DXA scanning and its interpretation in osteoporosis

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The recent growth in the clinical use of bone densitometry began with the introduction of the first dual X-ray absorptiometry (DXA) scanning systems in the late 1980s. Today, scans to measure bone mineral density are seen as having an essential role in the evaluation of patients at risk of osteoporosis.

Growing awareness of the impact of osteoporosis on the elderly population (Cooper et al, 1992), the consequent costs of health care (Ray et al, 1997), and the development of new treatments to prevent fractures (Black et al, 1996; Ettinger et al, 1999; Harris et al, 1999; Neer et al, 2001) have led to rapid growth in demand for bone densitometry services. With improvements in technology, scan times have decreased from around 10 minutes for early dual X-ray absorptiometry (DXA) systems to only a few seconds with modern equipment (*Figure 1*). Alongside conventional measurements of spine and hip bone mineral density (BMD), a variety of different types of specialized equipment for investigating the peripheral skeleton are also available (*Figure 2*).

THE DEFINITION OF OSTEOPOROSIS

In the early 1990s, a consensus meeting defined osteoporosis as: 'a systemic skeletal disease characterized by low bone mass and microarchitectural deterioration of bone tissue, with a consequent increase in bone fragility and susceptibility to fracture' (Consensus Development Conference, 1993). It should be noted that this definition does not require an individual to have sustained a fracture before a diagnosis of osteoporosis is made, but introduces the concept of low bone mass and its relationship to increased fracture risk. While it could be argued that it is wrong to define a disease on the basis of what is essentially a risk factor, i.e. low BMD, there is nevertheless some logic to this, as fractures occur late in the disease process when skeletal integrity is already compromised. It is, therefore, desirable to identify those individuals at high risk with a view to instituting appropriate treatment.

Today, there is general agreement that BMD measurements are the most effective way of identifying those patients most at risk of fracture (Kanis et al, 1997). Indeed, the widespread availability of DXA systems has led to a working definition of osteoporosis based on BMD. In 1994, a World Health Organization (WHO) report recommended an epidemiological definition of osteoporosis based on a BMD measurement of the spine, hip or forearm expressed in standard deviation (SD) units called T-scores (WHO, 1994). A patient's T-score is calculated

Figure 1. A dual X-ray absorptiometry scanner for measuring spine and hip bone mineral density. On modern machines it takes only 10 seconds to perform a scan.

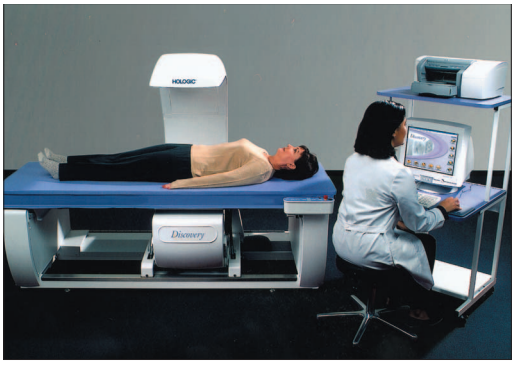

Figure 2. A peripheral dual X-ray absorptiometry (DXA) scanner for measuring forearm bone mineral density. Peripheral DXA systems are smaller and cheaper than spine and hip systems such as that shown in Figure 1.

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by taking the difference between the measured BMD and the mean BMD of healthy young adults matched for gender and ethnic group, and dividing by the young adult population SD (*Figure 3*).

A T-score indicates the difference between the patient's measured BMD and the ideal peak bone mass achieved by a young adult (Heaney et al, 2000). A negative T-score indicates that either the patient failed to achieve the optimum peak bone mass or subsequently lost bone mass as a result of the effects of ageing or disease. The WHO report classifies a patient as having osteoporosis if their T-score ≤ -2.5 at the spine, hip or forearm (*Table 1*). The WHO study also proposed an intermediate state referred to as osteopenia that was defined by a T-score between -2.5 and -1. A T-score ≥-1 was regarded as normal. A fourth state of 'established osteoporosis' was also proposed, denoting osteoporosis as defined above, but in the presence of one or more documented fragility fractures.

Figure 3. An explanation of T- and Z-scores. Z-scores express the difference between measured bone mineral density (BMD) and the normal BMD for healthy subjects matched for age, gender and ethnic origin in units of the population standard deviation. T-scores make a similar comparison to the normal BMD for healthy young adults.

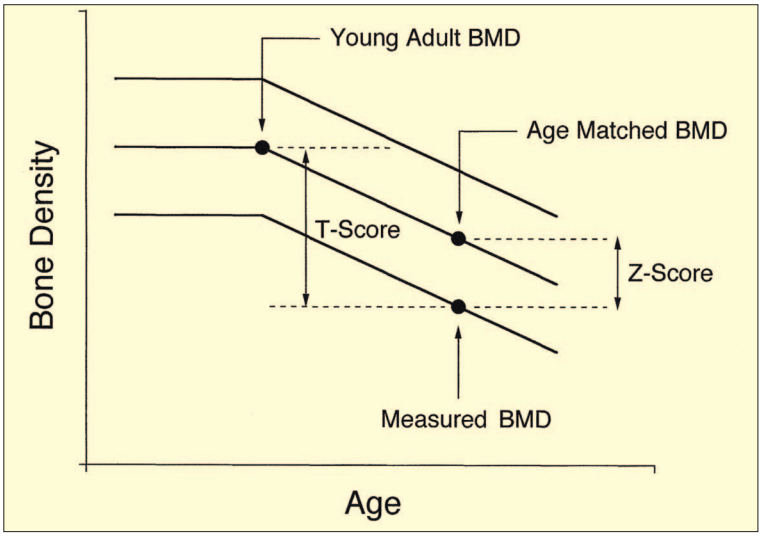


TABLE 1.
World Health Organization definitions of osteoporosis and osteopenia

Terminology	T-score definition
Normal	T ≥ -1.0
Osteopenia	-2.5 < T < -1.0
Osteoporosis	T ≤ -2.5
Established osteoporosis	T ≤ -2.5 in the presence of one or more fragility fractures

From World Health Organization (1994)

The WHO report definitions of osteoporosis, osteopenia and normal are intended to identify patients with high, intermediate and low risk of fracture respectively. However, an important limitation of these definitions is that they apply only to DXA measurements at the sites specified and cannot automatically be applied to other sites in the skeleton or to alternative measurement techniques (Faulkner et al, 1999).

The rationale for the WHO definition of osteoporosis is that it captures around 30% of postmenopausal women (Kanis et al, 1997). This figure was chosen because it approximates to the lifetime risk of fracture for a 50-year-old white woman (WHO, 1994). In comparison, it can be argued that the WHO definition of osteopenia captures too high a percentage of women to be clinically useful, and nowadays this term is being used less often, particularly in the context of making therapeutic decisions. In contrast, the WHO definition of osteoporosis has had a major influence on clinical practice, to the extent that if the question is: 'Does this patient have osteoporosis?' this is now regarded as a T-score issue.

Alongside the T-score, another useful way of expressing BMD measurements is using Z-scores. Like the T-score, the Z-score is expressed in units of the population SD. However, instead of comparing the patient's BMD with the young adult mean, it is compared with the mean for a healthy normal subject matched for age, gender and ethnic origin (*Figure 3*). Although Z-scores cannot be used to diagnose osteoporosis, they nevertheless remain a useful concept because they express a patient's risk of sustaining an osteoporotic fracture relative to their peers with every 1 SD reduction in BMD equating to an approximate two-fold increase in the likelihood of fracture (Marshall et al, 1996).

DXA BONE DENSITY MEASUREMENTS OF THE CENTRAL SKELETON

DXA equipment for the assessment of the central skeleton (*Figure 1*) is used for BMD measurements of the spine (*Figure 4*) and hip (*Figure 5*). These are usually regarded as the clinically most important sites because they are frequent sites of fractures that cause substantial impairment to quality of life, morbidity and mortality. A measurement of hip BMD is known to be the most reliable way of evaluating the risk of hip fracture (Marshall et al, 1996). Also, because of the metabolically active trabecular bone in the vertebral bodies, the spine is the best site for monitoring response to treatment (Eastell, 1998). The fundamental principle behind DXA is the measurement of the transmis-

sion through the body of X-rays of two different energies (Genant et al, 1996). Because of the dependence of the attenuation on atomic number and X-ray energy, measuring the transmission at two different energies enables the amounts of bone and soft tissue to be determined. DXA scanning of the central skeleton has become the most widely used bone densitometry technique because of its ability to measure spine and hip BMD with high precision and to identify patients with osteoporosis on the basis of the WHO definition.

DXA BONE DENSITY MEASUREMENTS OF THE PERIPHERAL SKELETON

Despite the widespread popularity of spine and hip DXA, there is continuing interest in new peripheral DXA (pDXA) devices for assessing sites such as the forearm, heel or hand (*Figure 2*). The first densitometers were forearm scanners that used a radioactive source. In recent years the technology has been updated by replacing the radioactive source with a low voltage X-ray tube and using the principles of DXA to measure BMD. The advantages of pDXA systems include their small size and low cost. However, epidemiological studies show that the discriminatory ability of peripheral BMD measurements to predict hip fractures is poorer than when hip BMD is used (Marshall et al, 1996). Also, these types of measurement are unsuitable for patient follow-up studies (Bouxsein et al, 1999).

REFERRAL AND INTERPRETATION OF A PATIENT'S DXA SCAN

The clinical indications for performing a bone density study are summarized in guidelines published by the Royal College of Physicians (1999). The Royal College of Physicians' recommendations are summarized in *Table 2*.

The starting point for the interpretation of a DXA bone density study is the computer-generated scan report (*Figures 4* and *5*). The information provided includes: the BMD scan image, a reference range plot in which the patient's BMD and age are plotted with respect to the reference population, the BMD results interpreted in terms of T- and Z-scores calculated from the reference data.

The first step in the interpretation of DXA studies is a careful scrutiny of the scan image to ensure that anatomical artefacts do not affect the findings. For spine scans these may include degenerative disease, vertebral fractures and metal artefacts (*Figure 6*). Their effect on scan interpretation may be assessed by noting the trend in T- or Z-score results at each vertebral level, which should agree reasonably closely. If the BMD of an individual vertebra is falsely elevated by an artefact it should be excluded from the analysis. For spine scans it is important to check that the correct vertebrae have been chosen for analysis. Usually this is either L1–L4 or L2–L4, although sometimes analysis may be performed by mistake on T12–L3 or L2–L5. In elderly subjects the spine scan may be of little diagnostic value if there is extensive degenerative disease. In such patients a more reliable measure of skeletal status is obtained from the hip BMD, or in patients with a hip replacement, a measurement at the forearm.

Figure 4. Computer printout of a spine dual X-ray absorptiometry (DXA) scan for a 74-year-old white woman. The printout shows: (a) scan image of the lumbar spine; (b) patient's age and BMD plotted with respect to the reference range; (c) BMD figures for individual vertebrae and total spine (L1–L4) together with interpretation in terms of T-scores and Z-scores.

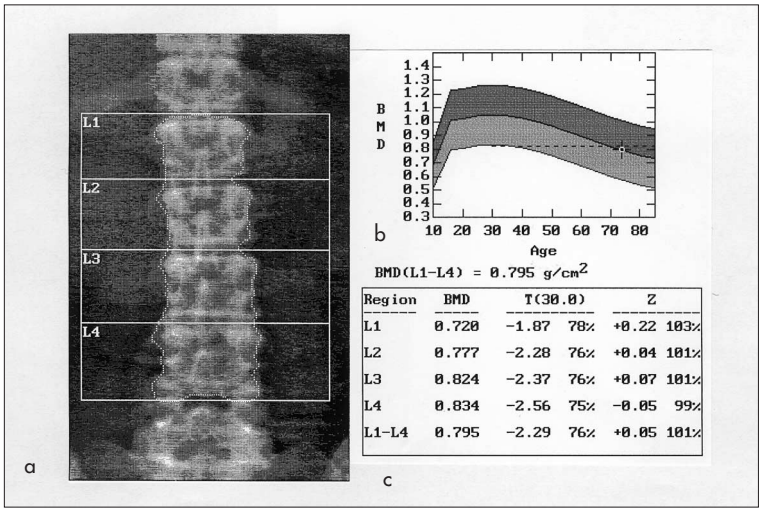


Figure 5. Computer printout from a hip dual X-ray absorptiometry scan for a 76-year-old white woman. The printout shows: (a) scan image of the hip; (b) patient's age and bone mineral density (BMD) for the total hip region plotted with respect to the reference range; (c) BMD figures for five different regions in the hip (femoral neck, greater trochanter, intertrochanteric, total hip and Ward's triangle) together with interpretation in terms of T-scores and Z-scores.

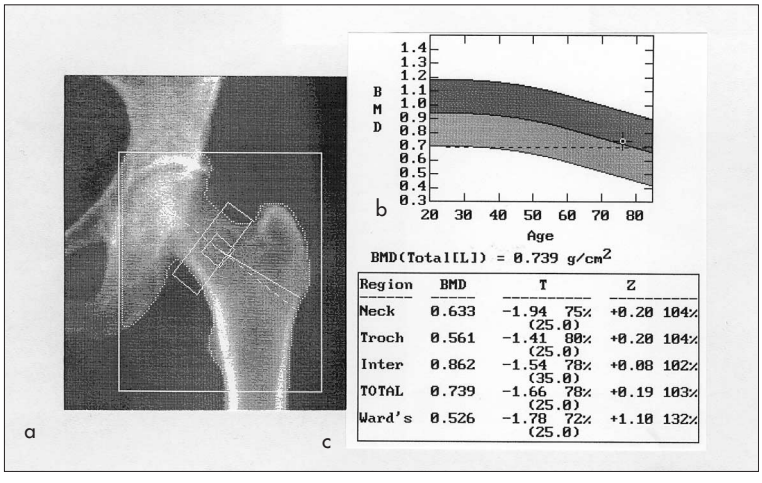


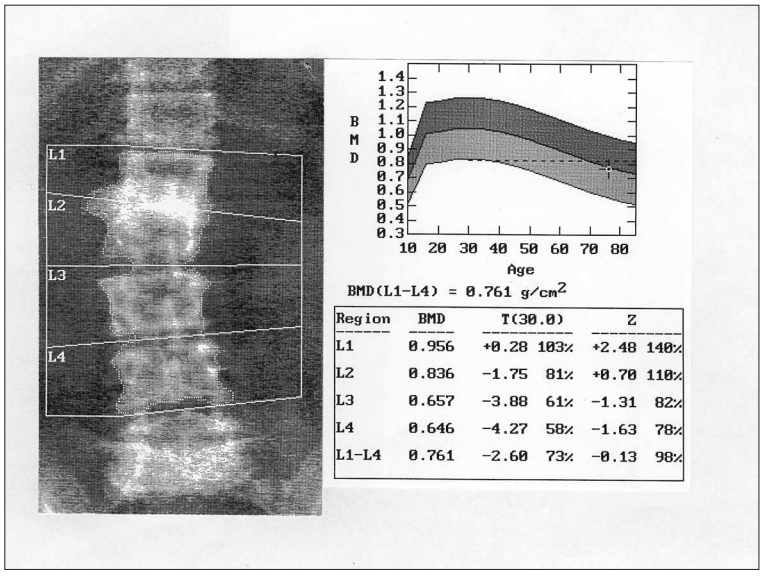
TABLE 2.
Referral criteria for dual X-ray densiometry and clinical indications for bone mineral density measurements

Presence of strong risk factors	Oestrogen deficiency	Premature menopause (age < 45 years)
		Prolonged secondary amenorrhoea (> 1 year)
		Primary hypogonadism
	Corticosteroid therapy	Prednisolone > 7.5 mg/day for 1 year or more
	Maternal family history of hip fracture	
	Low body mass index (< 19 kg/m^2)	
	Other disorders associated with osteoporosis:	Anorexia nervosa
		Malabsorption syndrome
		Primary hyperparathyroidism
		Post-transplantation
		Chronic renal failure
		Hyperthyroidism
		Prolonged immobilization
		Cushing's syndrome
Radiographic evidence of osteopenia and/or vertebral deformity		
Previous fragility fracture, especially of the hip, spine or wrist		
Loss of height, thoracic kyphosis (after radiographic confirmation of vertebral deformities)		

From Royal College of Physicians (1999)

Careful examination of the scan image is also important for hip studies. The hip can show a range of anatomical variations some of which may make the placement of the standard region of interest (ROI) boxes difficult. Incorrect rotation or abduction of the leg during scanning is also a major source of error. A correctly positioned and analysed hip DXA scan is shown in *Figure 5*. Inspection of scan images is particularly important when interpreting follow-up studies. Repeat scans should always be performed on the same machine. The scan images should always be compared with previous studies. For the spine, a check should always be made that the same vertebrae were used in the analysis. For hip scans, it is important that the angles of rotation and abduction of the femur are the same and that the ROI boxes are placed in a consistent manner.

Figure 6. Computer printout of a spine dual X-ray absorptiometry scan for the same 76-year-old white woman whose hip scan is shown in* Figure 5. *There is evidence of degenerative disease in L1 and L2 that shows up in the elevated T- and Z-scores for these vertebrae. In comparison, the spine scan with minimal evidence of degenerative disease shown in* Figure 4 *shows close agreement in T- and Z-score between the different vertebrae.



The National Osteoporosis Society (NOS) has issued guidelines for the interpretation and reporting of spine and hip DXA scans that are summarized in *Table 3* (NOS, 2002). The basis of these guidelines is the WHO definition of osteoporosis, i.e. a T-score less than or equal to -2.5, applied to BMD measurements at the lumbar spine and total hip sites. It is important to be aware that the guidelines summarized in *Table 3* apply only to postmenopausal women. The interpretation of T-scores for other patient groups, i.e. premenopausal women, men and children, is discussed below.

The NOS guidelines recommend that scan reports should include the values of the BMD, T- and Z-scores at the spine and hip. If the spine and hip T-scores are both greater than -1.0 the results are normal and the patient should be reassured that she is not at high risk of an osteoporotic fracture. If at least one T-score is less than -1.0, but both are greater than -2.5, the results indicate osteopenia and preventive treatment should be considered in certain circumstances (*Table 3*). If at least one T-score is less than -2.5 the results are interpreted as showing osteoporosis and preventive treatment is indicated.

ADDITIONAL ISSUES IN THE INTERPRETATION OF DXA SCANS

The NOS guidelines for the interpretation of spine and hip DXA scans are intended to apply to postmenopausal women up to the age of 75 years. Care is needed in other situations. For example, BMD scans in children are interpreted using Z-scores rather than T-scores since skeletal development is incomplete. It is desirable that bone density studies in children are performed in centres with experience in interpreting the results. Care over interpretation is also necessary for premenopausal women whose management will differ from that of postmenopausal women. Men are another special case. Although T- and

Z-score results in men are usually calculated using male reference data, some guidelines recommend that treatment thresholds should be set at the same BMD level as for women (Kanis and Glüer, 2000).

Follow-up DXA scans are often performed to monitor response to treatment. The appropriate time interval is determined from the concept of the 'least significant change' in BMD. For any change in BMD to be true with 95% confidence the measured change must exceed 2.8 times the precision error of the measurement. For spine and total hip BMD measurements this results in a figure of 4.5% for the least significant change. Since it is unlikely that such a change will be detectable in less than 2 years, scans should not normally be repeated more frequently than this.

CONCLUSIONS

With their advantages of high precision, short scan times and low radiation dose, DXA scanners are well suited to meet the need for patient measurement equipment to assist in the diagnosis of osteoporosis and help decisions about treatment. Spine and hip DXA scans of postmenopausal women are interpreted using the WHO definition of osteoporosis of a T-score less than -2.5 at one or other sites. Care is needed when interpreting other types of measurements or investigations of other groups of patients, as the WHO definition of osteoporosis may not be applicable. **HM**

Conflict of interest: none.

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TABLE 3.
National Osteoporosis Society recommendations for the reporting of spine and hip dual X-ray absorptiometry scans

If the T-scores for the spine and total hip bone mineral density (BMD) are both greater than -1.0, standard report reads: The results are normal and the patient should be reassured
If at least one T-score for spine or total hip BMD is less than -1.0 but both are greater than -2.5, standard report reads: The results show osteopenia and treatment may be considered if: (a) the patient has previously had a low trauma fracture; (b) is receiving glucocorticoid therapy; or (c) has a low BMD for age (Z-score of less than -1). Even if no treatment is given lifestyle advice to improve BMD should be provided and BMD re-measured in 3–5 years
If at least one T-score for spine or total hip BMD is less than -2.5, standard report reads: The results confirm osteoporosis and treatment is indicated

From National Osteoporosis Society (2002)

KEY POINTS

- Dual X-ray absorptiometry scanners are well suited to make the diagnosis of osteoporosis and aid decisions about treatment to prevent fragility fractures.
- A measurement of hip bone mineral density (BMD) is the most reliable way of evaluating the risk of hip fracture.
- A measurement of spine BMD is the most reliable way of monitoring response to treatment.
- In elderly patients the spine scan may be of little diagnostic value if there is extensive degenerative disease.
- The clinical indications for performing a bone density study are summarized in guidelines published by the Royal College of Physicians.
- Spine and hip BMD scans in postmenopausal women are interpreted using the World Health Organization (WHO) definition of osteoporosis of a T-score at either site less than or equal to -2.5.
- The WHO definition of osteoporosis may not be applicable when interpreting measurements other than those at the spine, hip or forearm or investigations in other groups of patients.