

Essentials of Bone Densitometry for the Medical Physicist

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Human Skeleton: The human skeleton consists of over 200 bones of different sizes and shapes that play a variety of roles in maintaining our health and well-being. Bones provide the basic structural framework for our muscles and allow us to stand upright and move about. Bones also encase and protect sensitive organs of the body such as the brain, heart, spinal cord and eyes from injury from external forces. Teeth are hard specialized bones which provide us nourishment by grinding and tearing our food. The tiniest bones of the body are those that reside in the inner ear which provide a transmission path for sound vibration to reach the brain and enables us to hear. Bones also play a hidden but equally important role in the biochemistry of our bodies serving as a reservoir for calcium which is essential for the proper nerve conduction and muscle action. Because of calcium's importance, its level in the blood is closely monitored and regulated; if it falls too low, calcium is released from the bone to maintain the proper level in the blood and excreted if the calcium level is too high. Maintaining the proper level is termed homeostasis and involves complex regulatory mechanism beyond the scope of this discussion.

Bone Tissue: Bone is a living tissue which can change to meet its many roles. Specialized cells, called osteocytes, interspersed throughout the bone, continuously remove and replace bone. Osteoclasts are osteocytes which destroy or resorb bone to release calcium while osteoblasts build or replace bone tissue. Osteoclasts remove about 0.5 grams of calcium daily (the skeleton has about 1000 grams of calcium) while osteoblasts build new bone at about the same rate. This normal process of bone remodeling renews our skeleton approximately every 7 years. When we are young and actively growing, osteoblasts build more bone than osteoclasts resorb and the skeleton grows and builds bone until into the 20's. Unfortunately after about age 35, more bone is removed than replaced resulting in a gradual decrease in bone mass with age. This loss of bone occurs throughout the skeleton and often results in a condition called osteoporosis, which quite literally means, porous bone. Bones of the skeleton become more porous, thinner and lighter. Osteoporosis, especially in women, weakens the skeleton increasing the incidence of fractures of the hip, spine, wrist and other bones from little or minimal trauma.

Composition of Bone Tissue Bone consists of approximately equal volumes of bone mineral crystals, collagen and water. The bone mineral crystals are rod shaped with a diameter of 2 - 7 nm and length 5 - 10 nm ($1 \text{ nm} = 10^{-9} \text{ m}$) and are composed of calcium hydroxyapatite, $\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_6$. Trace amounts of potassium, manganese, chlorine and other elements are present in the bone crystals, but it is the calcium which absorbs x-rays so much better than the

surrounding tissue which is the reason x-rays show bone so well. While the hydroxyapatite crystals make up only one-third of the volume of the bone, they account for more than one-half of its total weight. The organic matrix is composed of many fine collagen fibers bundled together and oriented predominately in a direction parallel to the load-bearing axis of the bones with the minute crystals intimately bonded to the fibers.

Mechanical Properties of Bone: Bones' mechanical properties are considerably different from either of its two primary materials-collagen and bone mineral crystals-and is considered to be a two-phase material. Removing either phase results in a drastic change in mechanical properties. By dissolving the mineral phase from a bone, a collagen replica of the bone is produced, which is flexible, somewhat elastic and which can be easily bent. While it is strong in tension (i.e., to being stretched), it offers practically no resistance to compression. On the other hand, removing the collagen by incinerating the bone at a high temperature results in a brittle fragile chalk-like replica, which has practically no strength in either tension or compression. The precise nature of the interaction between these dissimilar materials which produce the remarkable physical properties of bone is unknown. Nevertheless, the combination of a soft flexible collagen phase and the minute hard bone mineral crystals produce a material which is as stronger than granite in compression and equal to oak in tension.

Age Related Changes in Bone: Bone is a living tissue and is constantly remodeled throughout life. After growth stops and peak bone mass is reached in young adulthood, the rate of bone resorption becomes slightly greater than the rate of bone formation and bone is progressively lost from the skeleton. Typically, this imbalance results in a loss of about 0.5-1% per year and occurs in both sexes and all races. Nearly all bones of the skeleton are affected to some degree or another with the patterns of loss varying from bone to bone. The total anatomic bone volume, i.e., its size, remains relatively unchanged with advancing age with the loss in bone mass occurring within the bone. Compact bone in the shaft of the long bones becomes thinner and more porous, and cancellous bone is lost throughout the body. Women, on average, have lower bone mass than men at all ages, and this disparity grows with increasing age. The rate of bone loss is greater in women than men with women experiencing accelerated bone loss in the decade following menopause. Later in life bone loss in women continues but at a slower rate than seen in the immediate post menopausal years. Throughout their lifetime women lose nearly 40% of their bone, while men lose about 25%. The rate of loss varies from between individuals because of the factors such as body weight, level of physical activity, amount of calcium and vitamin D in the diet, cigarette smoking, alcohol consumption, disease or long-term use of certain medications.

The major determinant of bone strength is its mass or the amount of bone that is present. Intuitively, this relationship makes sense and biomechanical tests have shown that nearly 80% of the strength of bone is accounted for by bone mass. As a result of the normal age-related loss of bone, the incidence of fragility fractures (fractures caused by minimal or no trauma) increases with age and low bone mass is the main characteristic of these types of fractures.

Osteoporosis: Osteoporosis is defined as a systemic disorder of the skeleton which is characterized by low bone mass and micro-architectural deterioration of bone tissue with a consequent increase in bone fragility and susceptibility to fracture. Osteoporosis is a major national health problem which affects an estimated 25 million men and women. Since women have lower bone mass than men at all ages, they are more susceptible and four out of five individuals with osteoporosis are women. The most common osteoporotic fractures are those of the vertebrae, hip and wrist and their incidences increases with age.

Vertebral fractures increase after menopause while the number of hip fractures incident is delayed until age 65 when they then appear to increase exponentially. Colles' fractures of the wrist also increase with age but appear to level off at about 60 to 65 years of age. This plateau may be due to decreased mobility and physical impairment. While age is a factor in the increasing number of fractures with age, the diminution of bone is a stronger factor and there is a higher incidence of fractures with decreasing bone mineral density (BMD). BMD stands for a special quantity, bone mineral density, defined as the amount of bone mineral mass (grams) present in a region of the skeleton divided by the projected area of that region.

Osteoporotic fractures cause significant morbidity and mortality for the individual and poses a significant economic cost to society. Vertebral fractures cause loss of height, pain and deformity. Wedge fractures commonly seen in the upper spine result in a condition called "Dowager's Hump", or technically, kyphosis. The upper spine curves outward and the lower spine curves inward into an S shape causing a hump in the upper back causing problems with breathing, walking and mobility. These vertebral fractures may be painful and although they heal, the deformity caused cannot be reversed. Fractured vertebrae occur in nearly one-third of all American women over age 50 and may exceed 75% in older women.

Hip fractures pose an even more significant risk of death and disability compared to vertebral fractures. Of the 300,000 hip fractures which occur every year in the United States, more than 30,000 will die within the first year after the fracture. Most who suffer a hip fracture never fully recover and many never walk again unassisted. Nearly half will require nursing home care after the fracture and never return to their own home. The economic costs of hospitalization, rehabilitation and long-term care of individuals who have suffered a hip fracture are more than \$10 billion annually. As the average age of the American population increases, it is anticipated that a significant increase in individual sufferings and economic costs will occur unless individuals at high risk of fracture can be identified and treated.

Quantitative Measurement Techniques: Since bone strength is proportional to bone mass, measurement of bone mass or, what is commonly called, bone density, provides the means to diagnosis osteoporosis and to estimate an individual's future fracture risk. Quantitative measurements of the bone density of the lumbar spine, hip, forearm and heel have proven to be as effective at predicting fracture risk as high blood pressure or high cholesterol levels in the blood are at predicting the risk of stroke or heart disease. Table 1 is a partial list of clinical noninvasive techniques for the measurement of bone density in vivo. Precision and accuracy are used to characterize the performance of quantitative bone measurement techniques. The meaning and importance of these terms will be considered when discussing the individual techniques.

Table 1 Non-Invasive Bone Measurement Technique In Vivo

Technique	Measurement Site	Precision (%)	Accuracy (%)	Effective Dose (microSievert)
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
	-Lat	2-3	5-15	3.0
	Femur	1-5	~6	1.0
	Total Body	<1	3	1-3
QCT	Spine “True Density”	2-4	5-14	60
QUS (2000)	Calcaneus SOS	3-1.2	Unknown	0
	Calcaneus BUA	1.5-4	Unknown	0

Conventional Radiographs: While ordinary radiographs are excellent at showing a fracture, the subjective evaluation of a radiograph is not quantitative and cannot reliably measure the amount of bone present at a skeletal location. More than 30% of the bone mass must be lost before the loss it can be recognized radiographically.

Radiogrametry: Radiogrametry or radiographic morphometry is an attempt to utilize radiographic images to measure bone loss by quantifying the dimensions of anatomical features of bone, such as the thicknesses of the bone in the midshaft regions of the phalanx or metacarpal. Cortical thickness data are useful for comparative group studies of skeletal size of men and women of different races, different treatments and of age-related changes. Since radiogrametry’s precision is limited, i.e., 3-5%, and the change in an individual’s cortical thickness is usually small, radiogrametry is unable to reliably detect early bone loss or to monitor bone change in an individual.

Quantitative Ultrasonometry(QUS): Clinical ultrasound units for quantitative assessment of skeletal status have been available since the early 1990's. There are currently a wide variety of different machines on the market with FDA approval for clinical use.

Ultrasound has been used in the field of nondestructive testing extensively, and because of its noninvasive nature, ultrasonometry is attractive and at the ultrasound property provide information regarding the mechanical properties of bone. As can be seen from the list, the calcaneus is the most popular measurement site. This is because heel is 90% trabecular bone and

has a much higher metabolic turnover rate than cortical bone. Thus, the heel manifests bone metabolic change before cortical bone. It is also easily accessible. The size of the heel bone are fairly flat and parallel, thus reducing repositioning problems. The fingers and the tibia are also used for the measurement of the speed of sound.

Generally, QUS units show a greater diversity in basic technologies than is seen with bone densitometers. QUS measure broadband ultrasound attenuation (BUA), the speed of sound (SOS) in bone and other derived parameters such as Stiffness, and Soundness. Measurement sites include the heel, phalanges and tibia. Most units still couple the ultrasound probe to the bone using a gel or water bath. Because of the differences among the different units plus the lack of an absolute standard for the ultrasound measured, the relationships between different QUS instruments are uncertain.

QUS has been shown to discriminate individuals with fracture from age match normal with about as much power as conventional absorptiometric techniques. The ultrasound parameters were found to be significantly lower in the fracture group. In addition, a number in the prospective studies have found that QUS can be used to predict the risk of osteoporotic fractures in elderly women.

In cross-sectional studies, QUS parameters have shown significant decreases during the period immediately following menopause. Significant changes are also seen in the very elderly subjects where DXA parameters generally show less traumatic changes. Although measurement precision is generally poorer than DXA techniques, QUS parameters parallel the changes in the modulus of elasticity and bone strength. QUS techniques are fairly well correlated to DXA measurements of the peripheral bones, and the Hologic Sahara expresses the measured quantity in terms of g/cm^2 . QUS parameters are however only moderately correlated to the BMD of the central skeleton.

The roles of QUS in the clinic are currently for the diagnosis of osteoporosis and prediction of fracture risk. Monitoring skeletal changes, because of low measurement precision not recommended.

.Radiographic Absorptiometry: In radiographic absorptiometry, RA, previously called photodensitometry, a radiograph of the hand and an aluminum step wedge is taken using a conventional x-ray unit. The optical densities of the radiographic images of the bone and aluminum wedge are measured using a device called an optical densitometer. (Optical density is defined as the \log_{10} of the ratio of light intensity incident on the radiographic film to the intensity of the light transmitted through the film.) Bone mass is determined as equivalent to the mass of aluminum at which the optical densities of the bone and the aluminum wedge in the film are equal. Technical difficulties with x-ray beam hardening and scatter radiation prevent accurate measurement of the bones of the spine or femoral neck and limits RA to measurement of the extremities. The precision of such measurements is 2-4%. While RA is relatively inexpensive and is potentially a simple test for osteoporosis, few clinical studies have yet proven its diagnostic effectiveness.

Dual Energy Absorptiometry, (DXA/DPA): It is desirable to be able to measure these locations because these are regions where osteoporotic fractures often occur. Dual energy absorptiometry is a technique which enables the direct determination of bone mass at these

skeletal location by simple mathematical manipulations of the transmissions of two different energy beams through the body. Dual (energy) photon absorptiometry, DPA was developed in the early 1970's with again much of the pioneering work done at the University of Wisconsin. Early DPA units used a radioactive material, gadolinium-153, as the source of two distinct energy photon beams at about 44 keV and 100 keV. As with SPA, an x-ray tube has replaced the radioactive source and now all commercial dual energy absorptiometers use an x-ray tube as the source of two beams rather than gadolinium-153. These units are referred to as dual (energy) x-ray absorptiometers or DXA. Two different energy x-ray beams are produced by either switching the voltage applied to the x-ray tube between a high and low voltage, or by selectively filtering an x-ray beam with materials called k-edge filters. K-edge filters were typically made of cerium, samarium or gadolinium. Because x-ray attenuation is much greater at energies just below the K edge than above the K edge, the filter separates the x-ray spectrum into the high and low energy beams. The transmissions of the low and high energy x-ray beams through the body are measured as a function of position. The transmissions can be used to compute an estimate of the mass of bone at each location in the scan.

For a typical DXA scan the patient lies supine with the lower legs elevated and supported on a cushion to flatten the spine against the table. The x-ray tube located beneath the patient is coupled to the detector located above the patient. In first generation DXA units, the x-ray beam is collimated into a pencil-beam several mm in diameter. This beam is scanned in a *boustrophedonic* pattern- *boustrophedonic* derives from the Greek term for the pattern followed by an oxen plowing a field- across the patient. The time to complete a scan of the spine or proximal femur was about 10 minutes for this first generation units. First generation DXA units are typically able to resolve objects on the order of 1.5 - 3 mm in size. Second generation DXA units utilize a fan x-ray beam which is detected by a linear array of individual detectors. Transmission data are simultaneously acquired in a line, consequently, second generation DXA units are faster than first generation units with better spatial resolution than pencil-beam units.

Quantitative Computed Tomography (QCT):Quantitative computed tomography (QCT) was first used in the early 1980' for measurement of the density of the lumbar spine. Computed tomography is an imaging technique which produces a cross-sectional image from the transmissions of a narrow fan beam of x-ray measured at multiple views through the patient. QCT, when appropriately calibrated, gives the volumetric density of the bone in g/cc. Because of its three-dimensional nature, QCT can measure either the more metabolically active trabecular bone or compact bone at nearly any skeletal sites. QCT commonly is used to measure the trabecular bone of the central region of the lumbar vertebrae. A conventional CT scanner is usually used but dedicated CT units for measurement of the forearm are available.

In a QCT scan, a calibration phantom is placed beneath the patient and simultaneously scanned with the patient. The phantom is a crescent-shaped Lucite container filled with water in which are mounted a number of Lucite tubes containing aqueous solutions of different concentrations of dipotassium hydrogen phosphate. Dipotassium hydrogen phosphate solutions are bone equivalent (bone equivalent means that the material is nearly equivalent to x-ray attenuation properties of bone) so different concentrations represent different bone densities. Because of leakage problems with fluid-filled phantoms, solid calibration phantoms with calcium hydroxyapatite mixed with epoxy are now most commonly used.

A QCT scan of a patient through the abdomen with the calibration phantom in place is obtained. The mean CT number of each tube is determined and a regression equation is determined which relates the mean CT number of each tube to the solution concentration in the tubes. Bone density of the vertebral body is then found by using the regression equation to convert the mean CT number of the central region of the vertebrae into equivalent bone density expressed in mg/cc. Typically, the second, third and fourth lumbar vertebrae are measured. QCT is most often performed using a single x-ray beam energy with a lower x-ray tube current than ordinarily used for an imaging study to minimize a patient dose.

Precision of QCT in vivo is 2 to 4% with accuracy errors of 5 to 15% commonly found. QCT precision depends upon a number of factors such as scanner stability, beam hardening, patient size, patient position within the scan field, etc. However, because of the inhomogeneous distribution of bone in the central region of the vertebral body, the major determinant of precision is selection of the region of interest in the vertebral body to be analyzed. QCT manufacturers have reduced this source of error by developing software which locates the vertebral body, its outside edges and uses specific anatomical features of the vertebrae to automatically and consistently select the region of interest.

With single energy QCT the accuracy is dependent on the fat content of the marrow spaces in the vertebral body. As the fat content increases, the apparent bone density decreases and vice versa. Dual energy QCT, in which QCT scans are performed at two different x-ray beam energies, improves accuracy, but precision is significantly poorer than single energy QCT. Dual energy QCT, consequently, is used only in limited research applications.

BONE MINERAL REPORT. The BMD report contain patient demographic data, an image of the area scanned, the locations of the regions of interest superimposed on the image, the BMD, and the BMC and/or the projected area of the bone scanned. Standardized scores, i.e., the T-score, Z-score, the percent of young normal and/or the percent of age matched normal for each measurement site are also given. A graph showing the patient's BMD compared to the manufacturer's reference normal data base or to the patient's previous scans values can also be displayed.

A patient's BMD is compared to the mean BMD of young normals of the same sex and to the mean BMD of their peers, i.e., both age and sex-matched. These comparisons are normalized using the population's standard deviation. The T-Score is defined as,

$$T - Score \equiv \frac{BMD(\text{patient}) - BMD(\text{young adult})}{Standard Deviation}$$

The Z-Score is defined as,

$$Z - Score \equiv \frac{BMD(\text{patient}) - BMD(\text{peers})}{Standard Deviation}$$

To illustrate the calculation of the

T- and Z-scores, consider a 56-year old Caucasian woman whose BMD of the femoral neck is 0.735 g/cm^2 . The mean BMD for young women, 20-29 year old, is 0.97 g/cm^2 with a standard deviation of 0.10 g/cm^2 . The T-score is simply **-2.34**. A T-score this low indicates that her bone density is significantly below young normal value and the patient is at increased risk of fracture.

RELATIVE RISK OF FRACTURE AND BMD: Since bone strength and bone density are highly related, one would expect that individuals with low bone mass would also have an increased risk of fragility fracture. This has proven to be the case in numerous studies which demonstrate that the age adjusted relative risk of fracture increases rapidly with each decrease of one standard deviation in BMD. Table 3 contains the relative risks for hip fracture, new vertebral fractures and all non-vertebral fractures for BMD measured at the proximal femur, lumbar spine, distal radius and calcaneus. All measurement sites provide statistically significant relative risks and all sites provide comparable relative risk estimates. It does seem that the BMD of the proximal femur is better at predicting fractures of the femoral neck than other measurement sites on the skeleton.

It can be seen that an individual's fracture risk approximately doubles for each standard deviation decrease in BMD regardless of measurement site. This means that a woman who's BMD is two standard deviations below normal is at four times the risk of fracture compared to a woman with normal BMD and if three standard deviation below the risk is increased by a factor of eight.

Relative Risk of Fracture per One Standard Deviation Decrease in Bone Mass

Measurement Site	Hip Fractures	Vertebral Fractures	All Fractures
Proximal Femur	2.4	2.3	1.6
Spine	-	2.2	1.6
Distal Radius	2.6	1.9	1.6

DIAGNOSIS OF OSTEOPOROSIS With the development of DXA units capable of highly precise and accurate measurements of BMD in vivo, the paradigm for diagnosing osteoporosis, has shifted from focusing on the occurrence of the fragility fracture to that of the risk of suffering a fragility fracture in the future. Rather than actually calculating a fracture risk, the individual's T-score is used to classify the individual as normal, osteopenic (a fancy word that means little bone) or osteoporotic. The World Health Organization has suggested that "**normal**" bone mass is defined when the T-score is no lower than -1.0, "**osteopenia**" is a T-score between -1.0 and -2.5 and "**osteoporosis**" is a T-score lower than -2.5. An additional classification for individuals with a T-score below -2.5 and one or more fragility fractures is called "**severely osteoporotic**". This classification scheme is intended to reflect the patient's risk of suffering a future fracture and is based on epidemiologic fracture data and BMD in adult Caucasian women. It is not yet known if these classifications can be applied to other ethnic groups, men, or patients with bone loss induced by long term use of drugs.

Precision: Precision is a measure of the ability of a measurement technique to obtain the same results in repeated measurements of the same subject. The precision of a technique is important because the precision determines the minimum change that can be statistically recognized as real and not simply due to measurement errors. The standard deviation of a series of measurements or the coefficient of variation, CV, (the standard deviation divided by the mean and expressed as a percentage) are commonly used to characterize the precision of a technique. If a technique with a precision of 1% is used to measure the bone mineral density of a patient, on two occasions, one year apart, the difference between the two readings must exceed 2.8% for a physician to be confident that a change has actually occurred. It can be shown from elementary statistics that the magnitude of the difference between two readings, taken at different times must be greater than 2.8 times the CV to be interpreted as an actual increase or decrease at the 95% confidence level. Thus, a system with a CV of 2% would not be capable of statistically recognizing a change of less than 5.6%. Since the rate of change of bone in both healthy and patients with bone disease is small, typically less than 1% per year, a quantitative technique intended to measure changes in bone is clearly more desirable than one with a poorer precision.

Accuracy: The accuracy of a technique is a measure of how well the measured quantity reflects the true or actual value of the quantity measured. Accuracy is also expressed in percent and is defined as the percent difference between the true and measured values compared to the true value of the quantity measured. The accuracy of a technique is an important technique characteristic when comparing measurements of the same quantity using two different techniques. Consider, a specific patient who is scanned with two different bone densitometers, each of which have an accuracy of 5%, but in opposite directions. In this situation there will be a discrepancy between the densitometer's readings of 10%. It would be difficult to tell if a difference between readings obtained with different densitometers was a real change in the patient's bone or simply due to using different densitometers. Fortunately, most clinical situations do not involve interpretation of the bone density of the same individual measured using different densitometers, but more commonly is a comparison of two readings of the same individuals made at different times using the same densitometer. Precision is generally a more important characteristic of a technique than the technique's accuracy.

DXA AND QCT RADIATION DOSES AND RISKS: A routine DXA scan of the hip or spine delivers a small radiation dose to the patient. Dose to the skin, i.e., where the beam enters the patient, is less than 50 microGray for the typical first generation DXA unit. Although skin dose is easily measured, it does not reflect the actual radiation risk since only a small part of the body is exposed. Also, because of attenuation by overlying tissue the dose to sensitive organs beneath the skin is significantly lower than the dose to the skin. In order to estimate the impact of a partial body irradiation, the concept of effective dose, that is the dose to the whole body that carries the same risk as the partial body dose, has been developed by the International Commission on Radiation Protection, ICRP.

The effective dose from a particular partial body irradiation such as a DXA scan is found

by multiplying the radiation dose to the radiation sensitive organs included in the scan field and an organ weighting factor associated with the morbidity of a cancer caused by a high dose of radiation and relative length of life lost per unit dose to the sensitive organ. Using The ICRP methodology, the effective dose the typical densitometers for the lumbar spine and hip is ~ 1.0 μSv

For perspective on the magnitude of a 1 μSv effective dose, it is informative to compare it to the effective dose we all receive from background radiation. Background radiation dose comes from cosmic rays and naturally occurring radioactive materials in the earth. The average effective dose to an individual in the U.S. from background radiation is approximately 3000 μSv per year, or about 8 μSv per day. Thus a DXA scan of the hip and spine is similar to the amount of radiation we receive in about 6 hours.

The effective dose from a QCT bone density study can also be estimated using the ICRP methodology. A typical QCT bone density study involves the acquisition of a lateral CT localization image CT to select the location of the CT slices through the central regions of the vertebral bodies. Three to four CT slices are then performed through the lumbar vertebrae, typically L1, L2 L3 and L4. When the CT scanner is operated in the low or minimal dose mode, the effective dose about 60 μSv , with 30 μSv coming from localization scan and 30 μSv from the CT scans themselves.

The cancer risk from either DXA and QCT procedures is extremely small because of the low EDE's. For those who like a numerical estimate of the risk, the hypothetical risk can be calculated using risk factors from the National Academy of Sciences report on the Biological Effect of Ionizing Radiation, BEIR V. BEIR V estimates the risk of dying from a cancer caused by radiation is 0.04 per Sievert. An individual's hypothetical risk from a DXA or QCT scan is simply the BEIR V risk factor times the effective dose. Thus, for an effective dose of 1 μSv from DXA scans, or 60 μSv from a QCT scan, the risks respectively are 4×10^{-8} and 2.4×10^{-6} . These risk estimates means that if group of 1 million individuals received a DXA scan and another group of 1 million individuals received a QCT scan the expected number of excess cancer deaths in the DXA group would be 0.04 while in the QCT group one expects 2.4 excess cancer deaths. To put these numbers into perspective consider that the natural risk of dying from cancer is approximately 1 in 5. Thus, in the absence of either the DXA or QCT one expects approximately 200,000 cancer deaths to occur.

Both DXA and QCT are low radiation dose procedures and are acceptable for routine monitoring of patients to follow the progression of bone disease or to monitor the effectiveness of therapy. The total population risk of radiation induced damage from these procedures is small, and is outweighed by the benefits of the bone densitometry measurements for the diagnosis of osteoporosis, estimate of future fracture risk, or monitor disease of therapeutic induced changes in bone.