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# DUAL-ENERGY X-RAY ABSORPTIOMETRY (DEXA) IS THE GOLD STANDARD TEST FOR THE ASSESSMENT OF BONE DENSITY

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**ABSTRACT**
DEXA (dual x-ray absorptiometry) scans measure bone density (thickness and strength of bones) by passing a high- and low-energy x-ray beam (a form of ionizing radiation) through the body, usually in the hip and the spine. DXA scans and whole-body bone scans are similar tests. Both tests involve scanning your bones, but providers use them to check different aspects of your bone health. DXA scans are special X-rays that measure your bone density to screen you for osteoporosis and other conditions that weaken your bones.

**KEYWORDS:** DEXA, osteopenia, osteoporosis, radiology, MRI, CT scan, BMD, Vit D, Rheumatoid arthritis, Z-score, T-score.

**Overview:** Bone density scans, also known as DEXA scans, help to work out your risk of breaking a bone. They're often used to help diagnose bone-related health problems, such as osteoporosis, or to assess the risk of getting them. A DEXA scan is the most common way to measure bone density. But your provider may order more tests to confirm a diagnosis or to find out if bone loss treatment is working. These include a calcium blood test, a vitamin D test, and/or tests for certain hormones. Your healthcare provider may recommend a DEXA scan to test for osteoporosis or thinning of your bones. Screening for osteoporosis is recommended for women who are 65 years old or older and for women who are 50 to 64 and have certain risk factors, such as having a parent who has broken a hip. DXA works by sending two low-dose X-rays which are absorbed differently by bones and soft tissues. The density profiles from these X-rays are used to calculate bone mineral density. –1 or higher, your bone is healthy. –1 to –2.5, you have osteopenia [Osteopenia is a loss of bone density. Having reduced bone density means your bones don't have as much mineral content as they should. This can make them weaker and increase your risk of bone fractures (broken bones). If you have osteopenia, your bone density is lower than average. It can progress to osteoporosis.], a less severe form of low bone mineral density than osteoporosis [Osteoporosis is a bone disease that develops when bone mineral density and bone mass decreases, or when the structure and strength of bone changes. This can lead to a decrease in bone strength that can increase the risk of fractures (broken bones).]. –2.5 or lower, you might have osteoporosis. Groups who need regular DXA scans include people: Assigned female at birth (AFAB) older than 65. Assigned male at birth (AMAB) older than 70. Older than 50 who've broken a bone in the past. Magnetic Resonance Imaging (MRI) is frequently utilized to aid in the comprehensive assessment of back pain, while dual-energy x-ray absorptiometry (DEXA) is the gold standard test for the assessment of bone density.[1,2]

**Figure 1: DEXA Scan.**

The lower the density, the greater the risk of fracture. DXA is painless and takes about 10 minutes. You probably already know that 100% orange juice is packed with vitamin C (which supports cartilage formation), but it also naturally contains other nutrients that are key to bone health. While a DEXA scan provides some information about bone health, different imaging tests are required for properly diagnosing bone cancers. Other tests like X-rays, CT scans, MRIs, and bone scans are much better for seeing if there are any abnormal growths or damage to the bones that could be cancer. Dual-energy X-ray absorptiometry (DEXA) is an imaging technique. It provides whole body and regional estimates of the three main body components: fat, lean soft tissues and bone mineral mass. Some software can estimate visceral fat from the android/abdominal region (validated only in adults). Dual-energy X-ray absorptiometry (DXA or DEXA) is a scan that is used to determine the density of bone to assess its strength. It is a standard method for diagnosing osteoporosis; used in combination with risk factors (the so-called "FRAX" method), it is also considered an accurate way to estimate fracture risk. Bone density scanning, also called dual-energy x-ray absorptiometry (DXA) or bone densitometry, is an enhanced form of x-ray technology that is used to measure bone loss. DXA is today's established standard for measuring bone mineral density (BMD).[3,4] A bone mineral density (BMD) test measures calcium and other minerals in bone. Bones containing more minerals are denser, so they tend to be stronger and less likely to break. Bones can become less dense as we age or if we develop certain medical conditions. When too much bone is lost, osteoporosis can develop. Normal bone density — People with normal bone density have a T-score between +1 and -1. People who have a score in this range do not typically need treatment, but it is useful for them to take steps to prevent bone loss, such as having adequate amounts of calcium and vitamin D and doing weightbearing exercise.

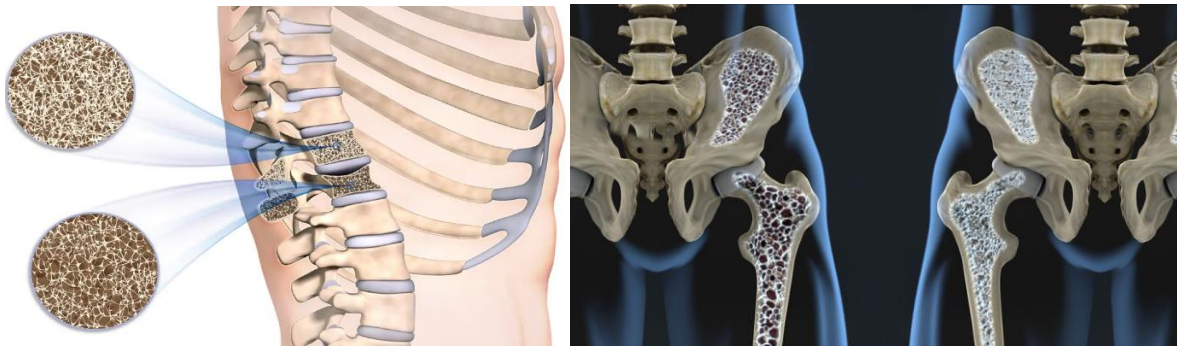

**Figure 2: Osteoporosis.**

A T score of -1 to +1 is considered normal bone density. A T score of -1 to -2.5 indicates osteopenia (low bone density). A T score of -2.5 or lower is bone density low enough to be categorized as osteoporosis. A DEXA scan is the most common way to measure bone density. But your provider may order more tests to confirm a diagnosis or to find out if bone loss treatment is working. These include a calcium blood test, a vitamin D test, and/or tests for certain hormones. Unlike ordinary X-rays, DEXA scans can measure tiny reductions in bone density. This makes it possible to diagnose osteoporosis in its early stages, before you break a bone. A DEXA scan also uses a low dose of radiation, which means the risks to health are much lower than with standard X-rays. A DEXA scan is the most common way to measure bone density. But your provider may order more tests to confirm a diagnosis or to find out if bone loss treatment is working. These include a calcium blood test, a vitamin D test, and/or tests for certain hormones. Dual-energy X-ray absorptiometry (DEXA) is an imaging technique. It

provides whole body and regional estimates of the three main body components: fat, lean soft tissues and bone mineral mass. Some software can estimate visceral fat from the android/abdominal region (validated only in adults). Dexa body composition scans offer a high level of accuracy. They also have detailed insights into your body's composition. While the precision is commendable, individuals should consider the disadvantages. These include radiation exposure, cost, and accessibility before opting for Dexa scans. DXA works by sending two low-dose X-rays which are absorbed differently by bones and soft tissues. The density profiles from these X-rays are used to calculate bone mineral density. The lower the density, the greater the risk of fracture. DXA is painless and takes about 10 minutes.[4,5]

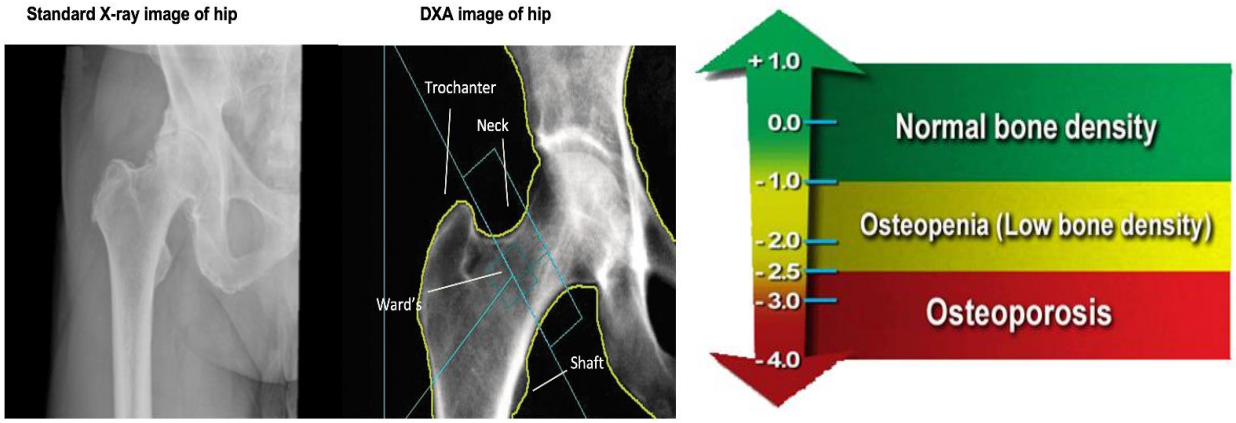


**Figure 3: X-ray and DEXA Scan.**

MRI is the modality of choice for detailed imaging of soft tissues, crucial for identifying brain tumors, spinal injuries, and joint issues. In contrast, DEXA scans are the go-to for bone density evaluations, crucial for osteoporosis risk assessment.

Bone density, or bone mineral density, is the amount of bone mineral in bone tissue. The concept is of mass of mineral per volume of bone (relating to density in the physics sense), although clinically it is measured by proxy according to optical density per square centimetre of bone surface upon imaging. Bone density measurement is used in clinical medicine as an indirect indicator of osteoporosis and fracture risk. It is measured by a procedure called densitometry, often performed in the radiology or nuclear medicine departments of hospitals or clinics. The measurement is painless and non-invasive and involves low radiation exposure. Measurements are most commonly made over the lumbar spine and over the upper part of the hip. The forearm may be scanned if the hip and lumbar spine are not accessible. There is a statistical association between poor bone density and higher probability of fracture. Fractures of the legs and pelvis due to falls are a significant public health problem, especially in elderly women, leading to substantial medical costs, inability to live independently and even risk of death. Bone density measurements are used to screen people for osteoporosis risk and to identify those who might benefit from measures to improve bone strength.[6,7]

**Testing:** A bone density test may detect osteoporosis or osteopenia. The usual response to either of these indications is consultation with a physician. Bone density tests are not recommended for people without risk factors for weak bones, which is more likely to result in unnecessary treatment rather than discovery of a weakness.

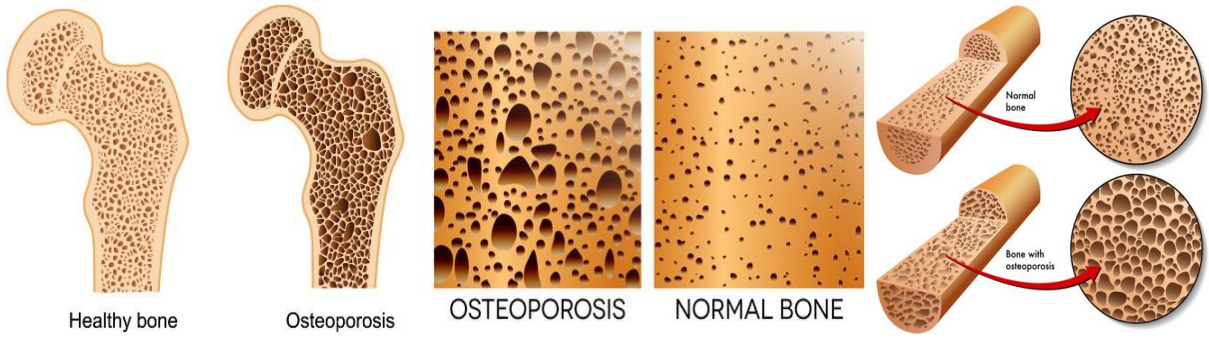


**Figure 4: Healthy Bone and Fragile Bone.**

Bone density scanning, also called dual-energy x-ray absorptiometry (DXA) or bone densitometry, is an enhanced form of x-ray technology that is used to measure bone loss. DXA is today's established standard

for measuring bone mineral density (BMD). An x-ray exam helps doctors diagnose and treat medical conditions. A DXA scan is an imaging test that measures the strength of your bones. It uses X-rays to measure your bone density. DXA is an abbreviation for dual-energy X-ray absorptiometry. Healthcare providers sometimes refer to DXA scans as bone density scans, DXA scans or bone density tests. If your T-score is: –1 or higher, your bone is healthy. –1 to –2.5, you have osteopenia, a less severe form of low bone mineral density than osteoporosis. –2.5 or lower, you might have osteoporosis. A finding of high BMD on routine DXA scanning is not infrequent and most commonly reflects degenerative disease. However, BMD increases may also arise secondary to a range of underlying disorders affecting the skeleton. Good sources of calcium include dairy products, almonds, broccoli, kale, canned salmon with bones, sardines and soy products, such as tofu. If you find it difficult to get enough calcium from your diet, ask your doctor about supplements. Medicare generally covers DXA scans every other year for women over the age of 65 and men over the age of 70. Other medical organizations and the Bone Health and Osteoporosis Foundation recommend that scans can begin even earlier, as early as age 50, for women and men who have risk factors for fractures.[8,9]

**Indications for testing:** The risk factors for low bone density and primary considerations for a bone density test include:

- Females age 65 or older.
- Males age 70 or older.
- People over age 50 with:
- Previous bone fracture from minor trauma.
- Rheumatoid arthritis.
- Low body weight.
- A parent with a hip fracture.
- Individuals with vertebral abnormalities.
- Individuals receiving, or planning to receive, long term glucocorticoid (steroid) therapy.
- Individuals with primary hyperparathyroidism.
- Individuals being monitored to assess the response or efficacy of an approved osteoporosis drug therapy.
- When androgen deprivation therapy is being planned for prostate cancer.
- Individuals with a history of eating disorders.

Other considerations that are related to risk of low bone density and the need for a test include smoking habits, drinking habits, the long-term use of corticosteroid drugs, and a vitamin D deficiency.

**Test result terms**

Results of the test are reported in three forms:

- Measured areal density in g $cm^{-2}$.
- Z-score: the number of standard deviations above or below the mean for the patient's age, sex and ethnicity.
- T-score: the number of standard deviations above or below the mean for a healthy 30-year-old adult of the same sex and ethnicity as the patient.

**Types of tests:** While there are many types of bone mineral density tests, all are non-invasive. The tests differ according to which bones are measured to determine the test result.

These tests include:

- Dual-energy X-ray absorptiometry (DXA or DEXA)
- Trabecular bone score
- Dual X-ray Absorptiometry and Laser (DXL)
- Quantitative computed tomography (QCT)
- Quantitative ultrasound (QUS)
- Single photon absorptiometry (SPA)
- Dual photon absorptiometry (DPA)
- Digital X-ray radiogrammetry (DXR)
- Single energy X-ray absorptiometry (SEXA)

DXA is the most commonly used testing method as of 2016. DXA works by sending two low-dose X-rays which are absorbed differently by bones and soft tissues. The density profiles from these X-rays are used to calculate bone mineral density. The lower the density, the greater the risk of fracture. DXA is painless and takes about 10 minutes. The DXA test works by measuring a specific bone or bones, usually the spine, hip, and wrist. The density of these bones is then compared with an average index based on age, sex, and size. The resulting comparison is used to determine the risk for fractures and the stage of osteoporosis (if any) in an individual. Quantitative ultrasound (QUS) has been described as a more cost-effective approach for measuring bone density, as compared to DXA. This eventually led to the transition to DXA in 1987. Using x-rays as the energy source increased resolution, precision and dramatically reduced scan time to six minutes. Later improvements, replacing rectilinear scanning with array or fan beam, further decreased scan times to one or two minutes. **John R Cameron**, a pioneering medical physicist from Wisconsin, US, and the father of the modern dual-energy x-ray absorptiometry (DXA) scan – today's established standard for measuring bone mineral density (BMD). The DEXA scan was invented in **1987**, during a bonafide resurgence in medical technology and practice. Prior to this technology, physicians who wanted to investigate bone structure more closely needed to make use of long-high exposure x-rays.[9,10] The technology and the science of 2 dimensional measurement of bone mass was pioneered by 2 men of genius and vision: **Dr. Richard Cameron and Dr. Richard Mazzes.**

**Figure 5: Dr. Richard Cameron and Dr. Richard Mazzes [DEXA inventors].**

Average bone mineral density = BMC/W [g/cm$^2$]
BMC = bone mineral content = g/cm
W = width at the scanned line

**Interpretation:** Results are generally scored by two measures, the T-score and the Z-score. Scores indicate the amount one's bone mineral density varies from the mean. Negative scores indicate lower bone density, and positive scores indicate higher. Less than 0.5% of patients who underwent DXA-scanning were found to have a T- or Z-score of more than +4.0, often the cause of an unusually high bone mass (HBM) and associated with mild skeletal dysplasia and the inability to float in water.

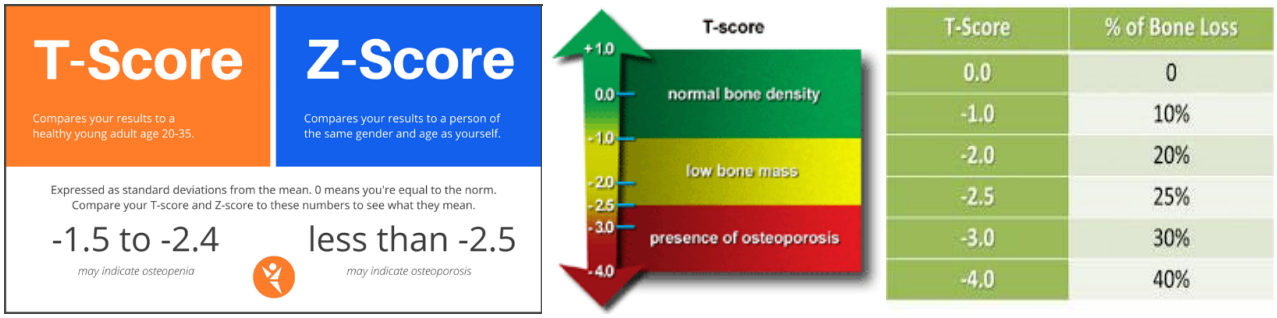


**Figure 6: T-score & Z-Score.**

**T-score:** The T-score is the relevant measure when screening for osteoporosis. It is the bone mineral density at the site when compared to the "young normal reference mean". It is a comparison of a patient's bone mineral density to that of a healthy 30-year-old. The US standard is to use data for a 30-year-old of the same sex and ethnicity, but the WHO recommends using data for a 30-year-old white female for everyone. Values for 30-year-olds are used in post-menopausal women and men over age 50 because they better predict risk of future fracture.[10,11] The criteria of the World Health Organization are:

- Normal is a T-score of −1.0 or higher
- Osteopenia is defined as between −1.0 and −2.5
- Osteoporosis is defined as −2.5 or lower, meaning a bone density that is two and a half standard deviations below the mean of a 30-year-old man/woman.

Hip fractures per 1000 patient-years

| WHO category | Age 50–64 | Age > 64 | Overall |
|---|---|---|---|
| Normal | 5.3 | 9.4 | 6.6 |
| Osteopenia | 11.4 | 19.6 | 15.7 |
| Osteoporosis | 22.4 | 46.6 | 40.6 |

**Figure 7: DEXA Scan Result.**

**Z-score:** The Z-score for bone density is the comparison to the "age-matched normal" and is usually used in cases of severe osteoporosis. This is the standard score or number of standard deviations a patient's bone mineral density differs from the average for their age, sex, and ethnicity. This value is used in premenopausal women, men under the age of 50, and in children and adolescents. It is most useful when the score is less than 2 standard deviations below this normal. In this setting, it is helpful to scrutinize for coexisting illnesses or treatments that may contribute to osteoporosis such as glucocorticoid therapy, hyperparathyroidism, or alcoholism.[12,13]

**Prevention:** To prevent low bone density it is recommended to have sufficient calcium and vitamin D. Sufficient calcium is defined as 1,000 mg per day, increasing to 1,200 mg for women above 50 and men above 70. Sufficient vitamin D is defined as 600 IUs per day for adults 19 to 70, increasing to 800 IUs per day for those over 71. Exercise, especially weight-bearing and resistance exercises are most effective for building bone. Weight-bearing exercise includes walking, jogging, dancing, and hiking. Resistance exercise is often accomplished through lifting weights. Other therapies, such as estrogens (e.g., estradiol, conjugated estrogens), selective estrogen receptor modulators (e.g., raloxifene, bazedoxifene), and bisphosphonates (e.g., alendronic acid, risedronic acid), can also be used to improve or maintain bone density. Tobacco use and excessive alcohol consumption have detrimental effects on bone density. Excessive alcohol consumption is defined as more than one standard-sized alcoholic beverage per day for women, and drinking two or more alcoholic beverages per day for men.[14,15]

**Genetics:** Bone mineral density is highly variable between individuals. While there are many environmental factors that affect bone mineral density, genetic factors play the largest role. Bone mineral density variation has been estimated to have 0.6–0.8 heritability factor, meaning that 60–80% of its variation is inherited from parents. Because of the heritability of bone mineral density, family history of fractures is considered as a risk factor for osteoporosis. Bone mineral density is polygenic and many of the genetic mechanisms remain poorly understood.[16,17]

Genetic diseases associated with bone mineral density: There are several rare genetic diseases that have been associated with pathologic changes in bone mineral density. The table summarizes these diseases:

**Disease:** Osteogenesis imperfect, Osteogenesis imperfect, Osteoporosis pseudoglioma, Osteopetrosis, Camurati-Engelmann disease, Van Buchem disease, Severe infantile osteopetrosis

## CONCLUSION

Bone densitometry, also called dual-energy x-ray absorptiometry, DEXA or DXA, uses a very small dose of ionizing radiation to produce pictures of the inside of the body (usually the lower (or lumbar) spine and hips) to measure bone loss. It is commonly used to diagnose osteoporosis, to assess an individual's risk for developing osteoporotic fractures. DXA is simple, quick and noninvasive. It's also the most commonly used and the most standard method for diagnosing osteoporosis. This exam requires little to no special preparation. Tell your doctor and the technologist if there is a possibility you are pregnant or if you recently had a barium exam or received an injection of contrast material for a CT or radioisotope scan. Leave jewelry at home and wear loose, comfortable clothing. You may be asked to wear a gown. You should not take calcium supplements for at least 24 hours before your exam. Bone density scanning, also called dual-energy x-ray absorptiometry (DXA) or bone densitometry, is an enhanced form of x-ray technology that is used to measure bone loss. DXA is today's established standard for measuring bone mineral density (BMD). An x-ray exam helps doctors diagnose and treat medical conditions. It exposes you to a small dose of ionizing radiation to produce pictures of the inside of the body. X-rays are the oldest and most often used form of medical imaging. DXA is most often performed on the lower spine and hips. In children and some adults, the whole body is sometimes scanned. Peripheral devices that use x-ray or ultrasound are sometimes used to screen for low bone mass, mostly at the forearm. In some communities, a CT scan with special software can also be used to diagnose or monitor low bone mass (QCT). This is accurate but less commonly used than DXA scanning. DXA is most often used to diagnose osteoporosis, a condition that often affects women after menopause but may also be found in men and rarely in children. Osteoporosis involves a gradual loss of bone, as well as structural changes, causing the bones to become thinner, more fragile and more likely to break. DXA is also effective in tracking the effects of treatment for osteoporosis and other conditions that cause bone loss. The DXA test can also assess an individual's risk for developing fractures. The risk of fracture is affected by age, body weight, history of prior fracture, family history of osteoporotic fractures and life style issues such as cigarette smoking and excessive alcohol consumption. These factors are taken into consideration when deciding if a patient needs therapy.

Bone density testing is strongly recommended if you:

- are a post-menopausal woman and not taking estrogen.
- have a personal or maternal history of hip fracture or smoking.
- are a post-menopausal woman who is tall (over 5 feet 7 inches) or thin (less than 125 pounds).
- are a man with clinical conditions associated with bone loss, such as rheumatoid arthritis, chronic kidney or liver disease.
- use medications that are known to cause bone loss, including corticosteroids such as Prednisone, various

anti-seizure medications such as Dilantin and certain barbiturates, or high-dose thyroid replacement drugs.
- have type 1 (formerly called juvenile or insulin-dependent) diabetes, liver disease, kidney disease or a family history of osteoporosis.
- have high bone turnover, which shows up in the form of excessive collagen in urine samples.
- have a thyroid condition, such as hyperthyroidism.
- have a parathyroid condition, such as hyperparathyroidism.
- have experienced a fracture after only mild trauma.
- have had x-ray evidence of vertebral fracture or other signs of osteoporosis.
  The Vertebral Fracture Assessment (VFA), a low-dose x-ray examination of the spine to screen for vertebral fractures that is performed on the DXA machine, may be recommended for older patients, especially if:
- they have lost more than an inch of height.
- have unexplained back pain.
- if a DXA scan gives borderline readings.
- the DXA images of the spine suggest a vertebral deformity or fracture.

On the day of the exam you may eat normally. You should not take calcium supplements for at least 24 hours before your exam. You should wear loose, comfortable clothing, avoiding garments that have zippers, belts or buttons made of metal. Objects such as keys or wallets that would be in the area being scanned should be removed. You may need to remove some clothing and/or change into a gown for the exam. Remove jewellery, removable dental appliances, eyeglasses, and any metal objects or clothing that might interfere with the x-ray images. Inform your physician if you recently had a barium examination or have been injected with a contrast material for a computed tomography (CT) scan or radioisotope scan. You may have to wait 10 to 14 days before undergoing a DXA test. Women should always tell their doctor and technologist if they are pregnant. Doctors will not perform many tests during pregnancy to avoid exposing the fetus to radiation. If an x-ray is necessary, the doctor will take precautions to minimize radiation exposure to the baby. There are two types of DXA equipment: a central device and a peripheral device. Most of the devices used for DXA are central devices, which are used to measure bone density in the hip and spine. They are usually located in hospitals and medical offices. Central devices have a large, flat table and an "arm" suspended overhead. Peripheral devices measure bone density in the wrist, heel or finger and are often available in drugstores and on mobile health vans in the community. The pDXA devices are smaller than the central DXA devices, weighing only about 60 pounds. They may have a portable box-like structure with a space for the foot or forearm to be placed for imaging. Other portable technologies such as specially designed ultrasound machines, are also sometimes used for screening. However, central DXA is the standard technique. The DXA machine sends a thin, invisible beam of low-dose x-rays with two distinct energy peaks through the bones 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.

DXA machines feature special software that compute and display the bone density measurements on a computer monitor. Your doctor will likely do this exam on an outpatient basis. A radiologist, a doctor trained to supervise and interpret radiology examinations, will analyze the images. The radiologist will send a signed report to your primary care or referring physician who will discuss the results with you. DXA scans are also interpreted by other physicians such as rheumatologists and endocrinologists. A clinician should review your DXA scan while assessing the presence of clinical risk factors such as:
- rheumatoid arthritis
- chronic renal and liver disease
- respiratory disease
- inflammatory bowel disease

Your test results will be in the form of two scores:
**T score** — This number shows the amount of bone you have compared with a young adult of the same gender with peak bone mass. A score of -1 and above is considered normal. A score between -1.1 and -2.4 is classified as osteopenia (low bone mass). A score of -2.5 and below is defined as osteoporosis. The T score is used to estimate your risk of developing a fracture and also to determine if treatment is required.

**Z score** — This number reflects the amount of bone you have compared with other people in your age group and of the same size and gender. If this score is unusually high or low, it may indicate a need for further medical tests.

Small changes may normally be observed between scans due to differences in positioning and usually are not significant.

Benefits
- DXA bone densitometry is a simple, quick and noninvasive procedure.
- No anesthesia is required.
- The amount of radiation used is extremely small—less than one-tenth the dose of a standard chest x-ray, and less than a day's exposure to natural radiation.
- DXA bone density testing is currently the best standardized method available to diagnose osteoporosis and is also considered an accurate estimator of fracture risk.
- DXA is used to make a decision whether treatment is required and it can be used to monitor the effects of the treatment.

- DXA equipment is widely available making DXA bone densitometry testing convenient for patients and physicians alike.
- No radiation stays in your body after an x-ray exam.
- X-rays usually have no side effects in the typical diagnostic range for this exam.

Risks

- There is always a slight chance of cancer from excessive exposure to radiation. However, given the small amount of radiation used in medical imaging, the benefit of an accurate diagnosis far outweighs the associated risk.
- Women should always tell their doctor and x-ray technologist if they are pregnant. See the Radiation Safety page for more information about pregnancy and x-rays.
- The radiation dose for this procedure varies.
- No complications are expected with the DXA procedure.

Doctors take special care during x-ray exams to use the lowest radiation dose possible while producing the best images for evaluation. National and international radiology protection organizations continually review and update the technique standards radiology professionals' use. Modern x-ray systems minimize stray (scatter) radiation by using controlled x-ray beams and dose control methods. This ensures that the areas of your body not being imaged receive minimal radiation exposure.

Limitations: A DXA test cannot predict who will experience a fracture but can provide a relative risk and it is used to determine whether treatment is required. Despite its effectiveness as a method of measuring bone density, DXA is of limited use in people with a spinal deformity or those who have had previous spinal surgery. The presence of vertebral compression fractures or osteoarthritis may interfere with the accuracy of the test; in such instances, CT scans may be more useful. Central DXA devices are more sensitive and better standardized than pDXA devices but they are also somewhat more expensive. A test done on a peripheral location, such as the heel or wrist, may help predict the risk of fracture in the spine or hip. These tests are not as helpful in following response to treatment, however, and if they indicate that drug therapy is needed, a baseline central DXA scan should be obtained. Follow-up DXA exams should be performed at the same institution and ideally with the same machine. Bone density measurements obtained with different DXA equipment cannot be directly compared.

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