Frequently Asked Questions About Bone Mineral Density Test

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ABSTRACT

Since osteoporosis has become an important problem especially in postmenopausal women, bone mineral density testing is the test that provides early detection and thus guides appropriate management according to the results. This screening test could help reduce or prevent incidence of future osteoporotic fractures. This article summarizes about the frequently-asked questions dealing with bone mineral density testing, such as scanning technique, principal of the test, which regions to be measured, clinical indications and how to interpret the results.

Keywords: Bone mineral density, BMD, dual-energy x-ray absorptiometry, DXA, osteoporosis

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INTRODUCTION

Osteoporosis is a silent disease, but it is preventable and treatable. Osteoporosis is a skeletal disorder characterized by compromised bone strength predisposing to an increased risk of fracture.[1] A bone density test is the only test that can diagnose osteoporosis before the fracture begins. This test helps to estimate the density of the bones and the chance to get fracture. It is recommended to have a routine bone density test of the hip (femur) and lumbar spine, which are the common sites of fracture to diagnose osteoporosis when it is appropriate.

Osteoporosis is an important problem of aging people worldwide. In Thailand, the prevalence has been increasing with advancing age especially above 50 years of age. According the survey during 2000-2001, the prevalence of osteoporosis in Thai women who were 40-80 years old was 19.8% and 13.6% for lumbar spine and femoral neck, respectively.[2] A year later, Pongchaiyakul et al., reported the prevalence of osteoporosis in rural Thai area about 24.7% and 19.3% for lumbar spine and femoral neck, respectively.[3] However, the prevalence of osteoporosis in Thai men was somewhat lower about 4.6% and 12.6% for lumbar spine and femoral neck, respectively.[4]

Why measure bone mineral density?

Since osteoporotic bones have increased risk for fragility fractures, these considerably could result in disability, morbidity and mortality of the affected people. In addition, bone mineral density testing is the only way to diagnose osteoporosis earlier. Thus, the BMD measurement will guide for effective prevention and early treatment, which would be really beneficial for quality of life.

Which instrument to use?

A bone mineral density test or bone density test is a quantitative noninvasive test that measures the mineral density of the bone. The device used for this test may be called a bone densitometer. Dual-energy x-ray absorptiometry (DXA) is generally accepted as a gold standard method to

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measure bone mineral density (BMD). Therefore, this test is sometimes called a ***DXA scan***.

The DXA technique has excellent precision about 1.0%-1.5% and high accuracy with T-score errors only of ± 0.5 for spine and hip BMD.[5]

A central DXA bone densitometer is recommended for diagnosis of osteoporosis since it can measure the BMD of spine and hip. This central device can also measure the forearm and total body BMD (Fig 1) while the other type called peripheral device is only capable of measuring BMD of peripheral bones, such as wrist, heel, and fingers. This peripheral device may be used for screening, but not for the diagnosis of osteoporosis.

What is the principle of a DXA scan?

A DXA scan measure BMD by using the attenuation of two low-dose X-ray beams with different energy peaks through the bone being examined. One peak is absorbed mainly by soft tissue and the other by bone. The soft tissue amount can be subtracted from the total and what remains is a patient's bone mineral density. This type of measurement is areal, providing a two-dimensional representation of bone. Thus, the unit of BMD measured by DXA is gram/square centimeter (g/cm^2).

The first generation DXA scanners used a pencil x-ray beam and single detector and scanned in a rectilinear fashion. Second-generation machines use a fan-beam x-ray with multiple detector arrays instead of a single detector. These machines are considerably faster and produce a higher resolution image. The image resolution has been much improved to be about 0.5-0.7 mm in the third generation DXA scanners.[6]

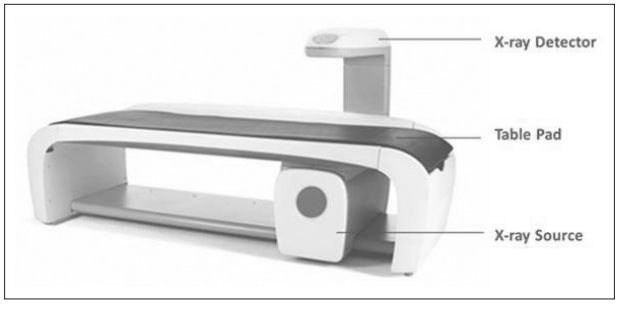


Fig 1. DXA bone densitometer

What are the objectives of a bone density test?

The objectives of this test are as follows:

1. Diagnosis of osteoporosis
2. Prediction of fracture risk and helping determine the treatment
3. Monitoring the change in BMD following treatment.

Who should have a bone density test done?

According to 2013 international society of clinical densitometry (ISCD) recommendation, who should have a BMD testing is listed in Table 1.[7]

Is there any contraindication for the test?

The test should be avoided during pregnancy even though the radiation exposure is very little.

Which bones to measure?

For the diagnosis of osteoporosis, BMD of lumbar spine and hip is routinely measured, with some occasion that BMD of the forearm may be also required (Fig 2) under the following circumstances[7]:

- Hip and/or spine cannot be measured or interpreted.
- Hyperparathyroidism
- Very obese patients (over the weight limit for DXA table)

Spine: Posteroanterior (PA) lumbar spine of L1-L4 levels, preferably at least two vertebrae are included for analysis if some artifacts or structural changes exist. Lateral spine should not be used for diagnosis of osteoporosis.

Hip or femur: Femoral neck, or total proximal femur, whichever is the lowest.

Forearm: 33% radius or one-third radius of the non-dominant forearm.

The regions of interest (ROIs) for measuring BMD of lumbar spine, hip, and forearm are illustrated in Fig 3.

Is there any preparation required prior to the test?

Prior to the exam

- Avoid calcium supplements at least 24 hours.
- Avoid barium, contrast study or radionuclide

TABLE 1. Indications for bone mineral density testing according to 2013 ISCD recommendations.[7]

Sex	Age group	Criteria required
Women	Age 65 and older	All
	Post-menopausal women younger than 65	Risk factors*
	During menopausal transition	Risk factors*
Men	Age 70 or older	All
	Age younger than 70	Risk factors*
Both sexes	Adults of any age	• Adults with a fragility fracture • Adults with a disease or condition associated with low bone mass or bone loss • Adults taking medications associated with low bone mass or bone loss. • Anyone being considered for pharmacologic therapy • Anyone being treated, to monitor treatment effect. • Anyone not receiving therapy in whom evidence of bone loss would lead to treatment

*Risk factors such as low body weight, prior fracture, high risk medication use, disease or condition associated with bone loss.

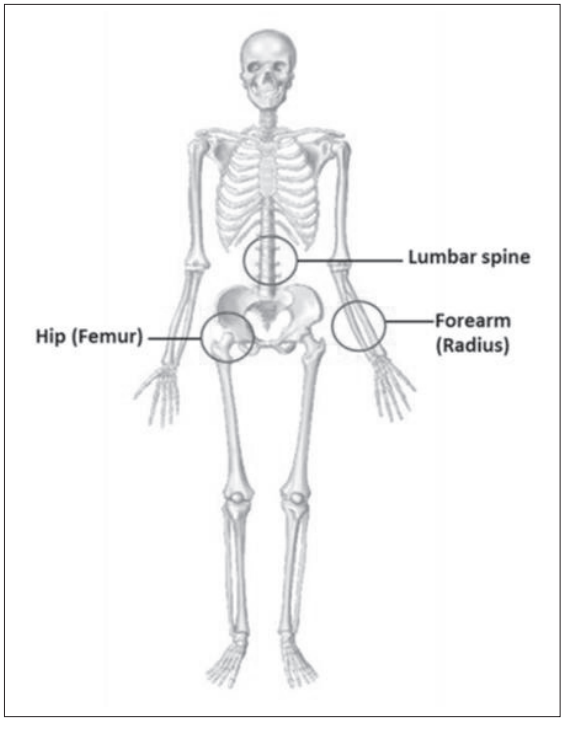


Fig 2. Skeletal sites for standard BMD measurement

scan recently, depending on types of the studies. Some contrast agents such as noted in contrast myelography may be retained for a very long period of time. Thus, complete history taking of such radiological examinations prior to the DXA scan is really helpful.

On the day of exam
- Remove body piercings located below the neck
- Do not wear clothing with underwire bras, zippers, belts or metal buttons

How is the bone density test done?

The test is done while lying down on a DXA table wearing a gown. The technologist will start the machine by moving back and forth as it measures the bone density. Furthermore, no any injection or medication is administered for the test. During the measurement, certain positioning is required for each region, commonly at lumbar spine, hip, and probably forearm, for which the non-dominant side is preferred.

How long does it take for the whole study?

A bone density test is a simple and quick procedure, taking only about 10-20 minutes to complete the study depending on how many regions are measured.

What is the radiation risk from the test?

The amount of x-ray exposure from a DXA scan is really low especially for the first-generation pencil-beam devices, which is about 0.001

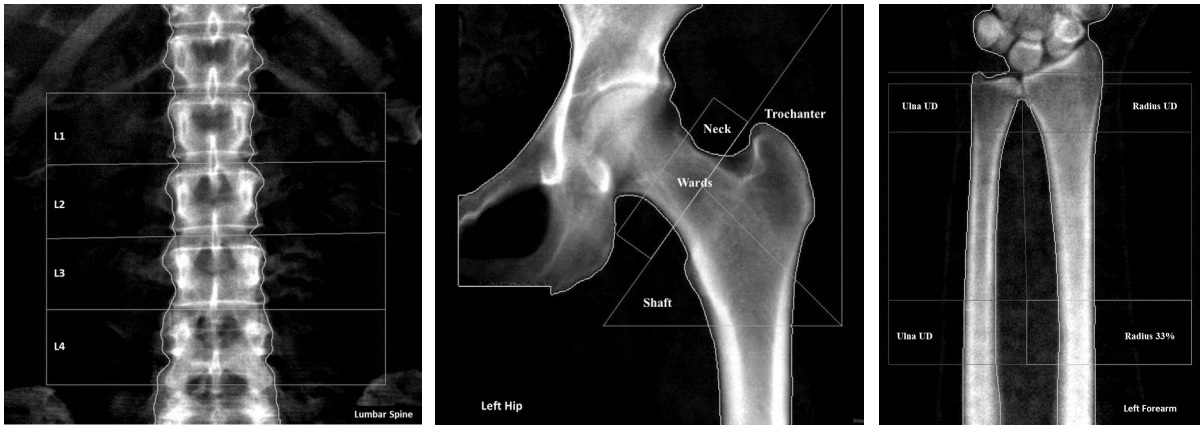


Fig 3. Regions of interest for measuring BMD of lumbar spine (A), hip (B), and forearm (C).

millisievert (mSv) or 1 microsievert (μSv). However, the doses are considerably higher for the fan-beam devices. Effective doses from DXA of spine and hip are 0.013 and 0.009 mSv respectively.[8]

Thus, the radiation dose from a routine DXA SCAN is similar to that from a chest x-ray exam. According to International Commission on Radiological Protection (ICRP), the effective dose limits for a public individual is 1 mSv or 1000 μSv in a year.[9] Thus, the radiation exposure from a DXA scan is really safe. Furthermore, radiation exposure of a DXA scan is generally less than other frequently ordered radiological examinations as listed in Table 2.[8,10]

What does the BMD testing provide?

A bone density testing provides how much mineral is in the bones, called bone mineral content (BMC) expressed in grams (g). BMC per area is described as bone mineral density or BMD which is expressed in gram/square centimeter (g/cm^2). In other words, BMD = BMC/area.

Usually the BMD results are also shown in terms of T-score or Z-score. T-score is used for postmenopausal women and men above the age of 50, while Z-score is used for children, premenopausal women, and men below the age of 50.

T-score is defined as number of standard deviations (SD) that the patient's BMD is above

TABLE 2. Effective radiation dose of a DXA scan and various diagnostic radiological procedures.

Examination	Average effective dose (mSv)
Dual x-ray absorptiometry (DXA)	0.001-0.022
Plain radiograph	
Chest	0.02
Skull	0.1
Cervical spine	0.2
Thoracic spine	1.0
Lumbar spine	1.5
Abdomen	0.7
Pelvis	0.6
Hip	0.7
Mammography	0.4
Intravenous urography	3.0
CT scan	
Head	2.0
Neck	3.0
Chest	7.0

or below average BMD of young adult reference population.

Z-score is defined as number of standard deviations (SD) that the patient's BMD is above or below average BMD of age-match reference population.

T-score and Z-score are calculated by the formulas as shown below

$$\text{T-score} = \frac{\text{BMD patient} - \text{BMD young-normal reference}}{\text{SD young-normal reference}}$$

$$\text{Z-score} = \frac{\text{BMD patient} - \text{BMD age-match reference}}{\text{SD age-match reference}}$$

How the BMD results are interpreted?

According to WHO classification, BMD results of postmenopausal women are classified into 3 categories[11] as shown in Table 3.

Although NHANES III database of young adult Caucasian females age 20-29 years done in 1988-1994 was originally used as a reference for calculation of T-scores in postmenopausal women[12], the 2013 ISCD recommendations also apply these references and the WHO classification for postmenopausal women of other ethnic groups as well as men age 50 and older of all ethnic groups.[7]

On the other hand, Z-score alone is not used to diagnose osteoporosis. A Z-score above -2.0 SD is considered ***"within the expected range for age"*** and a Z-score of -2.0 SD or lower is considered ***"below the normal range expected for age"***.

What are the pitfalls/artifacts found on DXA images?

Improper scan acquisition and analysis is one of the most common pitfalls for the interpretation of BMD results.

Proper positioning during the scanning as well as correct placement of ROIs for BMD analysis are the keys for correct measurement of BMD.

Artifacts in DXA images can be divided into two categories, which are external and internal artifacts.[13,14]

External artifacts: Buttons, wired bra, zippers, wrist bands, navel rings

The patients should be informed to remove all these external artifacts prior to the scanning.

Internal artifacts:

- Common artifacts include degenerative disease, fractures, surgical clips, metallic devices such as pacemakers, orthopedic device, abnormal calcification such as aortic calcification, renal stones, gallstones.
- Less common artifacts include retained high-density contrast medium and calcium medication. Other structural changes of lumbar spines can also produce errors for BMD measurement
  - Congenital development: anomaly in spinal segmentation may cause misidentification of vertebral bodies.
  - Bone loss: bony destruction such as osteolytic metastasis or postsurgical bone loss such as post laminectomy. These result in underestimation of BMD.
  - Compression fractures: This condition can artificially elevate BMD by reduction of the area of the vertebral bodies.

DXA artifacts can be summarized as those resulting in under or over estimation of BMD, which are described in Table 4.[15]

Thus, the vertebrae that are significantly affected by local structural changes should be deleted from the BMD analysis for more

TABLE 3. Interpretation of BMD results according to WHO classification.[11]

BMD results	T-scores
Normal	-1.0 SD or above
Low bone mass (Osteopenia or low bone density)	Between -1.0 and -2.5 SD
Osteoporosis	-2.5 SD or below
Severe osteoporosis (Established osteoporosis)	-2.5 SD or below with history of fragility fracture

TABLE 4. DXA artifacts.

Artifacts causing overestimation of BMD:
Bone pathologies producing high density lesions
Degenerative change and hyperostosis (osteophytes)
Vertebral fracture
Osteoblastic metastases
Vertebral haemangioma
Ankylosing spondylitis with paravertebral ossification
Post treatment
Vertebroplasty/kyphoplasty
Surgical instruments
Strontium ranelate therapy
Extraosseous high density or metallic objects or materials
Overlying objects (wallets, buttons, coins, navel rings)
Extraneous calcification (lymph nodes, aortic calcification)
Retained contrast materials from the prior contrast myelography
Poor positioning
Inadequate internal rotation of femoral neck
Artifacts causing underestimation of BMD:
Bone pathologies producing low density lesions
Osteolytic metastases
Post treatment
Laminectomy
Barium/contrast medium in bowel
Recent radionuclide studies

accurate interpretation. Usually at least two vertebrae are required for interpretation since BMD from only single vertebra is not used for diagnosis of osteoporosis.

How often should a bone density test be repeated?

Serial BMD measurement is useful in several aspects.

1. To determine whether treatment should be started.

2. To monitor therapeutic response by finding an increase or stability of bone density.

3. To detect an individual who has no response to the treatment by finding continuing bone loss, which needs reevaluation of treatment and seeking for secondary causes of osteoporosis.

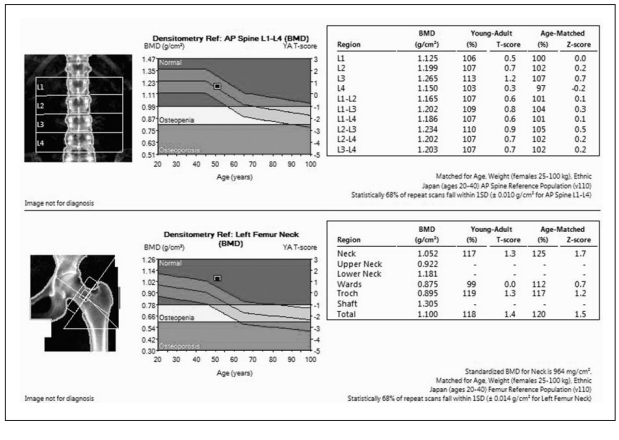
According to ISCD, serial BMD testing should be done when the expected change in BMD equals or exceeds the least significant change (LSC). The interval between BMD measurements may be varied depending on patients' clinical status, and usually one year after beginning or changing therapy is appropriate. However, in conditions with rapid bone loss, such as glucocorticoid treatment, more frequent BMD testing is also practical.[7]

According to national osteoporosis foundation (NOF), serial BMD testing should be obtained one to two years after starting medical treatment for osteoporosis and every two years thereafter. More frequent BMD testing may be warranted in certain clinical situations with rapid bone loss and less frequent follow-up in the patients who have no major risk factors and have initial normal or slightly low T-score values.[16]

Nevertheless, the serial BMD measurement should be done with the same equipment at the same facility using the same regions of interest to achieve the most accurate comparison.

What does the DXA report look like?

The BMD report typically contains name, age, sex, height, body weight, reference population, model of DXA device, and figures of the regions measured, showing the image and ROIs, graph of BMD compared to the reference population, details of BMD of each region and the value of T-score. (Fig 4)



Region	BMD (g/cm²)	Young-Adult (%)	Young-Adult T-score	Age-Matched (%)	Age-Matched Z-score
L1	1.125	106	0.5	100	0.0
L2	1.199	107	0.7	102	0.2
L3	1.265	113	1.2	107	0.7
L4	1.150	103	0.3	97	-0.2
L1-L2	1.165	107	0.6	101	0.1
L1-L3	1.202	109	0.8	104	0.3
L1-L4	1.186	107	0.6	101	0.1
L2-L3	1.234	110	0.9	105	0.5
L2-L4	1.202	107	0.7	102	0.2
L3-L4	1.203	107	0.7	102	0.2

Matched for Age, Weight (females 25-100 kg), Ethnic
Japan (ages 20-40) AP Spine Reference Population (v110)
Statistically 68% of repeat scans fall within 1SD (± 0.010 g/cm² for AP Spine L1-L4)

Region	BMD (g/cm²)	Young-Adult (%)	Young-Adult T-score	Age-Matched (%)	Age-Matched Z-score
Neck	1.052	117	1.3	125	1.7
Upper Neck	0.922	-	-	-	-
Lower Neck	1.181	-	-	-	-
Wards	0.875	99	0.0	112	0.7
Troch	0.895	119	1.3	117	1.2
Shaft	1.305	-	-	-	-
Total	1.100	118	1.4	120	1.5

Standardized BMD for Neck is 964 mg/cm².
Matched for Age, Weight (females 25-100 kg), Ethnic
Japan (ages 20-40) Femur Reference Population (v110)
Statistically 68% of repeat scans fall within 1SD (± 0.014 g/cm² for Left Femur Neck)

Fig 4. BMD reports of lumbar spine and hip

How to predict fracture risk?

Since BMD is highly correlated with bone strength, low BMD is the best predictor of fracture.

Apart from BMD, several underlying clinical risk factors also contribute to fracture risk such as age, gender, prior fracture, low body weight, glucocorticoids, diabetes, rheumatoid arthritis, hyperparathyroidism, hyperthyroidism, smoking, and low calcium intake.[17]

In 2008, WHO fracture risk assessment tool was created by Kanis J et al.,[18] so called FRAX®, which is also available online at http://www.shef.ac.uk/FRAX/. This tool is used to calculate the 10-year probability of major osteoporotic and hip fractures, which is applied for untreated women and men age between 40 and 90 years by using the femoral neck BMD and also clinical risk factors. This tool is used to guide for treatment decision when DXA scan shows low bone mass with no prior hip or vertebral fracture. Several population categories, including Thais, are available. (Fig 5)

The clinical risk factors that are concerned in the FRAX® tool are age, sex, BMI, prior fragility fracture, parental history of hip fracture, current tobacco smoking, long-term use of corticosteroids, rheumatoid arthritis, alcohol intake of 3 or more units per day, and other secondary causes of osteoporosis.

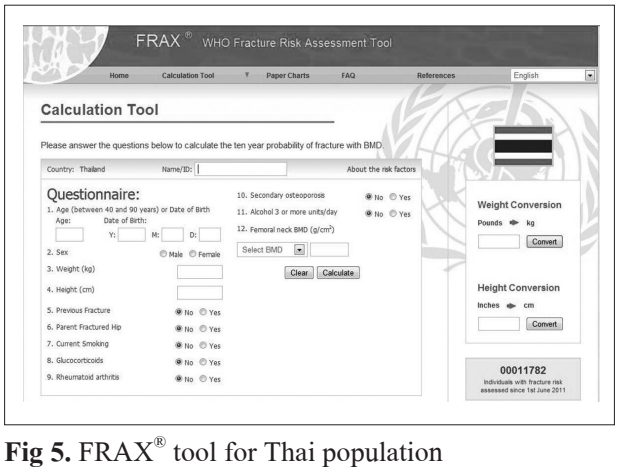


Fig 5. FRAX® tool for Thai population

When the pharmacologic treatment should be started?

According to NOF[19], pharmacologic treatment should be considered in the following conditions:

- In those with hip or vertebral fractures.
- In those with T-scores ≤-2.5 SD at the femoral neck, total hip, or lumbar spine by DXA.
- In postmenopausal women and men age 50 and older with low bone mass at hip, or lumbar spine by DXA and a 10-year hip fracture probability ≥3% or a 10-year major osteoporotic fracture probability ≥20% based on the FRAX® tool.

Is there any online information about osteoporosis in Thai?

More information about osteoporosis in Thai is available at Thai Osteoporosis Foundation (TOPF) website.[20]

CONCLUSION

Osteoporosis is a common skeletal disorder especially in aging people, resulting in increased risk of future fracture which raises disability and also mortality. Measurement of BMD using central DXA technique has been widely accepted as the gold standard for diagnosis and management of osteoporosis. Screening BMD in appropriate groups of people as guided by ISCD recommendation will lead to early diagnosis and appropriate management. This reduces the incidence of fracture and results in improving the quality of life. More information about osteoporosis in Thai is also available at Thai osteoporosis foundation (TOPF) website.

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