

# DUAL X-RAY ABSORPTIOMETRY (DXA): BASIC TECHNIQUES AND CLINICAL FACTS

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Osteoporosis is a chronic condition of multifactorial etiology involving systemic skeleton characterized by decreased bone mass and deterioration of bony microarchitecture. The result is fragile bones and an increased risk of fractures, even after subtle trauma. Osteoporosis is a significant health problem and approximately 10 million people in the United States have osteoporosis. An additional 33.6 million people have low bone density of the hip and are at risk for osteoporosis.<sup>1</sup> Each year in the UK an estimated 260 000 osteoporotic fractures occur among women aged 50 years and over, including over 70 000 cases of hip fracture.<sup>2</sup> Hip and vertebral fractures are associated with significant morbidity and an increased risk of death.<sup>3</sup> By the year 2020 it is projected that the UK population aged over 85 years will double from 1.2 million to 2.1 million, so the prevention of fragility fractures will assume increasing importance.<sup>4</sup> Ability for early detection of osteoporosis before fractures occur and use of effective therapy are the recent advancements. Estimation of bone mineral density (BMD) plays a pivotal role in this regard.

In 1987 estimation of BMD using dual energy X-ray absorptiometry (DXA) was introduced for routine clinical use and in 1994 World Health Organization declared DXA as the gold standard for BMD estimation in its technical report.<sup>5</sup>

## Basic Principles of DXA

When a three-dimensional absorber (such as human body) is scanned by X-ray, it produces two-dimensional flat image on the photographic film. The human body

does not act as a homogeneous absorber; a single energy X-ray beam cannot differentiate among the different components such as fat mass, lean mass and bone. For this, dual energy X-ray technique was utilized. Bone mineral density measurement using dual energy X-ray absorptiometry (DXA) has great clinical significance in the early detection and diagnosis of osteoporosis. X-ray absorption is the basic mechanism for discrimination between organs in a body under X-ray observation. Exactly how much X-ray is absorbed by different tissues is determined by Lambert's law and is given by

$$I = I_0 e^{-\mu x}$$

where  $I$  is the X-ray intensity emerging from tissue,  $I_0$  is the X-ray intensity incident on the tissue,  $x$  is the tissue thickness and  $\mu$  is the mass attenuation coefficient.

The DXA principle is based on the fact that mass attenuation coefficient ( $\mu_m$ ) for different tissues decreases at different rates with increase in X-ray energy. At low X-ray energy, mass attenuation coefficient of bone ( $\mu_b$ ) is very high compared to soft tissue ( $\mu_s$ ); and at high X-ray energy, ' $\mu_b$ ' is approximately equal to that of ' $\mu_s$ ' as shown in (Fig.1).<sup>6</sup>

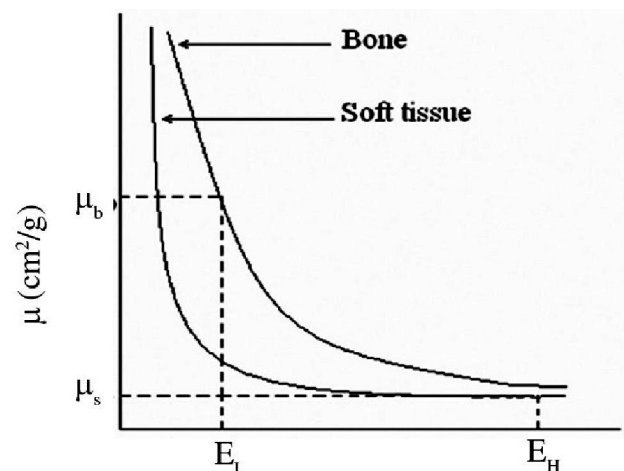


Figure 1: The mass attenuation coefficient versus X-ray photon energy

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## **Types of DXA Scanners**

Depending upon regions to be imaged, DXA scanners are of two types.

1. Central Scanners: Central scanner allows measurement of BMD of the hip and spine, which are considered to be the best sites for monitoring overall BMD, and for predicting fracture. Larger whole body scanners can also be used to measure body composition (fat mass, lean body mass, and bone mass).

Central scanners can be subdivided according to the shape of the scanning x-ray beam. These include Pencil Beam, Narrow Angle Fan Beam, Wide Angle Fan Beam, and Flash Beam scanners. Moving from pencil beam to flash beam; in general, the scan time decreases, but the patient dose and cost increases. Pencil Beam scanners use a fine pencil beam of x-rays combined with a single detector. This scans the patient in a raster fashion back and forth along the patient. Narrow angle fan beam scanners scan the patient in a similar raster fashion, except that the x-ray beam is about 4cm wide and is detected using an array of detectors. The patient is thus scanned in a series of ribbons, which greatly reduces scan time. Wide angle fan beam scanners use a much wider beam of x-rays and a longer array of detectors which scans the patient in a single pass (i.e. there is no need for raster scanning back and forth across the patient). The Digital Flash Beam scanner consists of a 2 dimension flash for a 1.5 second exposure. This flash eliminates the scanning process and is therefore the fastest type of scanner.

2. Peripheral Scanners: Peripheral scanners are small portable devices which measure BMD in the heel or forearm. These can be used for screening to estimate overall fracture risk, but they are less accurate than state of the art hip/spine scanners and cannot be used for monitoring therapy.

## **Estimation of Body Composition**

DEXA is the latest and most accurate mean of determining body composition. In addition to precise estimation of , it also estimates body fat percentage; lean body mass; fat mass; and the distribution of fat and lean tissue in the arms, trunk, and legs. DEXA

output even provides the differences in lean mass and fat mass between the left and right sides. This information can be particularly important for athletes who wish to develop symmetrical bodies or who, because of the nature of the sport, need to produce the same muscular power in each leg or in each arm.

## **Indications for DXA**

Bone density testing is indicated for the following individuals: women 65 years of age and older, postmenopausal women under age 65 years with risk factors, men 70 years of age and older, adults with fragility fracture, adults taking a medication or adults with a disease or condition associated with low bone mass or bone loss, any individual being treated for low bone mass to monitor treatment effect, and any individual in whom evidence of bone loss would affect treatment decisions.<sup>7</sup>

## **Patient Preparation**

Patient should wear comfortable clothing without metal parts like buttons, buckles or clasps (no jeans). Do not wear jewelry or any body piercings at the time of examination. In case of metallic implants over hips or spine, let the technologist know before commencing the procedure. If patient is pregnant or think may be pregnant test should be cancelled. DXA should be performed at least 14 days after any barium or other contrast x-rays or scans. There is no restriction to food or drink. Calcium or mineral supplements are advised to stop 24 hours before the test.

## **DXA Results**

Central dual-energy X-ray absorptiometry (DXA) is the gold standard for non-invasive measurement of bone mineral density (BMD). Using this value and subject demographics, DXA software calculates T-scores and Z-scores. Professional society guidelines for the management of osteoporosis are based on T-scores and Z-scores, rather than on the actual BMD value.

T-scores are calculated by taking the difference between a patient's measured BMD and the mean BMD in healthy young adults, matched for gender and ethnic group, and expressing the difference relative to the

young adult population standard deviation (SD):

$$\text{T-Score} = \frac{\text{Measured BMD} - \text{Young adult mean BMD}}{\text{Young Adult population SD}}$$

There has been a consensus that spine and hip BMD measurements in postmenopausal white women should be interpreted using the WHO T-score definitions of osteoporosis and osteopenia Table 1.<sup>8</sup>

Terminology	T-Score Definition
Normal	$T \geq -1.0$
Osteopenia	$-2.5 < T < -1.0$
Osteoporosis	$T \leq -2.5$
Established Osteoporosis	$T \leq -2.5$ in the presence of one or more fragility fractures.

**Table 1.** The World Health Organization definitions of osteoporosis and osteopenia used to interpret spine, hip and forearm DXA scan results in postmenopausal white women.

A T-score of 0 means that the patient has a BMD value equal to the mean for young adults. A T-score of -2.5 means that the patient has a BMD value that is 2.5 standard deviations below the mean.

Reference data base for T-score use a uniform Caucasian (non-race adjusted) female or male normative database for women or men of all ethnic groups. However, National Health And Nutrition Examination Survey III (NHANES III) database should be used for T-score derivation at the hip regions. Z-scores are calculated by taking the difference between a patient's measured BMD and the mean BMD expected for patient's peer, matched for gender and ethnic group, and expressing the difference relative to the young adult population standard deviation (SD):

$$\text{Z-Score} = \frac{\text{Measured BMD} - \text{Age matched mean BMD}}{\text{Age matched population SD}}$$

Fracture risk is reliably predicted by an inverse relation with BMD. For this purpose BMD is converted into Z-score and fracture risk increases exponentially with decreasing Z-score. Results are usually in term of relative risk (RR), which is defined as the increase risk of fracture for each unit decrease in Z-score.<sup>9</sup>

The WHO fracture risk calculator uses Z-scores based on age and gender only; the Hologic machines give Z-scores for age, gender and race, and the Lunar machines for age, gender, race and weight.

For bone density, the Z-score will tell you if the bone density is close to the average value for the person's characteristics such as age, race and gender, but that still does not tell you if the bone is strong. Elderly white women have weak bones even if the bone density is average.

Hip BMD is the most reliable measurement for predicting hip fracture risk<sup>10</sup> and of spine for monitoring treatment.<sup>11</sup> In postmenopausal women and in men Age 50 and older, T-scores are preferred for reporting using WHO densitometric classification Table 1. For females prior to menopause and in males younger than age 50, Z-scores, not T-scores, are preferred.<sup>7</sup>

## Follow up DXA Study

Serial BMD testing can be used to determine whether treatment should be started on untreated patients, because significant loss may be an indication for treatment. Serial BMD testing can monitor response to therapy by finding a responder (i.e. an increase or stability of bone density) or non-responder (loss of bone density) suggesting the need for reevaluation of treatment and evaluation for secondary causes of osteoporosis. Intervals between BMD testing should be determined according to each patient's clinical status: typically one year after initiation or change of therapy is appropriate, with longer intervals once therapeutic effect is established. In conditions associated with rapid bone loss, such as glucocorticoid therapy, testing more frequently is appropriate.<sup>7</sup>

## Radiation Dose to Staff and Protective Measures

The dose to staff in DXA facilities is generally small. However, new developments in DXA imaging technology (fan beam, cone beam, C-arm configurations) can result in larger scattered exposure levels. In some examinations the operator may be present in the scanning room; thus the scattered radiation from the total annual patient workload must be considered when assessing occupational dose

levels. The reported scatter dose rates at 1m from the central axis of the patient table range from few tenths of a  $\mu\text{Sv/h}$  to 5  $\mu\text{Sv/h}$ , depending of the scanner model. From these values, recent calculations and measurements indicate that the annual dose for an average workload (20 patients/day) at 1m from the scanner will be between 0.1 and 1.5 mSv depending the model of the scanner.<sup>12</sup> In practical terms, the operators' desk should be positioned at least 1m away from a pencil beam, and at least 2m from a fan-beam system. Some older models, that are not now common, require a distance of 3.5 m. In the case of fan-beam and cone-beam configurations or if the distances above cannot be accommodated, the use of protective screens may be considered. With these precautions it is probable that the operator dose will be in the lower range of acceptable occupational exposures.<sup>13</sup>

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