Bone densitometry and osteoporosis: a practical guide

This article discusses the evolution of central dual-energy X-ray absorptiometry (DXA) as a tool for the diagnosis and management of postmenopausal osteoporosis. The derivation of normal values is considered and this is then linked with guidance on clinical interpretation. Peripheral densitometry can indicate risk of fracture in certain situations, but is not covered here.

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Bone-mineral density (expressed in g/cm²) is defined as the average concentration of mineral per unit area of bone. It is a parameter used to diagnose osteoporosis and assess relative risk of fracture. Although bone density is not the only factor influencing bone strength, it determines 70–80% of the variance,[1] and unlike other components such as bone quality (ie, architecture, turnover, microfractures, and mineralisation) and bone size, it can be readily measured. Bone-mineral density relates closely to the ability of bone to withstand force.

Why DXA?

The accuracy of biological measurement is determined by systematic errors (ie, observer or interpretational) or non-systematic errors (related to confounding factors within the patient, such as changes in fat content of body or bone marrow, osteophytes, or soft-tissue calcification). These data can then be quantified to derive an accuracy error.

The non-systematic error introduced, for example, by marrow fat is at least five times greater with quantitative CT than with DXA. In the case of another technique, dual photon absorptiometry, systematic errors were unacceptably high because of variations in performance of the radiation source. Accuracy error of all these techniques varies from 1% to 10%, whereas population variance of bone-mineral density is from 10% to 50%. Thus, a technique with a relatively high accuracy error (eg, more than 10%) would not be suitable for a population with variance of 20% or less (figure 1).[2]

DXA was, therefore, selected as the favoured tool for measuring bone-mineral density because of its small accuracy error in relation to the variance of the population.[2] It is considered the gold-standard investigation because it is the most accurate way of measuring bone-mineral density, and uses a low dose of radiation (one-tenth that of a chest X-ray).

Definitions and concepts of osteoporosis

Osteoporosis is a skeletal disorder characterised by compromised bone strength predisposing patients to an increased risk of fracture.[3] Osteoporosis is diagnosed accoring to T-score (table 1). T-scores compare the patient with young adults of the same sex, whereas Z-scores compare the DXA result with the patient's peers. Both are standard deviations.

T-score = measured bone-mineral density – young adult mass bone-mineral density / young adult standard deviation.[4]

	T-score
Normal	–1 or higher
Osteopenia	–1 to –2
Osteoporosis	–2·5 or lower
Established or severe osteoporosis	less than –2·5 with one or more associated fractures[2,4]

Table 1: Diagnosis of osteoporosis
This definition was proposed by WHO in 1994, and is based on measurement of bone-mineral density (g/cm²), with reference to the number of standard deviations (T-score) from the bone-mineral density in an average 25-year-old adult.
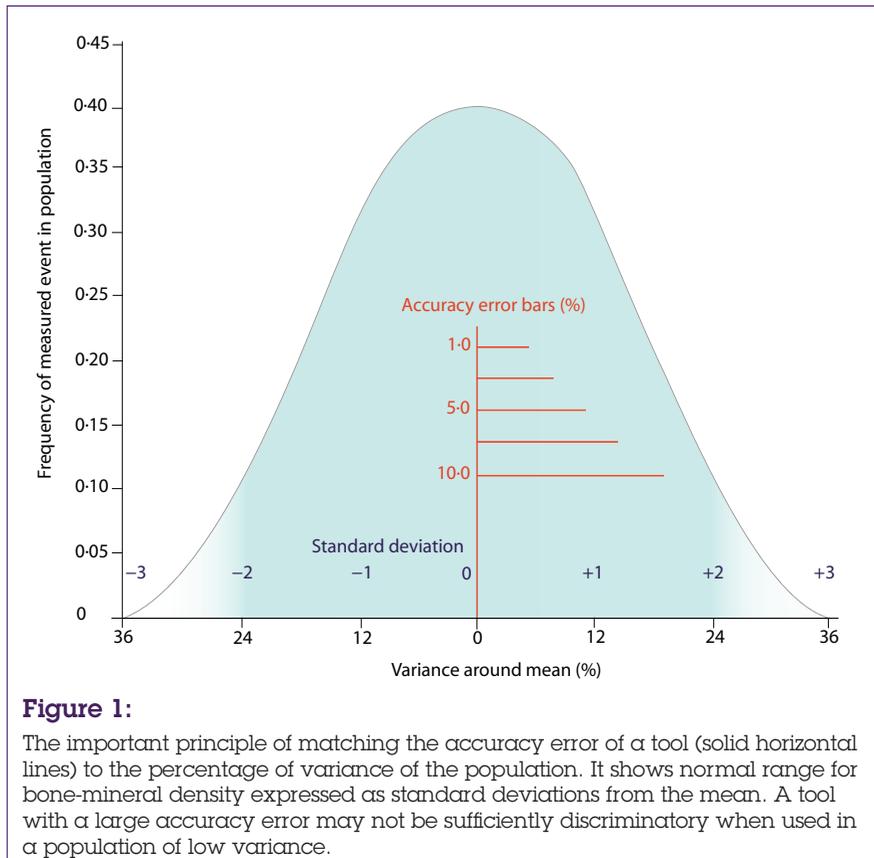
Figure 1:

The important principle of matching the accuracy error of a tool (solid horizontal lines) to the percentage of variance of the population. It shows normal range for bone-mineral density expressed as standard deviations from the mean. A tool with a large accuracy error may not be sufficiently discriminatory when used in a population of low variance.

Z-score = measured bone-mineral density – age-matched mean bone-mineral density / age-matched standard deviation.[4]

Bone density has a Gaussian or normal bell-shaped distribution (figure 1). Osteopenic patients, although at less risk, numerically exceed the osteoporotic category and are thus the group in which most (almost half) fragility fractures occur.[5] In other words, most of the women aged 70 years who have a fracture, will not actually have osteoporosis as defined by WHO. Almost all major intervention trials, however, recruited women with osteoporosis, thus therapeutic decisions for those with osteopenia can be difficult.

The cut-off T-score of –2·5 or lower is based on epidemiology rather than a therapeutic threshold. At age 70 years, women have a 30% lifetime risk of fracture and the bottom 30% at this same age have a T-score of –2·5 or worse. Hence, this score was taken by the WHO study group as a point to define those with a bone-mineral density significantly disturbed to warrant the recognition of a disease state rather than being an extreme variation of normal. These definitions, however, are not so firmly linked by evidence to the risk of fracture in other groups such as:

premenopausal women, men, or non-whites. Moreover, WHO did not specify which skeletal sites should be used for diagnosis in such groups.[6]

Derivation of population reference values

From the preceding section, we can thus appreciate that rather than absolute readings of bone-mineral density, T-scores are a more useful way of classifying the individual within the relevant population. At one time, however, variations in normal values between different scanners such as GE Lunar, Norland, and Hologic meant that an individual could have different T-scores depending on the machine used. As a result of this discrepancy, more patients apparently had osteoporosis when scanned with Hologic than with Lunar.[7]

To obtain consistent T-scores, a reference database was needed. Since 1974, the National Center for Health Statistics (Maryland, USA) had done periodic nationwide surveys to gather population data for several fields such as dietary intake, physical examination, and laboratory investigations. Between 1988 and 1994, a third such study—the National Health and Nutritional Examination Survey (NHANES III) was done covering 33,994 people aged 2 months and older. Bone densitometry was included among the parameters measured. A few years after completion of the study, Hologic began supplying new densitometry data software to all DXA scanners replacing the previous database.[4,7]

The NHANES reference values are in fact lower than the original Hologic values. Thus, some patients previously considered as osteopenic became normal and some with osteoporosis were now designated as osteopenic.[7] Using these new data, 13–18% (4–6 million) US non-Hispanic white women older than 50 were estimated to have osteoporosis, representing a decrease of around 60%.[8]

Additionally, Hologic altered the primary region of interest from the femoral neck to the total hip in keeping with the recommendations of the International Committee for Standards in Bone Measurement.[9] This change halved the precision error linked with the hip sub-regions.[4] The normal values for the spine, and hence its T-scores, were unchanged.[7]
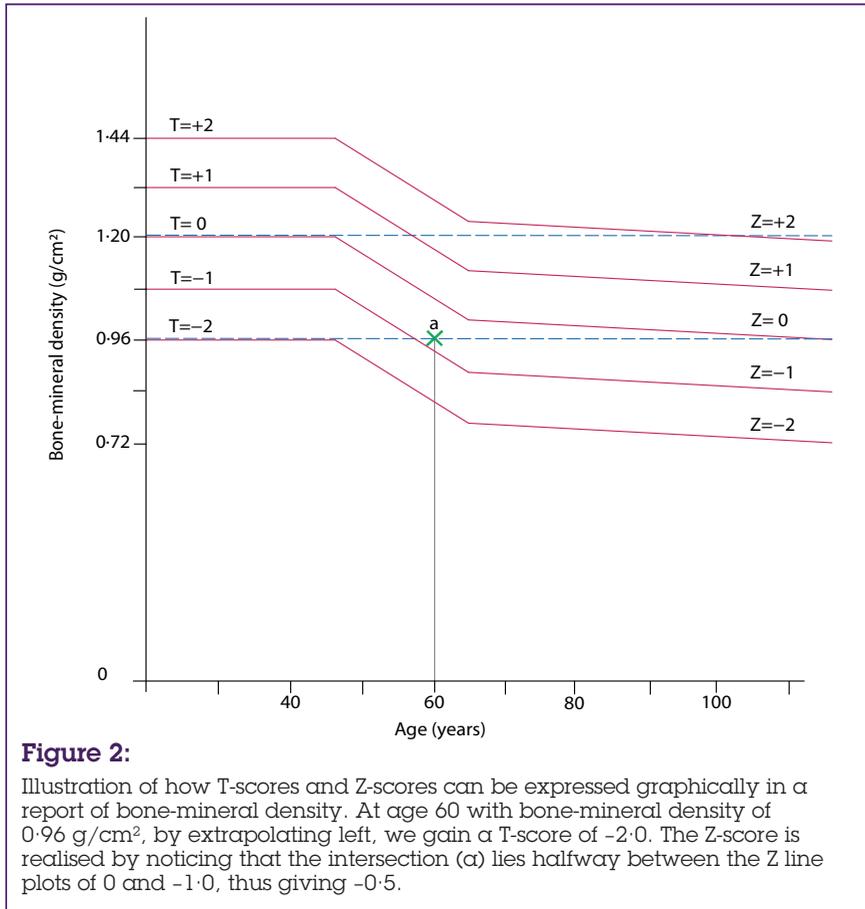
Figure 2:
Illustration of how T-scores and Z-scores can be expressed graphically in a report of bone-mineral density. At age 60 with bone-mineral density of 0·96 g/cm², by extrapolating left, we gain a T-score of –2·0. The Z-score is realised by noticing that the intersection (a) lies halfway between the Z line plots of 0 and –1·0, thus giving –0·5.

Norland and Hologic by providing values that were specific to both sex and race, but Asian people were not included.[11] Thus, the NHANES reference values now provide the preferred database that is installed in new DXA scanners.[12] In this way, for the hip region at least, a standardised result is produced, which is reproducible across different machines.[13]

Structure of DXA reporting

Central DXA measurements are taken from both the hip and lumbar vertebra (L1 to L4). The technique requires attention to positioning (especially for hip) and careful scrutiny of confounding factors such as degenerative disease, vertebral fractures, and metal parts. Affected vertebrae should be excluded from the analysis. If their presence prohibits a reliable measurement at this site, it is preferable to consider the hip only, or to use a peripheral area such as forearm. The diagnosis of osteoporosis should be based on the lower score of either the spine or hip. Z-score is not used for diagnosing osteoporosis.

With regard to race-specific data, Lunar had used data from white people only to derive their reference range used for calculating T-scores.[10] However, NHANES-III continued an improvement started by

Box: Risk factors for osteoporotic fracture

The risk factors recognised by NICE in its current appraisal consultation document dealing with primary fracture prevention are:

1. Parental history of hip fracture;
2. Oestrogen deficiency;
3. Low bone-mass index (defined as <22 kg/m²);
4. Current smoking;
5. Alcohol intake of >3 units per day;
6. Use of systemic steroids;
7. Medical conditions associated with low bone mineral density (eg, rheumatoid arthritis, inflammatory bowel disease, chronic obstructive pulmonary disease, endocrine disorders).[20]

	Clinical interpretation
−1 at both hip and spine	Reassure the patient
−1 to −2·5 at any site	Consider treatment if the patient has low Z-score (−1), and risk factors, (fragility fracture, steroid use). If no treatment is given, the patient should be advised about lifestyle modification and followed-up in 3·5 years
−2·5 or lower at any site	Consider treatment

Table 2: Interpretation of T-score results

Densitometry result

The report often contains an image of the hip or spine and usually both a graphical and tabular representation of the T-scores and Z-scores, as derived from the bone-mineral density.[14] A Z-score of 0 denotes a value that is exactly at the mean for the patient's age. Z-scores less than −1 are considered to represent a substantially increased risk of fracture. Since low bone-mineral density can commonly be found in elderly people, comparison with the age-matched norms can be misleading.[14] As we progress beyond the age of 40 years the gap between T-scores and Z-scores gradually widens (figure 2).

Clinical interpretation

Every reduction in bone-mineral density of one standard deviation equates to a 1·5–2·5 times increase in relative risk of fracture.[4,15] Thus, someone with a T-score of −1·0 is almost twice as likely to have a fracture as they would be with a score of 0. The basic recommendations shown in table 2 are often attached to densitometry reports. Clinical decisions on therapeutic intervention should not be based purely on densitometry readings.

Age and previous history of fracture are important risk factors independent of bone-mineral density. A previous fracture doubles the risk further and it is higher still for a vertebral fracture. For a given bone-mineral density, the risk of fracture increases with age. At a bone density of 0·7 g/cm², for example, the observed incidence of fracture per 1000 patient years almost doubles between the age groups of 70–74 and 80 and older.[16]

This increased risk is relative and does not tell us the absolute risk, which is expressed as 10-year fracture prediction and requires consideration of life expectancy.[17] For example, a woman of 60 has a 10-year probability of hip fracture of about 2·4%. With addition of one risk factor (box) this likelihood rises to around 4·75%.[17] According to the T-score, this would increase further to more than 20% if she were to have osteoporosis (less than −2·5) as opposed to osteopenia.[17] The risk is site specific, thus density measured at spine best reflects increased vertebral fracture risk, but it also provides an index of global fracture risk.[18]

WHO has incorporated the interplay between risk factors and bone-mineral density into an absolute fracture-risk assessment tool called FRAX.[19] It is a sophisticated, computer-driven tool (available at www.shef.ac.uk/frax) that requires input of data for clinical risk factors (box 1) and bone-mineral density. It then provides 10-year absolute risk values for hip fractures and all osteoporotic fractures.[21] In this way, clinical decisions can be aided by firm numerical data, but the threshold for intervention, at the moment, remains a matter for debate.

We have no conflict of interest.

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