

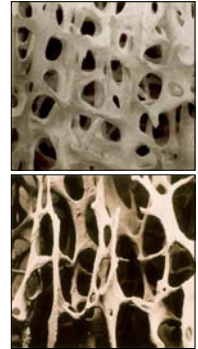


## Radiation Dose & BMD Accuracy: results & findings of EU DEXA study.

Ann Larkin

## Bone Densitometry (DEXA)

- DEXA scanning is currently the gold standard method to measure bone mineral density.
- DEXA systems are particularly important in the screening for and management of osteoporosis.
- In recent years there has been rapid growth in the use of DEXA systems in private and public medical institutions.
- Currently there is approx 71 licensed DEXA systems in Ireland.



System	Lunar (PB)	Lunar (FB)	Hologic	Lexxos
Dual kVp Production	76kVp kVp filtered	76kVp kVp filtered	100kVp & 140kVp Switched kVp	75kVp & 140kVp Pulsed kVp
mA	1.5 mA	0.75mA, 3mA	2.5mA, 3mA	7mA (75kVp) & 3.8mA (140kVp)
Beam Shape	Pencil Beam	Fan Beam	Fan Beam	Cone Beam
AP Spine	> 3 mins	< 1 min	< 1 min	~3.5 secs
Tube Position	Under couch	Under couch	Under couch	Over couch
Detector Type	Single detector: NAI PM tube, counting with energy discrimination <b>Raster Scan</b>	Linear array of detectors: Cadmium-Zinc-Telluride (CZT) detector <b>Single sweep across pt</b>	Linear array of detectors: Photodiode, CdWO4 integrated circuit <b>Single sweep across pt</b>	Digital detector: scintillation screen (Gd2, O2S), photodiodes, 512x512, pixel size 400 µm. <b>Flash acquisition</b>



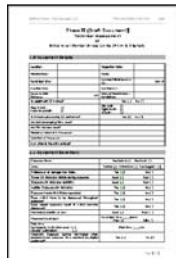
## Sentinel Study

- Equipment Survey
- QC Survey
- Patient Dose
- Bone Mineral Density Accuracy & Precision

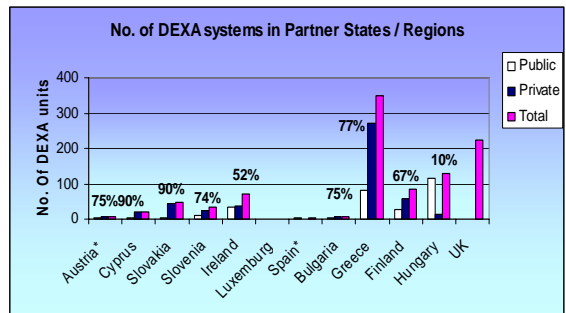


## Equipment Survey

- A questionnaire was distributed amongst SENTINEL partner states to obtain information about the number and type of DEXA scanners in their countries.
- Responses were received from twelve partners.



## Equipment Survey





## Equipment Survey

- A recent publication by Kanis [2006] defines the recommended number of diagnostic DEXA scanners per million population in a country as 10.6 for optimal management of osteoporosis. Some countries fall below this target level.
- By 2050, the worldwide incidence of hip fracture in men is projected to increase by 310% and 240% in women [Gulberg, 1997].
- As the drive to better manage osteoporosis within the European healthcare system gains momentum, it is possible there will be a further increase in the number of DEXA scanners in member states.
- One of the recommendations of the EU Osteoporosis Consultation Panel (2004) was to investigate the cost/utility ratio of introducing population screening programs.

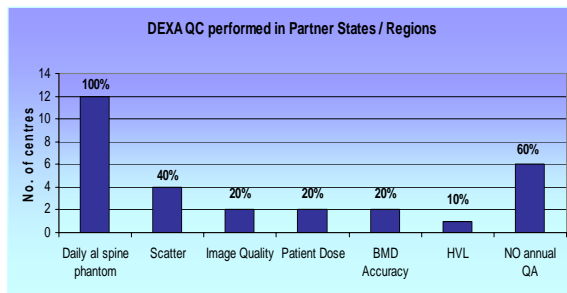


## QC Survey

- A questionnaire was distributed amongst SENTINEL partner states to obtain information about the number and type of DEXA scanners in their countries.
- Responses were received from eight partner states.
  - Five member states confirm that no routine QC or acceptance testing is performed by physicists in their countries.
  - One member state performs annual dose rate measurements.
  - One member state performs a full range of dose and image quality checks annually.
  - All states perform a daily QC using a manufacturer supplied phantom.



## QC Survey



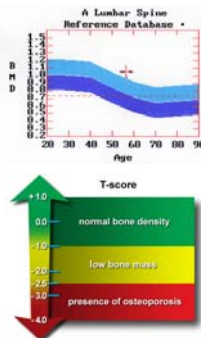
## DEXA QC Study

- This study presents the results of 21 DEXA systems:
  - 4 Pencil Beam,
  - 16 Fan Beam (1 c-arm)
  - 1 Cone Beam,
  - Three Manufacturers



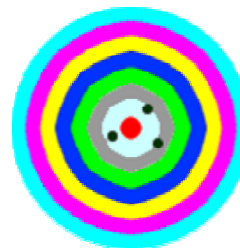
## Bone Mineral Density (BMD)

- BMD – the integral mass of bone mineral content (BMC) per unit projected area ( $g/cm^2$ )
- A DEXA scan report compares the patient's BMD values with those of young normal patient (T score) and with age matched normal patient (Z score).
- By comparing a patient's bone density against their peers, patients can then be classified as normal, osteopenic or osteoporotic.
- According to World Health Organization (WHO) guidelines, a BMD score in a postmenopausal Caucasian woman that is more than 2.5 standard deviations below the average for the young healthy female population implies a diagnosis of osteoporosis



## BMD

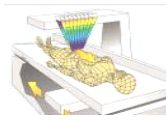
### Accuracy



### Precision



## BMD



### Factors affecting the accuracy & precision of DEXA

- Machine related artefacts such as beam hardening, detected scatter and system drift can introduce errors.
- Interference from Isotopes (Nuc Med facility in close proximity)
- Random errors due to photon & electronic noise
- Literature suggests that DEXA can be used to detect small changes in bone mineral content at multiple anatomical sites, with excellent precision (0.5 -> 2%) and accuracy (3->5%) [Sorenson et al, 1998]
- Other studies report accuracy as 5% and precision as 2-6% [e-radiography.net]

## BMD

- The accuracy and precision of the BMD values on DEXA scanners in this survey were assessed in two ways:

1. The BMD was assessed using the manufacturer supplied spine phantom and the results obtained compared to the calibration values of the phantom.
2. Comparison of BMD values for the various scanners was assessed using the European Spine Phantom (ESP).
3. Each phantom was scanned three times on the available scan modes

Region	Est. Area (cm <sup>2</sup> )	Est. BMC (grams)	BMD (gms/cm <sup>2</sup> )
L1	10.12	5.82	0.497
L2	12.12	7.16	0.591
L3	13.88	8.88	0.673
L4	15.93	11.81	0.741
TOTAL	51.25	32.79	0.640



## Hologic Spine Phantom



### Typical Specifications:

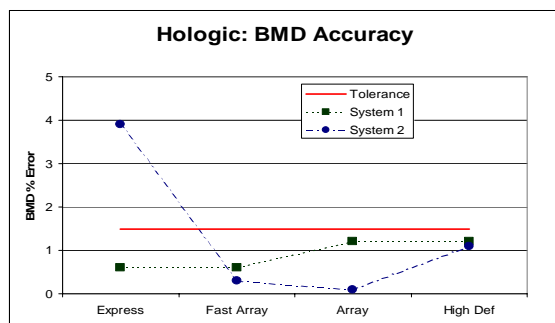
Accuracy = +/- 1.5%

Precision = 1 %

- Hologic anthropomorphic lumbar spine consists of four moulded lumbar vertebrae.
- The four vertebrae are made of hydroxyapatite powder (HAP) embedded in a 17 x 15 x 18cm block of epoxy resin, a pseudo-soft tissue equivalent material.
- The vertebrae are of uniform density throughout and so do not represent differences between trabecular and cortical bone or offer a range of BMD values.
- It provides a simulation of L1 to L4 lumbar spine vertebrae in a patient of about 170cm height.

## Hologic BMD

### Hologic: BMD Accuracy

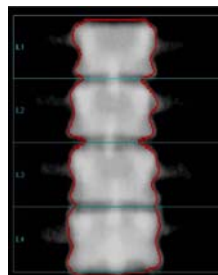


## Hologic BMD

### Precision:

System 1: 0.4 -> 0.7 %

System 2: -0.5%



## GE Spine Phantom



### Typical specifications:

L<sub>2</sub> - L<sub>4</sub>

- Accuracy: +/- 3%
- Precision: +/- 1%

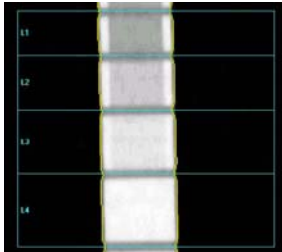
- Lunar spine phantom is a rectangular aluminium bar with dimensions 16 x 4 x 1cm, representing lumbar vertebrae L1-L4. The base of T12 and top of L5 vertebrae are also mimicked in the phantom.

- Differing vertebrae densities are identified by the varying thickness of aluminium in a series of steps and the area of each vertebrae is also varied.

- Each step has a known area, BMC and BMD value. Calibration value is stated as L2-L4 BMD.

- Phantom is placed in a 15cm water bath to simulate soft tissue.

## Lunar BMD



- Semiautomated analysis was used, with the only intervention being slight adjustment of the intervertebral space lines within the regions of interest, as would be typical for a normal patient scan.
- 11 Lunar systems analysed
- All systems were within tolerance for precision and accuracy

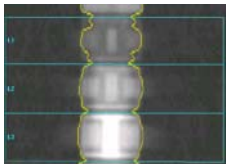
## BMD

- Literature highlights the lack of standardization in bone mineral measurements between manufacturers [Lu, 2001].
- For example, BMD measured on the Lunar DPX-L will be approx 12-15% higher than that measured on the Hologic QDR 2000 [Genant, 1994].
- Most authors claim that these differences are clinically relevant and published conversion factors do exist to compare BMD results from different manufacturers [Genant, 1994, Lu 2001], however attention needs to be paid to the accuracy of these tables.

UCSF Universal Cross-Calibration [2] Formulas for Femur Neck BMD	
Cross-calibration Femoral neck BMD	
Hologic	$= (0.856 \times \text{LUNAR}) - 0.008 = (0.856 \times \text{Norland}) + 0.051$
LUNAR	$= (1.015 \times \text{Hologic}) + 0.142 = (0.945 \times \text{Norland}) + 0.115$
Norland	$= (0.961 \times \text{LUNAR}) - 0.037 = (1.030 \times \text{Hologic}) + 0.058$

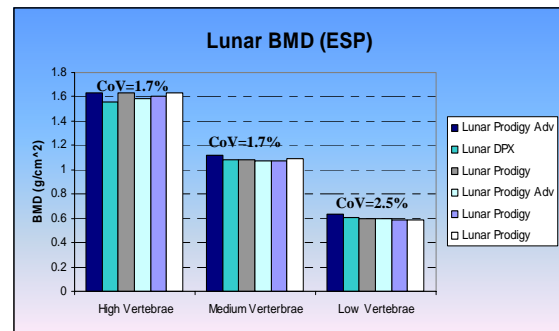
[Fogarty, 1999]

## European Spine Phantom (ESP)

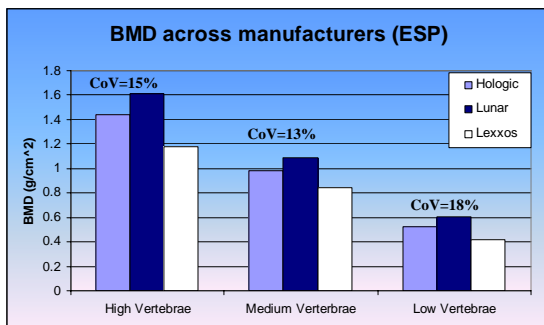


- Comparison of BMD values for different scanners was assessed using the European Spine phantom (ESP) [Kalender 1995].
- The ESP is made of resin-based water equivalent material containing three anthropomorphic vertebrae L1-L3.
- Each vertebrae has a different BMC and subsequent standardized BMD of 500, 1000 and 15000 mg cm<sup>-2</sup>
- The vertebrae are embedded in a tissue equivalent plastic, moulded into an oval phantom with dimensions of 28 x 18 cm.
- Can be used for cross comparison and calibration of DEXA systems and CT systems from different manufacturers.

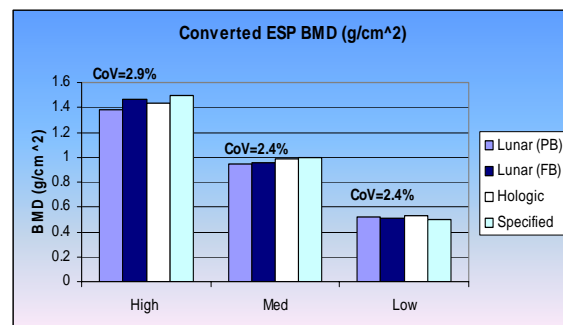
## ESP:BMD



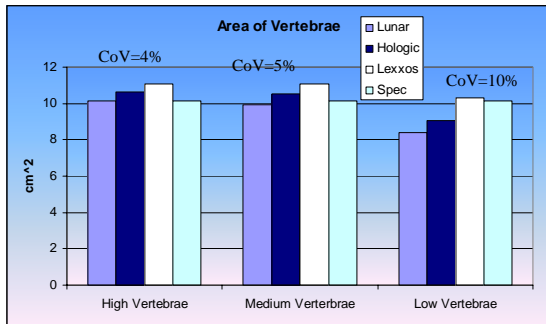
## ESP:BMD



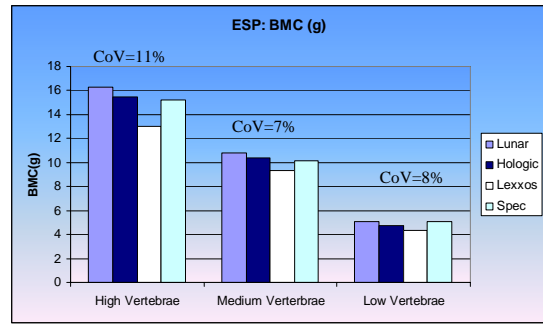
## ESP:BMD



## ESP: Area



## ESP: BMC



## BMD Summary

Most systems were within tolerance for the manufacturer supplied phantoms.

Good correlation found on the BMD of the ESP for systems of the same manufacturer

Between manufacturers:

- BMD: CoV up to 18% (reduces to 3% when conversion tables employed)
- Area: CoV up to 10% (edge detection algorithms)
- BMC: CoV up to 11%

Literature recommends in vitro and in-vivo cross calibration of systems for clinical trials, or if a new system is purchased.

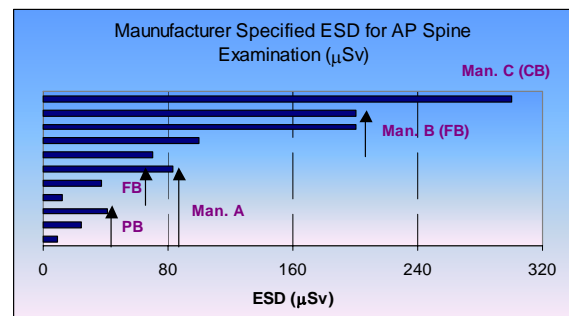
## Patient Entrance Surface Dose (ESD)



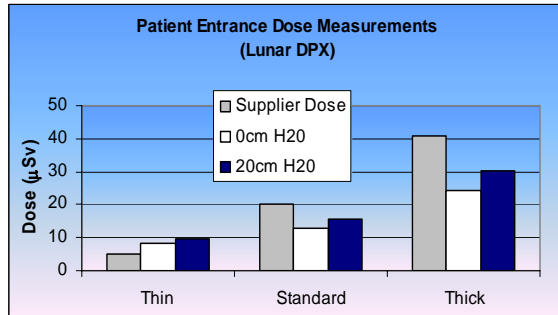
## ESD

- ESD determined by machine dependent parameters such as source-detector geometry, focal spot size, source collimation, tube current and source spectra.
- Most DEXA scanners do not incorporate DAP meters or AEC and the DEXA operator generally only has limited control over the selection of the exposure parameters.
- In DEXA scanners from some manufacturers the operator can adjust the collimation in one plane only, and the selection of the scan mode (patient size) adjusts the mA accordingly.
- mA dependant on selected scan protocol (0.75mA to 7mA).
- Scan protocol can be selected by operator or can be automatically selected based on patient weight & height.

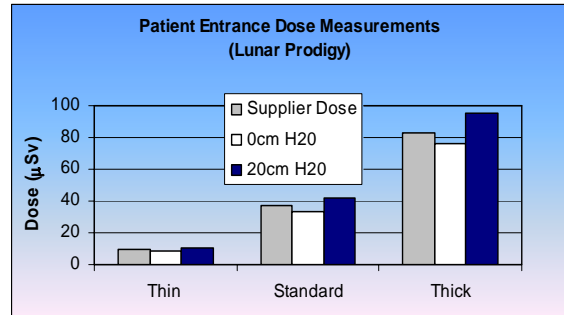
## ESD



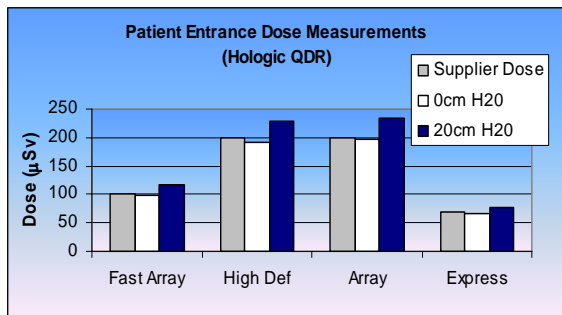
## ESD



## ESD



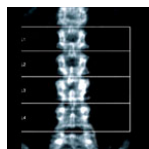
## ESD



## ESD

- **Results:**
- Deviation from specified **ESD** ranged from -25% to +35%, mean of -4%
  - Dose increases by a factor of ~3 for **ESD** for different scan protocols on the same scanner – operator training
  - **ESD** Cone Beam & Fan Beam scanners >> **ESD** Pencil Beam scanners

## Patient Effective Dose (PED)



## PED

Standard Patient: Spine plus dual hip

System	Pencil	Fan	Cone
Lunar (standard patient mode)	0.5µSv	2µSv	-
Hologic (Array Mode)	6µSv	32µSv	-
Lexxos (small / std patient)	-	-	18µSv

For comparison: Dental X-Ray 1 – 8µSv  
Chest X-Ray: 30-50µSv

## PED

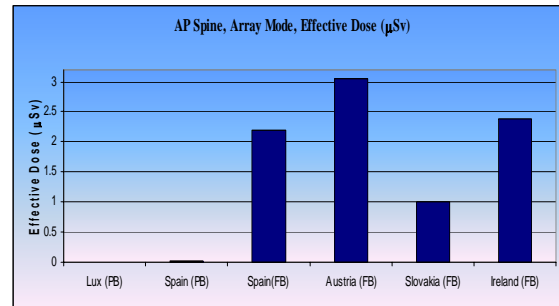
- Method by Huda [1994] to derive **ED** from **ESD**
- $PED (\mu Sv) = ESD (mSv) \times Area (cm) \times Factor (0.05 \mu Sv/mSv cm^2)$

### ➤ Results:

- Dose for Cone Beam & Fan Beam scanners >> Pencil Beam scanners.
- Total effective dose to the patient from a spine and femur DEXA examination is comparable to, at most, a few days natural background radiation.
- Associated with the increase in patient dose and higher patient throughput with the latest generation DEXA scanners is a greater occupational hazard to staff from scattered radiation



## PED



## PED - Summary

- Even low dose techniques that expose patients to ionisation radiation requires an assessment of the risk of radiation injury.
- For low doses, as encountered in DEXA, the principal risks to patients are the stochastic process of carcinogenesis and genetic effects [Lewis, 1994]
- DEXA scans can result in dose to radiosensitive tissues in abdomen, bone marrow, stomach, colon and ovaries (WB & Hip).
  - Patient population for DEXA scans is no longer just post-menopausal women
  - Current method of calculating **ED** is quite simplistic and should be reviewed.
  - Need to ensure operators of DEXA scanners are trained on RP / dose reduction principles.

## Summary

- Despite the dose increases associated with advances in technology, patient doses from DEXA remain low when compared with natural background and other common radiological examinations.
  - However, any equipment that exposes patients to ionising radiation should be subject to regular performance checks.
  - On-going dose monitoring is essential to establish DRLs and tolerances
- BMD is not consistent between manufacturers