



# Technical White Paper: Bone Densitometry

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Developed by CRCPD's Task Force  
on Bone Densitometry (H-30)

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## EXECUTIVE SUMMARY

The Conference of Radiation Control Program Directors' (CRCPD) Task Force on Bone Densitometry (H-30) was assigned by the Healing Arts Council on Emerging Issues (HAC-EI) to address issues on bone densitometry. Issues for clarification included the practice of precision testing in which multiple bone density determinations are performed on one patient, the use of quantitative computed tomography (QCT) densitometry, and radiation dose to patients and operators.

This White Paper addresses the various methods of measuring bone density, the qualifications and responsibilities of personnel, the rationale for precision testing, and the dose the patient and operator may receive.

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## INTRODUCTION

Osteoporosis is a highly prevalent and disabling disease, characterized by low bone mass with resultant bone fragility and increased risk of fracture. Osteoporosis is diagnosed if bone density is abnormally low and meets recognized criteria for osteoporosis at one or more anatomic sites. The most widely used criteria for judging osteoporosis is from the World Health Organization.

Fractures due to osteoporosis affect 50 percent of women and 12 percent of men over the age of 50. When these fractures involve the hip or vertebrae, there is significant deterioration in the quality of life, with pain and impaired mobility. The associated costs for hospitalization, surgery, rehabilitation, long-term care, loss of work, and medications exceed \$17 billion annually (2003 dollars) in the United States. Treatments are available to slow or halt bone deterioration, and in many cases increase bone density. Since osteoporosis is a "silent" disease, with no signs or symptoms until a fracture occurs, medical diagnostic testing is required to allow for preemptive treatment. The most reliable means of diagnosis is determination of bone density.

A nationwide survey conducted by the Task Force on Bone Densitometry revealed significant variations in knowledge about bone densitometry and in the states' regulations pertaining to it. Eighty-three percent of the responding states require that all units utilizing ionizing radiation be registered with state radiation control programs. However, some peripheral densitometry units involve such low radiation exposure that some states have waived any additional regulatory requirements.

Some states without understanding the need for precision testing have prohibited the measurement despite low radiation doses and limited numbers of repeat densitometry determinations. Their major concern, of course, is the apparent unnecessary radiation to a few, select patients. To address the benefit versus risk issue, those exposed to the additional, small amount of radiation (equal to approximately an additional 6-12 hours of background radiation) are providing a benefit to themselves and all others by validating the results of bone mineral density (BMD) exams for that facility. Without precision testing, the BMD study is of no value resulting in thousands of patients being exposed to unnecessary radiation. The Task Force has taken this opportunity to address these issues and organize information available on bone densitometry practices and radiation exposure levels.

Bone densitometry is a quantitative measurement of bone mass or density, similar to blood pressure measurement or laboratory analysis of a blood sample. Even though some bone densitometers can produce exceptionally good skeletal images, it is not a radiograph, nor does it have the same properties. Bone densitometry is a non-invasive, inexpensive examination, using a very small amount of ionizing radiation, and when performed correctly produces dependable results. The current most common densitometry method is dual energy x-ray absorptiometry (DXA).

## **METHODS OF MEASURING BONE DENSITY**

There are several methods to measure bone mineral density (BMD) and strength by utilizing ionizing radiation or ultrasound. The accuracy and precision varies between methods. Plain radiography and radiogrammetry were the earliest radiographic means, followed by radiographic absorptiometry. Single and dual photon absorptiometry followed, which utilized radionuclide sources. Single-energy x-ray absorptiometry was then developed, employing a single energy x-ray beam. These methods have largely been superseded by dual energy x-ray absorptiometry (DXA), quantitative computed tomography (QCT), and peripheral ultrasound.

Bone density can be measured centrally (spine and hip), or peripherally on the appendicular skeleton (extremities). Very low dose peripheral x-ray densitometry and heel ultrasound have value as screening tests for osteoporosis, but once a patient is diagnosed with low bone density and put into a treatment or follow-up program, BMD is best followed with either DXA or QCT of the lumbar spine and hip. For patients with discrepancies between hip and lumbar spine BMD, bone density of the wrist and forearm may be added.

### **PLAIN RADIOGRAPHY**

Early attempts to quantify bone density utilized plain skeletal radiography. However, bone demineralization becomes visually apparent only after a bone density loss of 40% or more. This resulted in highly subjective grading systems based on evaluation of the trabecular patterns of the bone and the thickness of the vertebral cortex. Plain radiography has been replaced by more quantitative methods of bone densitometry.

**Radiogrammetry** is a plain radiography BMD technique that utilizes measurement of the bones on a hand radiograph. Originally, a fine caliper was used to measure the cortical and medullary width of the metacarpal bones. Several measurements were acquired to calculate the bone density. Current digital technology facilitates computer analysis of bone dimensions. Radiogrammetry has limited precision, and changes in cortical thickness are usually quite small, resulting in poor reliability of radiogrammetry in the detection of early bone loss or in serially monitoring small changes over time.

Products using computerized radiogrammetry:

Pronosco X-posure system (Denmark)  
(Radiograph of hand)

Photodensitometry is similar to radiogrammetry, but includes an aluminum step wedge that is placed on the film at the time the radiograph is taken. The step wedge provides known densities and enables compensation for variations in exposure settings, beam energy, and film development. The density of the skeletal image is quantified using a scanning photodensitometer.

## **RADIOGRAPHIC ABSORPTIOMETRY (RA)**

Radiographic Absorptiometry is derived from radiographic photodensitometry. Two x-rays of the hand are taken with slightly different exposure techniques using a standard radiographic unit, with an aluminum step wedge included on each film. Both films are then sent to a central laboratory where they are digitized and analyzed by a computer.

Products using computer-enhanced Radiographic Absorptiometry:

OsteoGram  
(Two radiographs of hand)

MetriScan  
Radiographic absorptiometry with storage phosphor technology

## **SINGLE PHOTON ABSORPTIOMETRY (SPA)**

Absorptiometry is based on the fact that attenuation of an x-ray beam is proportional to the mass of an object in the path of the beam: the greater the density of the object, the fewer photons pass through it. The difference in radiographic density of body tissues creates the contrast necessary to visualize anatomic structures on a radiograph. In SPA, a radionuclide (usually iodine-125 or americium-241) is the photon source and a scintillation detector quantifies photon transmission through the body part to determine bone density. SPA is valid only when the body part is embedded in a uniform thickness of soft tissue. Consequently, with SPA the body part to be studied must be submerged in a water bath, thereby limiting the examination to the extremities (usually forearm or heel).

## **DUAL PHOTON ABSORPTIOMETRY (DPA)**

Dual Photon Absorptiometry involves the same basic principle as SPA. However, by employing two different isotopes or one with two distinct peaks (e.g., gadolinium-153 with energies at 44 and 100 keV [kiloelectron volt]), it is possible to mathematically separate attenuation due to soft tissues from that due to bone mineral. The results are then calibrated using standards created from ashed bone. DPA does not require compensation for non-uniform tissue thickness, and eliminates the need for a water bath. It is considered superior to SPA, because it enables BMD determination of the spine and hip.

DPA has limitations. The highly trabecular vertebral body cannot be separated from the cortical posterior elements, and the cortical shell of the vertebral body cannot be separated from the trabecular interior. Overlying calcifications in the soft tissues or abdominal aorta may attenuate the beam and spuriously increase bone density values. Also, both SPA and DPA require adjustment for the decay and periodic replacement of the expensive radionuclide source (~\$5,000 in 2001

[4]). As the source decayed, values obtained by DPA increased by as much as 0.6% monthly. After replacement of the source, bone density readings could fall by as much as 6.2% [16]. Formulas have been developed to compensate for the effect of source decay, but concern regarding precision and accuracy persist. Scan times are long--approximately 30 minutes for central body sites like the hip and spine--and spatial resolution with DPA is limited. SPA and DPA have been largely replaced by DXA, which has lower operating cost, greater precision, and ease of use.

### **SINGLE-ENERGY X-RAY ABSORPTIOMETRY (SXA)**

Single-energy x-ray absorptiometry is the x-ray counterpart of single photon absorptiometry. Like SPA, SXA requires a water bath or tissue-equivalent gel surrounding the region being measured to correct for non-uniform thickness, and is therefore used on extremities. SXA is being replaced by portable, dual-energy x-ray absorptiometry units now being used to measure forearm and heel bone densities.

### **DUAL-ENERGY X-RAY ABSORPTIOMETRY (DXA)**

Dual-energy x-ray absorptiometry (DXA) is similar to DPA, but utilizes x-rays rather than isotopes. DXA uses the same principle as DPA in that two energy peaks are used to separate bone from soft tissue. This is accomplished with K-edge filters at a fixed kVp (kilovoltage, peak) or alternating pulses. Norland uses a samarium filter that results in energy peaks of 45 and 80 keV and GE Lunar uses a cerium filter that results in energy peaks of 38 and 70 keV. Hologic applies alternating pulses such as 70 (or 100) and 140 kVp or 43 and 110 keV. DXA units are used to scan extremities such as the forearm, the central skeleton such as the lumbar spine and hip, or can be operated for whole-body scanning to evaluate the entire skeleton or to measure body composition (e.g., fat, bone, and muscle mass).

The image of the scanned body part is used for quality assurance in monitoring the accuracy of patient positioning and noting artifacts and anatomical abnormalities contributing to bone density. Artifacts and abnormalities include metallic joint prostheses, abnormal bone growths, or healed fractures. The conventional screening protocol calls for BMD of the first through fourth lumbar vertebrae and one or both hips. If a non-removable artifact is demonstrated, such as a hip fixation pin or an old fracture, densitometry of the contralateral (opposite) hip may be substituted. If there is a discrepancy between hip and lumbar spine BMD, densitometry of the left forearm may be performed.

DXA offers several advantages over DPA. There is no source decay and therefore no need to replace the source or correct for drift in patient values due to radioactive source decay. Tighter beam collimation is achieved, resulting in less dose overlap between scan lines and thus a lower patient radiation dose, greater image resolution, shorter scan times, and improved precision.

Individual bone densitometry units will yield different BMD measurements due to variations in



dual energy scanning methods, differences in calibration, detectors, edge detection software, regions of interest, and different patient population databases used for comparison. Conversion formulas have been published [7, 9, 11, 25] which may be used to convert BMD measurements from any model densitometer of a given manufacturer to the BMD of another manufacturer's device. While these conversion equations are useful for evaluating an individual's BMD measured on different manufacturers' densitometers, errors in these conversion equations are too great to allow serial measurements of BMD using devices from different manufacturers as a guide for individual patient treatment. For this reason it is recommended that, when possible, patients undergoing serial BMD over the course of years have their examinations performed at the same facility and on the same densitometry unit, to increase the likelihood that interval changes in BMD determinations accurately reflect changes in bone mineral density.

A developing application of DXA is the determination of lean muscle mass and body fat. It is being used on competitive athletes, sometimes under research protocols, to evaluate the effects of training regimens and dietary interventions such as protein supplements. Clinical applications include the evaluation of patients with wasting diseases or abnormal body composition due to certain therapies or diseases.

### **Pencil beam vs. fan beam DXA scanners**

Used in the evaluation of the central skeleton, pencil beam scanners employ a collimated or narrowed x-ray beam (2-3 mm) that moves in a rectilinear fashion in tandem with the detector. Fan beam scanners use a much broader or fan shaped beam with multiple detectors. This enables the entire scan line to be quantified instantly and can shorten the scan time to as little as ten seconds for a PA lumbar spine study compared to ten minutes for early generation SXA. Fan beams also permit the acquisition of lateral thoracic and lumbar spine scanning for evaluating bone density in the presence of compression fractures of the spine. Overall, the fan beam scanner offers shorter scan times allowing greater patient throughput, better resolution, and slightly higher radiation doses.

#### Central DXA Pencil Beam\*

DPX-Plus (GE Lunar)	Excell (Norland)
DPX-L (GE Lunar)	Excell plus (Norland)
DPX-NT (GE Lunar)	XR-26 (Norland)
DPX-IQ (GE Lunar)	XR-36 (Norland)
DPX-MD (GE Lunar)	XR-46 (Norland)
DPX-MD+ (GE Lunar)	QDR 1000 (Hologic)
DPX-NT (GE Lunar)	QDR 2000 (Hologic)

\*Some of these units may no longer be manufactured, but may still be in the field.

### Central DXA Fan Beam\*

Delphi (Hologic)  
Discovery QDR 4500 A (Hologic)  
Discovery QDR 4500 C (Hologic)  
Discovery QDR 4500 SL(Hologic)  
Discovery QDR 4500 W (Hologic)  
Expert-XL (GE Lunar)  
Prodigy (GE Lunar)  
iDXA (GE Lunar)

\* Some of these units may no longer be manufactured, but may still be in the field.

### **Morphometric X-ray Absorptiometry (MXA)**

Later generation DXA scanners have incorporated special software to detect the presence of vertebral compression fractures by viewing the spine in the lateral projection. This technique has been variously called morphometric imaging, vertebral fracture assessment (VFA), instant vertebral assessment (IVA), or lateral vertebral assessment (LVA), and is based on computer analysis of vertebral body dimensions. With computer analysis providing more accurate information, the vertebral heights can be measured to quantitatively diagnose compression fractures.

EXPERT-XL (GE Lunar)  
QDR 4500 A (Hologic)  
QDR 4500 SL (Hologic)  
iDXA (GE Lunar)

### **Peripheral X-ray Densitometry (pDXA)**

Small portable DXA units are being utilized for peripheral densitometry of the finger, heel and forearm. Their main application is in mobile screening.

accuDEXA (finger) (Schick)  
Apollo (heel) (Norland)  
DexaCare DTX-200 (forearm) (Osteometer MediTech)  
DexaCareG-4 (forearm) (Osteometer MediTech)  
pDEXA (forearm)(Norland)  
PIXI (heel and forearm) (GE Lunar)

Although peripheral scanners produce good screening information, they are not as accurate as central DXA at detecting small changes in BMD. Therefore, it has been recommended that persons with a low BMD on a peripheral system be referred to a site with central DXA or QCT for further evaluation. This is an accepted standard of medical practice, acknowledged by Medicare, which covers payment for additional central DXA or QCT for diagnosis and for follow-up for progression and monitoring treatment of disease.

## Mode

Some bone densitometry systems offer different modes to scan patients. These modes can narrow and/or shorten the field size, change mA, or change scan time depending on the patient's size, the projection, or the required resolution.

## **QUANTITATIVE COMPUTED TOMOGRAPHY (QCT)**

Quantitative Computed Tomography (QCT) can be performed with most existing CT units. However, to adapt an existing CT scanner for QCT measurement of bone density requires software and mineral reference standards (phantoms) with sophisticated calibration and positioning techniques. The software and reference phantom are used to convert CT attenuation coefficient (Hounsfield Units) to bone equivalent values.

Careful calibration and quality assurance programs are mandatory, especially when the instrument is used for both routine imaging and measuring bone density. Dedicated CT scanners are recommended for BMD.

Unique to QCT is the three-dimensional or volumetric measurement of bone and the spatial separation of trabecular from cortical bone. It is primarily used to measure the trabecular bone of the central region of the lumbar vertebral body. QCT requires the use of a standard reference phantom at the time of scanning. A scout view assists in localization, and is followed by thin (several millimeter thick) slices through the center of two or more vertebral bodies and/or regions of the hip.

A limiting factor in QCT is the fat in the vertebral bone marrow. Marrow fat increases with age, resulting in increasing error in the accuracy of spine QCT measurements. The error can be partially corrected by employing dual-energy QCT (DEQCT). Although the dual-energy scanner can correct for changes in marrow fat and increase the accuracy of the measurement, it does so at the cost of increased complexity, reduced precision (5% vs. 1-3% for single energy), and higher radiation exposures. The use of DEQCT is usually limited to research centers. However, because QCT can isolate and measure trabecular bone, which is more metabolically active than cortical bone, rates of change in disease tend to be greater with QCT than those observed with DPA or DXA, and changes are therefore more detectable. This increased sensitivity of QCT should be weighed against its limitations and the increased radiation dose—especially from CT units that are unable to achieve lower radiation dose levels. Compared to DXA, single energy QCT exposure can be on the order of 20-40 times greater depending on techniques and number of slices.

## **PERIPHERAL QCT (pQCT)**

The more recent availability of a portable, peripheral QCT (OrthoMetrics) device has increased an interest in its use for the measurement of bone density in the forearm. Measurements of the

radius take less time, have good precision and accuracy, expose the patient to less radiation, and the exposed field is remote to radiation-sensitive organs.

## **QUANTITATIVE ULTRASOUND (QUS)**

Ultrasound densitometers, commonly referred to as quantitative ultra-sonometers (QUS), provide a measurement of bone properties without the application of ionizing radiation. It has been shown to be a good predictor of fracture risk. QUS measures the distance between two points and the time required for the sound wave to travel between these two points. Faster speeds correlate with greater bone density and strength or fracture resistance.

Depending on the manufacturer, ultrasound densitometry may not produce an image; it provides a quantitative assessment of bone density related properties and elasticity. Both bone density and bone quality determine resistance to fracture. The speed of sound (SOS) through bone is inversely related to the risk of fracture. SOS and another ultrasound parameter, broadband ultrasound attenuation (BUA), can be applied to determine stiffness, which is another indicator of bone mineral density.

The measurement differences between ultrasound bone densitometers are even greater than those between DXA devices. This is due to the different frequency ranges, transducers, and different regions of interest measured.

The most common site for QUS is the calcaneus (heel), but there are QUS devices for evaluation of the radius, finger or tibia. QUS has proven to be useful as a screening tool, but because of low measurement precision, it is not recommended for serial monitoring of skeletal changes.

Achilles+ (GE Lunar) (heel)  
Achilles Express (GE Lunar) (heel)  
Achilles InSight (GE Lunar) (heel)  
McCue C.U.B.A. Clinical (Contact Ultrasound Bone Analyzer) (Norland) (heel)  
Omnisense 7000S Ultrasound Bone Sonometer (Sunlight Medical) (forearm)  
QUS-2 (Quidel) (heel)  
UBIS 5000 DMS (Diagnostic Medical Systems) (heel)  
Sahara Clinical Bone Sonometer (Hologic) (heel)  
UltraSure DTU-one (Osteometer MediTech) (heel)

## **QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL**

Bone densitometry systems are found not only in various medical practices, but also in non-traditional settings such as pharmacies, health fairs, nutrition clinics and fitness centers. In essence, bone densitometry units can be found anywhere.

Those operating bone densitometry units include physicians, radiologic technologists, nurses, medical assistants, and office clerks. In many states there are statutes and regulations governing operators of radiation-producing devices. Currently, x-ray machine operators are regulated to some degree in 39 states. Many states require non-physician operators of these units to be either a radiologic or a nuclear medicine technologist. Some states also require specific training in bone densitometry. However, a nationwide survey done in 2004 by the University of Tennessee Health Sciences Center of DXA users on training requirements for DXA operators in physician offices showed that 16 states had no certification requirements for central DXA operators. Among responders who indicated that their state did not require authorization, certification, or licensure ( $n=1673$ ), 65.5% ( $n=1095$ ) were wrong in that their state actually did have regulatory requirements [6]. Moreover, practitioners are often unaware of whether the states in which they practice have any training requirements for central DXA operators.

Although peripheral, central, and whole-body bone densitometry deliver low radiation doses to patients compared to general-purpose radiographic systems, a level of competency is necessary to minimize unnecessary exposure and to produce accurate results. The anatomical areas irradiated by central DXA and QCT include bone radiation-sensitive organs, such as the bone marrow, with scattered radiation to the reproductive organs. Poor patient positioning may result in unintended and unnecessary exposure, not only to the patient, but also to the staff administering the examination.

The operators of bone densitometry equipment utilizing ionizing radiation must have knowledge of anatomy, densitometry techniques, radiation safety, basic statistics, quality control procedures, data acquisition, scan analysis, and disease processes such as osteoporosis or extra calcifications that could affect the outcome. The operator must also understand the concept of precision and how to measure it. Licensed physicians, and radiologic and nuclear medicine technologists who are registered with the American Registry of Radiologic Technologists (ARRT) or equivalent registry or who have state certification/licensure have the basic qualifications to perform BMD studies. All operators should have training specific to the equipment they operate.

Registered technologists can pursue additional certification in bone densitometry through the ARRT. The International Society for Clinical Densitometry (ISCD) is a non-profit organization with over 6,000 members that provides training courses in bone densitometry for physicians and technologists, including a certification examination and registry. Certification by nationally recognized organizations results in greater competency of operators, more accurate results, and reduced radiation exposure. Certification is in addition to the operator training provided by equipment manufacturers specific to their marketed units, and is required by some states. Accuracy and reproducibility of BMD determinations is largely operator dependent.

## **RATIONALE FOR PRECISION TESTING IN BONE DENSITOMETRY**

To determine whether a change in a patient's bone density is statistically significant, it is necessary to determine the precision or precision error of the measurement process. Precision is the ability to reproduce a quantitative measurement when a test is repeated under identical circumstances. All quantitative clinical tests have some inherent variation and are not perfectly reproducible. Lack of reproducibility of BMD determinations is due to variation in patient positioning by an individual operator or between different operators, lack of consistency in data analysis, and the inherent precision error of the technique. Common operator errors include poor patient positioning, inconsistent selection of vertebral levels, poor placement of disc markers for the lumbar spine, improper hip rotation, and inconsistent determination of regions of interest of the hip. Precision testing is an important way of determining reproducibility of bone densitometry examinations in the clinical setting.

Precision testing is a necessary component of a bone densitometry service. Although it involves additional radiation exposure to a few patients, the amount of radiation is low and patient selection for participation in precision testing minimizes radiation risks. The benefit is enhanced diagnostic accuracy and the ability to monitor serial changes in a patient's BMD. A diagnosis of osteoporosis often commits a patient to years of pharmacological treatment. Errors in the performance or interpretation of BMD can result in prolonged unnecessary pharmacological treatment or, conversely, in lack of or delay in treatment, and the possibility of potentially preventable debilitating osteoporosis insufficiency fractures. Knowledge of the precision of BMD determinations is particularly important in interpreting serial BMD, since the rate of change in bone density is very slow, in the range of 0.5 to 2% per year. The least significant change (LSC) must be determined to meaningfully analyze serial measurements.

Precision can be expressed as the standard deviation (SD), or as the coefficient of variation (CV) or percent coefficient of variation (%CV). These parameters are used to assist clinical assessment by determining the smallest change in bone density that is biologically significant and the minimum time interval for follow-up bone density measurements. It is recommended that a precision assessment be performed for each operator or technician at a facility. The facility's precision error and LSC are the averages of all operators performing bone densitometry. An in-depth discussion of precision and precision testing for bone densitometry is presented in the reference by Bonnick and Johnson [5]. The following is a summary of the basics of precision testing.

### **PRECISION TESTING**

To obtain statistically valid results, multiple determinations of bone density are performed for a specific anatomical site, for example the hip or lumbar spine. The mean bone density is then determined. The number of bone density measurements that contribute independently to the mean is  $n - 1$ , where  $n$  is the number of bone density measurements. It is recommended that precision testing be performed to allow for 30 degrees of freedom, to insure statistical significance. Since

one of the measurements on a specific patient does not contribute independently to calculation of the mean BMD for that patient, one would perform 31 BMDs for 1 patient, 4 BMDs each for 10 patients, 3 BMDs each for 15 patients, or 2 BMDs each for 30 patients. Repeat BMDs on a patient should be performed within 2 to 4 weeks, and are easiest performed on the same day. The patient should be taken completely off the examination table after the initial BMD and repositioned on the table for each subsequent determination.

Although DXA conveys a relatively low radiation dose to the patient, the bone marrow is exposed and there is scattered radiation to the gonads. The following suggested guidelines were developed by the New Jersey Commission on Radiation Protection regarding the selection of patients for precision testing:

- Pregnant women, people under the age of 21 years, and radiation workers be excluded from precision testing.
- Care be taken to insure that women of childbearing age are not pregnant.
- Precision testing be performed on 30 patients, with two BMDs performed per patient, to give an appropriate level of statistical validity while limiting individual patient radiation exposure.
- Informed consent be obtained for precision testing, including an explanation of why the patient is being asked to undergo additional BMD determination, estimation of radiation dose, and rationale of the need for precision testing.
- No expense should accrue to the patient, since this is a facility quality assurance measure.

### Standard Deviation (SD) and Coefficient of Variation (CV)

To determine the standard deviation (SD) for BMD measurements on one patient, at least two BMD measurements are obtained of the same anatomic site. The mean bone density in grams per square centimeter ( $\text{g}/\text{cm}^2$ ) is determined. The difference between each BMD and the mean is calculated and squared. The squared numbers are then added, the total is divided by the number of measurements minus 1, and the square root is obtained. The standard deviation in  $\text{g}/\text{cm}^2$  for bone density measurements on a given patient, patient B, is:

$$SD_B = \sqrt{\frac{\sum_{i=1}^{n_B} (X_{iB} - \bar{X}_B)^2}{n_B - 1}}$$

In this equation,  $n_B$  is the number of measurements on patient B,  $X_{iB}$  is the numerical value of the  $i$ th bone density measurement of that patient, and  $\bar{X}_B$  is the patient's mean bone density.

The coefficient of variation is the proportion of the mean represented by the standard deviation, defined as:

$$CV = \frac{SD}{\bar{X}}$$

Alternatively, this can be expressed as a percentage:

$$\%CV = \frac{SD}{\bar{X}} (100)$$

As a measure of precision, facilities should determine SD and CV or %CV for each anatomic site they routinely evaluate for bone density. This should be reported as the root-mean-square SD ( $SD_{RMS}$ ) or root-mean-square CV ( $CV_{RMS}$ ):

$$SD_{RMS} = \sqrt{\frac{\sum_{i=1}^m (SD^2)}{m}}$$

$$CV_{RMS} = \sqrt{\frac{\sum_{i=1}^m (CV^2)}{m}}$$

In these equations,  $m$  is the number of patients. The standard deviation or coefficient of variation for each patient included in the precision study is squared, the values are summed, that number is divided by the number of patients, and the square root is then taken.

### Least Significant Change

$SD_{RMS}$  and  $CV_{RMS}$  can be used to determine the magnitude of change in bone density indicative of real biological change: the least significant change (LSC), which is reported in  $g/cm^2$ . The desired level of statistical confidence must be determined to derive the LSC and requires the application of statistical tables [5]. For bone densitometry 80% confidence is clinically adequate. Another factor in determining LSC is the number of bone density measurements on the patient at the specified site, at baseline BMD and at follow-up. LSC increases as the desired statistical level of confidence increases, and decreases with increasing number of BMD measurements.

For LSC at the 80% confidence level, on a patient with 1 baseline and 1 follow-up BMD:

$$LSC = 1.81 (Pr)$$

In this equation  $Pr$  is the precision value, either the  $SD_{RMS}$  or the  $CV_{RMS}$ . If the patient has had 2 baseline and 2 follow-up BMDs, the LSC at the 80% confidence level is:

$$LSC = 1.28 (Pr)$$



To determine the time interval for follow-up BMD, LSC is divided by the expected rate of change in bone density per year. The rate of change will depend on the patient's health, underlying disease processes, and pharmacological interventions.

### **Accuracy and Quality Control**

Experience with bone density measurements indicates that strict quality control including calibration and standardization procedures, is required to maintain both precision and accuracy for reliable measurements.

The importance of precision has been discussed above. Other quality control (QC) measures in densitometry primarily relate to the mechanical operation or accuracy of the unit. Norland and GE have internal systems and databases to which phantom scans are compared. Hologic uses a filtration system comprised of bone, tissue and air equivalents and an internal calibration reference to monitor calibration at each data point. Central DXA units electronically enter phantom or QC data into a Shewhart chart with a previously established baseline (the mean of ten initial control scans) and lines  $\pm 1.5\%$  from the mean [27]. Should the data points fall outside of the acceptable range, e.g., greater than  $\pm 1.5\%$  of mean for two consecutive QC tests, equipment service is required; patient data cannot be accepted into the computer until the unit is brought back into acceptable range. Another quality control measure employs a cumulative sum (CUSUM) chart that similarly tracks the operation of the unit. Sometimes both are used.

### **Databases**

All three manufacturers compare hip scans to the National Health and Nutrition Examination Survey III (NHANES III) of the US population. This database was created as a cooperative effort by Norland, GE and Hologic to establish a more uniform comparison for their equipment and patient populations.

Anatomic site-specific bone density databases have been developed by each manufacturer and may be classified by age, race, gender, height, and weight of the patient. This reference information is selected for comparison purposes prior to scanning the patient. The validity of the application of reference values to patients of different demographics, such as race, ethnic origin, and age, is a question of on-going clinical concern.

# **RADIATION DOSIMETRY CONSIDERATIONS IN BONE DENSITOMETRY**

## **ADULT DOSE**

As in any study involving ionizing radiation, dose is a consideration. In bone densitometry studies that utilize radiation, dose is contingent upon the method and mode of delivery and the significance of the exposure depends upon the body part irradiated. Today, the most common densitometry methods are Radiographic Absorptiometry (RA), Single-Energy X-ray Absorptiometry (SXA), Dual-Energy X-ray Absorptiometry (DXA), and Quantitative Computed Tomography (QCT).

Entrance surface doses (ESD) have been reported for peripheral scans using RA, pQCT, and SXA. They range from 16.6 $\mu$ Gy for SXA to 100 $\mu$ Gy for pQCT. With very few radiosensitive organs being irradiated during peripheral scanning (skin, red bone marrow, and bone surfaces) the effective dose will be very low (estimated at <0.1 $\mu$ Sv). Doses for SPA and DPA are dependent on the strength of the source and the beam characteristics, but entrance surface dose for DPA ranges from 50-150 $\mu$ Gy and for SPA of the radius is about 50 $\mu$ Gy [20].

There are many variables to consider when calculating effective dose to the patient, such as method of measuring or calculating entrance dose, method of determining effective dose including tissue weighting factors, field size, organs exposed, and scan speed; all of which make a direct comparison very complex. Because of the differences in the way dual energy x-rays are generated by the different manufacturers, the doses are different. The increase in photons in fan beam DXA devices, to improve image resolution, has resulted in higher dose to both patients and staff [23].

Peer reviewed publications report a variety of different doses due to the variation in equipment and methodology used to derive end results. The following is a table from Njeh et al [21] showing the different results of PA spine, proximal femur, and total body scans on several different DXA systems.

Table 1.

Reported Entrance Surface Dose ([ESD],  $\mu\text{Gy}$ ), Effective Dose ([ED],  $\mu\text{Sv}$ ), and Gonad dose ([GD],  $\mu\text{Gy}$ ) for Different Scan Modes and DXA Scanners

References	Manufacturer	PA Spine			Proximal Femur			Total Body		
		ESD	ED	GD	ESD	ED	GD	ESD	ED	GD
14	Hologic (QDR-1000)	60	0.5	0	60	0.1 (1.4)*	6.5	18	3.6 (4.6)*	5
14	Hologic (QDR-2000)	271	1.8	0	271	0.6 (5.9)*	26.5	11	2.7 (3.6)*	4.5
1	Lunar (DPX-L)	11.5	0.19	0	11.5	0.023 (0.14)*	1.2	NA	NA	NA
19	Lunar (DPX-L)	10.3	0.21	0	10.3	0.08 (0.15)*	0.66	NA	NA	NA
24	Hologic(QDR 4500) ([fast mode])	150	2.0	0	150	0.6 (5.4)*	48	NA	2.6 (3.4)*	4
26	Lunar (Expert-XL) ([fast mode])	NA	59	16	NA	40 (50)*	255	NA	75	77

\*The values in parentheses are dose calculations with the ovaries included. These values are also dependent on the scan time and milliamperes. The data for Ref. 14 (QDR 2000) are for 2-minute scans. QDR-4500 and Expert-XL, are fan beam densitometers. NA=not available. Lunar Corp., Madison, WI and Hologic, Waltham, MA.

Note: See Appendix B for a Units of Radiation Dose conversion table.

The effective doses reported in Table 1 could be compared to the effective doses experienced during an adult PA chest x-ray of about  $50\mu\text{Sv}$ , lateral views of the lumbar spine at  $700\mu\text{Sv}$  or a dental bitewing at  $100\mu\text{Sv}$  (ICRP 60 [12]).

Table 2. DXA Effective Dose to Patients:  $\mu\text{Sv}^*$

Scan Mode	QDR 1000/4000 Pencil Beam	QDR 4500/Delphi Fan Beam	DPX-L Pencil Beam	Prodigy Fan Beam
PA Spine (L1-L4)	0.5	2.0	0.21	0.7
Prox Femur (incl. ovaries)	1.4	5.4	0.15	0.7
Total Body (incl. ovaries)	4.6	3.4		0.6
Total Body (exc. ovaries)	3.6	2.6		0.5
Forearm	0.07	0.05		0.01

From Blake GM, Wahner HW, Fogelman I, "The Evaluation of Osteoporosis..." 1999[3]

\* Effective dose (formerly effective dose equivalent) is defined as the sum of the absorbed doses to each irradiated organ, weighted for the radiation type and radiosensitivity of the organ (calculated from ICRP 60). [12]

*Note: See Appendix B for a Units of Radiation Dose conversion table.*

The patient radiation dose from DXA varies between pencil beam and fan beam units.

Table 3. Effective Dose Ranges for DXA Pencil and Fan Beam in  $\mu\text{Sv}$

Scan Mode	DXA Pencil Beam	DXA Fan Beam
PA Spine L1 - L4	0.21-0.5	0.7-2.0
Prox Femur (incl. ovaries)	0.15-1.4	0.7-5.4
Total Body (incl. ovaries)	4.6	0.6-3.4
Total Body (excl. ovaries)	3.6	0.5-2.6
Forearm	0.07	0.01-0.05

Compiled from Blake GM, Wahner HW, Fogleman I, "The Evaluation of Osteoporosis...", 1999.

*Note: See Appendix B for a Units of Radiation Dose conversion table.*

A paper presented by Charles Wilson, Ph.D. at the AAPM's 2003 annual meeting indicated the following doses to patients:

Table 4. Non-Invasive Bone Measurement Technique in Vivo

Technique	Measurement Site	Precision (%)	Accuracy (%)	Effective Dose ( $\mu\text{Sv}$ )
RA	Phalanx Metacarpals	1-2	5-10	~5
SXA/DXA	Radius Calcaneus	1-2	~5	<1.0
DXA	Spine-PA	1-1.5	4-10	1.0*
	Spine-Lat	2-3	5-15	3.0
	Femur (Hip)	1.5	~6	1.0*
	Total Body	<1	3	1-3
QCT	Spine w/Lat scan "True Density"***	2-4	5-14	60
QUS 2000	Calcaneus SOS	3-1.2	Unknown	0
	Calcaneus BUA	1.5-4	Unknown	0

From Wilson, C.R., Essentials of Bone Densitometry for the Medical Physicist (2003) [28]

\*Compared to the effective dose to an individual in the U.S. from background radiation of approximately 3000  $\mu\text{Sv}/\text{year}$  or 8 $\mu\text{Sv}/\text{day}$  or 0.33 $\mu\text{Sv}/\text{hr}$ . DXA effective dose for spine and hip (2 $\mu\text{Sv}$ ) is about the same amount of radiation received from background in 6 hours.

\*\* True Density is  $\text{gm}/\text{cm}^3$  for the volumetric measurement with QCT. (The measurement for DXA is  $\text{gm}/\text{cm}^2$ .)

Note: See Appendix B for a Units of Radiation Dose conversion table.

## PEDIATRIC DOSE

Children may require densitometry to evaluate or monitor BMD in the course of chronic illness (e.g., inflammatory bowel disease with malabsorption and growth retardation; endocrine disorders) or pharmacologic treatment of disease (e.g., chemotherapy for cancer). BMD determination may result in treatment modification. When the BMD equipment permits, lower exposure to children can be achieved by using a lower technique, more tightly collimated field size, and faster scan times. However, faster scan times may reduce resolution. If no adjustments are available, the pediatric patient will experience effective doses about triple that of an adult due to the larger field size and higher dose to their internal organs because of less attenuation of x-rays by overlying tissue [2]. Systems require different software for pediatrics, for both scanning adjustments, and appropriate database comparison.

Table 5. Effective Dose for a Pediatric Scan Using a Lunar DPX-L

Scan	Mode	Pt. size	Age	Scan time	ESD( $\mu$ Gy)	ED ( $\mu$ Sv)
PA spine		6-16 cm	5	5 min	6.0	0.28
PA spine			10		6.0	0.20
Total Body	medium	15-25 kg	5	9 min	0.12	0.03
Total Body	Large	25-35 kg	10	12 min	0.1	0.02

From Njeh et al, 1997b[22]

*Note: See Appendix B for a Units of Radiation Dose conversion table.*

Several investigators (Ruiz et al., 1991; Chapple et al., 1993; Martin et al, 1994; Kyriou et al., 1996) have reported Entrance Skin Doses (ESD) from a PA chest that are in the range of 50-200 $\mu$ Gy for a five-year-old and 80-400 $\mu$ Gy for a ten-year-old. ESD for an abdominal x-ray ranged from 470-1200 $\mu$ Gy for a five-year-old and 770-1280 $\mu$ Gy for a ten-year-old. From these ESDs, Njeh et al [20,22] calculated effective doses (EDs) using Monte Carlo simulation. EDs were 5.2-37.8  $\mu$ Sv for a five-year-old PA chest and 7.9-43.2  $\mu$ Sv for a 10-year-old. Abdominal EDs were between 89.8-106 $\mu$ Sv for a five-year-old and 125-245 $\mu$ Sv for a 10-year-old. Comparing these doses to the effective dose of BMDs on five and ten-year-old children in Table 5, the BMD studies generate very low effective doses.

## **OPERATOR DOSE**

The Radiation Protection Branch of the Ministry of Health Service in British Columbia surveyed three BMD units in three different facilities for exposure to the bone densitometry operator [18]. At each facility two thermoluminescent dosimeters (TLDs) were affixed to each of the four walls at 120 cm from the floor and two additional monitors were placed at table height at the operator workstation, all for three months. Their findings are:

Table 6. Exposure to Operators from Three Different Units and Facilities.

	Facility 1 (Hologic QDR4500W)	Facility 2 (Norland EclipseXE)	Facility 3 (GE Prodigy Lunar)
X-ray field size	1.0 mm x 65 cm.	Pencil beam	19.2 mm x 3.3 mm
X-ray tube voltage	100/140 kVp	100 kVcp	76 kVcp
X-ray tube current	5 mA fixed	1 mA fixed	3 mA max. variable
Photon energies	100/140 kVp	46.8/80 keV	38/62 keV
Maximum exposure @ patient's head end normalized to 1 meter from center of beam	82.6 mR	13.8 mR	27.7 mR
Workload correction factor	1000/1476	1000/2008	1000/1300
Exposure per 1,000 scans	55.96 mR	6.87 mR	21.31 mR

Note: See Appendix B for a Units of Radiation Dose conversion table.

## QCT DOSE

QCT presents other difficulties in dose analysis. On earlier scanners, a significant problem was the non-uniformity of dose distribution within the patient due to the slices being contiguous or overlapping; helical scanners have essentially eliminated this issue. Other factors include scan parameters—kVp, mAs, slice thickness and number, or beam pitch on helical scanners, patient size, x-ray source detector geometry, and detector collimation. The dose delivered is highly scanner specific. There have been several different reports on entrance surface dose (with and without the routine lateral spine CT), computed tomography dose index (CTDI), mean depth dose, etc., but there is a lack of consistency in methodology. Huda and Morin have suggested another method of estimating effective dose using effective dose equivalents ( $H_E$ ), kVp, and filtration information [10]. Many computer programs compute effective dose for common radiological examinations, but not for BMD measurements. Lower doses can be achieved by using lower kVp (without a compensating increase in mAs) and/or lower mAs as shown by Kalender [13]. Kalender states that the increased noise generated by lower techniques is not objectionable for BMD studies. The high doses encountered during normal imaging CT are necessary in order to obtain the contrast and spatial resolution required to separate lesions from normal tissue. However, when measuring high Z material such as bone, high doses are generally not necessary. Caution should be applied to ensure that adequate quality is maintained with compromises in dose.

Effective doses have been reported for a tomogram scout and three slices between 200 and 370  $\mu$ Sv using 80 kVp (rather than 125 kVp) and depending on the mAs. Factors affecting dose are the CT unit, skin dose measurements,  $CTDI_w$ , patient size, and the volume scanned. In gen-

eral, QCT gives doses that are typically higher than plain radiographic examinations, and depending on settings, may be lower than regular CT imaging [20].

## **ROOM DESIGN CONSIDERATIONS FOR DXA**

The exposure to the operator depends upon the scan type and mode, the workload, and the relative position of the workstation to the scanning table. Operator dose can be reduced by the appropriate use of distance and shielding. Factors to consider are the greater scatter from fan beam units and having a room large enough to provide the distance necessary. Using shorter scan times (if unit permits) can reduce scatter, but with a trade-off in precision. Scanning the hip furthest from the operator will reduce some scatter, but that may not be an option.

The British Columbia study showed that the operator workstation is best positioned towards the patient's feet where the dose was lower than at the head or open side of the scanner. It was hypothesized that the lower scatter at the foot end was due to the elevated femurs during spine scans that attenuated the scatter from the body. At the foot end location, keeping a distance of not less than one meter away from the edge of the scanning table was adequate. If the workstation has to be placed at the head or open side of the scanner, a minimum distance of two meters away from the edge of the table should be maintained.

If the room configuration is not able to accommodate the necessary distance, the need for additional transparent lead-acrylic shielding for the operator should be based on the scatter exposure per scan at the operator console and the number of scans performed annually. A transparent shield is necessary as the operator must be able to view the patient during the exam. The operator dose evaluation must be made for an annual exposure with consideration given for scan volumes that fluctuate during the year. Because scatter doses are very low, dosimeters should be worn for at least three months to ensure a more accurate reading.

There are anecdotal stories of high exposures when an operator stands within several feet of the patient in some scans. No documentation of these findings by a qualified medical physicist in a controlled environment was available. One must take into consideration that scattered radiation can only be a small fraction of the direct beam exposure, which is small to begin with.

## **ROOM SHIELDING FOR DXA**

Per the British Columbia Ministry of Health Services' calculations, in operations of less than 7,500 exams per year (30 exams/day, 5 days/week, 50 weeks/yr) two pieces of 5/8" gypsum board is usually sufficient to protect people in adjacent areas from exceeding the dose limit. The International Commission on Radiological Protection (ICRP) recommends a dose limit of one mSv/year for members of the general public. (ICRP publication #60-1990 [12]).



## **PATIENT SHIELDING**

While the majority of BMD examinations are performed on elderly patients and post menopausal women, and radiation dose is low, there still may be questions regarding gonadal shielding for children, young adults, and women of childbearing age. However, because the x-ray beam is projecting posterior-anterior (PA) on most central units (GE Expert is the exception) any attempt at gonadal shielding has the potential to compromise the scan results. Additionally, the gonads are outside of the primary field used for the spine and proximal femur scans. With pencil-beam devices ovaries should not be exposed to either the primary beam or scattered radiation. However, Steel et al [26] demonstrated that with fan beam devices, the ovaries were exposed to scattered radiation during the PA spine scan. Scatter to the ovaries when performing hip DXA scans is dependent on the scan field size used. As with all radiographic procedures, women of child-bearing age should be interviewed as to the possibility of pregnancy prior to performance of the examination.

Despite the variables and methodologies involved with measuring DXA and QCT effective dose, the overall results show that BMD testing on adults and children is a low dose examination in comparison to other studies using ionizing radiation (e.g., plain radiographs).

## SUMMARY

Osteoporosis is a highly prevalent and disabling disease, characterized by low bone mass with resultant bone fragility and increased risk of fracture. Early diagnosis by bone densitometry (BMD) allows preemptive treatment, which can slow or halt bone deterioration, and can often increase bone density. A variety of bone densitometry procedures is available for osteoporosis screening, the most prevalent being Dual-Energy X-ray Absorptiometry (DXA), quantitative Computed Tomography (QCT), and Ultrasound Densitometry. For patients who require serial densitometry and follow-up of treatment, DXA and QCT are more quantitative and are preferred.

Any application of ionizing radiation, including BMD determinations, should be at the written order of a licensed physician or other licensed health care practitioner. The examination should be performed by a qualified individual, i.e., a licensed radiologic or nuclear medicine technologist or physician, or other appropriately credentialed individual as required by state regulations; and should be interpreted by a licensed physician trained in bone densitometry. The patient should be counseled about the effects of ionizing radiation in order to make an informed decision of whether to undergo the procedure. Individuals participating in research protocols should receive adequate information about the research project in order to make an informed decision about participation, and written informed consent should be obtained. Research protocols should be approved by Institutional Review Boards.

Operators of densitometry units require training to perform the examination accurately and reproducibly. The American Registry of Radiologic Technologists (ARRT) and the International Society for Clinical Densitometry (ISCD) provide additional certification in the performance of bone densitometry. The ISCD also offers educational programs on the performance, quality control, and interpretation of bone densitometry.

Facilities providing DXA and QCT should perform quality control and precision testing to ensure reproducibility and accuracy of results. Precision testing enables the facility to assess the smallest change in bone density that is biologically significant. Although it involves additional radiation exposure to a few patients, the amount of radiation is low and patient selection for participation in precision testing minimizes radiation risks. Errors in the performance or interpretation of BMD can result in prolonged, unnecessary pharmacological treatment or, conversely, in lack of or delay in treatment, and in potentially preventable, debilitating osteoporosis insufficiency fractures.

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Web sites:

American Registry of Radiologic Technologists (ARRT) [www.ARRT.org](http://www.ARRT.org) Offers certification in bone densitometry to ARRT registrants.

International Society of Clinical Densitometry (ISCD) [www.ISCD.org](http://www.ISCD.org) This site has notes and papers from their annual meetings and educational meetings, listings of educational courses, and certification examination dates and locations. They publish the *Journal of Clinical Densitometry*.

National Osteoporosis Foundation: [www.nof.org](http://www.nof.org) Indications for bone testing.

National Library of Medicine (PubMed) [www.pubmed.gov](http://www.pubmed.gov) Features abstracts on articles from medical journals. Full articles are available thru most library systems.

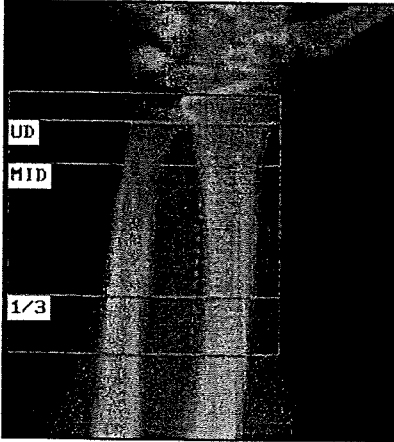
## **APPENDIX A.**

### **BMD REPORTS OF THE FOREARM, LUMBAR SPINE, AND HIP**

The following BMD reports of the forearm, lumbar spine, and hip show examples of what is included in a typical bone densitometry report. Bone mass is expressed in grams per square centimeter ( $\text{g}/\text{cm}^2$ ). The T-score is derived by comparing the patient's BMD to that of normal young adults aged 20-30 years of the same gender and, preferably, the same race or ethnic background. The Z-score is derived by comparing the patient's BMD to a reference population of the same age and gender. The World Health Organization defines normal bone density as a bone mass within 1 standard deviation (SD) of the mean for the young adult reference population. A BMD between -1 and -2.5 SDs below the young adult mean is considered osteopenia. Osteoporosis is a BMD of more than -2.5 SDs below the young adult mean. For each standard deviation below the normal range, fracture risk increases by two- to three-fold.

# RADIOLOGY PROFESSIONAL ASSOCIATION

k = 1.223 d0 = 63.1(1.000)[4]



Mar 15 09:22 2005 [175 x 92]  
Hologic QDR-4500 (S/N 48184)  
Left Forearm U8.26a:5

103150505 Tue Mar 15 09:21 2005  
Name: [REDACTED]  
Comment: BASELINE  
I.D.: [REDACTED]-4981 Sex: F  
S.S.#: - - Ethnic: C  
ZIP Code: Height: 5' 2"  
Operator: JI Weight: 135  
BirthDate: 08/01/49 Age: 55  
Physician: ROBINSON  
Forearm Length: 24.5 cm  
Image not for diagnostic use

TOTAL BMD CV IS LESS THAN 1.0%  
C.F. 1.041 1.018 1.000

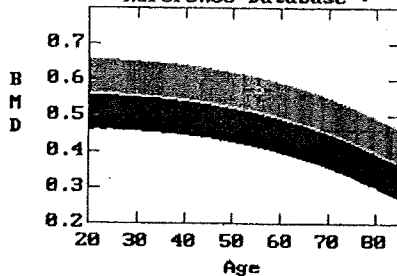
RADIUS + ULNA	Area (cm <sup>2</sup> )	BMC (grams)	BMD (gms/cm <sup>2</sup> )
UD	4.92	2.10	0.428
MID	11.94	6.87	0.575
1/3	5.37	3.68	0.686
TOTAL	22.23	12.65	0.569



# RADIOLOGY PROFESSIONAL ASSOCIATION

a L. Forearm

Reference Database \*



BMD(Radius+Ulna[LL] TOTAL) = 0.569 g/cm<sup>2</sup>

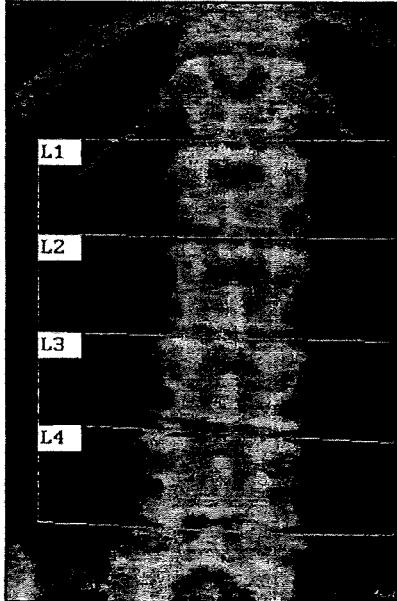
Region	BMD	T	Z
1/3	0.686	+0.03 100% (20.0)	+1.07 110%
MID	0.575	-0.24 98% (20.0)	+0.86 109%
UD	0.428	+0.31 104% (20.0)	+1.08 115%
TOTAL	0.569	+0.10 101% (20.0)	+1.14 111%

\* Age and sex matched  
T = peak BMD matched  
Z = age matched PS 10/25/91

103150505 Tue Mar 15 09:21 2005  
Name: [REDACTED]  
Comment: BASELINE  
I.D.: [REDACTED]-4981 Sex: F  
S.S.#: - - Ethnic: C  
ZIP Code: Height: 5' 2"  
Operator: JI Weight: 135  
BirthDate: 08/01/49 Age: 55  
Physician: ROBINSON



k = 1.135 d0 = 45.9(0.994H) 6.543 RADIOLOGY PROFESSIONAL ASSOCIATION



Mar 15 09:10 2005 [116 x 134]  
Hologic QDR-4500 (S/N 48184)  
Lumbar Spine V0.26f:5

I03150503 Tue Mar 15 09:08 2005  
Name: [REDACTED]  
Comment: BASELINE  
I.D.: [REDACTED]-4981 Sex: F  
S.S.#: - - Ethnic: C  
ZIP Code: Height: 5' 2"  
Operator: JI Weight: 135  
BirthDate: 08/01/49 Age: 55  
Physician: ROBINSON  
Image not for diagnostic use

TOTAL BMD CV FOR L1 - L4 1.0%

C.F. 1.041 1.018 1.000

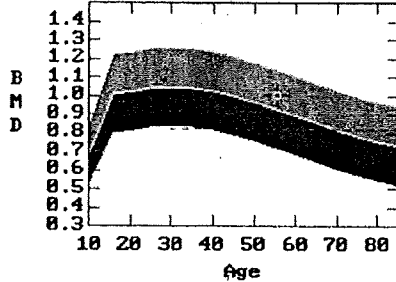
Region	Est.Area (cm <sup>2</sup> )	Est.BMC (grams)	BMD (gms/cm <sup>2</sup> )
L1	13.94	12.58	0.903
L2	15.36	14.80	0.963
L3	15.91	16.33	1.027
L4	16.81	18.17	1.081
TOTAL	62.02	61.88	0.998



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f Lumbar Spine

Reference Database \*



BMD(L1-L4) = 0.998 g/cm<sup>2</sup>

Region	BMD	T(30.0)	Z
L1	0.903	-0.20 98%	+0.76 110%
L2	0.963	-0.59 94%	+0.49 106%
L3	1.027	-0.52 95%	+0.61 107%
L4	1.081	-0.32 97%	+0.85 109%
L1-L4	0.998	-0.45 95%	+0.66 108%

\* Age and sex matched

T = peak BMD matched

Z = age matched

TK 11/04/91

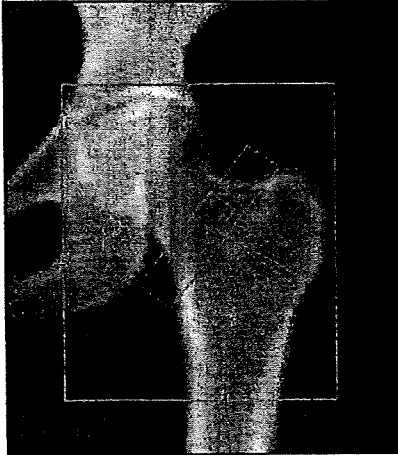
I03150503 Tue Mar 15 09:08 2005  
Name: [REDACTED]  
Comment: BASELINE  
I.D.: [REDACTED]-4981 Sex: F  
S.S.#: - - Ethnic: C  
ZIP Code: Height: 5' 2"  
Operator: JI Weight: 135  
BirthDate: 08/01/49 Age: 55  
Physician: ROBINSON





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k = 1.135 d0 = 48.4(1.001H) 6.111



Mar 15 09:17 2005 [88 x 106]  
Hologic QDR-4500 (S/N 48184)  
Left Hip V8.26f:5

I03150504 Tue Mar 15 09:15 2005

Name: ██████████  
Comment: BASELINE  
I.D.: █████-4981 Sex: F  
S.S.#: - - Ethnic: C  
ZIP Code: Height: 5' 2"  
Operator: JI Weight: 135  
BirthDate: 08/01/49 Age: 55  
Physician: ROBINSON  
Image not for diagnostic use

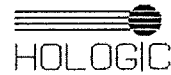
TOTAL BMD CV 1.0%

C.F. 1.041 1.018 1.008

Region	Est.Area (cm <sup>2</sup> )	Est.BMC (grams)	BMD (gms/cm <sup>2</sup> )
Neck	5.26	3.98	0.757
Troch	8.71	5.91	0.679
Inter	15.60	15.72	1.008
TOTAL	29.57	25.61	0.866
Ward's	1.13	0.64	0.567

Midline ( 96,114)-(154, 70)

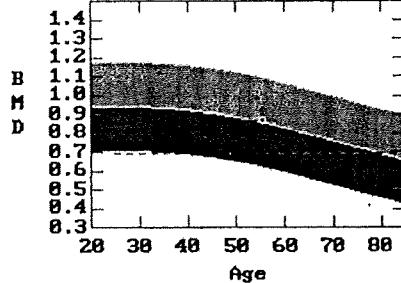
Neck -59 x 13 at [ 29, 71  
Troch 5 x 36 at [ 0, 81  
Ward's -11 x 11 at [ 10, 81



RADIOLOGY PROFESSIONAL ASSOCIATION

f Left Hip

Reference Database \*



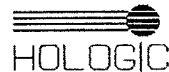
BMD(Total[LL]) = 0.866 g/cm<sup>2</sup>

Region	BMD	T	Z
Neck	0.757	-0.83 89% (25.0)	+0.25 104%
Troch	0.679	-0.24 97% (25.0)	+0.46 187%
Inter	1.008	-0.60 92% (35.0)	-0.13 98%
TOTAL	0.866	-0.62 92% (25.0)	+0.88 181%
Ward's	0.567	-1.43 77% (25.0)	+0.31 187%

\* Age and sex matched  
T = peak BMD matched  
Z = age matched NHA 02/01/97

I03150504 Tue Mar 15 09:15 2005

Name: ██████████  
Comment: BASELINE  
I.D.: █████-4981 Sex: F  
S.S.#: - - Ethnic: C  
ZIP Code: Height: 5' 2"  
Operator: JI Weight: 135  
BirthDate: 08/01/49 Age: 55  
Physician: ROBINSON



## APPENDIX B.

### CONVERSION TABLE

Units of Radiation Dose			
Quantity	SI/unit and symbol	Non-SI unit	Conversion factor
Entrance Skin Exposure (ESE) (in air)	N/A	Roentgen, R	N/A
Entrance Surface Dose (ESD) (converted to dose Gy)	Gray, Gy	N/A	1 R = 0.01Gy 0.01 mGy = 1 mR
Absorbed dose	Gray, Gy	rad	1 rad = 0.01 Gy 1 Gy = 100 rads
Effective dose (E or ED)	Sievert, Sv	rem	1 rem = 0.01 Sv 1 rem = 10 mSv 1 Sv = 100 rem

|  
milli (m) =  $10^{-3}$  or 0.001;    micro ( $\mu$ ) =  $10^{-6}$  or 0.000,001

## APPENDIX C.

### LIST OF ACRONYMS USED IN THIS DOCUMENT

ARRT	American Registry of Radiologic Technologists
BMD	Bone Mineral X-ray Absorptiometry
BUA	Broadband Ultrasound Attenuation
CT	Computed Tomography
CTDI	Computed Tomography Dose Index
CTDI <sub>w</sub>	Computed Tomography Dose Index, Weighted
CUSUM	Cumulative Sum
CV	Coefficient of Variation
%CV	Percent Coefficient of Variation
CV <sub>RMS</sub>	Root-Mean-Square CV
DPA	Dual Photon Absorptiometry
DXA	Dual-Energy X-ray Absorptiometry
ED	Effective Dose
ESD	Entrance Surface Dose
GD	Gonad Dose
H <sub>E</sub>	Effective Dose Equivalent
ISCD	International Society for Clinical Densitometry
IVA	Instant Vertebral Assessment
KeV	Kiloelectron Volt
kVp	Kilovoltage, Peak
LSC	Least Significant Change
LVA	Lateral Vertebral Assessment
MXA	Morphometric X-ray Absorptiometry
PA	Posterior-Anterior
pDXA	Peripheral X-ray Densitometry
pQCT	Peripheral Quantitative Computed Tomography
QC	Quality Control
QCT	Quantitative Computed Tomography
QUS	Quantitative Ultrasound
RA	Radiographic Absorptiometry
SD	Standard Deviation
SD <sub>RMS</sub>	Root-Mean-Square SD
SOS	Speed of Sound
SPA	Single Photon Absorptiometry
SXA	Single-Energy X-ray Absorptiometry
T-score	Comparison of the patient's BMD to that of normal young adults aged 20-30
TLD	Thermoluminescent Dosimeter
VFA	Vertebral Fracture Assessment
Z-score	Comparison of the patient's BMD to the average value expected for the patient's age

On the front page of this White Paper, the members of the committee that developed this document are listed, along with their CRCPD membership category, and their state. CRCPD's primary membership is made up of radiation professionals in state and local government who regulate the use of radiation sources. But anyone with an interest in radiation protection is eligible to join. An explanation of the membership categories of the committee members follows: Director Members are the directors of the radiation control program in each of the states, District of Columbia, Puerto Rico, and certain metropolitan areas. Associate Members are staff of the radiation control programs. Emeritus Members are former members recognized for outstanding service in the field of radiation protection. And Affiliate Members are members that are not employed by a State radiation control program.

The **Conference of Radiation Control Program Directors, Inc. (CRCPD)** is a 501(c)(3) non-profit non-governmental professional organization dedicated to radiation protection. CRCPD was formed in 1968.

- We promote radiological health in all aspects and phases;
- We encourage and promote cooperative enforcement programs with federal agencies and between related enforcement agencies within each state;
- We encourage the interchange of experience among radiation control programs;
- We collect and make accessible to the membership of the CRCPD such information and data as might be of assistance to them in the proper fulfillment of their duties;
- We promote and foster uniformity of radiation control laws and regulations;
- We encourage and support programs that will contribute to radiation control for all;
- We assist the membership in their technical work and development; and
- We exercise leadership with radiation control professionals and consumers in radiation control development and action.

**CRCPD's mission** is "to promote consistency in addressing and resolving radiation protection issues, to encourage high standards of quality in radiation protection programs, and to provide leadership in radiation safety and education."

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