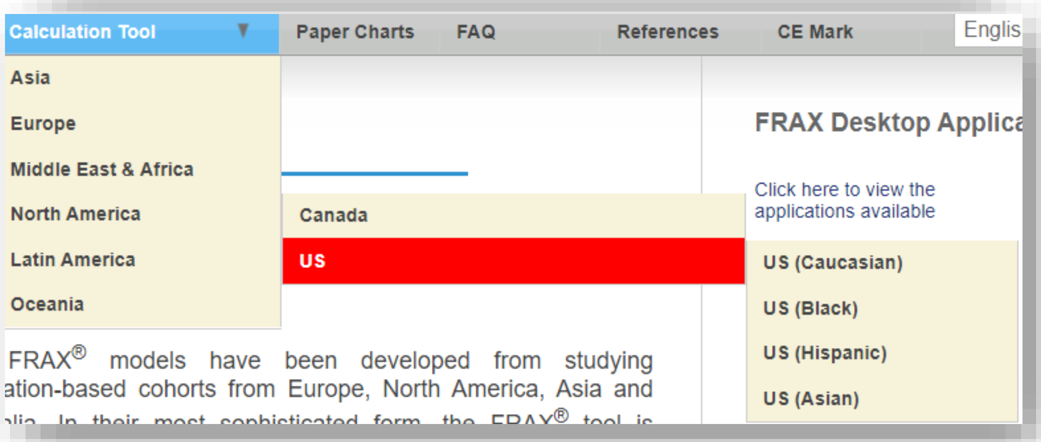


GE - Lunar

Fracture Risk Assessment Tools

- Multifactorial assessments
- Can be used with or without DXA BMD
  - FRAX *http://www.shef.ac.uk/FRAX/*
  - Garvan: *https://www.garvan.org.au/bone-fracture-risk*
  - qFracture: *https://qfracture.org/index.php*

http://www.shef.ac.uk/FRAX/



ISCD Best Practices Document

Best Practices for Dual-Energy X-ray Absorptiometry Measurement and Reporting: International Society for Clinical Densitometry Guidance

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Abstract

Dual-energy X-ray absorptiometry (DXA) is a technology that is widely used to diagnose osteoporosis, assess fracture risk, and monitor changes in bone mineral density (BMD). The clinical utility of DXA is highly

Who - can use the document

- Patients seeking a qualified testing center
- Primary care physicians determining the reliability of DXA providers they refer patients to.
- Bone densitometry providers benchmarking their service for quality
- Legislators and third-party payors
- Patient advocacy groups (e.g. NOF, NOS, OSC)

Where – Can you find the document

- The ISCD offers full access to the Journal for Clinical Densitometry article to any interested party:

  http://www.clinicaldensitometry.com/article/S1094-6950(16)30003-8/fulltexts (last accessed 4/23/2021)

Who's doing the interpretation?

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Patient Variable Data

Conditional Text
(left hip, 33% radius)

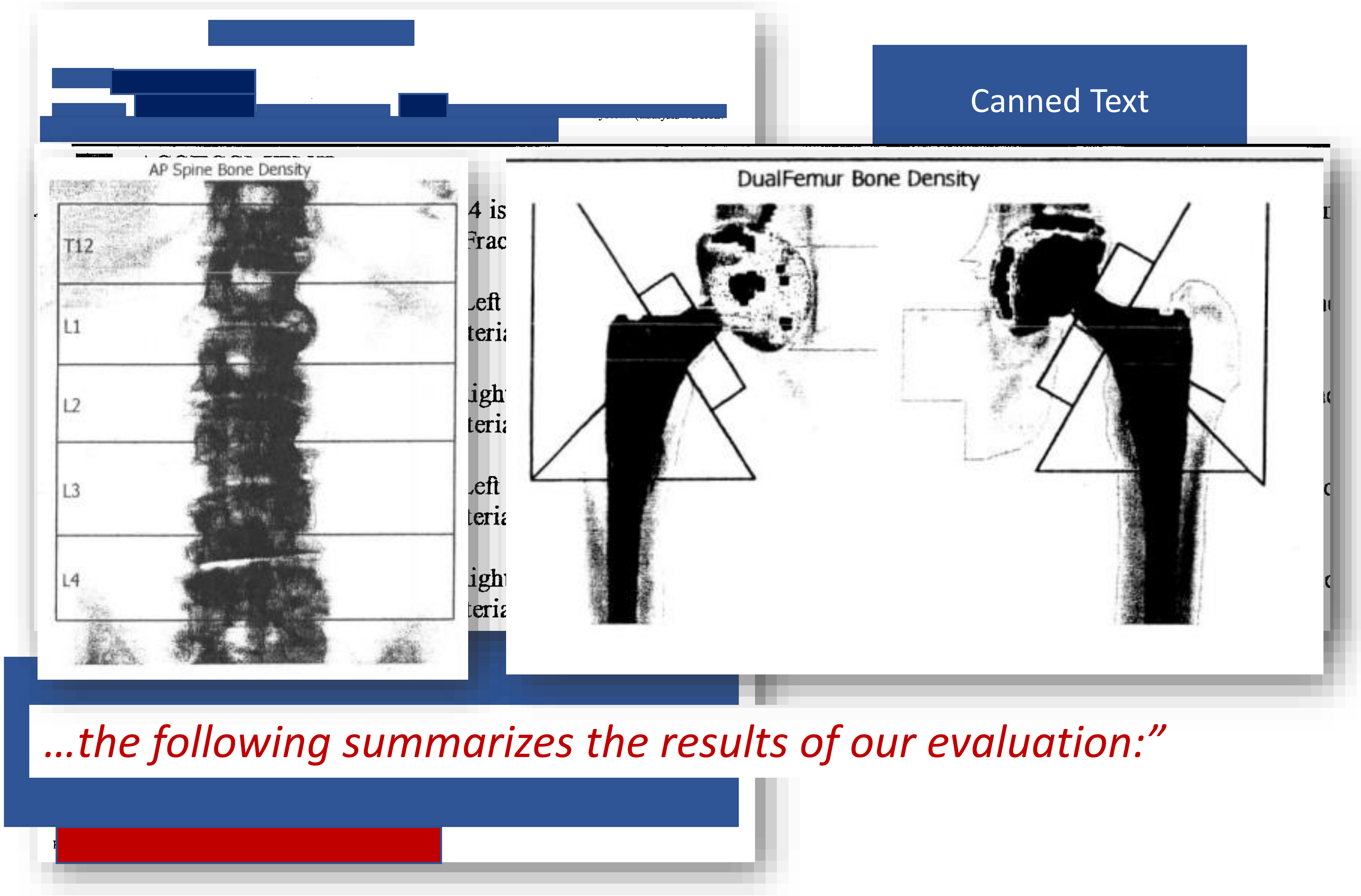
Calculated (T,Z,Dx)

ACR Definition of an Interpretation[1]:

- Requires "work" by a physician or equivalent (e.g. N.P.)
- Generate a "detailed" analysis of the case, including a review of:
  - Indications
  - Pertinent medical history
  - Veracity of the quantitative data (e.g. outliers)
  - Examine the underlying images for correctness
- Affix signature certifying ownership
- BMMA[2] : "In order to be eligible for reimbursement… bone density scans must include an interpretation by a physician…"

1: ACR Practice Guidelines and Technical Standards –Definition of Terms
2: https://www.congress.gov/bill/105th-congress/senate-bill/649

Does You DXA Provider Look at the Images?



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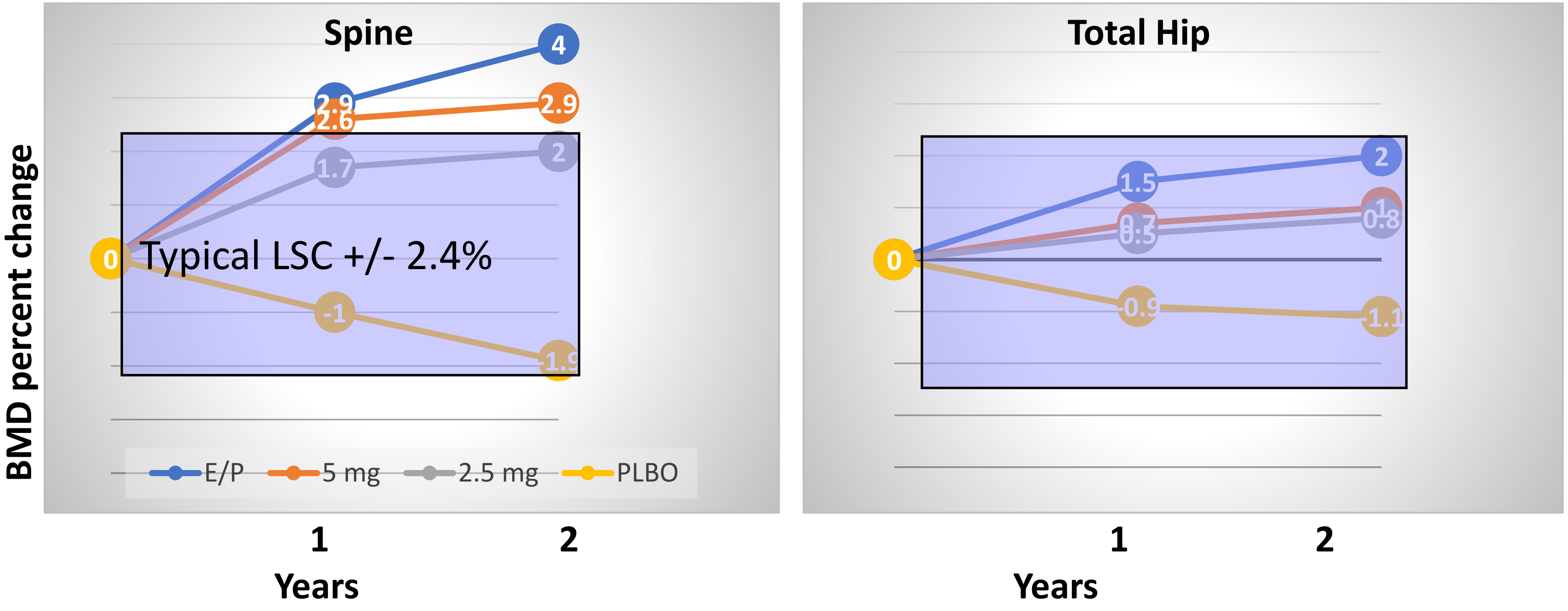
…the following summarizes the results of our evaluation:”

Precision and Monitoring Therapy

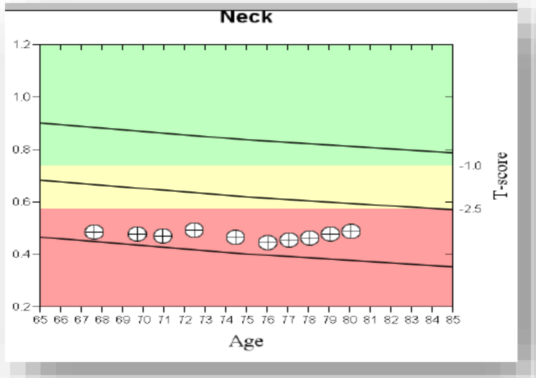
EPIC, US Cohort, Stratum 1 Alendronate Trial



Hosking D, et al. *J Bone Mineral Res* 1996; 11:S133

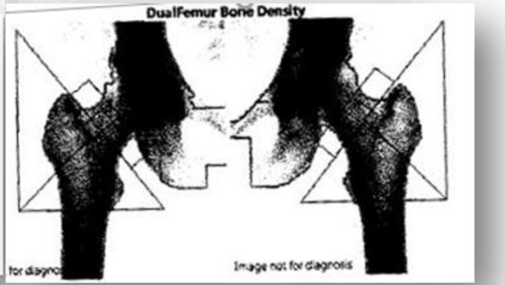
Assessing the Precision of DXA Providers

- Longitudinal Stability Femur Neck
- Rate of change
  - Spine ≥ Total hip> F. neck
- Precision errors
  - F. neck > total hip ≥ spine

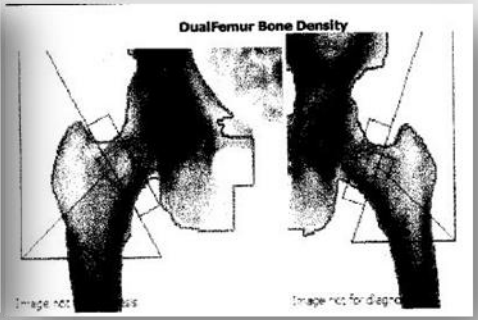


BMD Change (g/cm²) vs Baseline	vs Previous
0.003 (0.5%)	0.010 (2.1%)
-0.008 (-1.6%)	0.016 (3.4%)
-0.023 (-4.8%)	0.006 (1.3%)
-0.029 (-6.0%)	0.012 (2.7%)
-0.041 (-8.5%)*	-0.020 (-4.3%)
-0.021 (-4.4%)	-0.029 (-5.9%)
0.008 (1.7%)	0.022 (4.6%)
-0.014 (-2.8%)	-0.006 (-1.3%)
-0.007 (-1.5%)	-0.007 (-1.5%)

Region	BMD	% Peak	T-Score	Z-Score	% Change
Neck Left	0.720 g/cm²	69%	-2.3	-0.7	2.9%
Neck Left	0.700 g/cm²	67%	-2.4	-0.9	-1.7%
Neck Left	0.712 g/cm²	69%	-2.3	-0.8	1.9%
Neck Left	0.699 g/cm²	67%	-2.4	-1.0	-
Neck Right	0.737 g/cm²	71%	-2.2	-0.5	0.8%
Neck Right	0.731 g/cm²	70%	-2.2	-0.7	-1.2%
Neck Right	0.740 g/cm²	71%	-2.1	-0.6	3.9%
Neck Right	0.712 g/cm²	69%	-2.3	-0.9	-

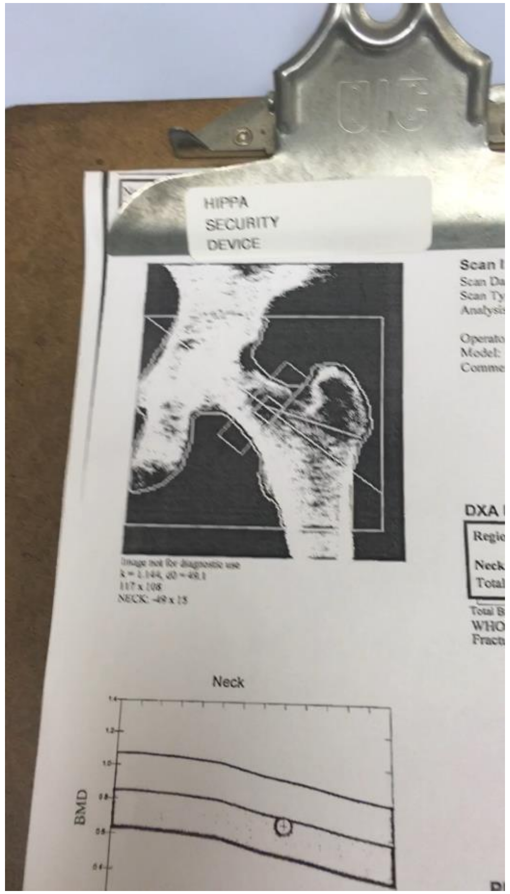


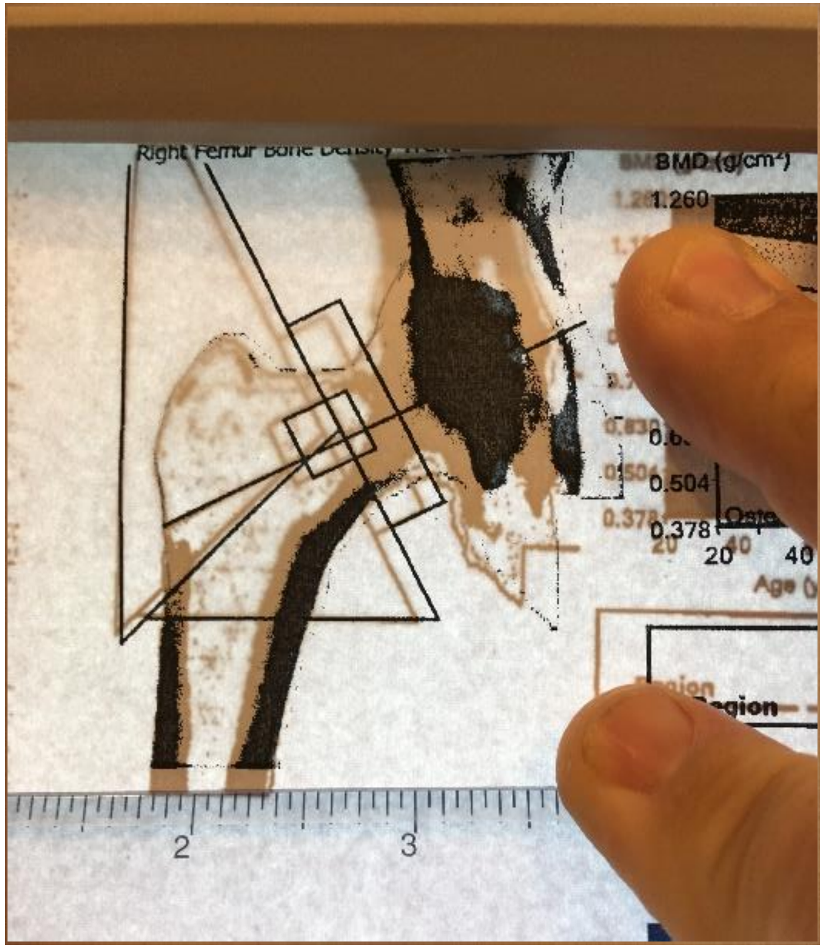
Region	BMD	% Peak	T-Score	Z-Score	% Change
Neck Left	0.897 g/cm²	86%	-1.0	1.6	17.4%
Neck Left	0.764 g/cm²	74%	-2.0	0.5	-
Neck Right	0.724 g/cm²	70%	-2.3	0.3	8.2%
Neck Right	0.669 g/cm²	64%	-2.7	-0.2	-
Total Left	0.823 g/cm²	82%	-1.5	1.0	6.1%
Total Left	0.776 g/cm²	77%	-1.8	0.5	-
Total Right	0.715 g/cm²	71%	-2.3	0.2	0.7%
Total Right	0.710 g/cm²	70%	-2.4	0.0	-



Assessing Quality of DXA Providers

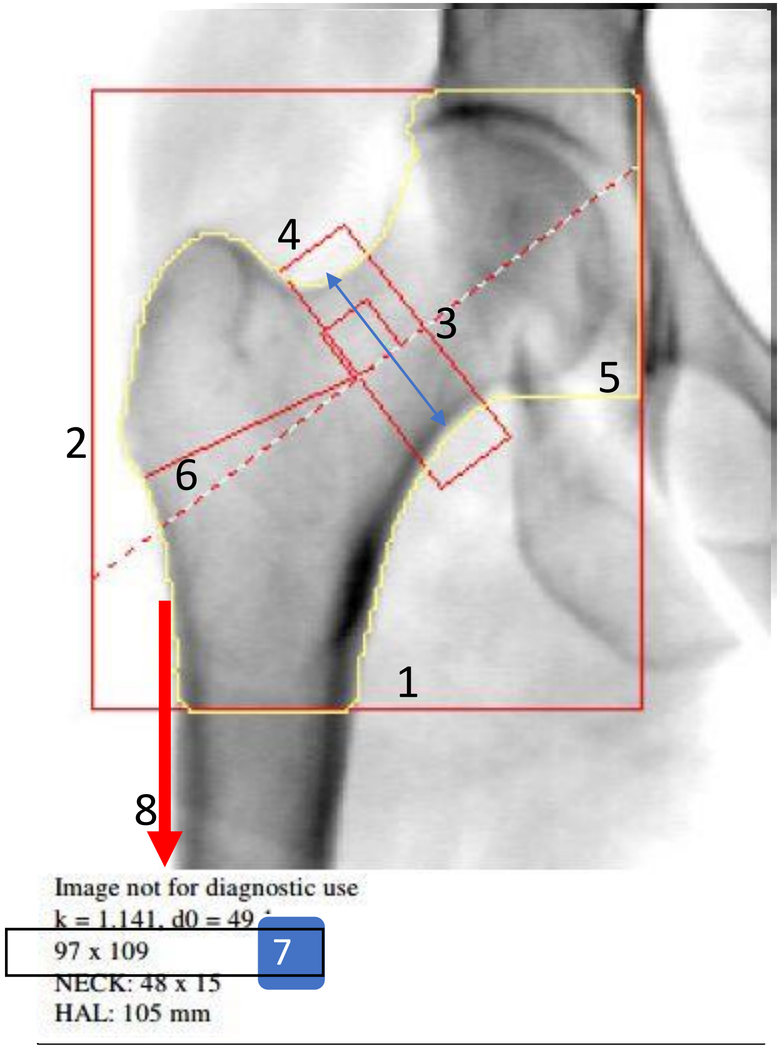
- Low Tech Quality Tools
- Flip chart
- A new use for your film viewer
- Hip positioning challenges
- Hip positioning solutions



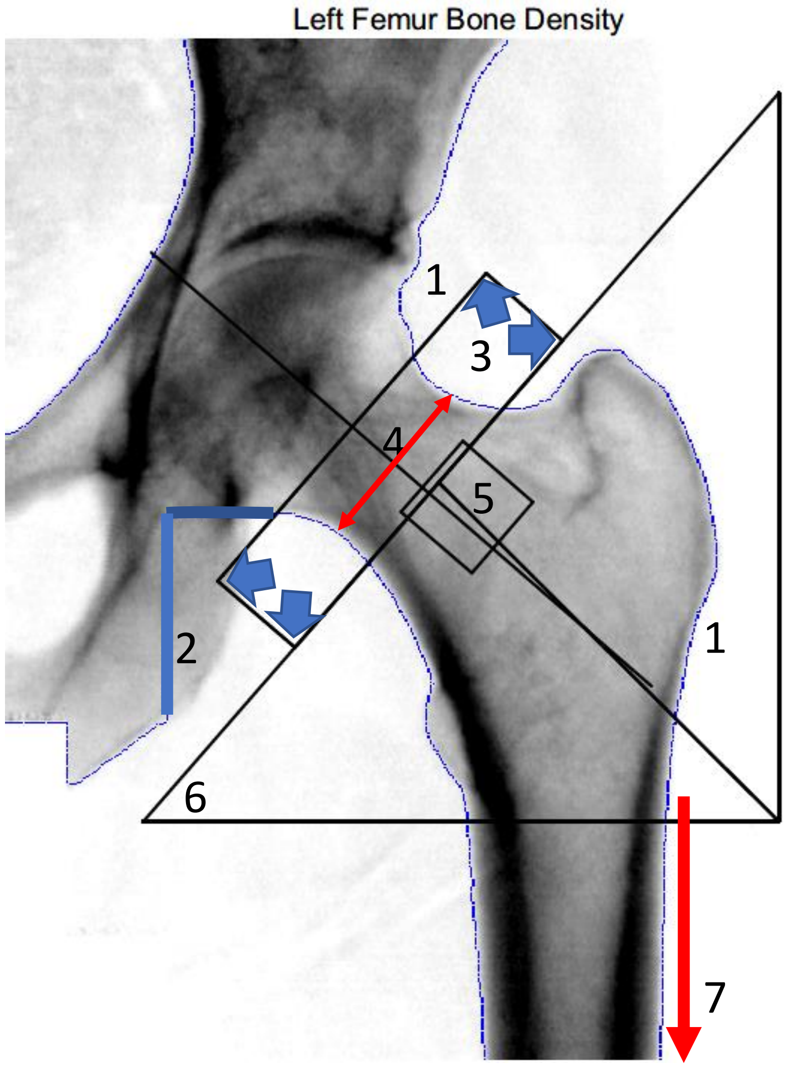


Hologic Hip Quality Checklist

1. Inferior global ROI box at 1 cm below base of lesser trochanter
2. Lateral aspect of greater trochanter 1 cm lateral to edge of scan field
3. Narrowest neck anatomy = narrowest bone map with midline bisecting and right angle to imaginary chord
4. Femur neck box lat/superior corner on bone map at notch of GT
5. Ischium not in neck box, or clearly deleted by tech
6. GT line above midline
7. Global ROI identical to prior study (follow-up in adults)
8. Abduction angle and lesser trochanter identical each visit



GE Hip Quality Checklist

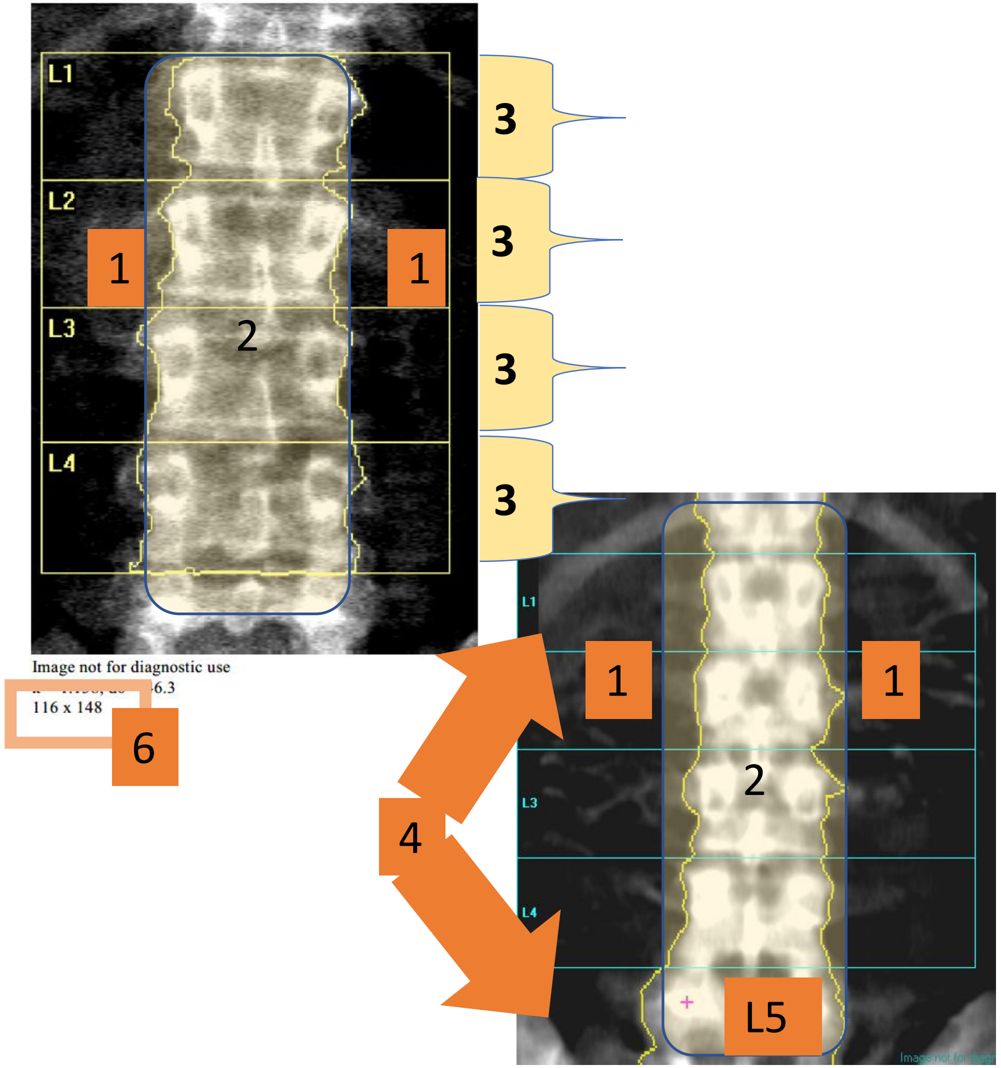


*Lentle B. et a, J Clin Densitom. 2016 Oct;19(4):515-521.

1. Bone edge lines accurately outline femur (esp. Gr.Troch profile and head of femur)
2. Ischium can be deleted by operator (straight lines) to satisfy #3
3. Femur neck ROI corners all in soft-tissue or deleted bone and only contain femur neck
4. Neck box crosses and includes narrowest portion
5. Wards region small and partially overlaps femur neck box*
6. Lower triangle only contains shaft (not ischium)
7. Abduction angle and lesser trochanter identical each visit

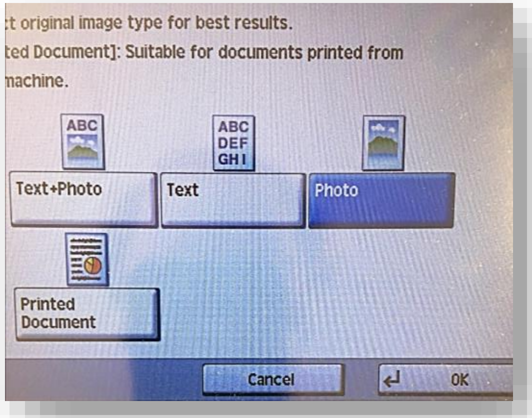
Spine Quality

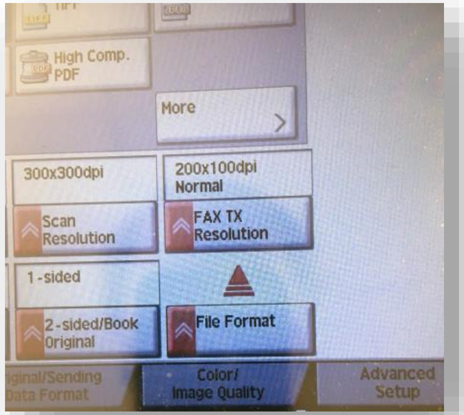
1. Equal amounts of soft-tissue area both sides of spine every visit
2. Bone map includes only spine
3. Vertebral heights roughly same and markers in disk space
4. Sacrum and clear ribs visible to insure all lumbar spine is scanned
5. Label " bottom up "
6. Hologic: box width =116, height same or slightly less with aging at follow-up
7. GE:Vertebral heights and total areas require review of an ancillary page (not shown)



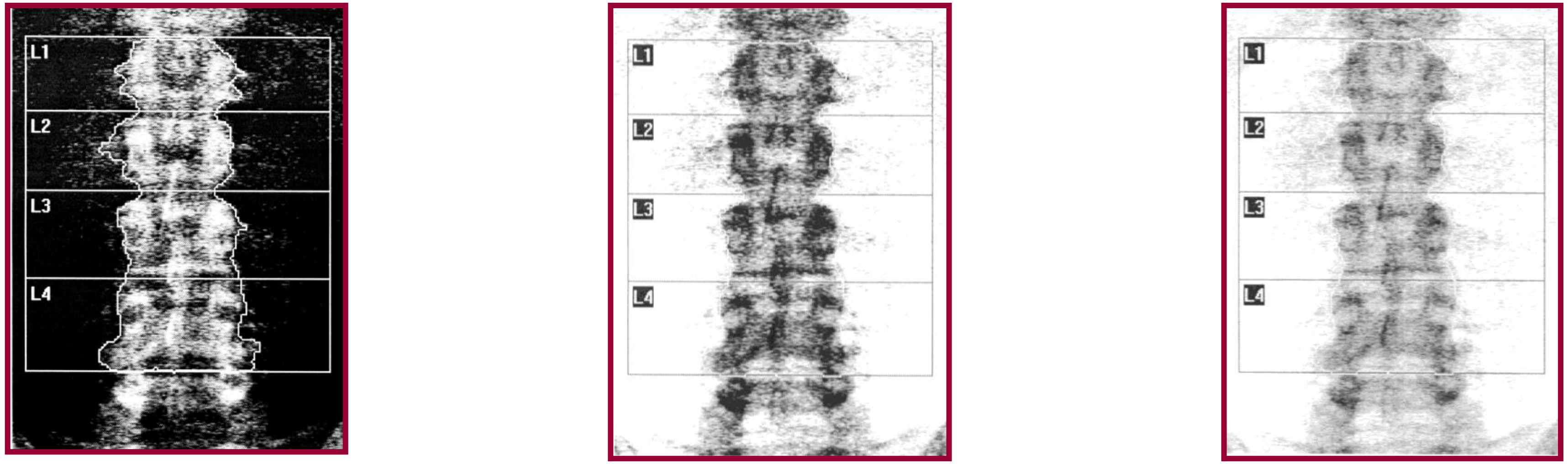
FAX Friendly Reports

- Use inverted gray scale, low contrast images
- Fax using half-tone and fine resolution
- Use largest image reports
- Always send area and BMC data of all regions and sub-regions including scan mode used
  - Ancillary report on GE-Lunar and Norland
  - Filing report on Hologic with ROI box sizes

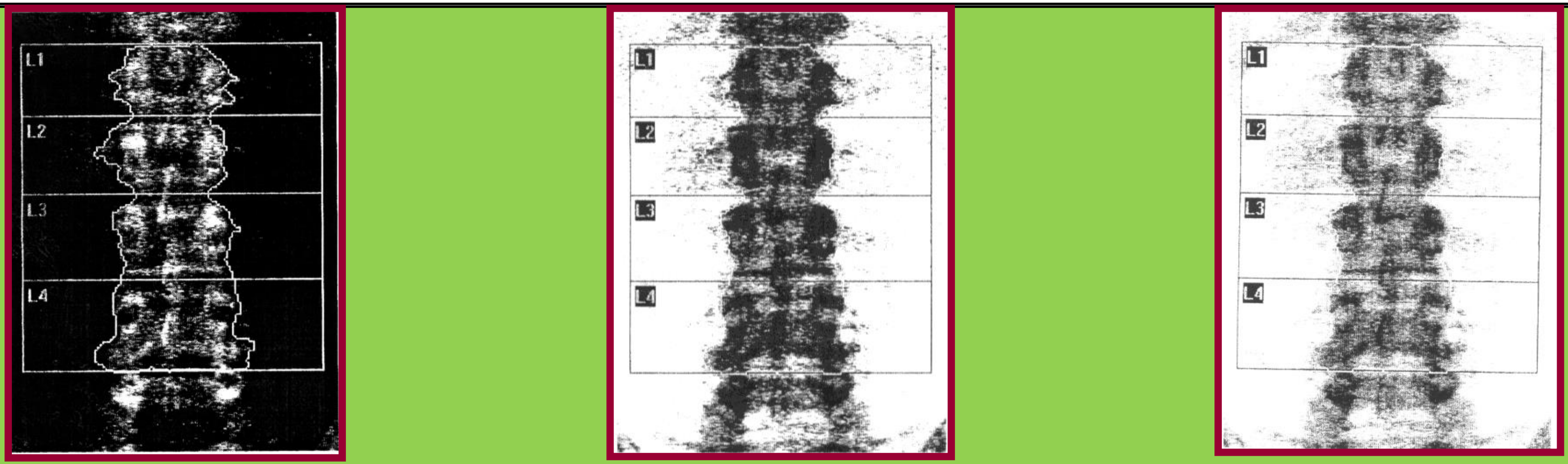




Faxing Etiquette Example



Original



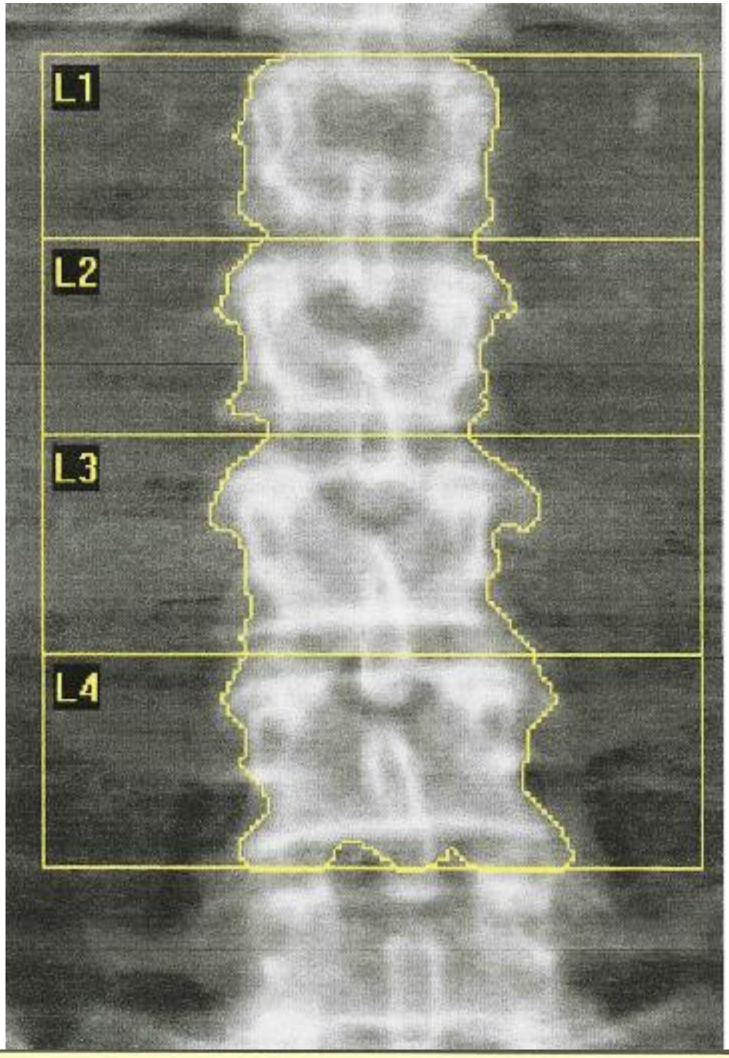
Half-tone Fine Resolution Setting

Image Assessment: P.A.R.E.D.

- **P** - Positioning
- **A** - Artifacts
- **R** – Regions of Interest
- **E** – Edge Detection
- **D** – Databases, Demographics

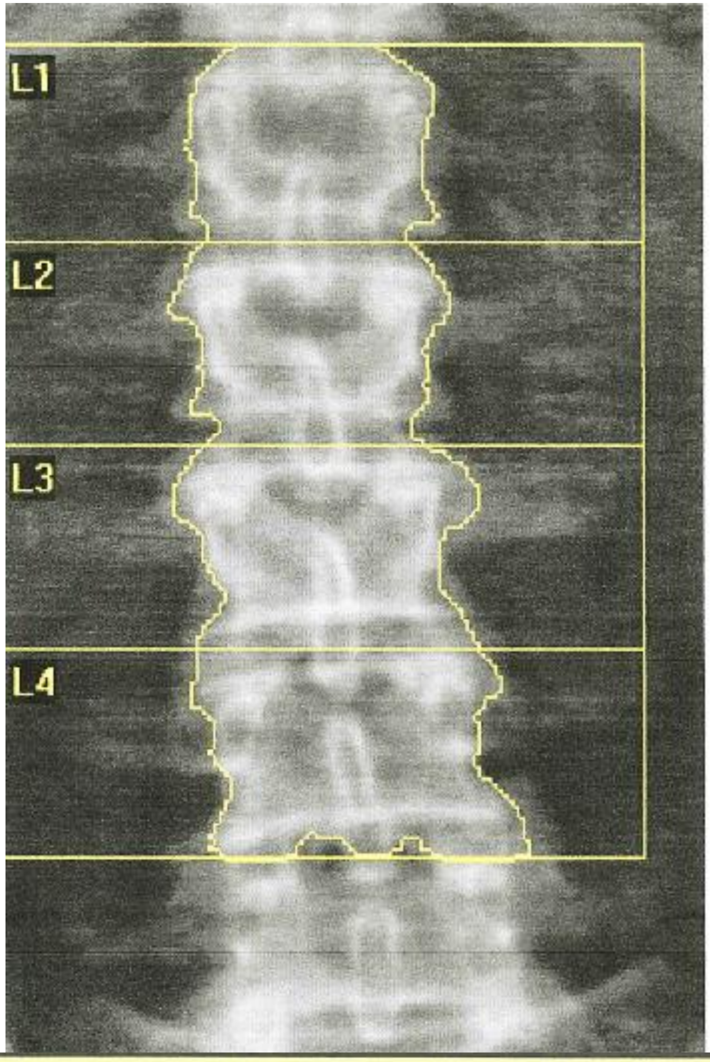
How to Evaluate Follow Up Scans

2012



Region	Area (cm²)	BMC (g)	BMD (g/cm²)	T - score	PR (%)	Z - score	AM (%)
L1	13.61	10.97	0.806	-1.7	81	-0.3	97
L2	15.02	13.57	0.903	-1.1	88	0.4	106
L3	18.07	16.05	0.888	-1.8	82	-0.1	98
L4	19.40	16.44	0.847	-1.9	80	-0.2	97
Total	**66.11**	**57.04**	**0.863**	**-1.7**	**82**	**-0.1**	**99**

2014



Region	Area (cm²)	BMC (g)	BMD (g/cm²)	T - score	PR (%)	Z - score	AM (%)
L1	14.27	11.44	0.801	-1.7	81	-0.2	98
L2	15.46	13.76	0.890	-1.3	87	0.5	106
L3	17.03	15.64	0.918	-1.5	85	0.3	104
L4	19.09	15.82	0.829	-2.1	78	-0.3	97
Total	**65.86**	**56.66**	**0.860**	**-1.7**	**82**	**0.0**	**100**

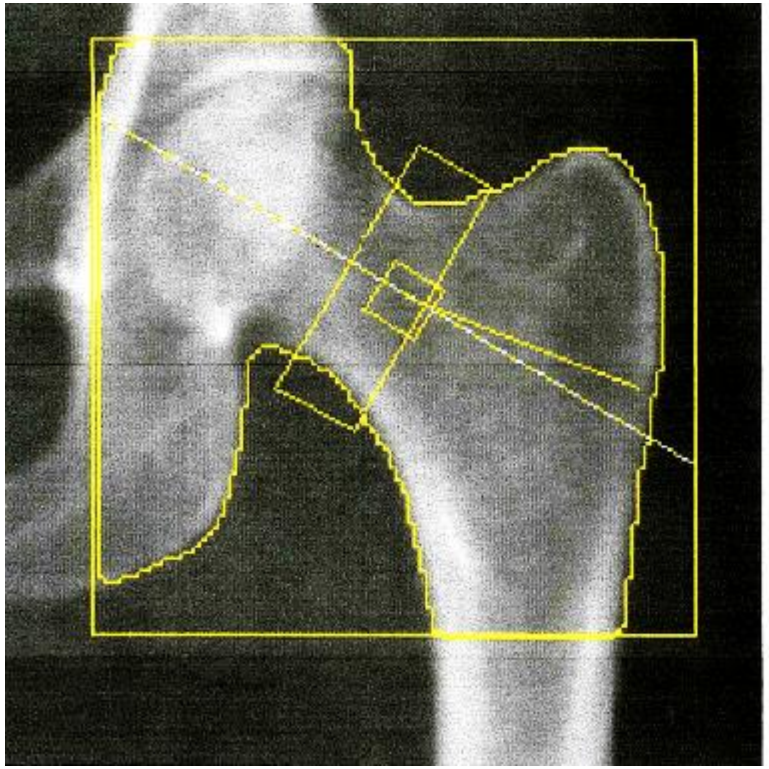
Line up pictures side by side to make sure levels, edge detection etc are the same

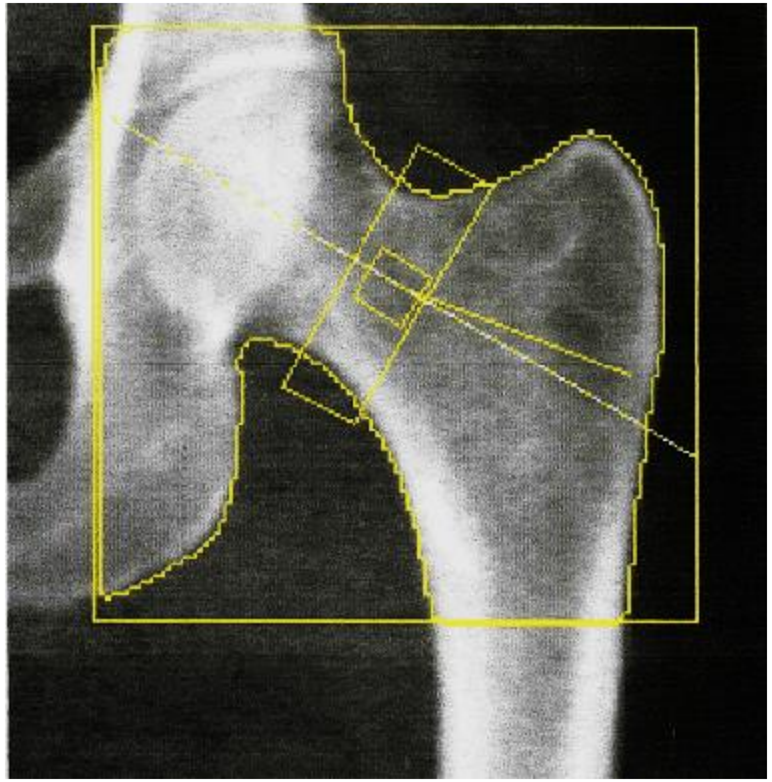
In Hologic check to make sure that the ROI size is the same

2012

2014

The scan will tell you the interval change in g/sq cm and % change from the previous scan and baseline – What do you do with that data?





Region	Area (cm²)	BMC (g)	BMD (g/cm²)	T - score	PR (%)	Z - score	AM (%)
Neck	5.16	3.89	0.753	-0.9	89	0.5	109
Total	**34.64**	**26.92**	**0.777**	**-1.4**	**82**	**-0.3**	**96**

Region	Area (cm²)	BMC (g)	BMD (g/cm²)	T - score	PR (%)	Z - score	AM (%)
Neck	5.21	3.79	0.728	-1.1	86	0.4	106
Total	**34.58**	**27.07**	**0.783**	**-1.3**	**83**	**-0.1**	**98**

Determining Change

Compare the BMD between two studies (don’t compare T-scores because these depend upon normative databases)

Know the precision error and 95% confidence intervals (least significant change) at your institution

Subtract the BMD from the one you are comparing with and see if the value exceeds the LSC

Example of a Change Calculation

Baseline spine BMD = 0.863 gm/cm2
Repeat spine BMD = 0.860 gm/cm2
Difference - <u>0.003 gm/cm2</u>

LSC 0.040 gm/cm2
= or Exceeds LSC NO

Therefore, this is a not significant loss of bone mineral density at this site

(You can't rely on the statistics from the machine because they are not done with a population like your population)

Performing a precision study to determine precision error and least significant change at your institution is important.

UAB POOLED PRECISION VALUES

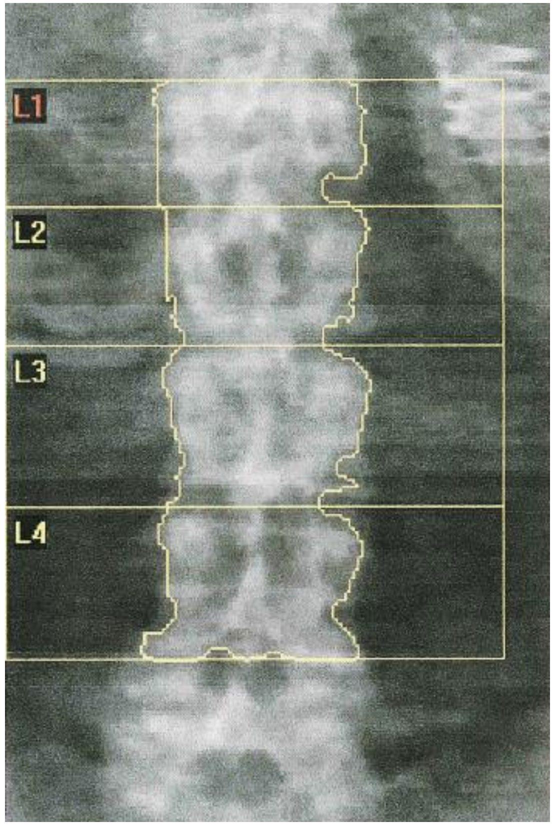
POOLED PRECISION				
	Lumbar Spine	Femoral Neck	Total Hip	1/3 Radius
Root mean squared S.D. (gm/cm^2)	0.015	0.012	0.013	0.008
Coefficient of variation	0.016	0.018	0.014	0.011
% coefficient of variation	1.57	1.76	1.39	1.15
RMS SD – LSC (gm/cm^2) – 95% confidence level	0.040	0.034	0.035	0.022
% CV - 95% confidence interval	4.34	4.87	3.86	3.18

IBJI PRECISION VALUES

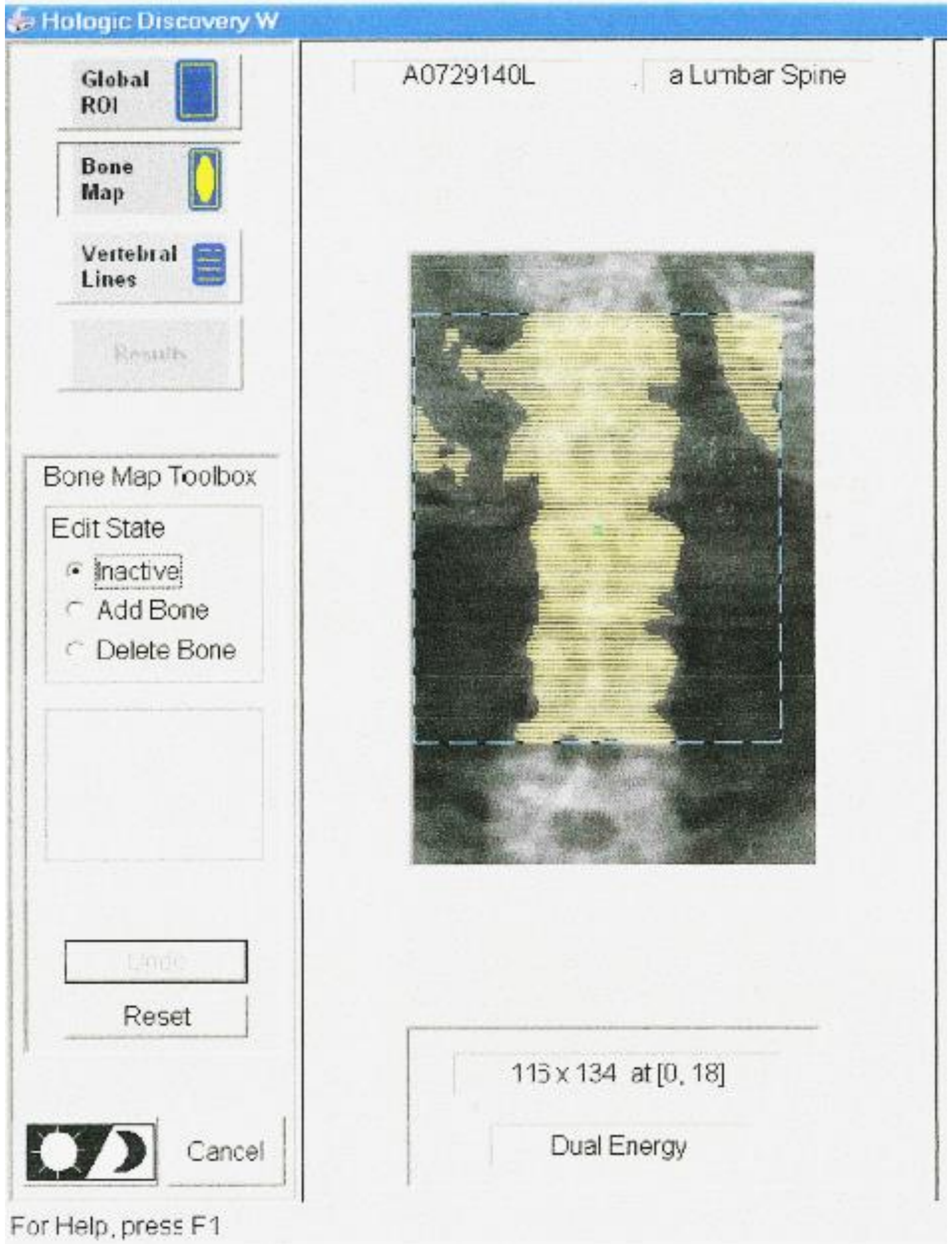
Region	Mean BMD	Prec.(SD)	CV%	LSC (g/cm2)	LSC%
Total Hip	0.705	0.007	1.0	0.019	2.7
FN	0.577	0.009	1.6	0.026	4.5
GT	0.546	0.007	1.3	0.020	3.6
L1-L4	0.743	0.008	1.1	0.023	3.1
L1-L3	0.714	0.009	1.3	0.025	3.5
L2-L4	0.773	0.009	1.2	0.026	3.4
L1,L3-L4	0.748	0.009	1.3	0.026	3.5
L1-L2,L4	0.731	0.010	1.4	0.028	3.9
L1-L2	0.678	0.011	1.6	0.029	4.3
L1,L3	0.710	0.011	1.5	0.030	4.3
L3-L4	0.794	0.011	1.4	0.030	3.8
L2-L3	0.751	0.011	1.5	0.031	4.1
L2,L4	0.772	0.012	1.6	0.034	4.4
L1,L4	0.734	0.013	1.7	0.035	4.7
L1	0.628	0.015	2.4	0.042	6.6
L3	0.776	0.015	1.9	0.041	5.3
L2	0.723	0.015	2.1	0.042	5.8
L4	0.809	0.017	2.1	0.048	5.9
1/3 Radius	0.543	0.009	1.7	0.025	4.6
UD Radius	0.311	0.008	2.6	0.022	7.1

ARTIFACTS AND INTERESTING SCANS

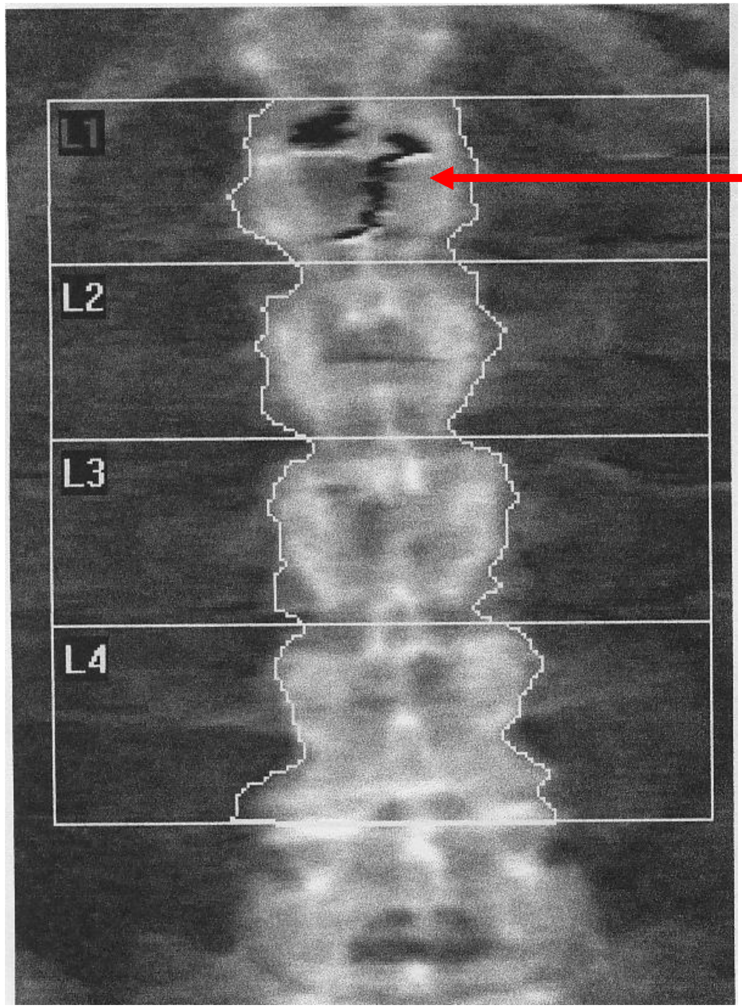
Should levels be deleted because of the artifacts in the soft tissue?



Region	Area (cm²)	BMC (g)	BMD (g/cm²)	T - score	PR (%)	Z - score	AM (%)
L2	13.76	11.91	0.866	-1.5	84	1.1	116
L3	15.56	13.36	0.858	-2.1	79	0.6	109
L4	15.41	11.87	0.770	-2.6	73	0.1	102
Total	**44.72**	**37.13**	**0.830**	**-2.3**	**77**	**0.4**	**106**

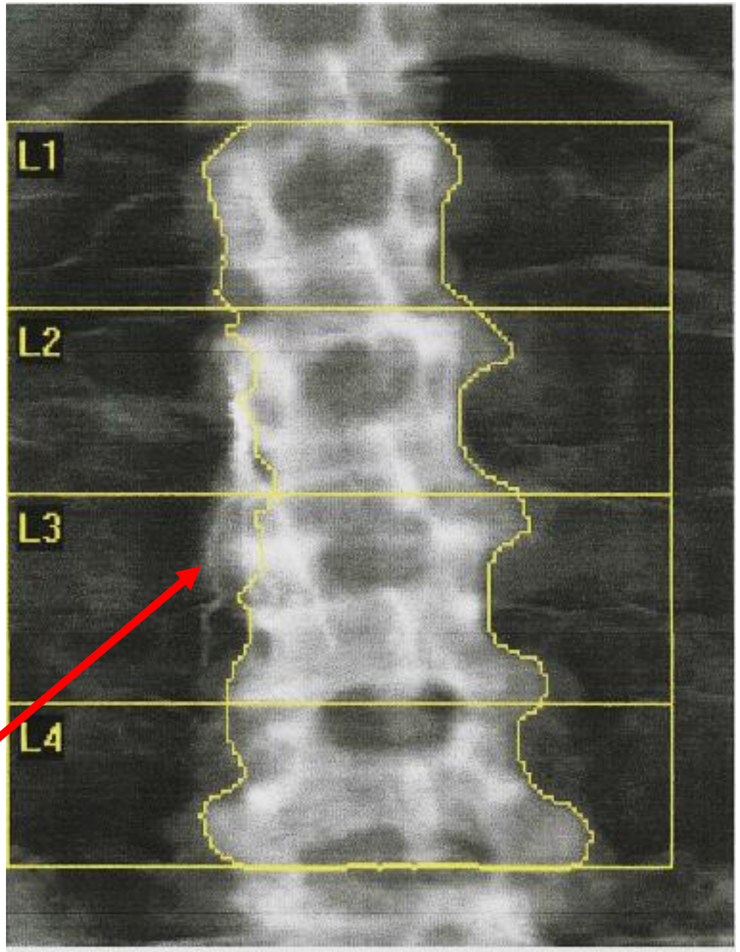


The rule of thumb is that generally omit things over the vertebral bodies, and check to see if things in the soft tissue that would affect the soft tissue baseline are omitted by the software.

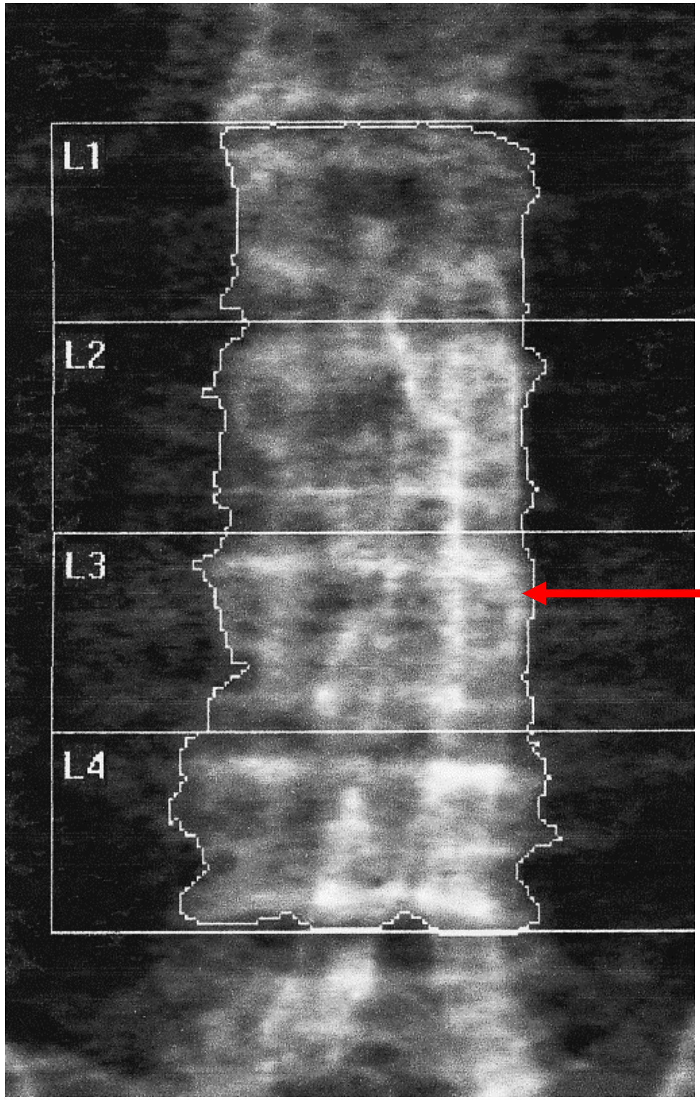


Black Hole Artifact – likely tantalum clips

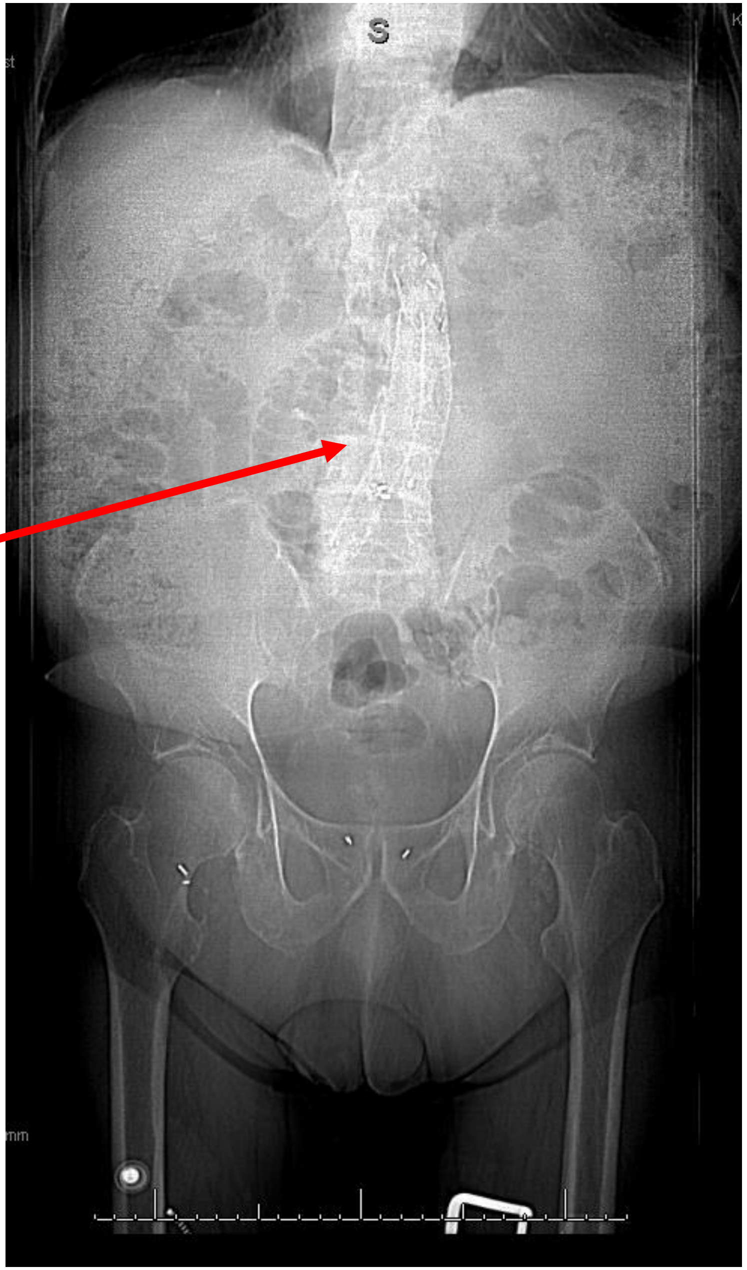
IVC Filter



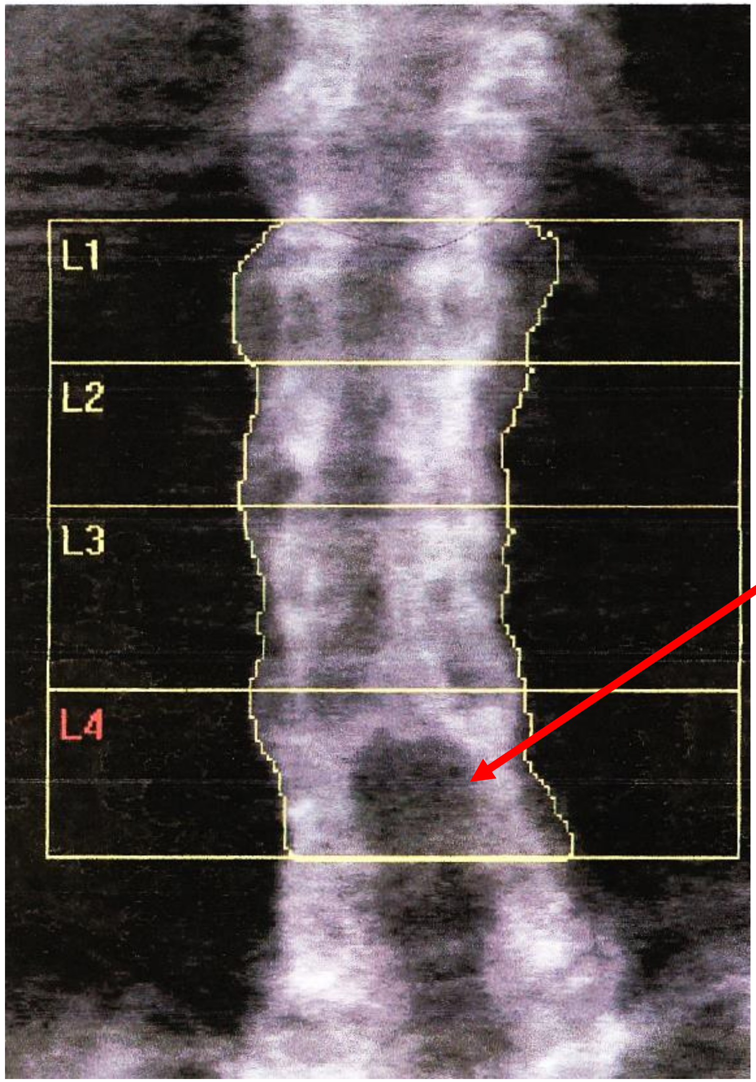
Region	Area (cm²)	BMC (g)	BMD (g/cm²)	T - score	PR (%)	Z - score	AM (%)
L1	12.97	10.77	0.831	-1.4	84	-0.8	91
L2	12.96	12.12	0.935	-0.8	91	-0.1	99
L3	16.68	15.81	0.948	-1.2	87	-0.4	95
L4	16.50	13.27	0.804	-2.3	76	-1.5	83
Total	**59.10**	**51.97**	**0.879**	**-1.5**	**84**	**-0.8**	**91**



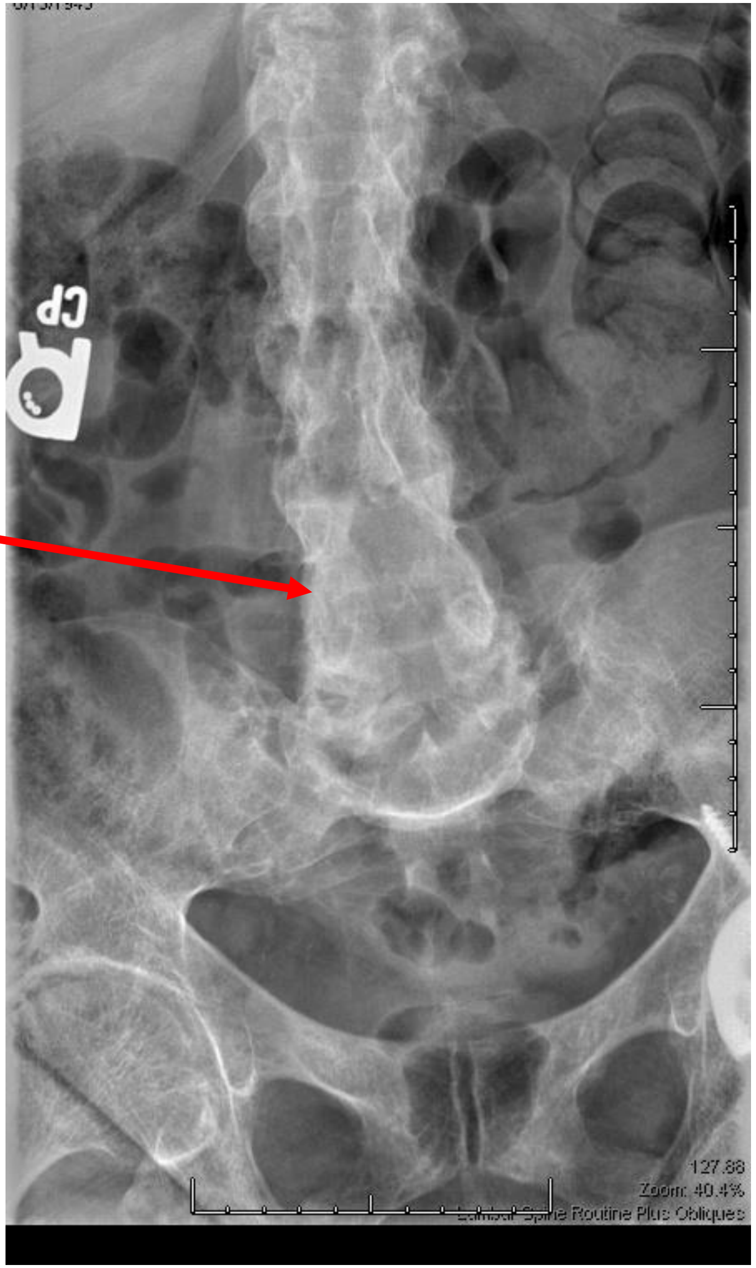
AAA repair stent graft



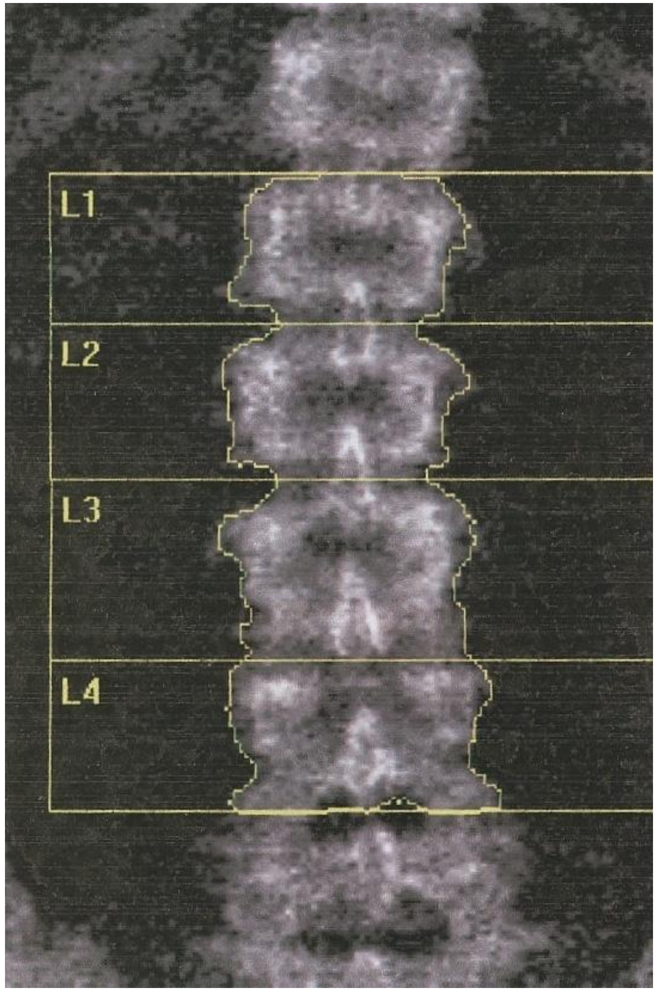
Region	Area (cm²)	BMC (g)	BMD (g/cm²)	T - score	PR (%)	Z - score	AM (%)
L1	18.61	19.07	1.024	0.1	102	1.0	112
L2	21.19	29.14	1.376	2.6	126	3.5	138
L3	20.43	24.90	1.219	1.1	110	1.9	121
L4	22.63	27.35	1.209	0.6	106	1.5	116
Total	**82.86**	**100.46**	**1.212**	**1.1**	**111**	**2.0**	**122**



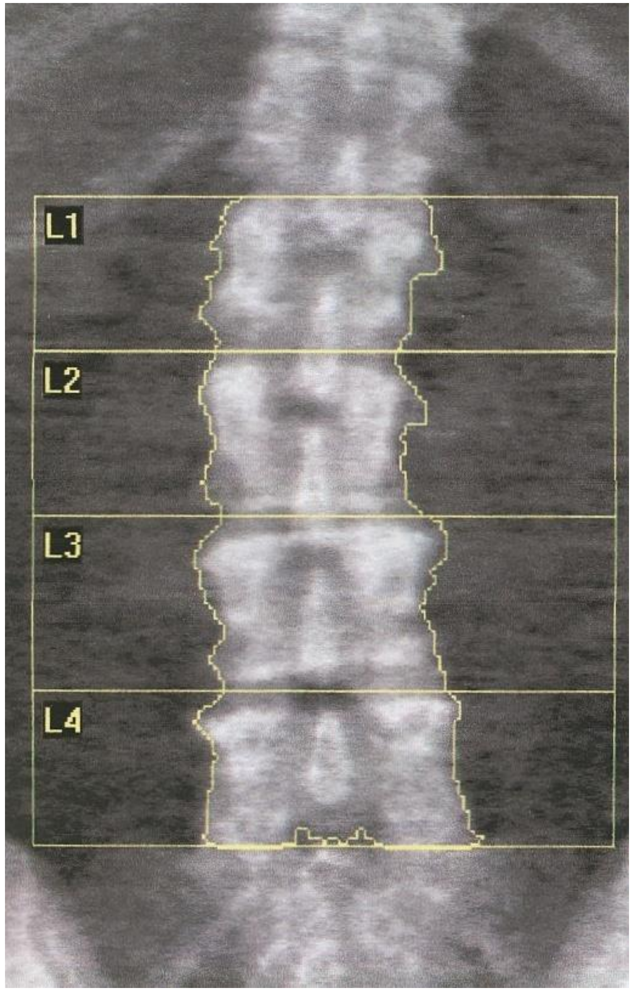
Laminectomy



Six “lumbar”



Four “lumbar”



Vertebral Segmentation

375 Patients with complete spine exams
(assumes 12 thoracic vertebra and first rib on T1)

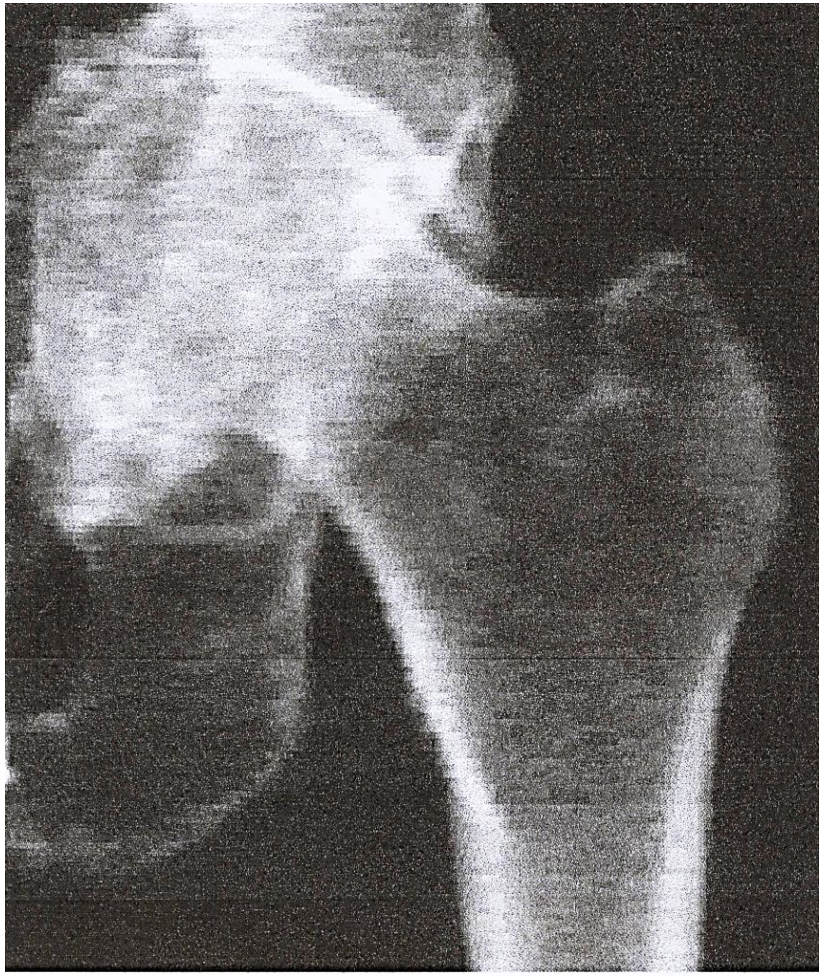
Appear as 5 Lumbar

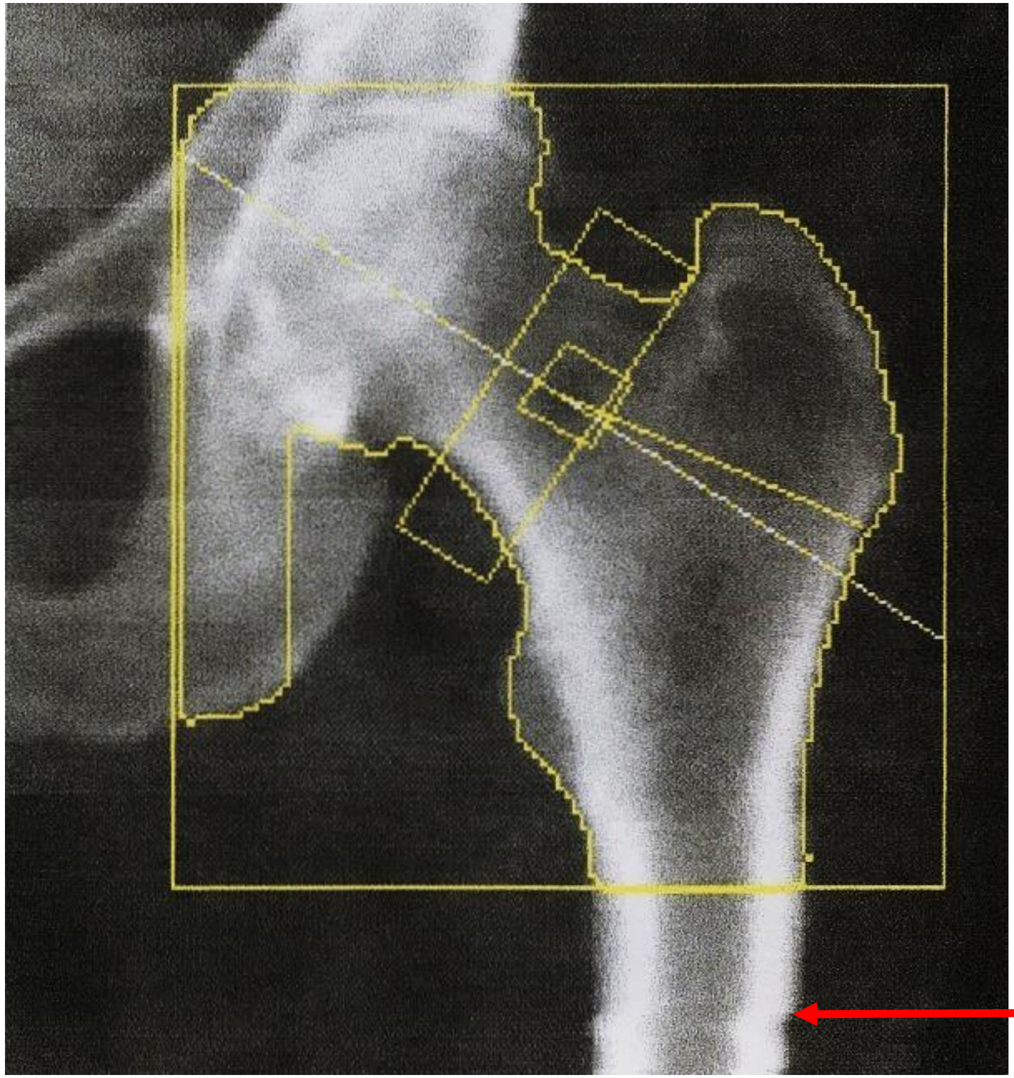
Appear as 6 Lumbar

# of Lumbar	Lowest Pair of Ribs			
	T-11	T-12	L1	Total
4	**5.3% (20)**	2.1% (8)	0% (0)	7.4% (28)
5	**7.2% (27)**	**83.5% (313)**	0% (0)	90.7% (340)
6	0% (0)	**0.8% (3)**	**1.1% (4)**	1.9% (7)
Total	12.5% (47)	86.9% (324)	1.1% (4)	100% (375)

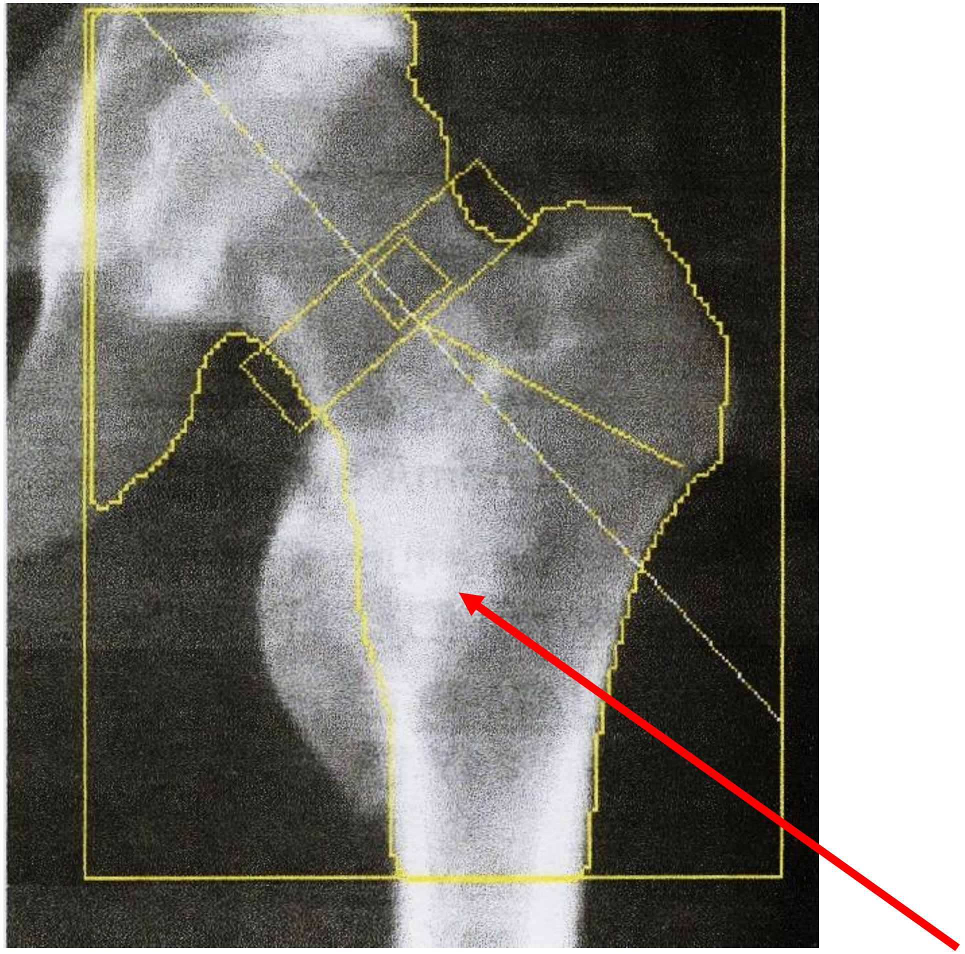
Peel NFA, et al. *JBMR* 1993;8:719-723.

Acetabula Protrusio

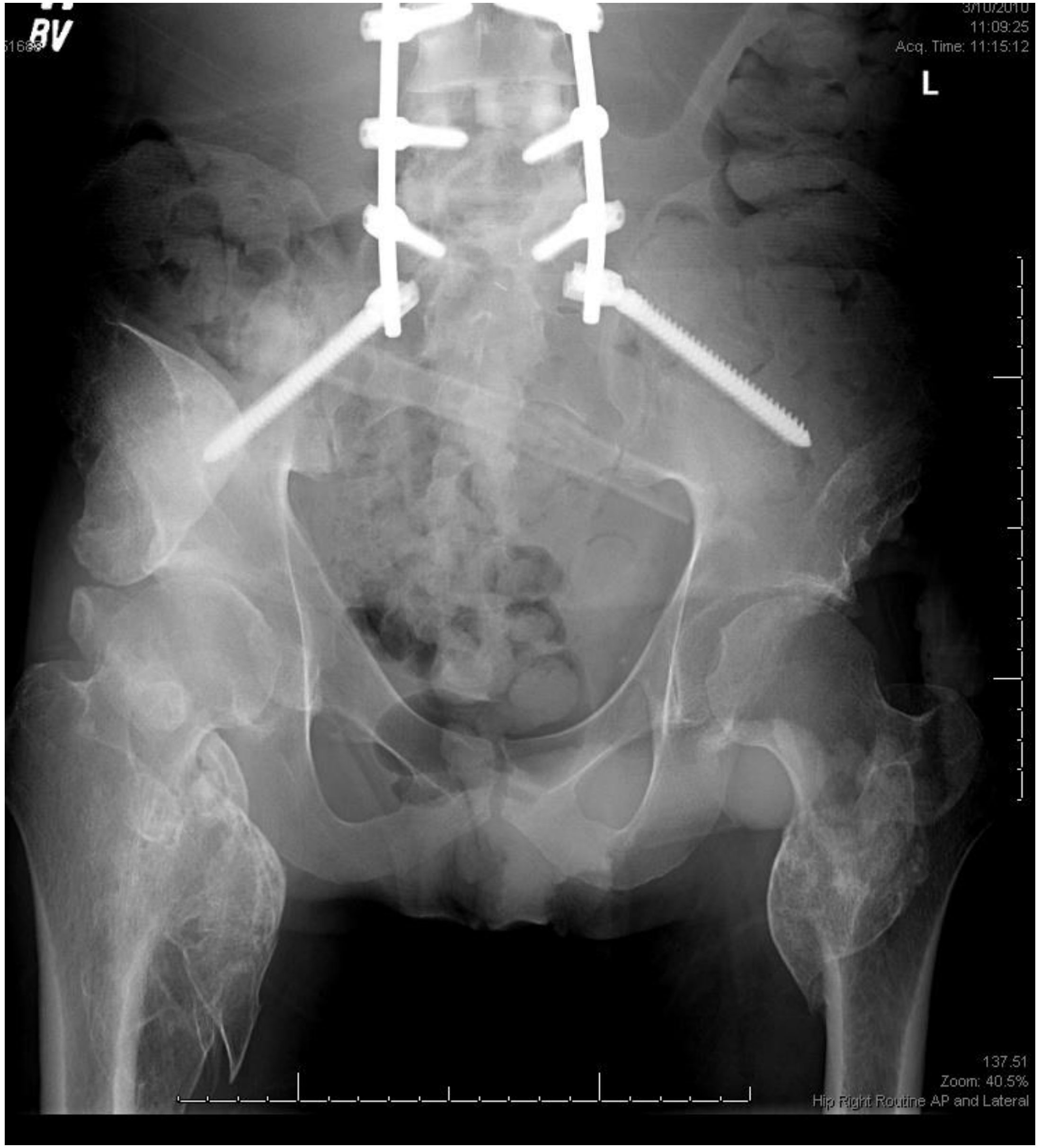


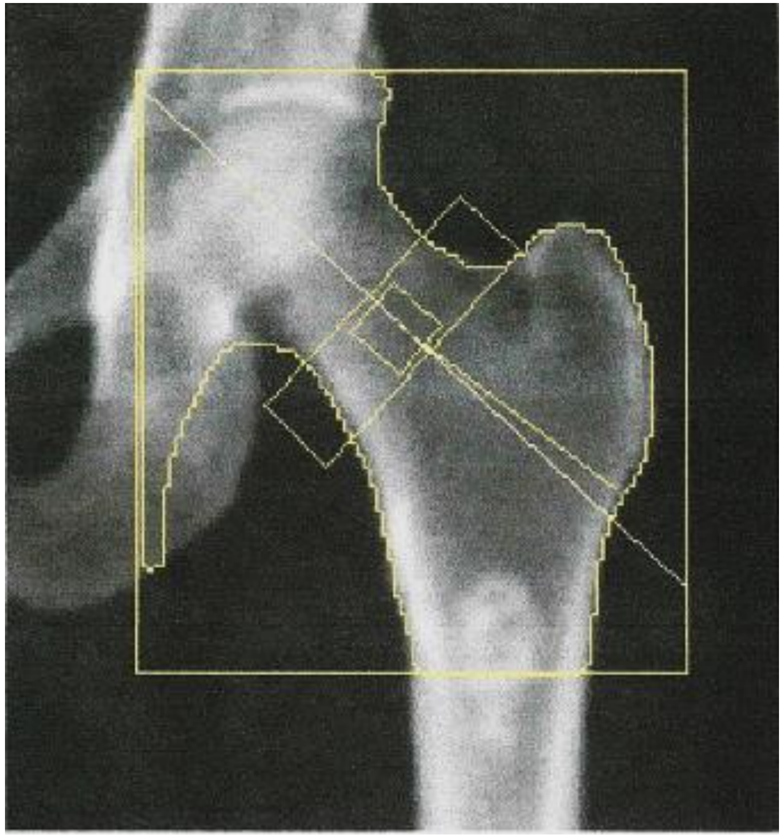


Motion Artifact



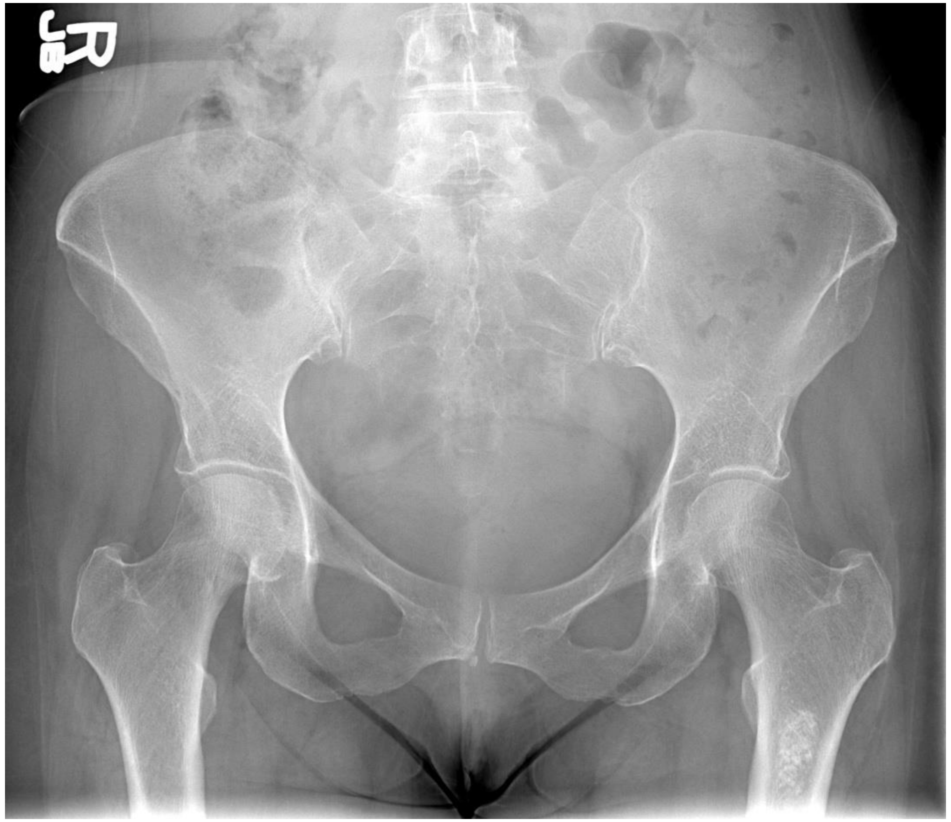
Heterotopic
Ossification





An **enchondroma** is a cartilage cyst found in the bone marrow. Typically, enchondroma is discovered on a X-ray scan. Enchondromas have a characteristic appearance on Magnetic Resonance Imaging (MRI) as well. They have also been reported to cause increased uptake on PET examination.

Region	Area (cm^2)	BMC (g)	BMD (g/cm^2)	T - score	PR (%)	Z - score	AM (%)
Neck	4.65	2.94	0.632	-2.0	74	-0.8	88
Total	29.90	23.34	0.781	-1.3	83	-0.5	93



Will the presence of the enchoncroma elevate BMD in the total hip?

Words of Wisdom

- Never change patient management without thorough review of images.

- "Trust, but verify"

  \- Ronald Reagan